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ELECTRONICS & TELECOMMUNICATION ENGINEERING

ELECTRONIC MEASUREMENTS AND INSTRUMENTATION

Volume - 1 : Study Material with Classroom Practice Questions

Chapter 1 Error Analysis, Units & Standards
(Solutions for Text Book Practice Questions)

Objective Practice Solutions

01. Ans: (a)

Sol: For 10V total input resistance

$$R_v = \frac{V_{fsd}}{I_{m\,fsd}} = 10/100\mu A = 10^5\Omega$$

Sensitivity = $R_v/V_{fsd} = 10^5/10$

$= 10k\Omega/V$

For 100V $R_v = 100/100\mu A = 10^6\Omega$

Sensitivity = $R_v/V_{fsd} = 10^6/100$

$= 10\ k\Omega/V$

(or)

$$\text{Sensitivity} = \frac{1}{I_{fsd}} = \frac{1}{100\times10^{-6}}$$

$= 10\ k\Omega/V$

02. Ans: (d)

Sol: Variables are measured with accuracy

x = ± 0.5% of reading 80 (limiting error)

Y = ± 1% of full scale value 100

(Guaranteed error)

Z = ± 1.5 % reading 50 (limiting error)

The limiting error for Y is obtained as Guaranteed

Error = 100×(± 1/100) = ± 1

Then % L.E in Y meter

$$20\times\frac{x}{100} = \pm 1$$

x = 5%

Given $w = xy/z$, Add all %L.E s

Therefore = ± (0.5% + 5% + 1.5%)

= ± 7%

03. Ans: (i) 41.97 (ii) 0.224 (iii) ± 0.1513

(Key changed)

Sol: Mean ($\overline{X}$) = $\frac{\Sigma x}{n}$

$$= \frac{41.7+42+41.8+42+42.1+41.9+42.5+42+41.9+41.8}{10}$$

= 41.97

$$SD = \sqrt{\frac{\Sigma d_n^2}{n-1}} \quad \text{for } n < 20 \quad d_n = \overline{X} - X_n$$

$$\sqrt{\frac{(0.27)^2+(-0.03)^2+(-0.17)^2+(-0.03)^2+(-0.13)^2+(0.07)^2+(-0.53)^2+(-0.03)^2+(-0.13)^2+(0.17)^2}{10-1}}$$

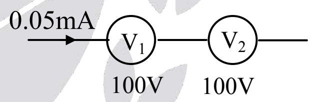
= 0.224

Probable error = ± 0.6745 × SD

= ± 0.1513

04. Ans: 150 V (Key changed)

Sol:



V_1 :

$S_{dc_1} = 10\,k\Omega/V$

$I_{fsd} = \frac{1}{S_{dc1}}$

= 0.1mA

V_2 :

$S_{dc_2} = 20\,k\Omega/V$

$I_{fsd} = \frac{1}{S_{dc2}}$

= 0.05 mA

The maximum allowable current in this combination is 0.05mA, since both are connected in series.

Maximum D.C voltage can be measured as

= 0.05 mA (10 k Ω/V×100+20 kΩ/V × 100)

= 3000 × 0.05 = 150 V

05.

Sol: Internal impedance of 1st voltmeter

$$= \frac{100\text{V}}{5\,\text{mA}} = 20\ \text{k}\Omega$$

Internal impedance of 2nd voltmeter

$$= 100 \times 250\ \Omega/\text{V} = 25\ \text{k}\Omega$$

Internal impedance of 3rd voltmeters,

$$= 5\ \text{k}\Omega$$

Total impedance across 120 V

$$= 20 + 25 + 5 = 50\ \text{k}\Omega$$

$$\text{Sensitivity} = \frac{50\,\text{k}\Omega}{120\,\text{V}} \Rightarrow 416.6\,\Omega/\text{V}$$

⇒ Reading of 1st voltmeter

$$= \frac{20\,\text{k}\Omega}{416.6\,\Omega/\text{V}} = 48\ \text{V}$$

Reading of 2nd voltmeter

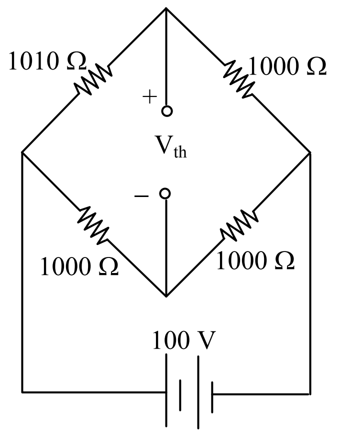
$$= \frac{25\,\text{k}\Omega}{416.6\,\Omega/\text{V}} = 60\ \text{V}$$

Reading of 3rd voltmeter

$$= \frac{5\,\text{k}\Omega}{4166\,\Omega/\text{V}} = 12\ \text{V}$$

06. Ans: (b)

Sol: $\text{Bridge sensitivity} = \dfrac{\text{Change in ouput}}{\text{Change in input}}$



$$= \frac{V_{th}}{10\,\Omega}$$

$$V_{th} = \frac{1010\times100}{2000} - \frac{1000\times100}{2000} = 0.25\text{V}$$

$$S_B = \frac{0.25\,\text{V}}{10\,\Omega} = 25\ \text{mV}/\Omega$$

07. Ans: (d)

Sol: $W_T = W_1 + W_2 = 100 - 50 = 50\ \text{W}$

$$\frac{\partial W_T}{\partial W_1} = \frac{\partial W_T}{\partial W_2} = 1$$

$$\text{Error in meter 1} = \pm\frac{1}{100}\times100 = \pm\ 1\ \text{W}$$

$$\text{Error in meter 2} = \pm\frac{0.5}{100}\times100 = \pm\ 0.5\ \text{W}$$

$W_T = W_1 + W_2 = 50 \pm 1.5\ \text{W}$

$W_T = 50 \pm 3\%$

08. Ans: (b)

Sol: $\text{Resolution} = \dfrac{200}{100}\times\dfrac{1}{10} = 0.2\ \text{V}$

09. Ans: (b)

Sol: $\%\ \text{LE} = \dfrac{\text{FSV}}{\text{true value}}\times\%\text{GAE}$

$$= \frac{200\,\text{V}}{100\,\text{V}}\times \pm2\%$$

$$= \pm\ 4\%$$

10. Ans: (c)

Sol: $\text{Power} = I^2R = (2)^2\ (100)$

$$= 400\ \text{W}$$

$$\%\ \text{Error} = \pm\left[2\left(\frac{\partial P}{\partial I}\right) + \frac{\partial P}{\partial R}\right]\times100$$

$$= \pm\ 2\ (1) \pm 0.2$$

$$= \pm\ 2.2\%$$

$$\text{Error} = \pm\frac{2.2}{100}\times 400$$
$$= \pm 8.8\ \text{W}$$

11. Ans: (c)

Sol: $R_T = R_1 + R_2 = 36 + 75 = 111\ \Omega$

$$\Delta R_T = \left(\frac{5}{100}\times 36\right)+\left(\frac{5}{100}\times 72\right)$$
$$= 5.55\ \Omega$$

$R_T = 111 \pm 5.55\ \Omega$

12. Ans: (a)

Sol: $R = \frac{V}{I}$

$$\frac{\Delta R}{R}\times 100 = \frac{\Delta V}{V}\times 100+\frac{\Delta I}{I}\times 100$$
$$\frac{\Delta R}{R}\times 100 = 2\% + 1\%$$
$$= 3\%$$

Conventional Practice Solutions

01.

Sol: (a) Sensitivity $|_{25°C} = \frac{3.0-1.5}{100-50} = 30\ \mu m/kg$

Sensitivity$|_{40°C} = \frac{3.5-1.9}{100-50} = 32\ \mu m/kg$

(b) Zero Drift = 0.3mm − 0mm = 0.3mm

Sensitivity Drift = 32μm/kg −30μm/kg

= 2 μm/kg

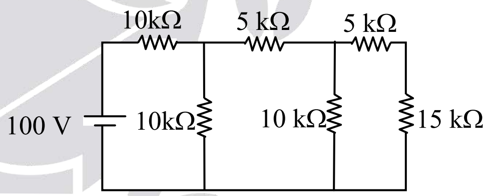
$$\text{Zero drift co-efficient} = \frac{0.3\text{mm}}{40°C-25°C}$$
$$= 20.0\ \mu m/°C$$

Sensitivity Drift co-efficient

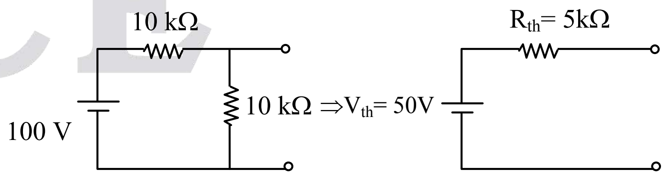
$$= \frac{2\mu m/kg}{40°C-25°C}$$
$$= 0.133\ \mu m/kg/°C$$

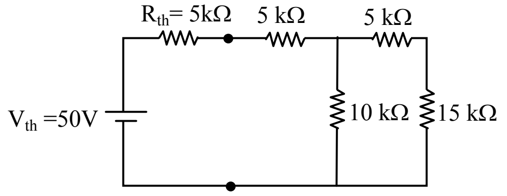
02.

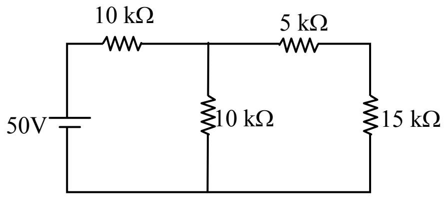
Sol:

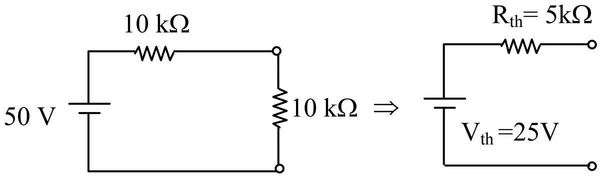


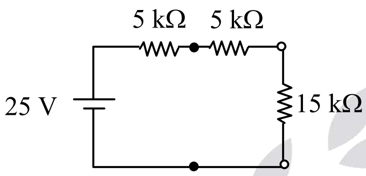
Using circuit minimizing techniques

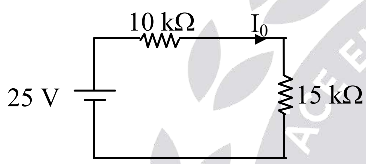








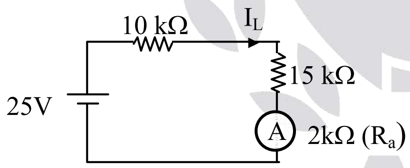




Value of current in 15kΩ

$(I_0) = \dfrac{25V}{10k\Omega + 15k\Omega}$

$I_0 = 1$ mA



(A) reading (I_L)

$$= \frac{25V}{10k\Omega + 15k\Omega + 2k\Omega} = 926\mu A$$

$I_L = 99\%\ I_0$ (from the question data)

$I_L = 0.99\ I_0,\ \ I_L = \dfrac{1}{1+\dfrac{R_a}{R_{ckt}}} I_0$

$$\frac{I_L}{I_0} = \frac{1}{1+\dfrac{R_a}{(10k + 15k\Omega)}}$$

$$\Rightarrow 0.99 = \frac{1}{1+\dfrac{R_a}{25k\Omega}}$$

$R_a = 250\ \Omega$

03. (a)

Sol: Accuracy → It indicates degree of closeness of measured value to the True value.

Precision: → Indicates the degree of closeness of measured values by an instrument for a fixed input quantity.

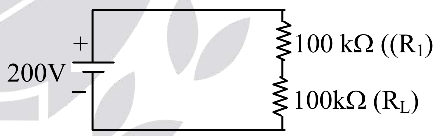
Sensitivity (s) → $\dfrac{\text{Change in output}}{\text{Change in input}}$

Unit of sensitivity depends on type of Instrument

For voltmeter sensitivity defined as $\dfrac{1}{I_{fsd}}\Omega / V$.

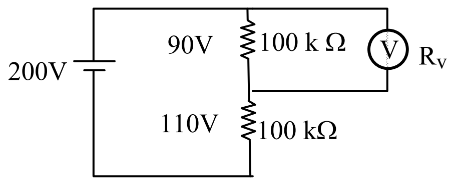
03. (b)

Sol:



$V_{R1} = 200V \times \dfrac{100k\Omega}{100k + 100k} = 100V$

A voltmeter when connected across either of two 100kΩ resistors (say upper one) acts as shunt for the portion of circuit. The voltmeter will then indicate a lower voltage drop than actually existed before the voltmeter was connected. This happens because of loading effect & mainly occurs with low sensitivity of Instrument. Assume voltmeter resistance as R_V.



Voltmeter Indication is '90 V'

R_{eq} = 100 kΩ// R_v = $\frac{100k\Omega \times R_V}{100k\Omega + R_V}$

$R_{Total} = (R_{eq} + 100)$ kΩ,

Voltage division

$90V = 200V \times \frac{R_{eq}}{100 + R_{eq}}$

R_{eq} = 81.8 kΩ

$R_{eq} = \frac{100k\Omega \times R_V}{100k\Omega + R_V}$

$\Rightarrow 81.8\ k\Omega = \frac{100k\Omega \times R_V}{100k\Omega + R_V}$

R_V = 450 kΩ

04.

Sol: Ranges:

(A) → (0 –5) A

(V) → (0 –250V)

(W) → (0 – 500 W)

Meter reading

I = 2.5A ± 0.5% fsd

⇒ I = 2.5 ± 1% of reading

V = 115V ± 0.5% fsd

⇒ V = 115V ± 1.086% reading

W = 220 W ± 1% fsd

⇒ W = 220W ± 2.27% reading

$\cos\phi = \frac{P}{VI}$

ln cosϕ = lnp – lnv– lnI

$$\frac{1}{\cos\phi} = \frac{1}{P}.\frac{dp}{d\cos\phi} - \frac{1}{V}\frac{dv}{d\cos\phi} - \frac{1}{I}\frac{dI}{d\cos\phi}$$

$$\frac{\Delta\cos\phi}{\cos\phi} = \frac{\Delta P}{P} - \frac{\Delta V}{V} - \frac{\Delta I}{I}$$

$$\frac{\Delta\cos\phi}{\cos\phi}\times 100 = \frac{\Delta P}{P}\times 100 + \frac{\Delta V}{V}\times 100 + \frac{\Delta I}{I}\times 100$$

= 2.27% + 1.086% + 1%

= 4.356% → max. uncertainty

05.

Sol: Expected value (A_T) = 20mA

Measured value (A_m) = 18mA

i) Absolute error = $A_m - A_T$ = 2mA

ii) Percentage error = $\frac{A_m - A_T}{A_T} \times 100$

= – 10%

iii) Relative Accuracy = 1– | error|

= 1– | 0.1| = 0.9

iv) Percentage Accuracy = 0.9 × 100 = 90%

v) Precision of 6^{th} measurement

$(X_n = X_6)$ = 18mA

$$\%\ P = \left(1 - \left|\frac{X_n - \overline{X}}{\overline{X}}\right|\right) \times 100$$

$$Avg(\overline{X}) = \frac{(16+19+20+17+21+18+15+16+18+17)\ mA}{10}$$

= 17.7 mA

$$\%\ P = \left(1 - \left|\frac{18mA - 17.7mA}{17.7mA}\right|\right) \times 100$$

= 98.3%

06.

Sol: Absolute error = 1.14 kΩ – 1.2 kΩ

= –0.06 kΩ

Absolute error = 1.26 kΩ – 1.2 kΩ

= 0.06 kΩ

Tolerance = ± 0.06 kΩ

Maximum resistance at 25°C is 1.26 kΩ

Temperature coefficient = +500 PPM/°C

Let R_1 = 1.26 kΩ at 25°C

$$= \frac{+500}{1{,}000{,}000} \times 1.26\,k\Omega = +0.63\ \Omega/°C$$

Change in temperature (ΔT) = 75°C – 25°C

= 50°C

The maximum resistance at 75°C

= 1.26 kΩ + 0.63 Ω/°C × 50°C

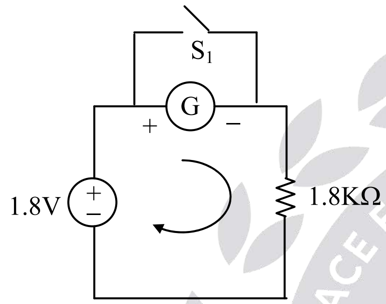
= 1.291 kΩ

Chapter 3 Electromechanical Indicating Instruments

Objective Practice Solutions

01. Ans: (d)

Sol: The pointer swings to 1 mA and returns, settles at 0.9 mA i.e, pointer has oscillations. Hence, the meter is under-damped. Now the current in the meter is 0.9 mA.



Applying KVL to circuit,

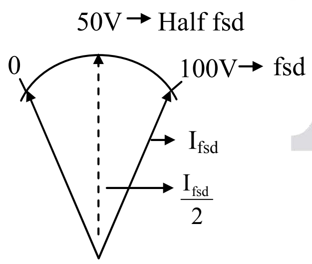
$1.8\text{ V} - 0.9\text{ mA} \times R_m - 0.9\text{ mA} \times 1.8\text{ k}\Omega = 0$

$1.8\text{ V} - 0.9\times10^{-3}\, R_m - 1.62 = 0$

$$R_m = \frac{0.18}{0.9\times10^{-3}} = 200\ \Omega$$

02. Ans: (c)

Sol:



$$S = \frac{1}{1000}\ \Omega/\text{volt}$$

$$S = \frac{1}{I_{fsd}}\ \Omega/\text{V}$$

$$I_{fsd} = \frac{1}{S} = \frac{1}{1000} = 1\text{ mA}$$

$100\text{ V} \rightarrow 1\text{ mA}$

$50\text{ V} \rightarrow\ ?$

$= 0.5\text{ mA}$

03. Ans: (c)

Sol: $T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$

$$K_c\theta = \frac{I^2}{2}\frac{dL}{d\theta}$$

$$25\times10^{-6}\times\theta = \frac{25}{2}\times\left(3-\frac{\theta}{2}\right)\times10^{-6}$$

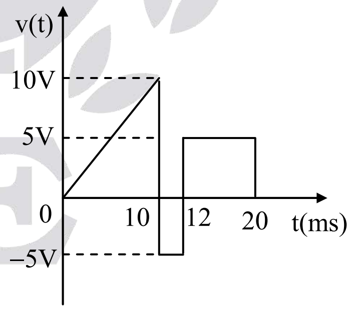
$$2\theta = 3-\frac{\theta}{2}$$

$$\frac{5}{2}\theta = 3$$

$$\theta = 1.2\text{ rad}$$

04. Ans: (a) (Key changed)

Sol:



PMMC meter reads Average value

$$V_{avg} = \frac{\left(\frac{1}{2}\times10\times10\text{ms}\right)+(-5\text{V}\times2\text{ms})+(5\text{V}\times8\text{ms})}{20\text{ms}}$$

$$= \frac{50-10+40}{20} = 4\text{V}$$

(or)

$$\text{Avg. value} = \frac{1}{20}\left[\int_0^{10}(1)\,t\,dt - \int_{10}^{12}5\,dt + \int_{12}^{20}5\,dt\right]$$

$$= \frac{1}{20}\left[\left[\frac{t^2}{2}\right]_0^{10} - 5[t]_{10}^{12} + 5[t]_{12}^{20}\right]$$

$$= 4\text{ V}$$

05. Ans: (a)

Sol:

	1°C↑	10°C	T_c	θ
Spring stiffness(K_c)	0.04%↓	0.4%↓	0.4%↓	0.4%↑
			T_d	θ
Strength of magnet (B)	0.02%↓	0.2%↓	0.2%↓	0.2%↓

Net deflection (θ_{net}) = 0.4%↑ – 0.2%↓

= 0.2% ↑

Increases by 0.2%.

06. Ans: 32.4° and 21.1° (Key changed)

Sol: $I_1 = 5$ A, $\theta_1 = 90°$; $I_2 = 3$ A, $\theta_2 = ?$

$\theta \propto I^2$ (as given in Question)

(i) Spring controlled

$\theta \propto I^2$

$$\frac{\theta_2}{\theta_1} = \left(\frac{I_2}{I_1}\right)^2$$

$$\Rightarrow \frac{\theta_2}{90} = \left(\frac{3}{5}\right)^2$$

$\theta_2 = 32.4°$

(ii) Gravity controlled

$\sin\theta \propto I^2$

$$\frac{\sin\theta_2}{\sin\theta_1} = \left(\frac{I_2}{I_1}\right)^2$$

$$\frac{\sin\theta_2}{\sin 90} = \left(\frac{3}{5}\right)^2$$

$$\Rightarrow \frac{\sin\theta_2}{1} = 0.36$$

$\theta_2 = \sin^{-1}(0.36) = 21.1°$

07. Ans: 3.6 MΩ

Sol: $V_m = (0 - 200)$ V ; S = 2000 Ω/V

V = (0 – 2000) V

$R_m = s \times V_m$

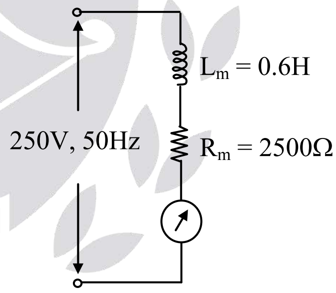
= 2000 Ω/V × 200 V = 400000 Ω

$$R_{se} = R_m\left(\frac{V}{V_m} - 1\right)$$

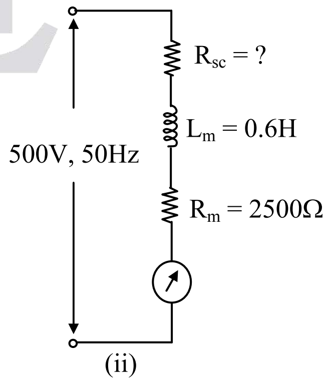
$$= 400000\left(\frac{2000}{200} - 1\right) = 3.6\text{ M}\Omega$$

08. Ans: 2511.5 Ω (Key changed)

Sol:



(i)



(ii)

Current is same in case (i) & (ii)

In case (i),

$$I_m = \frac{250\,V}{\sqrt{R_m^2 + (\omega L_m)^2}}$$

$$= \frac{250\,V}{\sqrt{(2500)^2 + (2\pi \times 50 \times 0.6)^2}}$$

= 0.0997 A

In case (ii),

$$I_m = \frac{250\,V}{\sqrt{(R_m + R_{se})^2 + (\omega L_m)^2}}$$

$$0.0997\,A = \frac{500\,V}{\sqrt{(2500 + R_{se})^2 + (2\pi \times 50 \times 0.6)^2}}$$

$$\sqrt{(2500 + R_{se})^2 + 35.53 \times 10^3} = \frac{500}{0.0997}$$

$$\sqrt{(2500 + R_{se})^2 + 35.53 \times 10^3} = 5.015 \times 10^3$$

$R_{se} = 2511.5\ \Omega$

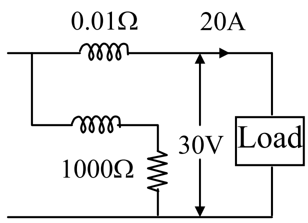
09. Ans: 0.1025 μF

Sol: $C = \frac{0.41\,L_m}{R_{se}^2}$

$$C = \frac{0.41 \times 1}{(2\,k\Omega)^2} = 0.1025\,\mu F$$

10. Ans: (c)

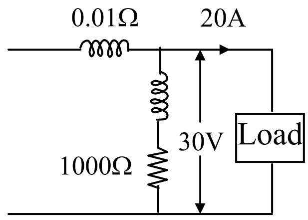
Sol: MC – connection



Error due to current coil

$$= \frac{20^2 \times 0.01}{(30 \times 20)} \times 100 = 0.667\%$$

LC - connection



Error due to potential coil

$$= \frac{(30^2/1000)}{(30 \times 20)} \times 100$$

= 0.15%

As per given options, 0.15% high.

11. Ans: (b)

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

Power factor = cos ϕ

= 0.917 lag (since load is inductive)

12. Ans: (c)

Sol: $R_{load} = \frac{V}{I}$

$$= \frac{200}{20} = 10\,\Omega$$

For same error $R_L = \sqrt{R_C \times R_V}$

$\therefore\ 100 = 10 \times 10^3 \times R_C$

$\Rightarrow R_C = 0.01\ \Omega$

13. Ans: (a)

Sol: $i(t) = 3 + 4\sqrt{2}\sin 314t$

PMMC reads average value.

$\therefore$ Average value = 3A

14. Ans: (b)

Sol: Hot wire ammeter reads RMS value

$$I_{rms} = \sqrt{2^2 + \left(\frac{4}{\sqrt{2}}\right)^2} = 3.46\,A$$

15. Ans: (d) (Key changed)

Sol: Moving Iron Ammeter, $\theta \propto I^2$

For 1 A dc $\rightarrow$ 20°

I_1 = 1 A, θ_1 = 20°

For 3 sin 314 t $\rightarrow$?

MI Ammeter measures the rms value of AC current

$$I_2 = \frac{I_m}{\sqrt{2}} = \frac{3}{\sqrt{2}},\ \ I_2 = \frac{3}{\sqrt{2}},\ \theta_2 = ?$$

$$\frac{\theta_2}{\theta_1} = \frac{I_2^2}{I_1^2}$$

$$\frac{\theta_2}{20} = \frac{(3/\sqrt{2})^2}{(1)^2}$$

$$\Rightarrow \theta_2 = 90^\circ$$

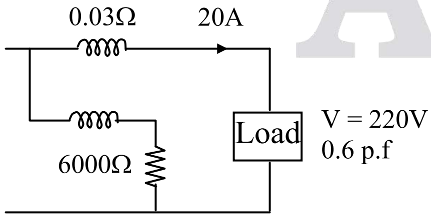
16. Ans: (a)

Sol: $V_{dc} = I_{dc} \times 10\,\Omega = \left(\frac{12+5}{2}\right) \times 10 = 85\,V$

17. Ans: (b)

Sol: Given that,

$R_c = 0.03\,\Omega$, $R_P = 6000\,\Omega$



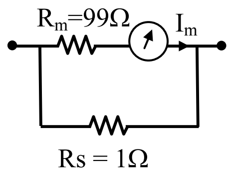
$$\%\ \text{Error} = \frac{I_L^2\, r_c}{VI\cos\phi} \times 100$$

$$= \frac{20^2 \times 0.03}{220 \times 20 \times 0.6} \times 100 = 0.45\%$$

Conventional Practice Solutions

01.

Sol:



(a) $I_m = I_{fsd} = 0.1mA$

* Voltage across instrument = $I_m R_m$

= 0.1mA × 99Ω = 9.9mv

* $I_{sh} = \frac{9.9mV}{1\Omega} = 9.9mA$

* $I_{total} = I = I_m + I_{sh} = 10mA$

(b) $I_m = 0.5 I_{fsd}$

= 0.5 × 0.1mA = 0.05mV

* voltage across instrument

= $I_m R_m$ = 0.05 × 99mV

= 4.95 mV

$$I_{sh} = \frac{4.95mV}{1\Omega} = 4.95mA$$

I_{total} = 0.05 +4.95 = 5mA

(c) 0.25 $I_{FSD} = I_m$ = 0.25× 0.1 = 0.025mA

Voltage across instrument

= $I_m R_m$ = 2.475 mV

$$I_{sh} = \frac{2.475}{1\Omega} = 2.475mA$$

$I = I_m + I_{sh}$ = 2.5mA

02.

Sol: Voltage across instrument for full scale deflection = 100mV.

Current in instrument for full scale deflection, $I = \frac{V}{R} = \frac{100 \times 10^{-3}}{20} = 5 \times 10^{-3}$ A

Deflecting torque, $T_d = BINA = BIN(\ell \times d)$

$= 100 \times B \times 30 \times 10^{-3} \times 25 \times 10^{-3} \times 5 \times 10^{-3}$

$= B \times 375 \times 10^{-6}$

$\therefore$ Controlling torque for a deflection $\theta = 120°$

$T_c = K\theta = 0.375 \times 10^{-6} \times 120$

$= 45 \times 10^{-6}$ N-m

At final steady position, $T_d = T_c$

or $375 \times 10^{-6} \times B = 45 \times 10^{-6}$

$\therefore$ Flux density in the air gap,

$$B = \frac{45\times10^{-6}}{375\times10^{-6}} = 0.12 \text{ Wb/m}^2$$

Resistance of coil winding, $R_c = 0.3 \times 20 = 6\ \Omega$

Length of mean turn

$l = 2\,(L+d) = 2\,(30+25) = 110$ mm

Let a be the area of cross-section of wire and P be the resistivity

Resistance of coil, $R_c = N\rho l/a$

$\therefore$ Area of cross-section of wire

$$a = \frac{100\times1.7\times10^{-8}\times110\times10^{-3}}{6}\times10^{6}$$

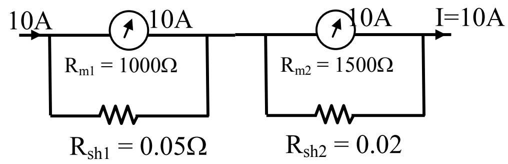
$= 31.37 \times 10^{-3}$ mm^2

Diameter of wire, d= $\left[(4/\pi)(31.37\times10^{-3})\right]^{\frac{1}{2}}$

$= 0.2$ mm

03.

Sol:



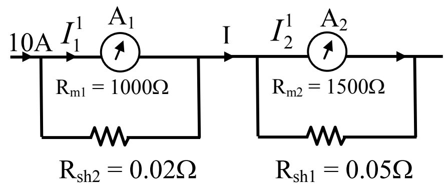
(Fig) with normal connections load is kept constant

$$I_1 = 10\text{ A} \times \frac{0.05\Omega}{1000+0.05}$$

$= 4.999 \times 10^{-4} = 0.5$mA

$$I_2 = 10\text{A} \times \frac{0.02}{1500+0.02} = 1.333\times10^{-4}$$

$= 0.133$ mA



With shunt connections interchanged

$$I_1^1 = 10A\frac{0.02}{1000+0.02} = 0.199\text{mA}$$

$$I_2^1 = 10A\frac{0.05}{1500+0.05} = 0.33\text{mA}$$

$0.49.mA \rightarrow 10A$

$0.19mA \rightarrow ?$

$$\Rightarrow A_1 = \frac{0.19}{0.44}\times10 = 3.87A$$

$0.13.mA \rightarrow 10A$

$0.33mA \rightarrow ?$

$$\Rightarrow A_2 = \frac{0.33mA}{0.13mA}\times10A = 25.38A$$

04.

Sol: **(a)** The internal resistance of 5Ω is due to copper only

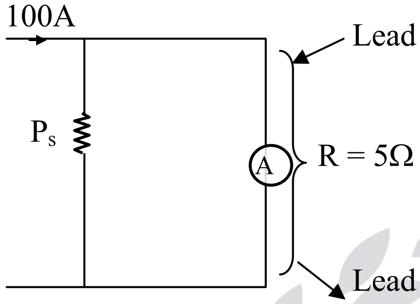
(b) A 4Ω manganin swamping resistor isused in series with a copper resistor of 1Ω. Assume the temperature coefficient of copper as 0.004 ohm/ ° C and that of manganin 0.00015 ohm /°C

(c) When the whole of the 5Ω constitute the resistance in the copper of the instrument coil and lead as shown in the figure.

Instrument current = 0.015A

∴ shunt current = 100 – 0.015

= 99.985 A



PD across the shunt = 0.015 × 5

= 0.075 V

∴ Shunt resistance $= \frac{0.075}{99.985}$

= 0.00075 Ω (manganin wire)

Then the shunt resistance at 10°C temperature rise

= 0.00075 × (1+ 10 × 0.00015)

= 0.000751 Ω

The instrument resistance after 10°C rise in temperature

= 5 × (1 + 10 × 0.004)

= 5.2Ω

The instrument current corresponding to 100 A input. In inverse proportion to the resistance forming the parallel circuit, A and B will be.

$= \frac{0.000751}{5.20075} \times 100 = 0.01444\text{A}$

and the instrument reading

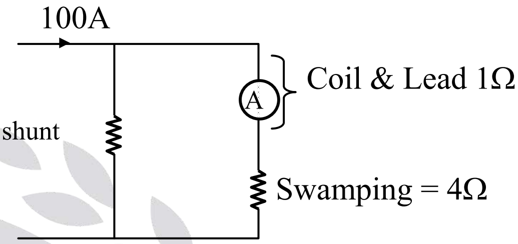
$= \frac{100}{0.015} \times 0.01444 = 96.27$ A

∴ Percentage error due to temperature rise

= 100 – 96.27 or 3.73% (10 W)

(b) The connections in this case are as shown resistance of the instrument → 100A

Circuit after 10°C rise in temperature



= 1 × (1+ 10× 0.004) +

4 × (1+10× 0.00015)

= 5.046 Ω

The shunt resistance after 10°C rise in temperature is still the same, that is 0.000751 Ω

Instrument current corresponding to 100A input

$= \frac{0.000751}{5.046751} \times 100 = 0.01488\text{A}$

And the instrument reading

$= \frac{100}{0.015} \times 0.01488 = 99.2$ A

∴ Percentage error due to the temperature rise

∴ = 100 –99.2 or 0.8% (10W)

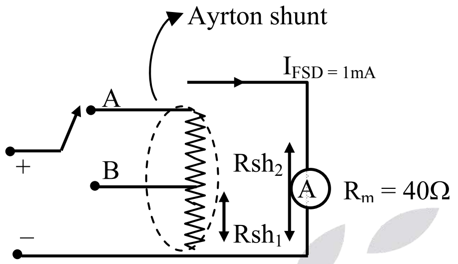
[This shows the great advantage of using a swamping resistance in parallel with the shunt]

05.

Sol: $R_m = 40\Omega$, $I_{FSD} = 1mA$

(0 - 10mA)

$$R_{sh1} = \frac{R_m}{m-1} = \frac{40}{\left(\frac{10mA}{1mA}-1\right)} = 4.44\Omega$$



* (0–50mA)

$$R_{sh} = \frac{R_m + R_{sh1}}{M_2} = \frac{40\Omega + 4.44}{50mA/1mA} = 0.88\Omega$$

06.

Sol: $L = (10 + 5\theta - 2\theta^2)\ \mu H$

$\frac{dL}{d\theta} = (5 - 4\theta)\ \mu H$ per radian

and also $\frac{dl}{d\theta} = \frac{2K\theta}{I^2}$

$\therefore (5-4\theta)\times 10^{-6} = \frac{2k\theta}{I^2}$

Substituting $\theta = 30°$ or $\frac{\pi}{6}$ radian and

I = 5A in above expression, we have

$$\left[5 - 4\times\frac{\pi}{6}\right]\times 10^{-6} = \frac{2k\times\frac{\pi}{6}}{(5)^2}$$

Or $K = 69.36 \times 10^{-6}$ N–m /radian

i.e., spring constant

$= 69.36 \times 10^{-6}$Nm/radian Ans

Substituting I = 10A and $K = 69.36 \times 10^{-6}$ in Equation (i) we have

$$(5-4\theta)\times 10^{-6} = \frac{2\times 69.36\times 10^{-6}}{10^2}\theta$$

Or $\theta = 0.928$ radian or 53.2° Ans

07.

Sol: It is given that

$I = 4\theta^n$

And we know that

$$\frac{dL}{d\theta} = \frac{2K\theta}{I^2} = \frac{2K\theta}{4^2\theta^{2h}} = \frac{1}{8}k\theta^{1-2n}$$

Integrating above expression we have

$$L = \frac{k\theta^{2-2n}}{8(2-2n)} + A = \frac{k\theta^{2-2n}}{16(1-n)} + A \ \ldots\ldots(i)$$

Where A is constant of integration

When I = 0, deflection $\theta = 0$

and $L = 10 \times 10^{-3}$ or 0.01H

Substituting I = 0, $\theta = 0$

And L = 0.01 H in Equation (1) we have

0.01 = 0+A

or A = 0.01

Substituting A = 0.01 in Equation (i) we have $L = \frac{k}{16(1-n)}\theta^{2-2n} + 0.01$

$$= \frac{0.6}{16(1-n))}\theta^{2-2n} + 0.01 \text{ Ans}$$

[$\therefore$ K = 0.6 N– m/rad]

(ii) substituting n = 0.75 in above expression we have

$$L = \frac{0.6}{16(1-0.75)}\ \theta^{(2-2\times 0.75)} + 0.01$$

$= 0.15\theta^{\ 0.5+0.01}$

Substituting $L = 60\times 10^{-3}$ or 0.06 in above expression we have

$0.06 = 0.15\ \theta^{0.5} + 0.01$

or deflection, $\theta = \left[\frac{0.05}{0.15}\right]^2 = 0.111$ radian

or 6.37° Ans

Current, $I = 4\theta^n = 4(0.111)^{0.75}$

$= 0.769$ A

08.

Sol: Current dawn by instrument when connected across 300 V ac

I_{ac} =100mA = 0.1A

At 50 Hz supply Instrument reactance,

$X_L = 2\pi fL = 2\pi \times 50 \times 0.8 = 251.33\ \Omega$

$= \frac{200.7 - 200}{200} \times 100 = 0.35\%$ Ans

09.

Sol: The deflecting torque, $T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$

I = 1.4 and 1.6, about 1.5 on either side, then $\frac{dL}{d\theta} = \frac{577.8 - 576.6}{61.5 - 49.5}$

$= \frac{1.2}{12} = 0.1 \times 10^{-6}$ H/deg

Or 0.1 ×57.3 = 5.73×10^{-6} H /rad

and $T_d = \frac{1}{2} \times 1.5^2 \times 5.73 \times 10^{-6}$

$= 6.44 \times 10^{-6}$ Nm

10.

Sol: The rate of change of mutual inductance is

$$\frac{dM}{d\theta} = \frac{k\theta}{I^2} = \frac{0.1 \times 10^{-6} \times 110}{(10)^2}$$

$= 0.11 \times 10^{-6}$ H/rad

$= 0.00192\ \mu$ H /degree

Final inductance

= initial inductance + change in inductance

$= 2.0 + 0.00192 \times 110 = 2.21\mu$ H

11

Sol: (i) 1. Frictional Error (Torque/weight):

- Potential coil has more number of turns so weight of moving coil is more.
- Then it has more frictional error as compared to M.C and M.I

2. Temperature Error:

- Because of presence of two coils net heat developed is more. Then temperature error is more as compared to other Instruments.

3. Frequency error:

- When it is used as a voltmeter (or) ammeter Net Inductance is more then the frequency error is more
- But when used as a wattmeter, inductance is very less, so frequency error is low.

Hystersis & Eddy current error:

- Because of the use of air core, the hysteresis and eddy current errors are almost zero.
- Both fixed coil & moving coils are electro magnet so poor magnetic field is present
- The external magnetic field can easily distort the inside operating field. Hence stray magnetic field is more as compared to other types of metets.

Note: For portable wattmeter, to reduce the stray magnetic field error; iron shielding is used.

- For precision wattmeters, to reduce stray magnetic field error, static system is used. In this, two set of fixed coil and moving coils are used.

(ii). $I(t) = 80 - 60\sqrt{2}\ \sin(\omega t + 30°)$ A

Dynamo Ammeter → rms

$$\Rightarrow I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta}$$

$$i^2 = 80^2 - \left(60\sqrt{2}\right)^2 \sin^2\left(\theta + \frac{\pi}{6}\right)$$

$$- 9600\sqrt{2}\ \sin\left(\theta + \frac{\pi}{6}\right)$$

$$= 6400 - 7200 \sin^2\left(\theta + \frac{\pi}{6}\right)$$

$$- 13576.4502 \sin\left(\theta + \frac{\pi}{6}\right)$$

$$= 6400 + 7200 \left(\frac{1 - \cos 2\left(\theta + \frac{\pi}{6}\right)}{2}\right)$$

$$- 13576.4502 \sin\left(\theta + \frac{\pi}{6}\right)$$

$$\Rightarrow DA = I_{rms}^2 = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta}$$

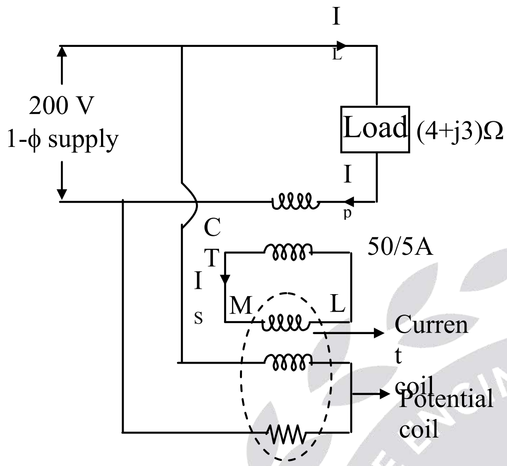
$$= 100 \text{ A}$$

Chapter 4 Measurement of Power & Energy

Objective Practice Solutions

01. Ans: (b)

Sol:



Potential coil voltage = 200 V

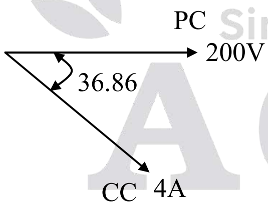
C.T. primary current (I_p)

$$I_P = I_L = \frac{200\,\text{V}}{\sqrt{4^2+3^2}\ \tan^{-1}\left(\frac{3}{4}\right)}$$

$$I_p = I_L = \frac{200\,\text{V}}{5\angle 36.86}$$

$$I_p = 40\angle -36.86$$

$$\frac{I_p}{I_S} = \frac{50}{5}$$



$$\frac{40}{I_S} = \frac{50}{5}$$

$$I_S = \frac{5}{50}\times 40 = 4\,\text{A}$$

C.T secondary (I_S) = $4\angle -36.86°$

Wattmeter current coil = I_C = $4\angle -36.86°$

Wattmeter reading

= 200 V × 4 × cos (36.86)

= 640.08 W

02. Ans: (a)

Sol: Energy consumed in 1 minute

$$= \frac{240\times 10\times 0.8}{1000}\times\frac{1}{60} = 0.032\,\text{kWh}$$

Speed of meter disc

= Meter constant in rev/kWhr × Energy consumed in kWh/minute

= 400 × 0.032

= 12.8 rpm (revolutions per minute)

03. Ans: (a)

Sol: Energy consumed (True value)

$$= \frac{230\times 5\times 1}{1000}\times\frac{3}{60} = 0.0575\ \text{kWhr}$$

Energy recorded (Measured value)

$$= \frac{\text{No. of rev (N)}}{\text{meter constant (k)}}$$

$$= \frac{90\ \text{rev}}{1800\ \text{rev/kWh}} = 0.05\ \text{kWhr}$$

$$\%\text{Error} = \frac{0.05-0.0575}{0.0575}\times 100$$

= – 13.04% = 13.04% (slow)

04. Ans: (c)

Sol: $$W = \frac{E_1}{\sqrt{2}}\times\frac{I_1}{\sqrt{2}}\cos\phi_1 + \frac{E_3}{\sqrt{2}}\times\frac{I_3}{\sqrt{2}}\cos\phi_3$$

$$W = \frac{1}{2}[E_1 I_1 \cos\phi_1 + E_3 I_3 \cos\phi_3]$$

05. Ans: (c)

Sol: V = 220 V, Δ = 85°, I = 5A

Error = VI [sin(Δ – ϕ) – cos ϕ]

(1) $\cos\phi$ = UPF, $\phi = 0°$

Error = $220\times5[\sin(85-0)-\cos 0]$

$= -4.185$ W $\simeq -4.12$ W

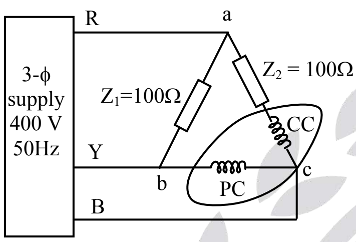
(2) $\cos\phi = 0.5$ lag, $\phi = 60°$

Error = $220\times5\,[\sin(85-60)-\cos 60]$

$= -85.12$ W

06. Ans: (c)

Sol:



Based on R-Y-B

Assume abc phase sequence

$V_{ab} = 400\angle0°$; $V_{bc} = 400\angle-120°$

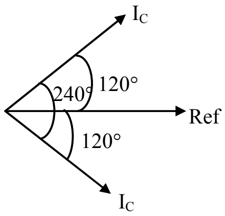
$V_{ca} = 400\angle-240°$ or $400\angle120°$

Current coil current $(I_c) = \dfrac{V_{ca}}{Z_2}$

$$= \frac{400\angle120^\circ}{100\,\Omega} = 4\angle120^\circ$$

Potential coil voltage $(V_{bc}) = 400\angle-120°$

$W = 400\times4\times\cos(240) = -800$ W



07. Ans: (d)

Sol: $V_L = 400$ V, $I_L = 10$ A

$\cos\phi = 0.866$ lag, $\phi = 30°$

$W_1 = V_L I_L \cos(30-\phi)$

$W_2 = V_L I_L \cos(30+\phi)$

$W_1 = 400\times10\times\cos(30-30) = 4000$W

$W_2 = 400\times10\times\cos(30+30) = 2000$W

08. Ans: W = 519.61 VAR

Sol:

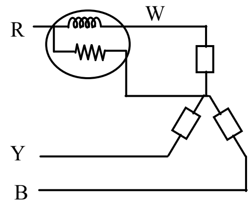


Fig. (a)

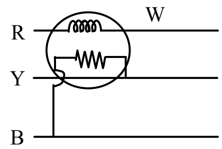


Fig. (b)

W = 400 watt; $W = V_{ph} I_{ph} \cos\phi$

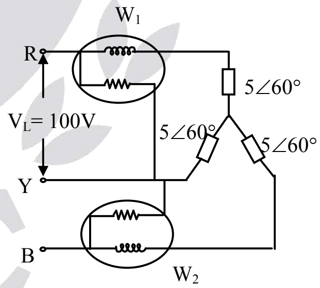
$V_{ph} I_{ph} = 400/0.8$

This type of connection gives reactive power

$$W = \sqrt{3}V_pI_p \sin\phi = \sqrt{3}\times\frac{400}{0.8}\times0.6 = 519.6\text{VAR}$$

09. Ans: 0 & 1000 W

Sol:



Y-phase is made common.

Hence wattmeter readings are

$W_1 = V_L I_L \cos(30+\phi)$

$W_2 = V_L I_L \cos(30-\phi)$

In star-connection

$I_L = I_{ph}$; $V_{ph} = \dfrac{V_L}{\sqrt{3}}$

$$I_L = I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{V_L/\sqrt{3}}{Z_{ph}}$$

$$I_L = I_{ph} = \frac{(100/\sqrt{3})}{5} = \frac{20}{\sqrt{3}} = 11.54A$$

$V_L = 100$ V, $I_L = 11.54$ A, $\phi = 60°$

$W_1 = 100 \times 11.54 \times \cos(30 + 60) = 0$ W

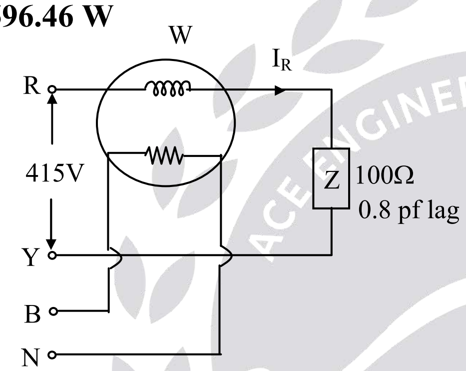
$W_2 = 100 \times 11.54 \times \cos(30 - 60)$

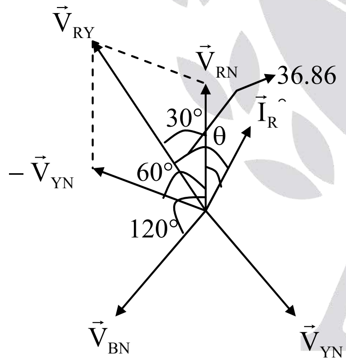
$= 999.393 \text{ W} \simeq 1000 \text{ W}$

$W_1 = 0$ W, $W_2 = 1000$ W

10. Ans: –596.46 W

Sol:





Current coil is connected in 'R_{phase}', it reads '$\vec{I}_R$' current.

Potential coil reads phase voltage i.e., $\vec{V}_{BN}$

$$W = \vec{V}_{BN} \times \vec{I}_R \times \cos(\vec{V}_{BN} . \vec{I}_R)$$

$V_L = 415$ V, $V_{BN} = \frac{415}{\sqrt{3}}$ V

$$I_R = \frac{V_{RY}}{Z} = \frac{415}{100} = 4.15 \text{ A}$$

$\cos\phi = 0.8$

$\Rightarrow \phi = 36.86$ between $\vec{V}_{RY}$ & $\vec{I}_R$

$\theta = 36.86° - 30° = 6.86°$

Now angle between $\vec{V}_{BN}$ and $\vec{I}_R$

$= 120 + 6.86 = 126.86°$

$$W = \frac{415}{\sqrt{3}} \times 4.15 \times \cos(126.86)$$

$= -596.467$ W

11. Ans: (c)

Sol: Meter constant = 14.4 A-sec/rev

= 14.4 × 250W-sec/rev

$$= \frac{14.4 \times 250}{1000} \text{ kW} - \text{sec/rev}$$

$$= \frac{14.4 \times 250}{1000 \times 3600} \text{ kWhr/rev}$$

Meter constant = $\frac{1}{1000}$ kWhr/rev

Meter constant in terms of rev/kWhr = 1000

12. Ans: (d)

Sol: $R_p = 1000\ \Omega$, $L_p = 0.5$ H, f = 50 Hz,

$\cos\phi = 0.7$,

$X_{Lp} = 2 \times \pi \times f \times L$, $\tan\phi = 1$

$= 2 \times \pi \times 50 \times 0.5$

$= 157\ \Omega$

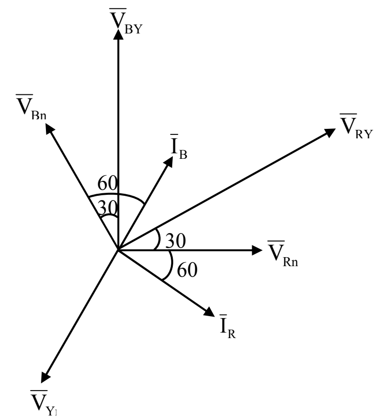
% Error = ± (tanϕ tanβ) × 100

$$= \pm\left(1 \times \frac{157}{1000}\right) \times 100$$

$= 15.7\% \simeq 16\%$

13. Ans: (d)

Sol:



$P = W_1 + W_2 + W_3 = 1732.05$

Power factor, $\cos\phi = \frac{1732.05}{3464} = 0.5$ lag

$\sqrt{3}\times 400\times I_L\times 0.5 = 1732.05$

$I_L = \frac{1732.05}{\sqrt{3}\times 400\times 0.5} = 5$ A

When switch is in position N

$W_1 = W_2 = W_3 = 577.35$ W $\Rightarrow$ balanced load

$\therefore$ total power consumed by load is

$W = W_1 + W_2 + \omega_3$

$W = 1732.05$ W

Given load is inductive

And VA draw from source = 3464 VA

$\therefore$ power factor $= \frac{W}{VA}$

$= \frac{1732.05}{3464} = 0.5$ lag

$\Rightarrow$ Power factor angle = –60° ($\because$ lag)

When switch is connected in Y position pressure coil of W_2 is shorted

So $W_2 = 0$ and phasor diagrams for other two are as follows

$W_1 = V_{RY}\ I_R$ cos(angle between $\bar{V}_{RY}$ and $\bar{I}_R$)

$= 400\times 5\times\cos(90^\circ) = 0$ W

$W_3 = V_{BY}\ I_B$ cos(angle between $\bar{V}_{BY}$ and $\bar{I}_B$)

$= 400\times 5\times\cos(30^\circ)$

$= 400\times 5\times\frac{\sqrt{3}}{2} = 1732$ W

$W_1 = 0$, $W_2 = 0$, $W_3 = 1732$ W

14. Ans: (c)

Sol: Energy recorded (kWhr)

$= \frac{5\text{ rev}}{1200\text{ rev/kwhr}} = 4.1667\times 10^{-3}$ kwhr

Energy = 4.1667 Whr

Load power $= \frac{4.1667\text{ Whr}}{75\text{ sec}} = \frac{4.1667\text{ Whr}}{\frac{75}{3600}\text{hr}}$

Load power = 200 W

15. Ans: (d)

Sol: Energy recorded (measured value)

$= \frac{51\text{ rev}}{360\text{ rev/kwhr}}$

$= 0.141667$ kwhr

Energy consumed (True value)

$= \frac{10\text{ kw}\times 50}{3600} = 0.13889$ kwhr

Error $= \frac{0.141667 - 0.13889}{0.13889}\times 100$

$= 1.999\% \simeq +2\ \%$

Conventional Practice Solutions

01.

Sol: Power calculated by freshman

$P = I^2 R = (30.4)^2 \times 0.0105$

$= 9.70368$ W

True value of current (I_T) =

$30.4A + \left(\frac{1.2}{100}\times 30.4A\right) = 30.77$ A

True value of resistance (R_T) =

$0.0105\Omega + \left(\frac{0.3}{100}\times 0.0105\Omega\right) = 0.010532\Omega$

True power (P_T) = $(30.77)^2 \times 0.010532\Omega$

$= 9.971$W

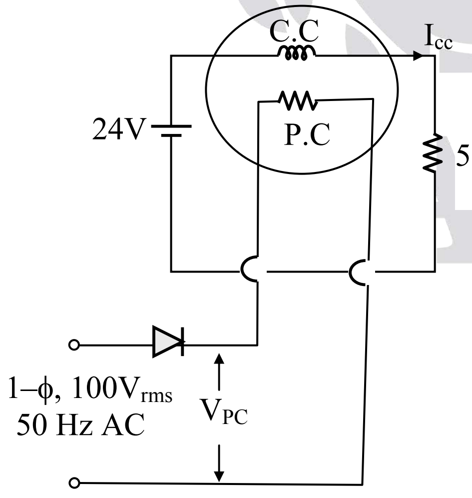
$$\frac{\textit{True value of power}}{\textit{power calculated by freshman}}\times 100$$

$$= \frac{9.971\text{W}}{9.70368}\times 100$$

$= 102.75\%$

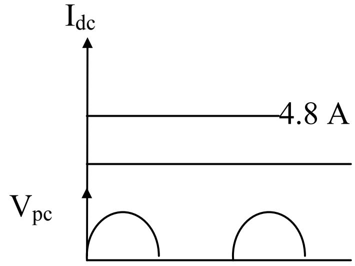
02.

Sol:



$I_{dc} = I_{cc} = \frac{24V}{5\Omega} = 4.8$A

$V_{rms} = 100$V, $V_{max} = 100\times\sqrt{2}$



Wattmeter reading (W)

$$= \frac{1}{2\pi}\int_0^{2\pi}(V_{pc}\times I_{dc})dwt$$

$$W = \frac{1}{2\pi}\left[\int_0^{\pi}(100\sqrt{2}\sin\omega t\times 4.8)d\omega t + \int_{\pi}^{2\pi}(0\times 4.8)d\omega t\right]$$

$$= \frac{4.8\times 100\sqrt{2}}{2\pi}\left[(-\cos\omega t)_0^{\pi}\right]$$

$= 216.07$ W

03.

Sol: $W_m = (1+\tan\phi\tan\beta)\, W_T$

$700W = (1+\tan\phi\tan 2)\, W_T$ ------ (1)

$620W = (1+\tan\phi\tan 1)\, W_T$ ------ (2)

$$\Rightarrow \frac{(1)}{(2)} = \frac{35}{31} = \frac{(1+\tan\phi\times 0.034)}{1+\tan\phi\times 0.0174}$$

$\Rightarrow (1+\tan\phi\times 0.0174)\,35$
$= (1+\tan\phi\times 0.03492)\,31$

$\Rightarrow 35+35\,(\tan\phi\times 0.0174)$
$= 31+31\tan\phi\times 0.03492$

$\Rightarrow 35-31 = 1.0852\tan\phi - 0.609\tan\phi$

$\Rightarrow 4 = 0.4762\tan\phi$

$\Rightarrow \phi = 83.2108$

$\cos\phi = 0.1182$

$$WT = \frac{700}{(1+\tan 83.2108\times\tan 2)}$$

$= 541.2407$

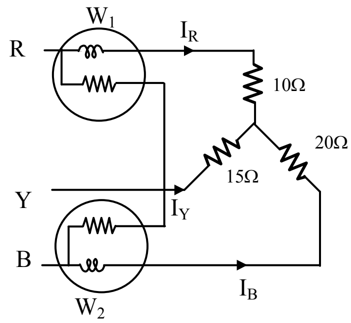
$V = 240$V

$P = VI\cos\phi$

$$\Rightarrow I = \frac{p}{v\cos\phi} = \frac{541.2407}{240\times 0.1182} = 19.079A$$

04.

Sol:



Consider RYB phase sequence

$$V_R = \frac{440V}{\sqrt{3}}\angle 0° = 254.03\angle 0° V$$

$V_Y = 254.03\ \angle -120° V$

$V_B = 254.03\ \angle -240° V$

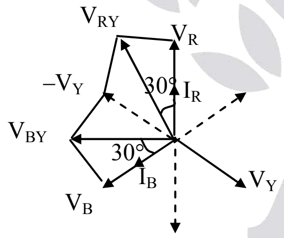
$$\Rightarrow I_R = \frac{V_R}{10\Omega} = \frac{254.03\angle 0}{10\Omega} = 25.403\angle 0$$

$$I_Y = \frac{V_y}{15\Omega} = \frac{254.03\angle -120}{15\Omega} = 16.935\angle -120$$

$$I_B = \frac{V_B}{20\Omega} = \frac{254.03\angle -240}{20\Omega} = 12.701\angle -240$$

According to connections

W = P.C voltage × C.C current × cost of angle between (P.C Voltage & CC current]



$W_1 = V_{RY} \times I_R \cos (V_{RY}\ \&\ I_R)$

$W_1 = 440V \times 25.403 \times \cos 30$

$= 9679.84W$

$W_2 = V_{BY} \times \cos (V_{BY}\ \&\ I_B) \times I_B$

$= 440V \times 12.701 \times \cos\ 30$

$= 4839.92$ W

3ϕ Total $P = W_1 + W_2$

$= 14.519$ kW

05.

Sol: **(i)** $P_1 = 5000W$, $P_2 = -1000W$

Total power $(P_T) = P_1 + P_2 \Rightarrow$

$5000 - 1000 = 4000W$

Power Factor Angle (ϕ)

$$= \tan^{-1}\left[\sqrt{3}\frac{P_1 - P_2}{P_1 + P_2}\right]$$

$$\Rightarrow \tan^{-1}\left[\sqrt{3}\left[\frac{5000-(-1000)}{5000-1000}\right]\right]$$

$$\Rightarrow \tan^{-1}\left[\sqrt{3}\left(\frac{6000}{4000}\right)\right] \Rightarrow \text{Tan}^{-1}\left[\frac{3\sqrt{3}}{2}\right]\phi$$

$= 68.94°$

$\therefore$ Power Factor $\cos\phi = \cos(68.94°)$

$\Rightarrow 0.3593$

≈ 0.36 Lag

(ii) Ans: Power consumed By each phase

$$= \frac{P_{Total}}{3} = \frac{4000}{3} = 1333.33W$$

In Δ connected system, voltage of each phase

$V_{ph} = V_L = 440V$

= supply voltage

→ current in each phase

$$= \frac{1333.33}{440 \times 0.36} = 8.41748\ \text{Amp}$$

→ Impedance of each phase

$$= \frac{440}{8.41748} = 52.27217\ \Omega$$

→ Resistance of each phase

$$= \frac{1333.33}{(8.41748)^2} = 18.818\,\Omega$$

→ Reactance (X) of each phase

$$= \sqrt{(52.27217)^2 - (18.818)^2} = 48.7674\Omega$$

→ In order that one of the wattmeter's should read zero, the power factor should be 0.5

∴ cos ϕ = 0.5, & Tanϕ = 1.73

∴ Reactance of circuit ⇒ X = RTanϕ

X = 18.818 × 1.73 ⇒ X = 32.55514Ω

∴ Capacitive Reactance Required

= 48.7674 – 32.55514

= 16.21226

$$\text{Capacitance (C)} = \frac{1}{2\pi\times 50\times 16.21226}$$

C = 196.33 μF

06.

Sol: Load power = 230 × 5×0.1 = 115W

Load power factor cosϕ = 0.1

∴ ϕ = 84.26° and sinϕ = 0.995 and tanϕ = 9.95

→ Resistance of pressure coil circuit

$R_p = 10000\Omega$

→ Reactance of pressure coil circuit

$= 2\pi \times 50 \times 100 \times 10^{-3} = 31.416\Omega$

As the phase Angle of pressure coil circuit is small,

$$\beta = \tan\beta \approx \frac{31.416}{10000} = 3.1416 \times 10^{-3}\text{ rad}$$

= 0.0031416 rad

→ When the pressure coil is connected on the load side the wattmeter measures power loss in pressure coil circuit in addition to load power

True power = VIcosϕ = 230 × 5 × 0.1

= 115W

Let us consider only the effect of Inductance

Reading of wattmeter = true power [1 + tanϕ Tanβ]

= 115 [1+ 9.95 × 0.00314] = 118.593W

→ Power loss in pressure coil circuit

$$= \frac{V^2}{R_p} = \frac{230^2}{10000} = 5.29\text{ W}$$

∴ Reading of wattmeter considering The power loss in pressure coil circuit

= 118.593 + 5.29 = 123.883

$$\text{Percentage error} = \frac{123.883-115}{115}\times 100$$

= 7.724%

07.

Sol: $E_{RY} = 400\angle 0°$, $E_{YB} = 400\angle -120°$,

$E_{BR} = 400\angle 120°$,

$$I_{RY} = \frac{400}{30-j40} = \frac{400}{50\angle -53°} = 8\angle 53° = 4.8 + j6.4$$

$$I_{RB} = \frac{400\angle 120°}{40}$$

$\Rightarrow 10\angle -60° = I_{ML}$,

[wattmeter current coil current]

For the wattmeter pressure coil circuit

$20\, I_{RB} + V_1V_2 - (-j40\, I_{RY}) = 0$

(i.e) $0 = 200\angle -60° + 40\angle 90° \times 8\angle 53° + V_1V_2$

$\therefore -V_1V_2 = 100 - j173 + 320\angle 143$

$= 100 - j173 - 255.6 + j195.2$

$\therefore -V_1V_2 = -155.6 + j20$

$V_1V_2 = 155.6 - j20 = 156.9\angle -7.3°$

∴ the reading of wattmeter = $I_{ML} \cdot V_1V_2$

$= 10\times 156.9 \times 10^{-3}\cos(52.7°)$ kW = 0.94 kW

08.

Sol: CBA → Phase sequence same as ACB phase sequence

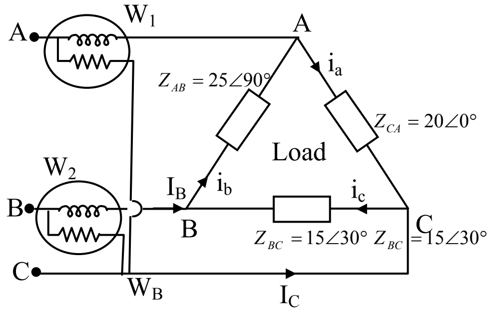


Fig.(b)

→ supply Line voltage = 230V

$V_{AC}\angle 0° = V_L\angle 0° = 230\angle 0°$

$V_{CB}\angle -120° = V_L\angle -120° = 230\angle -120°$

$V_{BA}\angle -240° = V_L\angle -240° = 230\angle -240°$

Phase current $(i_a) = \dfrac{V_{AC}\angle 0°}{20\angle 0°} = \dfrac{230\angle 0°}{20\angle 0°}$

$= 11.5\angle 0°$ A

$i_b = \dfrac{V_{BA}\angle -240°}{25\angle 90°} = 9.2\angle -330°$ A

$i_c = \dfrac{V_{CB}\angle -120°}{15\angle 30°} = \dfrac{230\angle -120°}{15\angle 30°}$

$= 15.33\angle -150°$ A

Line current $(I_A) = i_a - i_b$

$= [11.5\angle 0° - 9.2\angle -330°]$

$(I_A) = 11.5 - 9.2\left[\dfrac{\sqrt{3}}{2} + \dfrac{j}{2}\right]$

$(I_A) = 11.5 - 7.96743 - j4.6$

$(I_A) = 3.53257 - j4.6 = 5.8\angle -52.477$

$W_1 = V_{pc}\, I_{cc} \cos[\angle V_{pc}\ \&\ I_{cc}]$

$= V_{AC} \times I_A \cos[\angle V_{Ac}\ \&\ I_A]$

$= 230 \times 5.8 \times \cos[52.477°]$

$= 812.512$W

For W_2 Reading: $I_B = i_b - i_c$

$= 9.2\angle -330° - 15.33\angle -150°$

$I_B = 9.2\left(\dfrac{\sqrt{3}}{2} + \dfrac{j}{2}\right) - 15.33\left(\dfrac{-\sqrt{3}}{2} - \dfrac{j}{2}\right)$

$= 21.2436 + j12.265$

$I_B = 24.53\angle 30°$

$V_{BC} = V_{CB}\angle \theta + 180° = 230\angle -120° + 180°$

$V_{PC} = V_{BC} = 230\angle +60°$

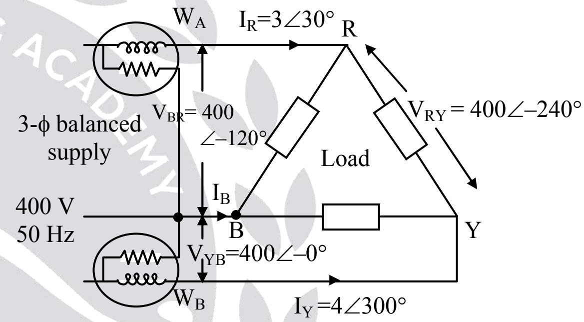
$= 230 \times 24.53 \cos(60° - 30°)$

$= 5641.9 \times 0.866$

$= 4886.6$W

09.

Sol:



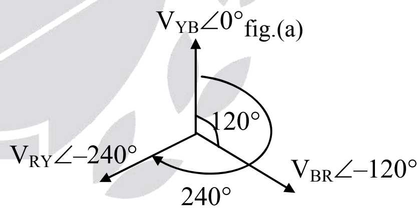


fig.(a)

$W_A = V_{RB} \times I_R \times \cos[\angle V_{RB}\ \&\ I_R]$

$V_{BR} = 400\angle -120°$, But $V_{YB}\angle 0°$

$V_{pc} = V_{RB} = 400\angle -120° + 180°$

$V_{RB} = 400\angle +60° = V_{PC}$

$W_A = 400 \times 3 \times \cos(60 - 30°)$

$= 1039.23$W

$W_B = V_{PC} \times I_{CC} \times \cos(\angle V_{pc}\ \&\ I_{CC})$

$V_{pc} = V_{YB} = 400\angle 0°$, $I_{CC} = I_Y = 4\angle 300°$

$W_B = 400 \times 4 \times \cos(-300°) = 800$ W

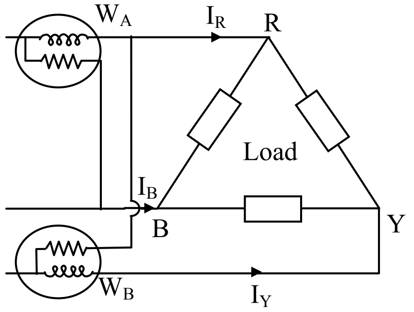


fig.(b)

$W_A = V_{PC} \times I_{CC} \times \cos\ (\angle V_{pc}\ \&\ I_{CC})$

$V_{PC} = V_{RB} = 400\ \angle{+60°}$

$I_{CC} = I_R = 3\ \angle\ 30°$

$W_A = 400 \times 3 \times \cos(60 - 30°)$

$W_A = 1039.23W$

$W_B = V_{PC} \times I_{CC} \times \cos\ (\angle V_{pc}\ \&\ I_{CC})$

$= V_{YR} \times I_Y \times \cos\ (\angle V_{YR}\ \&\ I_Y)$

$V_{PC} = V_{YR} = 400\angle -240+180°$

$[\because\ V_{RY} = 400\angle -240°]$

$V_{YR} = 400\angle -60°,\ I_{CC} = I_Y = 4\angle\ 300°$

$W_B = 400 \times 4 \times \cos(-60° - 300°)$

$W_B = 1600W$

10. Data not sufficient

11.

Sol: Phantom loading: when the current rating of a meter under test is high, a test with actual loading assignments would involve a considerable waste of power. In order to avoid this, phantom loading is done. Phantom loading consists of supplying the pressure coil circuit from a circuit of required normal voltage, and the current coil circuit from a separate low voltage supply. It is possible to circulate the rated current through the current circuit with a low voltage supply as the impedance of this circuit is very low. With this arrangement, the total power supplied for the test is that due to small pressure coil current at normal voltage, plus that due to the current with low voltage. Therefore, power required for testing the meter with phantom loading is comparatively very small.

Given data:

V = 230V, I = 12A

$\cos\phi = 0.8$lag, K = 1200 rev/kWh,

$N_1 = 1150$ rev

(i) Error in registration,

Actual kWh consumed

$= 230 \times 12 \times 0.8 \times \frac{1}{2} \times 10^{-3}$

= 1.104 kWh.

$\Rightarrow$ Actual revolutions registered

$= k \times kWh$

$= 1200 \times 1.104$

$N_2 = 1324.8$ Revolutions

$$\text{Error registration} = \frac{N_2 - N_1}{N_2} \times 100$$

$$= \frac{1324.8 - 1150}{1324.8} \times 100$$

= 13.2%

(ii) Revolutions per minute $= \frac{1324.8}{60}$

= 22.08 rev/min

Revolutions registered/min $= \frac{1150}{30}$

(half an hour measuring)

= 38.33rev/min

$$\%\ \text{Error} = \frac{38.33 - 22.08}{22.08} \times 100$$

= 73.6% (fast)

Rectification: In energy meter, error in rpm can be rectified by bringing the braking magnet near to the centre of disc.

Chapter 5 Bridge Measurement of R, L & C

Objective Practice Solutions

01. Ans: (a)

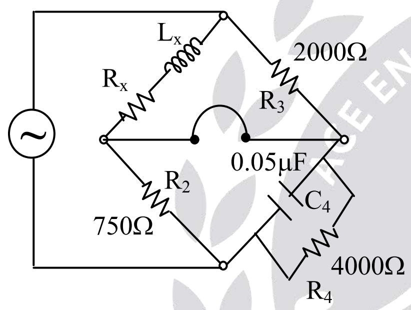
Sol: It is Maxwell Inductance Capacitance bridge

$R_x R_4 = R_2 R_3$

$$R_x = \frac{R_2 R_3}{R_4}$$

$$R_x = \frac{750 \times 2000}{4000}$$

$R_x = 375\ \Omega$



$$\frac{L_x}{C_4} = R_2 R_3$$

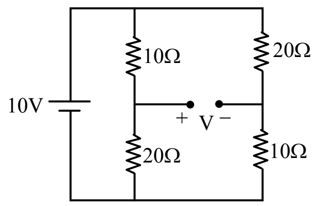
$L_x = C_4 R_2 R_3$

$L_x = 0.05 \times 10^{-6} \times 750 \times 2000$

$L_x = 75$ mH

02. Ans: (d)

Sol:



$V = V_+ - V_-$

$$= 10 \times \frac{20}{30} - 10 \times \frac{10}{30}$$

$= 6.66 - 3.33 = 3.33$ V

03. Ans: (c)

Sol: The voltage across R_2 is

$$= E\frac{R_2}{R_1 + R_2} = \frac{E}{2}$$

The voltage across R_1 is

$$= E\frac{R_1}{R_1 + R_2} = \frac{E}{2}$$

Now, $\frac{E}{2} = IR_3 + V$

$$I = \frac{E - 2V}{2R_3} \Rightarrow I = \frac{E - 2V}{2R}$$

and $\frac{E}{2} = IR_4$

$$\frac{E}{2} = \left(\frac{E - 2V}{2R}\right)(R + \Delta R)$$

$ER = (E - 2V)(R + \Delta R)$

$$R + \Delta R = \frac{ER}{(E - 2V)}$$

$$\Delta R = \frac{ER}{(E - 2V)} - R$$

$$= \frac{ER - ER + 2VR}{(E - 2V)}$$

$$\Delta R = \frac{2VR}{(E - 2V)}$$

04. Ans: (a)

Sol: The deflection of galvanometer is directly proportional to current passing through circuit, hence inversely proportional to the total resistance of the circuit.

Let S = standard resistance

R = Unknown resistance

G = Galvanometer resistance

θ_1 = Deflection with S

θ_2 = Deflection with R

$$\therefore \frac{\theta_1}{\theta_2} = \frac{R+G}{S+G}$$

$$\Rightarrow R = (S+G)\frac{\theta_1}{\theta_2} - G$$

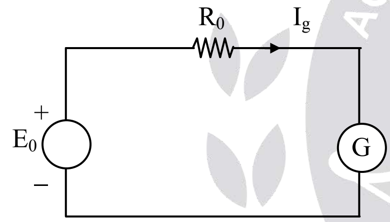
$$= (0.5\times10^6 + 10\times10^3)\left(\frac{41}{51}\right) - 10\times10^3$$

$= 0.4 \times 10^6\ \Omega$

$= 0.4\ M\Omega$

05. Ans: (a)

Sol: Thevenin's equivalent of circuit is



R_0 = Resistance of circuit looking into terminals b & d with a & c short circuited.

$$= \frac{RS}{R+S} + \frac{PQ}{P+Q} = \frac{1\times5}{1+5} + \frac{1\times Q}{1+Q}$$

$$= 0.833 + \frac{Q}{1+Q} K\Omega$$

Now, $R_0 + G = \dfrac{24\times10^{-3}}{13.6\times10^{-6}} = 1.765\ k\Omega$

(or) $R_0 = 1765 - 100 = 1665\ \Omega$

$$0.833 + \frac{Q}{1+Q} = 1.665$$

$\Rightarrow Q = 4.95\ k\Omega$

06. Ans: (c)

Sol: $R = \dfrac{0.4343\ T}{C\log_{10}\left(\dfrac{E}{V}\right)}$

$$= \frac{0.4343\times60}{600\times10^{-2}\times\log_{10}\left(\dfrac{250}{92}\right)}$$

$$= \frac{26.058}{260.49\times10^{-12}}$$

$R = 100.03 \times 10^9\ \Omega$

07. Ans: 0.118 μF, 4.26kΩ

Sol: Given: $R_3 = 1000\ \Omega$

$$C_1 = \frac{\varepsilon_0\varepsilon_r A}{d}$$

$$= \frac{2.3\times4\pi\times10^{-7}\times314\times10^{-4}}{0.3\times10^{-2}}$$

$C_1 = 30.25\ \mu F$

$\delta = 9°$ for 50 Hz

$\tan\delta = \omega C_1 r_1 = \omega L_4 R_4$

$\Rightarrow r_1 = 16.67\ \Omega$

Variable resistor $(R_4) = R_3\left(\dfrac{C_1}{C_2}\right)$

$R_4 = 4.26k\ \Omega$, $C_4 = 0.118\ \mu F$

08.

Sol: Resistance of unknown resistor required for balance

R = (P/Q)S = (1000/100) × 200 = 2000 Ω.

In the actual bridge the unknown resistor has a value of 2005 Ω or the deviation from the balance conditions is ΔR = 2005 – 2000 = 5 Ω.

Thevenin source generator emf

$$E_0 = E\left[\frac{R}{R+S} - \frac{P}{P+Q}\right]$$

$$= 5\left[\frac{2005}{2005+200} - \frac{1000}{1000+100}\right]$$

$$= 1.0307 \times 10^{-3}\,V.$$

Internal resistance of bridge looking into terminals b and d.

$$R_0 = \frac{RS}{R+S} + \frac{PQ}{P+Q}$$

$$= \frac{2005\times 200}{2005+200} + \frac{1000\times 100}{1000+100}$$

$$= 272.8\ \Omega$$

Hence the current through the galvanometer

$$I_g = \frac{E_0}{R_0 + G}$$

$$= \frac{1.0307\times 10^{-3}}{272.8+100}\,A$$

$$= 2.77\ \mu A.$$

Deflection of the galvanometer

$$\theta = S_i I_g = 10 \times 2.77$$

$$= 27.7\ mm/\Omega.$$

Sensitivity of bridge

$$S_B = \frac{\theta}{\Delta R}$$

$$= \frac{27.7}{5} = 5.54\ mm/\Omega$$

09. Ans: (d)

Sol: $R_1 R_4 = R_2 R_3$

$$R_4 = \frac{R_2 R_3}{R_1}$$

$$= \frac{5\times 100}{10} \pm (2\% + 5\% + 3\%)$$

$$= 50 \pm 10\%\ \Omega$$

10. Ans: (c)

Sol: Under balanced condition, current through Galvanometer is zero, then

$R_{eq} = (120\Omega + 80\Omega) \parallel (120\Omega + 80\Omega)$

$= 100\ \Omega$

$$I_B = \frac{1V}{100\Omega} = 10\ mA$$

11. Ans: (c)

Sol: $\text{Sensitivity} = \dfrac{\text{Change in output}}{\text{Change in input}}$

$$= \frac{3\ mm}{6\Omega} = 0.5\ mm/\Omega$$

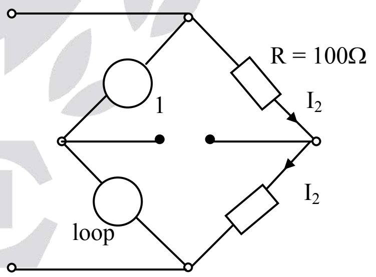
12. Ans: (d)

Sol: Changing the arms resistance by same value will not affect the Balance condition.

13. Ans: (a)

Sol: $V_1 = \sqrt{2}\cos(1000t)\ V$

$V_2 = 2\cos(1000t + 45^\circ)\ V$



Under balanced condition,

$V_1 = I_2 R$

$$I_2 = \frac{V_1}{R} = \frac{\sqrt{2}\cos 1000t}{100}$$

$$\left.\begin{aligned} I_2 &= 10^{-2}\times\sqrt{2}\cos(1000t) \\ V_2 &= 2\cos(1000t + 45^\circ) \end{aligned}\right\}\ \text{At } Z_x$$

'I_2' lags 'V_2' by 45°. So, Z_x has 'R' and 'L' in series.

$$R = Z\cos\theta = \frac{2}{10^{-2}\times\sqrt{2}}\cos 45^\circ = 100\ \Omega$$

$$X_L = Z\sin\theta$$

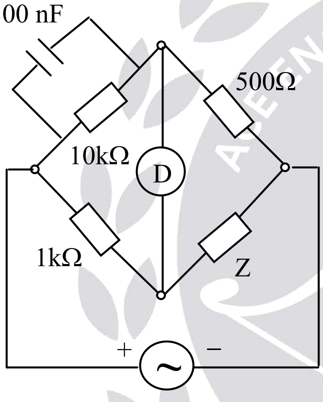
$$= \frac{2}{\sqrt{2}\times 10^{-2}}\sin 45^\circ = 100\ \Omega$$

$$X_L = \omega L$$

$$L = \frac{X_L}{\omega} = \frac{100}{1000} = 0.1\text{ H} = 100\text{ mH}$$

14. Ans: (b)

Sol:



$$R \parallel \frac{1}{j\omega C} = \frac{R}{1+j\omega RC}$$

$$\left(\frac{R}{1+j\omega RC}\right)Z = 1k\Omega\times 500\Omega$$

$$\left(\frac{10k\Omega}{1+j\omega\times 10k\Omega\times 100\times 10^{-9}}\right)Z = 1k\Omega\times 500\Omega$$

$$\frac{10^4\times Z}{1+j\omega\times 10^{-3}} = 50\times 10^4$$

$$Z = 50 + j\omega\times 0.05$$

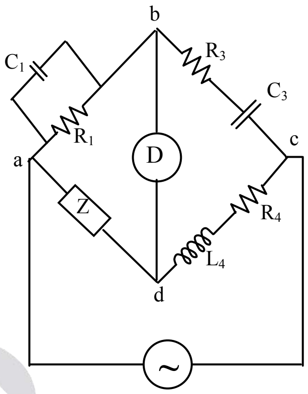
$$Z = R + j\omega L$$

$R = 50\ \Omega$ in series with $L = 0.05$ H

Conventional Practice Solutions

01.

Sol: The circuit diagram is shown below.



$Z_1 = 303.3\ \angle -72.4°$

$Z_3 = 1049.5\ \angle -17.7°$

$Z_4 = 274.8\ \angle\ 43.3°$

Using balance conditions,

$Z_1 Z_4 = Z_2 Z_3 \quad \rightarrow (1)$

$\theta_1 + \theta_4 = \theta_2 + \theta_3 \rightarrow (2)$

$Z_2 = 79.4$ (from (1))

$\theta_2 = -11.4°$ (from (2))

$\therefore Z_2 = 79.4\ \angle -11.4° = 77.8 - j15.7$

$R = 77.8$

$X_C = 15.7$

$C = 10.2\ \mu F$

So, resistance of value 77.8 Ω in series with C of value 10.2 μ F

02.

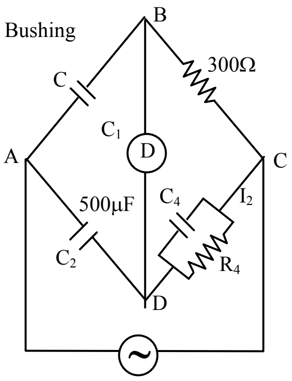
Sol: Given data: f = 50 Hz, $R_3 = 300\Omega$,

$C_2 = 500\ \mu F$, $R_4 = 72.6\ \Omega$, $C_4 = 0.148\ \mu F$

f = 50Hz

$Z_1 Z_4 = Z_2 Z_3$

$Z_1 = Z_2 Z_3 Y_4$



$$Z_1 = R_3 \times \frac{1}{j\omega C_2}\left[j\omega C_4 + \frac{1}{R_4}\right]$$

$$\frac{1}{j\omega C_1} = R_3\frac{C_4}{C_2} + \frac{R_3}{j\omega C_2 R_4}$$

$$C_1 = C_2\frac{R_4}{R_3} = 500\times10^{-12}\times\frac{72.6}{300} = 121\text{ PF}$$

If we consider in bushing R_1 in series

$$R_1R_4\frac{-jR_4}{\omega C_1} = -\frac{jR_3}{\omega C_2} + \frac{R_3R_4C_4}{C_2}$$

$$R_1 = \frac{R_3C_4}{C_2},\quad C_1 = C_2\frac{R_4}{R_3}$$

Loss angle $\tan\delta = \omega C_1R_1$

$$= \omega\times\frac{R_3C_4}{C_2}\times C_2\frac{R_4}{R_3}$$

$$= \omega C_4R_4$$

$$= 2\pi\times 50\times 72.6\times10^{-6}\times 0.148$$

$\delta = 0.1934°$

03.

Sol: We know that $\varepsilon_r = \frac{c_1 d}{\varepsilon_0 A}$

$$\Rightarrow \frac{\varepsilon_r\varepsilon_0 A}{d} = c_1$$

$$\Rightarrow \frac{2.3\times8.854\times10^{-12}\times314\times10^{-4}}{0.3\times10^{-2}} = c_1$$

$\therefore\ c_1 = 213.145\text{pF}$

$$r_1 = \frac{c_4}{c_2}R_3$$

$$R_4 = \frac{c_1}{c_2}R_3 = \frac{213.145\text{pF}}{50\text{ pF}}\times1000 = 4.269\text{ k}\Omega$$

$\tan\delta = 9^0$

$\delta = \tan^{-1}(9^0) = 1.46^0$

$\tan\delta = \omega\, c_4R_4$

$0.1583 = \omega C_4R_4$

$$c_4 = \frac{0.1583}{2\times\pi\times f\times R_4} = 0.1180\ \mu\text{F}$$

$$r_1 = \frac{c_4}{c_2}\times R_3 = \frac{0.1180\ \mu\text{F}}{50\text{ pF}}\times1000$$

$= 2.36\text{ M}\Omega$

04.

Sol: Given

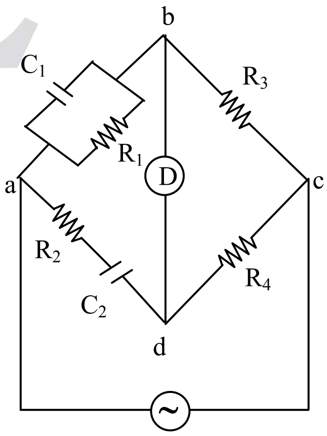
$R_1 = 800\ \Omega$

$C_1 = 0.4\ \mu\text{F}$

$R_4 = 1200\ \Omega$

$R_2 = 500\ \Omega$

$C_2 = 1\text{ pF}$



This is wien's bridge under balanced condition, $f = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$ Hz

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2}$$

$$\Rightarrow f = \frac{1}{2\pi\sqrt{800\times500\times0.4\times10^{-18}}} \text{Mz}$$

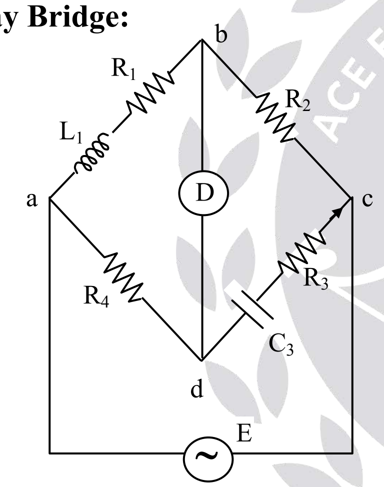
f = 397.9 kHz

also, $\frac{1200}{R_3} = \frac{500}{800} + \frac{0.4}{10^{-6}}$

$\Rightarrow R_3 = 3\ m\Omega$

05.

Sol: Hay Bridge:



At balance condition, $Z_1Z_4 = Z_2Z_3$ and phase angles are also equal.

Here, phase null condition means phase angles are equal.

$$\theta_1 = \tan^{-1}\left(\frac{\omega L_1}{R_1}\right)$$

(Or)

$$\tan\theta_1 = \frac{\omega L_1}{R_1} = \text{Quality factor}$$

$$\tan\theta_C = \tan\theta_3 = \frac{1}{\omega C_3 R_3}$$

$\theta_1 = \theta_3$ (because θ_3 is negative)

$$\frac{\omega L_1}{R_1} = \frac{1}{\omega C_3 R_3}$$

$$Q = \frac{\omega L_1}{R_1} = \frac{1}{\omega C_3 R_3}$$

Here $Q = \frac{1}{\omega C_3 R_3}$

Take 'I' is the current flowing in R_3 and 'C_3'.

So, $Q = \frac{I}{\omega C_3 (IR_3)}$

$$\Rightarrow \frac{I}{\omega C_3} \times \frac{1}{IR_3}$$

The potential drop in $C_3 = \frac{I}{\omega C_3} = V_{C_3}$

$\Rightarrow$ Voltage across 'C_3'

IR_3 = voltage across resistor 'R_3'

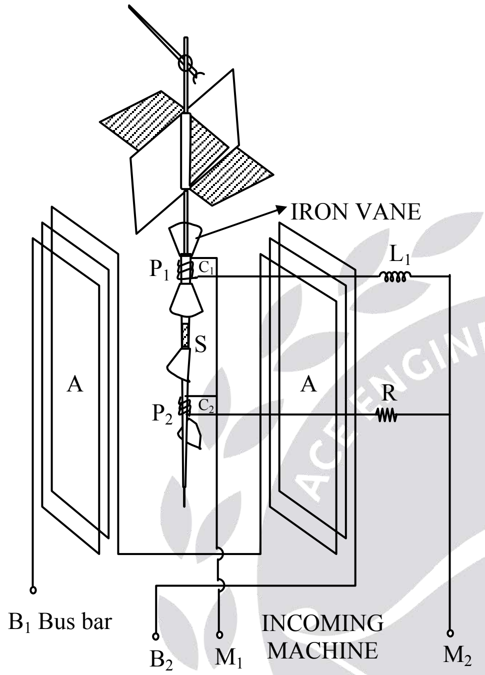
$$Q = \frac{\text{Voltage across } C_3}{\text{Voltage across } R_3}$$

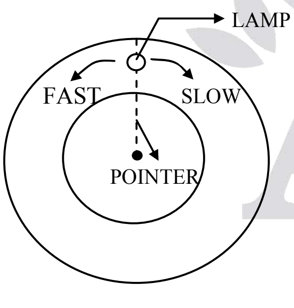
Chapter 6 Measurement of Frequency & PF

Conventional Practice Solutions

01.

Sol:





Constructional features of moving iron synchroscope:

- Figure above shows the construction of a moving iron synchroscope, which is due to Lip man.
- It has a fixed coil divided into two parts. This fixed coil A is designed for a small value of current and is connected in series with a resistance across two phases of the bus bar.
- There are two iron cylinders C_1 and C_2 mounted on the spindle. Each iron cylinder is provided with two iron vanes, whose axes are 180^0 out with each other.
- The iron cylinders are excited by two pressure coils P_1 and P_2, which are connected to two phases of incoming machine.
- One of the coils has a series resistance and the other has a series inductance.
- This is done in order to create an artificial phase difference of 90^0 between the currents of two pressure coils.
- There are no control springs. The instrument is provided with a pointer which moves over a dial marked fast and slow.

Principle of working:

- When the Frequency of incoming machine is the same as that of the bus bars, the instrument behaves exactly like the corresponding form of the power factor meter.
- The deflection of the pointer from the plane of reference is equal to phase difference between the two voltages.

- However, if the frequencies of the two voltages are different, the pointer rotates continuously at a speed corresponding to difference in frequency of the two voltages.
- The direction of rotation depends whether the incoming machine is too fast or too slow.
- Let v_1 and v_2 be the voltages of bus bar and incoming machine respectively.
- Let the frequencies of the two voltages be equal.

  Torques produced by coils P_1 and P_2 are

  $T_1 = kv_1v_2\sin\theta\cos(\pm\alpha)$

  $T_2 = kv_1v_2\sin(90^0-\theta)\cos(90^0\pm\alpha)$

  $= kv_1v_2\cos\theta\sin(\pm\alpha)$

  Where

  θ = deflection of the pointer from plane of reference. This plane of reference is the vertical position of the pointer.

  α = phase angle between the two voltages.
- The two torques are in opposite direction, therefore, under equilibrium

  $T_1 = T_2$

  $kv_1v_2\sin\theta\cos(\pm\alpha) = kv_1v_2\cos\theta\sin(\pm\alpha)$

  (or) $\theta = \pm\alpha$
- Thus the pointer is stationary and its deflection from plane of reference equals the phase difference between the two voltages.
- If the frequency of the incoming machine differs from that of the bus bars, the torques are

  $T_1 = kv_1v_2\sin\theta\cos(\pm\pi f't\pm\alpha)$

  And

  $T_2 = kv_1v_2\sin(90^0-\cos(90^0-(-2\pi f't \pm\alpha)$

  $= kv_1v_2\cos\theta\sin(\pm2\pi f't\pm\alpha)$

  Where

  $f' = f_2 - f_1$ = difference in two frequencies.

  Hence at equilibrium

  $\sin\theta\cos(\pm2\pi f't\pm\alpha) = \cos\theta\sin(\pm2\pi f't\pm\alpha)$

  (or)

  $\theta = 2\pi f't\pm\alpha$

  Thus, the moving system rotates with a frequency corresponding to difference in the two frequencies.
- The direction of rotation depends upon whether the frequency of incoming machine is higher (f' positive) or lower (f' negative) than the frequency at the bus bars
- The instant of synchronizing is when the pointer is stationary ($f' = 0$) and when it is at its vertical position.
- Moving iron synchroscopes are more common in use. They are cheap and their operation is simple and also they have a 360^0 scale.

02.

Sol: Construction and working principle of a single phase electro-dynamic power factor meter:

- The construction of a single phase electrodynamometer type power factor is shown in below figure. It consists of a fixed coil, which acts as the current coil.

- This coil is split up into two parts and carries the current of the circuit under test. Therefore, the magnetic field produced by this coil is proportional to the main current.
- Two identical pressure coils A and B pivoted on a spindle constitute the moving system
- Pressure coil A has a non inductive resistance R connected in series with it, and coil B has highly inductive choke coil L connected in series with it.
- The two coils are connected across the voltage of the circuit. The values of R and L are so adjusted that the two coils carry the same value of current at normal frequency. i.e. $R = \omega L$.
- The current through coil A is in phase with the circuit voltage, while that through coils B lags the voltage by an angle Δ which is nearly equal to 90^0
- The angle between the planes of coils is also made equal to Δ. There is no controlling device. Connections to moving coils are made through thin silver or gold ligaments, which are extremely flexible and thus, give a minimum control effect on the moving system.
- In order to simplify the problem, we assume that the current through coil B lags the voltage by exactly 90^0. Also that the angle between planes of coils is exactly 90^0(i.e.$\Delta = 90^0$)
- Now, there will be two deflecting torques, one acting on coil A and the other on coil B. The coil windings are so arranged that the torques due to the two coils are opposite in direction.
- Therefore, the pointer will take up a position where these two torques are equal.
- Let us consider the case of a lagging power factor of $\cos\phi$

Deflecting torque acting on coil A is:

$T_A = KVIM_{max} \cos\phi \sin\theta$

$\theta \rightarrow$ Angular deflection from the plane of reference,

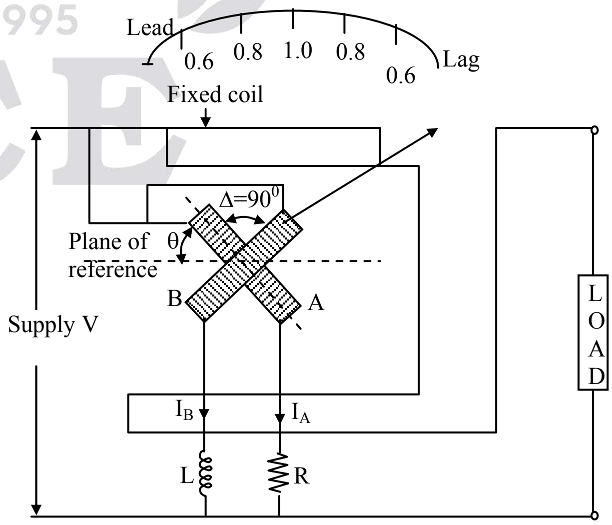
$M_{max} \rightarrow$ maximum value of mutual inductance between the two coils

This torque acts in the clockwise direction

Deflecting torque acting on coil B is:

$T_B = KVIM_{max} \cos(90^0 - \phi) \sin(90^0 + \theta)$

$= KVIM_{max} \sin\phi \cos\theta$



- This torque acts in the anticlock wise direction. The value of M_{max} is the same in the two expressions, owing to similar constructions of the coils.

- The coils will take up such a position that the two torques are equal.
  Hence at equilibrium $T_A = T_B$

$$KVIM_{max}\cos\phi\sin\theta = KVIM_{max}\sin\phi\cos\theta$$

$$\theta = \phi$$

$\therefore$ The deflection of the instrument is a measure of phase angle of the circuit. The scale of the instrument can be calibrated directly in terms of power factor.

Comparison with Moving Iron type power factor Meter:

1. The working forces are very large in moving iron type power factor meter, where as in electrodynamometer type, working forces are very small
2. All coils in a moving iron instrument are fixed and therefore, the use of ligaments is eliminated.
3. The scale in moving iron instrument extends up to 360^0
4. Moving iron instruments are simple and robust in construction, and also comparatively cheap
5. These instruments are less accurate than electrodynamometer type.

Chapter 7 Potentiometers & Instrument Transformers

Objective Practice Solutions

01. Ans: (d)

Sol: Under null balanced condition the current flow in through unknown source is zero. Therefore the power consumed in the circuit is ideally zero.

02. Ans: (d)

Sol: Potentiometer is used for measurement of low resistance, current and calibration of ammeter.

03. Ans: (a)

Sol: Since the instrument is a standardized with an emf of 1.018 V with sliding contact at 101.8 cm, it is obvious that a length 101.8 cm represents a voltage of 1.018.

Resistance of 101.8 cm length of wire

$= (101.8/200) \times 400$

$= 203.6\ \Omega$

$\therefore$ Working current $I_m = 1.018/203.6$

$= 0.005$ A

$= 5$ mA

Total resistance of the battery circuit

= resistance of rheostat

+ resistance of slide wire

$\therefore$ Resistance of rheostat

R_h = total resistance

– resistance of slide wire

$$= \frac{3}{5\times10^{-3}} - 400$$

$$= 600 - 400 = 200\,\Omega$$

04. Ans: (b)

Sol: Voltage drop per unit length

$$= \frac{1.45\,\text{V}}{50\,\text{cm}} = 0.029\ \text{V/cm}$$

Voltage drop across 75 cm length

$= 0.029 \times 75 = 2.175$ V

Current through resistor (I)

$$= \frac{2.175\,\text{V}}{0.1\,\Omega} = 21.75\ \text{A} \quad \text{(or)}$$

75 cm $\rightarrow$ 0.1 Ω

50 cm $\rightarrow$?

Slide wire resistance with standard cell

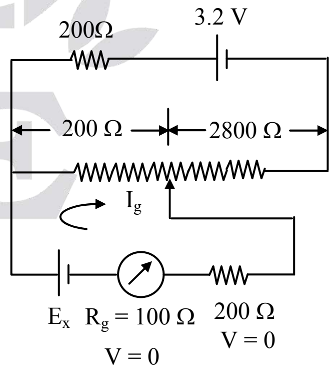
$$= \frac{50}{70} \times 0.1 = 0.067\ \Omega$$

Then $0.067 \times I_w = 1.45$ V

$$I_w = \frac{1.45}{0.067} = 21.75\ \text{A}$$

05. Ans: (a)

Sol:



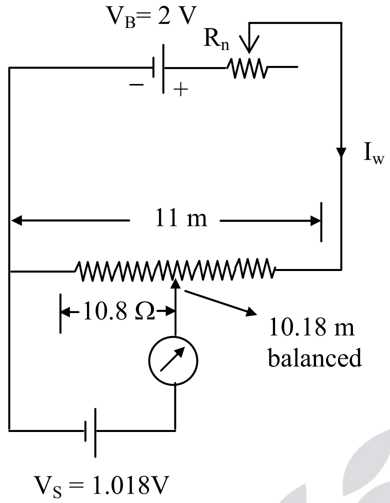
Under balanced, $I_g = 0$

$$E_x = 3.2\,\text{V} \times \frac{200}{(200+200+2800)} = 0.2\,\text{V}$$

$E_x = 200$ mV

06. Ans: (a)

Sol:



Resistance 1 Ω/cm

For 11 m → 11 Ω

For 10m + 18cm → 10.8Ω

$I_w \times 10.8\Omega = 1.018$ V

$$I_w = \frac{V_B}{R_n + 1_r}$$

$$\Rightarrow 0.1 = \frac{2}{R_n + 11\Omega}$$

$$R_n = \frac{2}{0.1} - 11$$

$$= 9\ \Omega$$

07. Ans: (a)

Sol: It is closed loop inverting amplifier

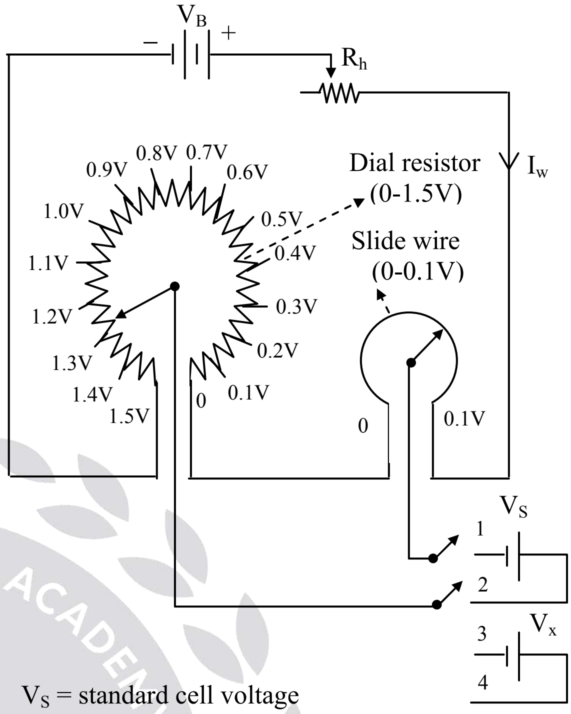
$$V_0 = -\frac{R_f}{R_i} V_{in}$$

$$= -\frac{15\,k\Omega}{10\,k\Omega} \times 1V$$

$$= -1.5\ V$$

08. Ans: (a)

Sol:



Dial resistor has 15 steps and each step is 10 Ω = 15 × 10 Ω = 150 Ω

Slide wire resistance = 10 Ω

Total resistance = 150+10 = 160 Ω

Working current (I_w) = 10 mA

Range of potentiometer

= 10mA × 160 Ω = 1.6 V

Resolution of potentiometer

$$= \frac{\text{working current} \times \text{slide wire resistance}}{\text{slide wire length}}$$

$$= \frac{10\ mA \times 10\ \Omega}{100\ cm}$$

$$= 0.001\ V/cm$$

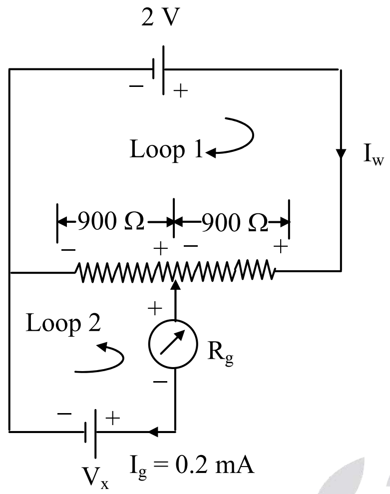
(1 div = 1 cm)

One fifth of a division can be read certainly.

$$\text{Resolution} = \frac{1}{5} \times 0.001 = 0.2\ mV$$

09. Ans: (d)

Sol:



Write KVL for loop 1

$2V - 900\ I_w - 900(I_w - 0.2mA) = 0$

$I_w = 1.211$ mA

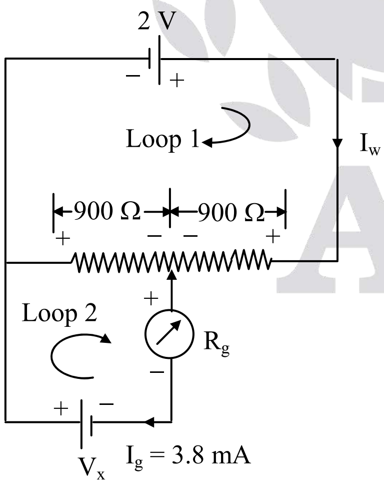
Write KVL for loop 2

$V_x + 0.2\ mA \times R_g - 900(I_w - 0.2mA) = 0$

$V_x + 0.2\times10^{-3}R_g - 900(1.211\times10^{-3} - 0.2\times10^{-3}) = 0$

$V_x = 0.909 - 0.2\times10^{-3}\ R_g$ ……. (1)

When V_x is reversed, the circuit is



Write KVL for loop (1)

$2 - 900I_w - 900(I_w - 3.8mA) = 0$

$I_w = 3.011$ mA

Write KVL for loop (2)

$V_x - 900(3.8mA - I_w) - 3.8mA\times R_g = 0$

$V_x - 900(3.8\times10^{-3} - 3.011\times10^{-3}) - 3.8\times10^{-3}\ R_g = 0$

$V_x = 0.710 + 3.8\times10^{-3}\ R_g$ ………(2)

Substitute (2) in eqn (1)

$0.710 + 3.8\times10^{-3}R_g = 0.909 - 0.2\times10^{-3}R_g$

$R_g = 49.72\ \Omega \simeq 50\ \Omega$

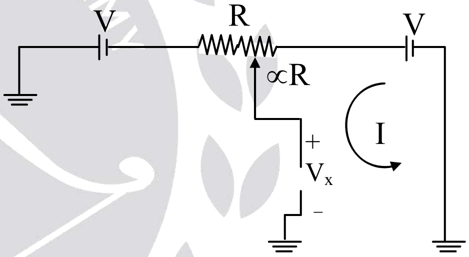
Substitute 'R_g' value in eqn (2)

$V_x = 0.710 + 3.8 \times 10^{-3} \times 50$

$= 0.9001V$

10. Ans: (a)

Sol:



$$I = \frac{2V}{R}$$

Apply KVL in loop

$-V + I\alpha R + V_x = 0$

$$-V + \frac{2V}{R} \times \alpha R + V_x = 0$$

$V - 2V\alpha = V_x$

$V_x = [1 - 2\alpha]\ V$

Conventional Practice Solutions

01.

Sol: The burden of secondary winding is purely resistive and therefore secondary winding PF is unity

PF of exciting current = 0.4

$\cos(90-\alpha) = 0.4$

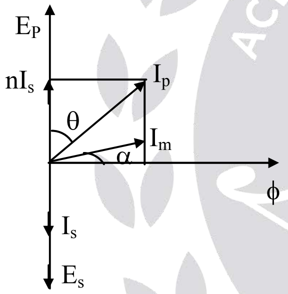
$\alpha = 23.57$

Exciting current $I_0 = 1A$

Nominal ratio $K_n = \frac{1000}{5} = 200$

Since there is no turn compensation, the turns ratio equal to the nominal ratio

$n = K_n = 200$



Rated secondary winding current, $I_s = 5A$

$nI_s = 200\times5 = 1000A$

Actual transformation Ratio

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

$$= 200 + \frac{1}{5}\sin(0+23.57) \quad = 200.08$$

$$\text{Ratio error} = \frac{K_n - R}{R}\times100$$

$$= \frac{\text{Nominal Ratio} - \text{actual ratio}}{\text{actual ratio}}\times100$$

$$= \frac{200-200.8}{200.8}\times100 = -0.04\%$$

Phone angle error

$$\theta = \frac{180°}{\pi}\left[\frac{I_0\cos(\delta+\alpha)}{nI_s}\right]$$

$$= \frac{180°}{\pi}\left[\frac{\cos(23.57)}{1000}\right]$$

$= 0.0525$

02.

Sol: Primary winding turns, $N_P = 1$

Secondary winding turns, $N_s = 300$

Turns ratio , $n = \frac{N_s}{N_p} = 300$

Secondary circuit burden impedance

$$= \sqrt{(1.5)^2 + (1.0)^2} = 1.8\ \Omega$$

Secondary winding circuit

$\cos\delta = \frac{1.5}{1.8}$ and $\sin\delta = \frac{1.0}{1.8} = 0.554$

$= 0.833$

Secondary induced voltage

$(E_s) = 5\times1.8 = 9.0V$

Primary induced voltage

$$E_P = \frac{E_s}{300} = \frac{9}{300} = 0.03V$$

Loss component of current referred to primary winding.

$$I_c = \frac{\text{iron loss}}{E} = \frac{1.2}{0.03} = 40A$$

Magnetizing current , I_m

$$= \frac{\text{magnetizing mmf}}{\text{Primary winding turns}}$$

$$= \frac{100}{1} = 100A$$

Actual ratio, $R = n + \frac{I_0}{I_c}\sin(\delta+\alpha)$

$$= n + \frac{I_e\cos\delta + I_m\sin\delta}{I_s}$$

$$= 300 + \frac{40\times0.833 + 100\times0.555}{5}$$

$$= 317.6$$

$K_n = n = 300$

Percentage Ratio = $\frac{K_n - R}{R}\times100$

$$= \frac{300-317.6}{317.6}\times100 = -5.54\%$$

Phase angle error $\theta = \frac{180°}{\pi}\left(\frac{I_m\cos\delta - Ie\sin\delta}{nI_s}\right)$

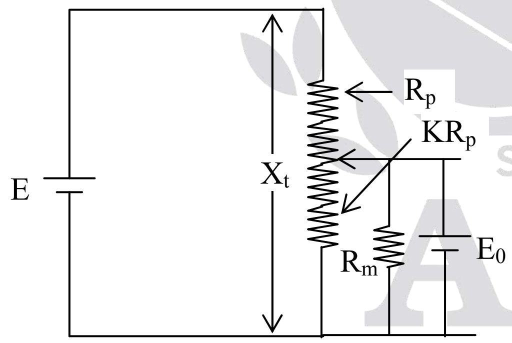
$$= \frac{180°}{\pi}\left(\frac{100\times0.833-40\times0.555}{300\times5}\right)$$

$$= 2.34°$$

03.

Sol:

(a)



Given: $X_t = 120\text{mm}$

$R_p = 24\text{k}\Omega$

$X_i = 40$ mm

So K R_p= 8kΩ

Voltage V across KR_p is

$$V = \frac{8}{24}E = 0.33E$$

after the connection of meter resistance

$R_{eq}= KR_p \parallel R_m$

$$\Rightarrow R_{eq} = \frac{15\times8}{15+8} = 5.211\text{k}\Omega$$

$$V_{eq} = \frac{5.211\times E}{(24-8)+5.211} = 0.2459E \text{ V}$$

$$\%\text{error}= \left(\frac{0.333-0.2459}{0.333}\right)\times100 = 26.22\%$$

(b) To keep error within 3% V_{new} is the voltage developed across the common resistance of R_{eq} and R_{new} .

$$3 = \frac{(0.33 - V_{new})E}{0.33E}\times100$$

$$V_{new} = 0.3233E \text{ V}$$

now $0.323 = \frac{R_{new}}{16+R_{new}}E$

$$\Rightarrow R_{new} = 7.64\text{k}\Omega$$

now, $R_{max} = \frac{8R_{new}}{8-R_{new}}$

$$= \frac{8\times7.6442}{8-7.6442} = 172\text{k}\Omega$$

04.

Sol: Phase angle of pressure coil circuit (β) = 30′

Phase angle of load = $\cos^{-1}(0.5)$ = 60°

Where

V = voltage across the load = 11 kV

I = load current = 100A

ϕ = Phase angle between current and voltage = 60°

α = phase angle bandwidth

Currents in the current and pressure coils of watt meter

V_s = voltage across secondary of the potential transformer.

I_s = secondary current of current transformer.

I_p = current in the wattmeter pressure coil.

β = angle by which I_s lags V_s on account of inductance of pressure coil = 30′ = 1/2°

δ = Phase angle of potential transformer = $45' = \frac{3}{4}^{o}$

θ = phase angle of current transformer = 90′

$= 1\frac{1}{2}^{o}$

Phase angle between pressure coil current I_P and current I_s of wattmeter current coil

$\alpha = \phi - \theta - \beta - \delta$

$= 60° - \frac{3°}{2} - \frac{1°}{2} - \frac{3°}{4}$

$= 57.25°$

$$\text{Correction factor} = k = \frac{\cos\phi}{\cos\beta.\cos\alpha}$$

$$= \frac{\cos 60°}{\cos(0.5°)\times\cos(57.25)}$$

$= 0.924$

$$\text{Percentage ratio error} = \frac{k_n - R}{R}\times 100$$

$$\text{Actual ratio } R = \frac{k_n \times 100}{(100 + \text{percentage ratio error})}$$

$$\text{Actual ratio of C.T} = \frac{20\times 100}{(100 - 0.2)}$$

$= 20.04$

$$\text{Actual ratio of P.T} = \frac{100\times 100}{(100 + 0.8)}$$

$= 99.2$

Power of lead

= k × actual ratio of P.T × actual ratio of C.T × wattmeter × wattmeter reading

(2) power of lead = 11kV ×0.5 ×100

= 0.924 × 20.4 × 99.2× wattmeter reading

(3) Wattmeter reading

= 294.18 Watts

Chapter 8 Cathode Ray Oscilloscope

Objective Practice Solutions

01. Ans: (b)

Sol: Time period of one cycle = $\frac{8.8}{2} \times 0.5$

= 2.2 msec

Therefore frequency = $\frac{1}{T} = \frac{1}{2.2 \times 10^{-3}}$

= 454.5 Hz

The peak to peak Voltage = 4.6×100

= 460 mV

Therefore the peak voltage V_m = 230 mV

R.M.S voltage = $\frac{230}{\sqrt{2}}$ = 162.6 mV

02. Ans: (c)

Sol: In channel 1

The peak to peak voltage is 5V and peak to peak divisions of upper trace voltage = 2

Therefore for one division voltage is 2.5V

In channel 2, the no. of divisions for unknown voltage = 3

Divisions = 3, voltage/division = 2.5

$\therefore$ voltage = 2.5 × 3 = 7.5 V

Similarly frequency of upper trace is 1kHz

So the time period T

(for four divisions) = $\frac{1}{f}$

$T = 1/10^3 \Rightarrow 1$ msec

i.e for four divisions time period = 1m sec

In channel 2, for eight divisions of unknown waveform time period = 2m sec.

03. Ans: (c)

Sol: No. of cycles of signal displayed

$= f_{signal} \times T_{sweep}$

$= 200\text{Hz} \times \left(10\,\text{cm} \times \frac{0.5\text{ms}}{\text{cm}}\right) = 1$

i.e, one cycle of sine wave will be displayed.

We know $V_{rms} = \frac{V_{p-p}}{2\sqrt{2}}$

$$V_{rms} = \frac{N_v \times \text{Volt/div}}{2\sqrt{2}}$$

$$\Rightarrow N_v = \frac{2\sqrt{2} \times V_{rms}}{\text{Volt/div}}$$

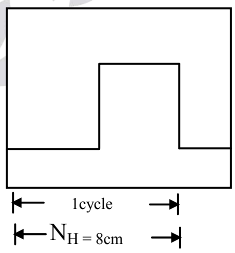
$$\Rightarrow N_v = \frac{2\sqrt{2} \times 300\text{mV}}{100\text{mv/cm}}$$

$\Rightarrow N_v = 8.485$cm

i.e 8.485cm required to display peak to peak of signal. But screen has only 8cm (vertical) As such, peak points will be clipped.

04. Ans: (b)

Sol:



→ Given data: Y input signal is a symmetrical square wave

$f_{signal} = 25\text{KHz}, \quad V_{pp} = 10\text{V}$

→ Screen has 10 Horizontal divisions & 8 vertical divisions which displays 1.25 cycles of Y-input signal.

$\rightarrow V_{PP} = N_V \times \frac{\text{VOLT}}{\text{div}}$

$\Rightarrow \frac{\text{VOLT}}{\text{div}} = \frac{V_{PP}}{N_V} = \frac{10\text{V}}{5\text{cm}} = 2 \text{ Volt/ c.m}$

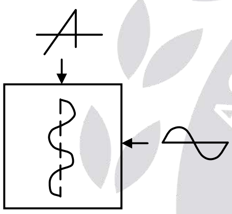
$\rightarrow T_{signal} = N_H \text{per cycle} \times \frac{\text{TIME}}{\text{div}}$

$\Rightarrow \frac{\text{TIME}}{\text{div}} = \frac{T_{signal}}{N_H \text{per cycle}}$

$= \frac{1}{25\text{kHz} \times 8\text{cm}} = 5\ \frac{\mu\text{s}}{\text{cm}}$

05. Ans: (a)

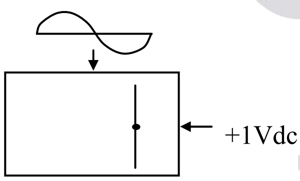
Sol: Frequency ratio is 2



$\therefore$ Two cycles of sine wave displayed on vertical time base

06. Ans: (a)

Sol:



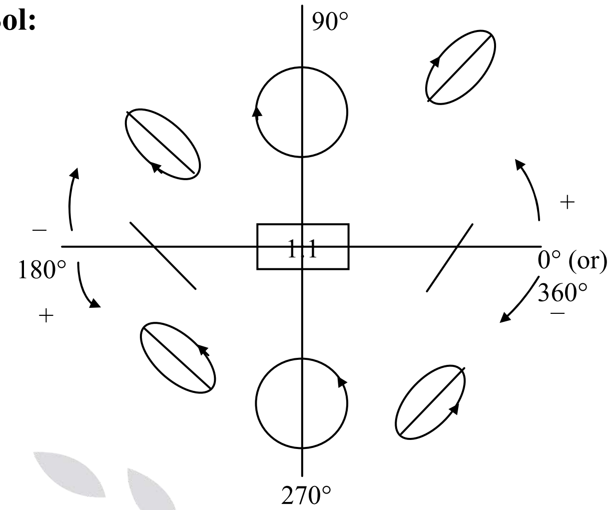
Vertical straight line

07. Ans: (a)

Sol: Since the coupling mode is set to DC the capacitance effect at the input side is zero. Therefore the waveform displayed on the screen is both DC and AC components.

08. Ans: (d)

Sol:

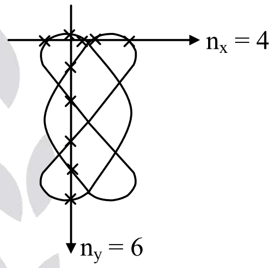


09. Ans: (b)

Sol: $f_y = \frac{n_x}{n_y} f_y$

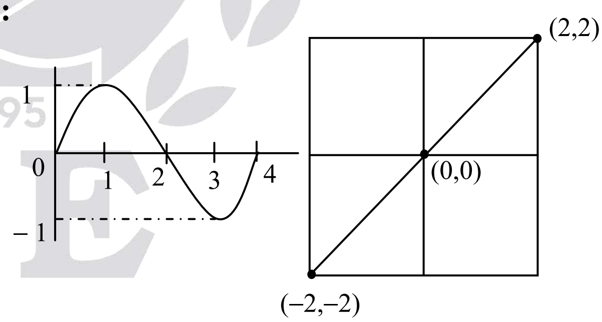
$= \frac{4}{6} \times 600\text{Hz}$

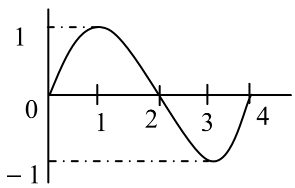
$= 400 \text{ Hz}$



10. Ans: (d)

Sol:





Let $K_y = K_x = 2\ {}^{\text{Volt}}/_{\text{div}}$

t	V_y	V_x	$d_y = k_y V_y$	$d_x = k_x V_x$	points
0	0	0	0	0	(0,0)
1	1	1	2	2	(2,2)
2	0	0	0	0	(0,0)
3	-1	-1	-2	-2	(-2,-2)
4	0	0	0	0	(0,0)

By using these points draw the line which is a diagonal line inclined at 45° w.r.t the x-axis.

11. Ans: (d)

Sol: Voltage signal = 5 sin (314t + 45°)

$$f_{signal} = \frac{314}{2\pi}\text{ Hz}$$
$$= 50\text{Hz}$$

No. of cycles of signal displayed

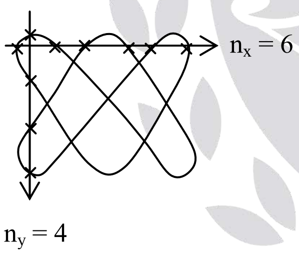
$= f_{signal}\times T_{sweep}$

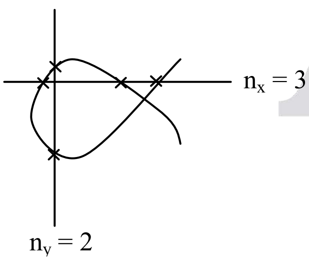
$= 50\times10\times5$ ms/div

$= 2.5$

12. Ans: (d)

Sol:





$$\frac{f_y}{f_x} = \frac{6}{4} \Rightarrow \frac{3}{2}$$

$$\frac{f_y}{f_x} = \frac{3}{2}$$

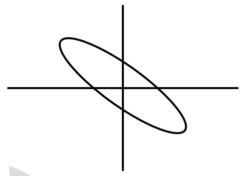
13. Ans: (a)

Sol: Lissajious figures are used for measurement of frequency and phase difference.

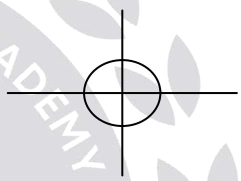
14. Ans: (d)

Sol:

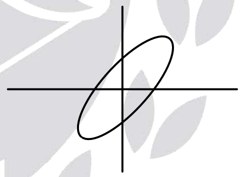
$90^0 < \phi < 180^0$



$\phi = 90^0$



$0^0 < \phi < 90^0$



Because of phase difference only figures changes from ellipse to circle and back to ellipse.

15. Ans: (d)

Sol: A trigger setting that ensures a stationary display is with trigger voltage level as 1.8V and trigger slope as –Ve.

Conventional Practice Solutions

01.

Sol: We know: $t_m = \sqrt{t_s^2 + t_0^2}$ or $t_s = \sqrt{t_m^2 - t_0^2}$

Where, t_m = measured rise time

t_s = actual or true rise time of signal

t_0 = oscilloscope rise time

Given that: t_0 = 15 ns & t_m = 20 ns

$\therefore t_s = \sqrt{t_m^2 - t_0^2} = \sqrt{(20ns)^2 - (15ns)^2} = 13.23ns$

Therefore, the actual rise time of signal is 13.23 ns.

02.

Sol: $v_x = \sqrt{\frac{2eV_a}{m}} = \sqrt{\frac{2 \times 1.602 \times 10^{-19} C \times 1000V}{9.11 \times 10^{-31}\ kg}}$

$= 1.87 \times 10^7$ m/s

03.

Sol: given that:

Probe resistance, $R_p = 4M\Omega$

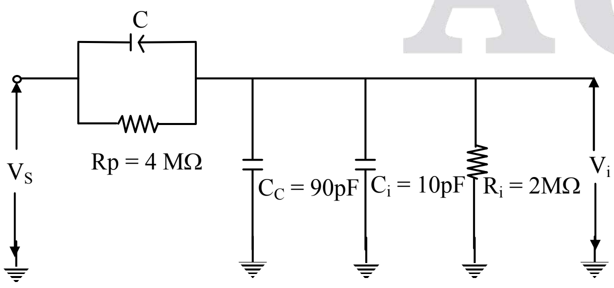
Probe capacitance, $C_p = C$

Cable capacitance, $C_c = 90pF$

CRO input resistance, $R_i = 2M\Omega$

CRO input resistance, $C_i = 10pF$

The equivalent circuit



We know $R_p C_p = R_i (C_c + C_i)$

$\Rightarrow C_p = \frac{2M\Omega(90pF + 10pF)}{4M\Omega}$ $\Rightarrow C_p = 50pF$.

$V_i = K.\ V_s$ where K is attenuation factor

$K = \frac{V_i}{V_s} = \frac{R_i}{R_p + R_i}$ (or) $\frac{C_p}{C_p + (C_i + C_c)}$

$\therefore K = \frac{2M\Omega}{6M\Omega}$ or $\frac{50pF}{150pF}$

$K = \frac{1}{3}$

i.e., The test signal voltage will be attenuated by 3 times.

04.

Sol: Given

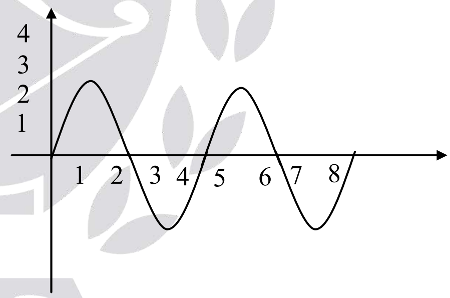
Vertical amplifier sensitivity = 5V/cm

Sweep speed = 50μs/cm

Peak – to Peak amplitude = 5.4 cm

Distance for two complete cycles = 8.4cm

From the above given data wave form can be constructed as shown below.



From the above wave form one cycle of wave form can be represented in 4.2 cm.

Voltage (Peak –Peak) = Vertical amplifier sensitivity × Peak to Peak amplitude.

$= 5.4 \times \frac{5V}{cm} = 27V$

Rms voltage $= \frac{V_{P-P}}{2\sqrt{2}}$

$= \frac{27}{2\sqrt{2}} = 9.54V$

Time period for one cycle

= sweep speed × distance for one cycle

= 50μs/cm × 4.2

= 210μs

$$\text{Frequency} = \frac{1}{\text{Time Period}} = \frac{1}{210\times10^{-6}}$$

= 4.76 kHz

(b) Voltage applied to Horizontal axis

= V_{m1} cosωt

Voltage applied to vertical axis = V_{m2} cosωt

When ωt = 0 then ,

$V_y = V_{m2} \sin(0) = 0$; $V_x = V_{m,}\cos(0) = V_{m1}$

When ωt = 30° then,

$V_x = 0.866V_{m1}$; $V_y = 0.5\ V_{m2}$

When ωt = 60° then,

$V_x = 0.5V_{m1}$; $V_y = 0.866\ V_{m2}$

When ωt = 90° then,

$V_x = 0$; $V_y = V_{m2}$

When ωt = 120° then,

$V_x = -0.5V_{m1}$; $V_y = 0.866\ V_{m2}$

When ωt = 150° then,

$V_x = -0.866V_{m1}$; $V_y = 0.5\ V_{m2}$,

When ωt = 180° then,

$V_x = -V_{m1}$; $V_y = 0$

When ωt = 210° then,

$V_x = -0.866\ V_{m1}$; $V_y =- 0.5\ V_{m2}$

When ωt = 240° then,

$V_x = -0.5V_{m1}$; $V_y =- 0.866\ V_{m2}$

When ωt = 270° then,

$V_x = 0$; $V_y = -\ V_{m2}$

When ωt = 300° then,

$V_x = 0.5V_{m1}$; $V_y = 0.866\ V_{m2}$

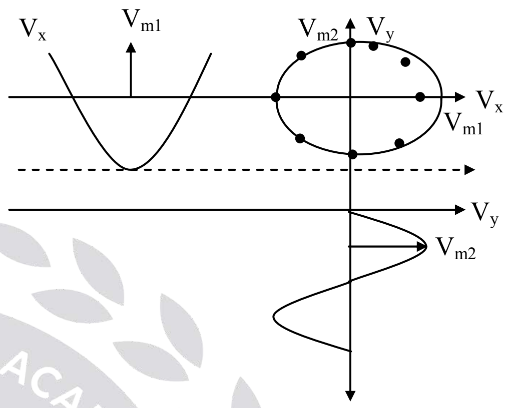
When ωt = 330° then,

$V_x = 0.866;V_{m1}$; $V_y = –0.5\ V_{m2}$

When ωt = 360° then,

$V_x = 1V_{m1}$; $V_y = 0$

If we plot the above obtained V_y and V_x values on x-y plot for different angles then it can be represented as.



From the above plot we can conclude that

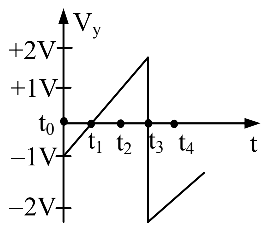
i) When $V_{m1} \neq V_{m2}$ the trace will be an ellipse with 'x' axis as major axis when $V_{m1} > V_{m2}$ and with 'y' axis as major axis when $V_{m2} > V_{m1}$.

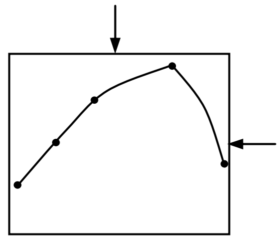
ii) When $V_{m1} = V_{m2}$ the trace will be a circle.

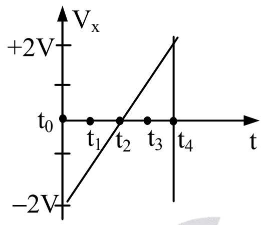
05.

Sol: Assume peak amplitude of saw tooth wave-form is 2V; the screen dimensions are 8 cm × 8 cm. The horizontal dial setting is 2 volt-cm. Given that y input saw tooth signal is leading x-input saw tooth signal by 90^0.

t	V_x	V_y
t_0	–2V	–1V
t_1	–1V	0
t_2	0	+1V
t_3	+1V	+2V
t_4	+2V	–1V







06.

Sol: $V_a = 2000V$

Length of deflecting plates $l_d = 2$ cm

Distance between the plates (d) = 0.5 cm

Distance between centre of plates to the screen = 30 cm

Deflection height of the beam (D) = 3cm

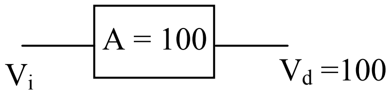
Gain of the amplifier (A) = 100

$$D = \frac{L\ell_d V_d}{2dV_a} \qquad (\because V_d = \text{deflection voltage})$$

$$V_d = \frac{2dV_a \times D}{L.\ell_d}$$

$$V_d = \frac{2 \times 0.5 \times 2000 \times 3}{30 \times 2}$$

$V_d = 100$ V



$$\frac{V_d}{V_i} = 100$$

$V_i = 1V$

Velocity of electron beam $(V_{ox}) = \sqrt{\frac{2qV_a}{m}}$

q → Charge of an electron = 1.65×10^{-9}C

V_a → anode voltage required = 2000 V

m → mass of an electron = 9.1×10^{-31} kg

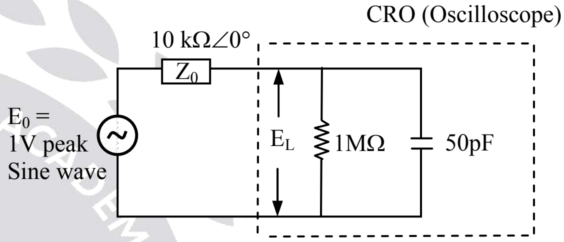
$$V_{ox} = \sqrt{\frac{2qV_a}{m}}$$

$$= \sqrt{\frac{2 \times 1.65 \times 10^{-19} \times 2000}{9.1 \times 10^{-31}}}$$

$= 26.93 \times 10^6$ m/s

07.

Sol:



(a) f = 100 kHz:

$$X_C = \frac{1}{2\pi \times 100\text{kHz} \times 50\text{pF}} = 32000\Omega$$

Impedance of oscilloscope

$$(Z_L) = \frac{R \times (-jX_c)}{R - jX_c}$$

$$Z_L = \frac{10^6 \times (-j32000\Omega)}{10^6 - j32000\Omega}$$

$= 32000\Omega \angle -90°$

Voltage indicated by CRO (E_L)

$$= \frac{E_0}{1 + Z_0/Z_L}$$

$$E_L = \frac{1V\angle 0^0}{1 + \frac{10k\angle 0^0}{32000\angle -90^0}}$$

$= 0.954V \angle -17.4°$ peak

(b) f = 1MHZ

$$X_C = \frac{1}{2\pi \times 1 \times 10^6 \times 50pF} = 3200\Omega$$

Impedance of oscilloscope (Z_L)

$$Z_L = \frac{10^6(-j3200\Omega)}{10^6 - j3200\Omega} = 3.2 \times 10^3 \angle -90°$$

Voltage indicated by CRO (E_L)

$$= \frac{E_0}{1 + Z_0 / Z_L}$$

$$E_L = \frac{1V\angle 0^0}{1 + \frac{10k\Omega \angle 0^0}{3.2 \times 10^3 \angle -90}}$$

$$= 0.304V\angle -72.3°$$

Chapter 9 Digital Voltmeters

Objective Practice Solutions

01. Ans: (a)

Sol: The type of A/D converter normally used in a $3\frac{1}{2}$ digit multimeter is Dual-slope integrating type since it offers highest Accuracy, Highest Noise rejection and Highest Stability than other A/D converters.

02. Ans: (d)

Sol: DVM measures the average value of the input signal which is 1 V.

$\therefore$ DVM indicates as 1.000 V

03. Ans: (c)

Sol: 0.2% of reading +10 counts $\rightarrow$ (1)

$$= 0.2 \times \frac{100}{100} + 10(\text{sensitivity} \times \text{range})$$

$$= 0.2 \times \frac{100}{100} + 10\left(\frac{1}{2\times 10^4} \times 200\right)$$

$$= 0.2 + 0.1 = \pm 0.3 \text{ V}$$

$$\%\text{error} = \pm\frac{0.3}{100}\times 100 = 0.3\%$$

04. Ans: (d)

Sol: When $\frac{1}{2}$ digit is present voltage range becomes double. Therefore 1V can read upto 1.9999 V.

05. Ans: (d)

Sol: $\text{Resolution} = \frac{\text{full}-\text{scale reading}}{\text{maximum count}} = \frac{9.999\text{V}}{9999}$

$= 1\text{mV}$

06. Ans: (b)

Sol: Sensitivity = resolution × lowest voltage range

$$= \frac{1}{10^4}\times 100 \text{ mV}$$

$$= 0.01 \text{ mV}$$

07. Ans: (c)

Sol: The DVM has $3\frac{1}{2}$ digit display

Therefore, the count range is from 0 to 1999 i.e., 2000 counts.

$$\text{Resolution} = \frac{\text{given voltage range}}{\text{Maximum count}}$$

$$= \frac{200\text{mV}}{2000} = 0.1\text{mV}$$

08. Ans: (a)

Sol: $\text{Resolution} = \frac{\text{max.voltage}}{\text{max.count}}$

$$= \frac{3.999}{3999} = 1\text{mV}$$

09. Ans: (b)

Sol: A and R are true, but R is not correct explanation for A.

10. Ans: (c)

Sol: When $\frac{1}{2}$ digit switched ON, then DVM will be able to read more than the selected range.

11. Ans: (b)

Sol: Given , $3\frac{1}{2}$ digit, FSD value of 200 mV

Resolution $= \frac{200\text{mV}}{2000} = 0.1\text{mV}$

$\therefore \text{Error} = \frac{0.5}{100} \times 100\text{mV} + 5 \times 0.1\text{mV}$

$= \pm 1 \text{ mV}$

$\therefore$ The value lies between 99.0 mV & 101.0 mV

12. Ans: (d)

Sol:
- The DVM has $3\frac{1}{2}$ digit display. Therefore, its scale resolution is 0.001
- Its resolution in 200mV range is 100mV
- The maximum voltage that can be measured in this 200mV lowest Range: 199.9mV.

13. Ans: (b)

Sol: For N-decade counter

Pulse width $_{(max)} = \frac{10^N}{f_{clk}}$

Resolution $\Rightarrow$ 1count $\Rightarrow 1.T_{clk}$

Resolution $= \frac{1}{f}$

Range of pulse width

$\Rightarrow \frac{1}{f}$ to $\left(\frac{10^N - 1}{f}\right)$

Conventional Practice Solutions

01.

Sol: The count range of $3\frac{1}{2}$ digit DVM is from 0 to 1999, i.e., 2000 counts.

Due to adding $\frac{1}{2}$ digit, the 1V range of this DVM extended to 2V and 10V range extended to 20V.

$$\left.\begin{array}{l}\text{resolution of } 3\frac{1}{2} \text{ digit DVM}\\ \text{in 1V range of operation}\end{array}\right\} = \frac{1}{2\times 10^3} \times 2\text{V}$$

$$= \frac{2\text{V}}{2000\,\text{counts}} = 1 \text{ mV}$$

$$\left.\begin{array}{l}\text{resolution of } 3\frac{1}{2} \text{ digit DVM}\\ \text{in 10V range of operation}\end{array}\right\} = \frac{1}{2\times 10^3} \times 20\text{V}$$

$$= \frac{20\text{V}}{2000\,\text{counts}} = 10 \text{ mV.}$$

02.

Sol: We know: $V_m T_1 = V_{ref} T_2$

$\Rightarrow V_m N_F = V_{ref}\ n$

$\Rightarrow V_m = \frac{V_{ref}}{N_F} \times n$

$= \frac{1000\text{V.}}{1000} \times 762 = 762\text{V.}$

03.

Sol: For analog multimeter

$V_m = 10\text{V}$, $V_{FS} = 20\text{V}$,

G.A.E = ± 2% of V_{FS}

In question asking amount of error in% means limiting error.

% Limiting error =

Measured value × $\frac{x}{100}$ **= G.A.E value form**

Where x → % limiting error

$= 10\times\frac{x}{100} = \frac{2}{100}\times(20)$

⇒ x = 4%

∴ % error = 4%

⇒ For $3\frac{1}{2}$ digital multimeter, accuracy of

±[0.5% of reading + 1 count]

⇒ For 1 count = $\frac{V_{FS}}{\text{Maximum value of Display}}$

⇒ For $3\frac{1}{2}$ DMM,

1	9	9	9	→ Maximum Display

1 count = $\frac{20}{1999} = 0.01$

$= \pm\left[\frac{0.5}{100}\times(10)+0.01\right] = 0.06$ This is absolute error

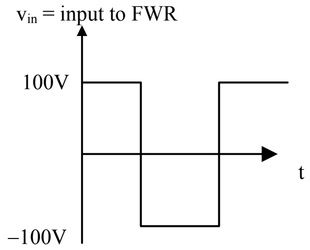
∴ % error = $\frac{0.06}{10}\times 100 = 0.6\%$

Chapter 10 Analog Electronic Voltmeters

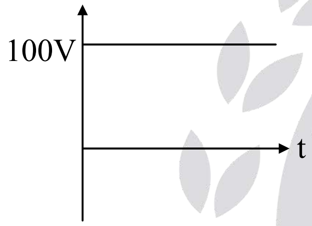
Objective Practice Solutions

01. Ans: (d)

Sol:



V_{out} = input to DC voltmeter



The output of FWR is fed as input to DC volt meter. As such, the DC voltmeter measures average value of V_{out}.

V_{avg} of V_{out} = 100V

$V_{rms(ind)} = 1.11 \times V_{avg} = 1.11 \times 100$ V

$= 111$ V

02. Ans: (b)

Sol: $V_{measured}(\text{rms}) = 1.11 \times$ average value

$= 1.11 \times 75$

$= 83.25$V

$$V_{True}(\text{rms}) = \frac{V_m}{\sqrt{3}} = \frac{150}{\sqrt{3}} = 86.6\text{V}$$

$$\%\ \text{error} = \frac{V_{measured} - V_{True}}{V_{True}} \times 100$$

$$= \frac{83.25 - 86.6}{86.6} \times 100$$

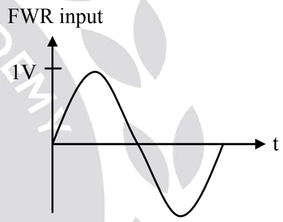
$= -3.87\%$

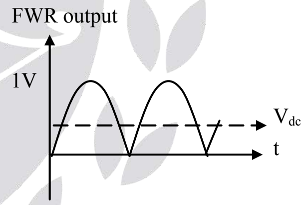
03. Ans: (a)

Sol: The full wave Rectifier type electronic AC voltmeter has a scale calibrated to read r.m.s value for square wave inputs. As such, the scale calibration factor used for deriving rms volt scale from DC volt scale is 1.

Reading = 1× V_{dc} Where V_{dc} is Average voltage of output of full wave Rectifier for given input.

- This voltmeter is used to measure a sinusoidal voltage





DC. voltmeter measures V_{dc} of output of FWR

$$V_{dc} = \frac{2V}{\pi}$$

Therefore, reading = $1 \times V_{dc} = \frac{2}{\pi}$V

04. Ans: (b)

Sol: A rectifier moving coil instrument consists of a rectifier at primary stage whose output is fed to PMMC meter.

As such, it measures average value but indicates rms value since scale is calibrated in terms of rms.

05. Ans: (d)

Sol: Assertion is wrong since Fullwave rectifier AC voltmeter is a derived rms meter and reads true rms of only one wave form which meter scale is calibrated.

06. Ans: (b) (Key changed)

Sol: $S_{AC} = 0.9\ S_{dc}$

$= 0.9\times10\ k\Omega/V$

$= 9\ k\Omega/V$

Input resistance in 10V range

$= 9\ k\Omega/V \times 10$

$= 90\ k\Omega$

07. Ans: (c)

Sol: Given data: Full wave Bride Rectifier AC voltmeter's AC volt range is 0-100V. The PMMC ammeter used in the design has full scale current rating of 1mA and internal resistance of 100Ω & diodes are ideal

$$R_s = 0.9\times\frac{V_{rmsFSD}}{I_{dcFSD}} - 2R_d - R_m$$

$$= 0.9\times\frac{100V}{1mA} - 100\Omega$$

$$= 90k\Omega - 100\Omega$$

$$= 89.9\ k\Omega$$

08. Ans: (a)

Sol: We know, for FWBR type AC voltmeter

$V_{rms} = 1.11\ (R_{v(fw)})\times I_{dc}$

$\Rightarrow 100kV = 1.11\ [x_c]\times45\times10^{-3}A$

$$\Rightarrow X_c = \frac{100\times10^3\,V}{1.11\times45\times10^3\,A}$$

$$\Rightarrow \frac{1}{2\pi fc} = \frac{100\times10^3\,V}{1.11\times45\times10^{-3}\,A}$$

$$\Rightarrow C = \frac{1.11\times45\times10^{-3}\,A}{2\pi\times50Hz\times100\times10^3\,V}$$

$$\simeq 15.9\times10^{-10}\ F$$

09. Ans: (d)

Sol: Multimeter measure voltage (ac & dc), current (ac & dc), resistance.

10. Ans: (c)

Sol: The meter reads full scale with 12V at M and range switch at B.

Now range switch is at D and meter reads full scale value.

Voltage at M is ?

At position B:

$$V_0 = V_s\left(\frac{1.2+0.6+0.12+0.06+0.02}{2+6+1.2+0.6+0.12+0.06+0.02}\right)$$

$= 12\times0.2 = 2.4$

At position D:

$$V_0 = V_s\left(\frac{0.12+0.06+0.02}{2+6+1.2+0.6+0.12+0.06+0.02}\right)$$

$2.4 = V_s\times0.02$

$V_s = 120V$

11. Ans: (b)

Sol: Given data: Voltmeter sensitivity is 20kΩ/V

Reading of 4.5V on its 5V full scale

Reading of 6V on its 10V full scale

- Say, voltage source is V_s and its internal resistance is R_s.

  5V range:

  $$R_v = 20\frac{k\Omega}{V}\times5 = 100\ k\Omega$$

$\rightarrow$ Reading $= V_s \times \dfrac{100k\Omega}{R_s + 100k\Omega}$

$4.5V = V_s \times \dfrac{100k\Omega}{R_s + 100k\Omega}$

$\therefore V_s = \dfrac{4.5V}{100k\Omega}(R_s + 100K\Omega)$ ……… (1)

10V Range:

$\rightarrow R_V = 20\dfrac{k\Omega}{V} \times 10V$

$= 200k\Omega$

$\rightarrow$ reading $= V_s \times \dfrac{200k\Omega}{R_s + 200k\Omega}$

$6V = V_s \times \dfrac{200k\Omega}{R_s + 200k\Omega}$

$\therefore V_s = \dfrac{6V}{200K\Omega}(R_s + 200k\Omega)$ ……. (2)

Solving eq (1) & (2)

$\dfrac{6V}{200k\Omega}(R_s + 200k\Omega)$

$= \dfrac{4.5V}{100k\Omega}(R_s + 100k\Omega)$

$R_s + 200k\Omega = 1.5(R_s + 100k\Omega)$

$0.5R_s = 50k\Omega$

$R_s = 100k\Omega$

Putting the value of R_s in eq (1)

$V_s = \dfrac{4.5V}{100k\Omega}(100k\Omega + 100k\Omega)$

$= 4.5V \times 2 = 9V$

Therefore, the voltage source is 9V and its internal resistance is 100kΩ.

12. Ans: (b)

Sol: For the measurement of the voltage of the order of mv, an amplifier- rectifier type VTVM is best suitable where the low magnitude input signal (AC) is first amplified and then rectified and then driven to PMMC meter.

Conventional Practice Solutions

01.

Sol: (i) Reading of true rms meter:

A true rms meter measures true rms value of input

$$V_{rms(true)} = \sqrt{\frac{1}{T_0}\int_0^{T_0} V^2(t)dt}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{T_0} V^2(t)dt}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi/2}(3V)^2 dt + \frac{1}{2\pi}\int_{\pi/2}^{2\pi}(-1V)^2 dt}$$

$$= \sqrt{\frac{9}{2\pi}\times(t)_0^{\pi/2} + \frac{1}{2\pi}(t)_{\pi/2}^{2\pi}}\ V$$

$$= \sqrt{\frac{9}{2\pi}\times\frac{\pi}{2} + \frac{1}{2\pi}\times\frac{3\pi}{2}}\ V$$

$$= \sqrt{\frac{9}{4} + \frac{3}{4}}\ V$$

$$= \sqrt{\frac{12}{4}}\ V$$

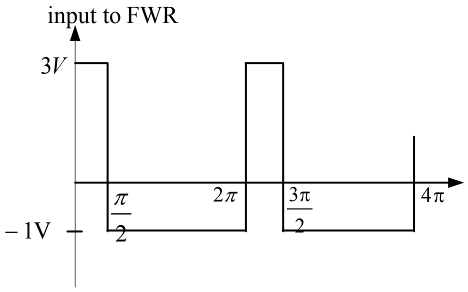
$\Rightarrow$Reading of true rms meter is $\sqrt{3}$ V i.e.,

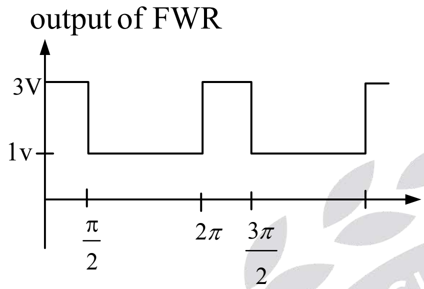
(ii) Reading of average measuring – rms indicating meter:

This meter consists of a full wave rectifier at the primary stage, whose output is fed to DC voltmeter and the scale is calibrated to read rms of sine wave.

$\therefore$ Reading = $1.11V_{dc}$

Where V_{dc} is average voltage of output of FWR for given input.





DC voltmeter measures "V_{dc} of output of FWR"

$$V_{dc} = \frac{1}{2\pi}\left[\int_0^{\pi/2} 3V dt + \int_{\pi/2}^{2\pi} 1V dt\right]$$

$$= \frac{1}{2\pi}\left[3V \times (t)_0^{\pi/2} + 1V \times (t)_{\pi/2}^{2\pi}\right]$$

$$= \frac{1}{2\pi}\left[3V \times \frac{\pi}{2} + 1V \times \frac{3\pi}{2}\right]$$

$$= \frac{3V}{4} + \frac{3V}{4} = \frac{6}{4}V \quad = 1.5 \text{ V}$$

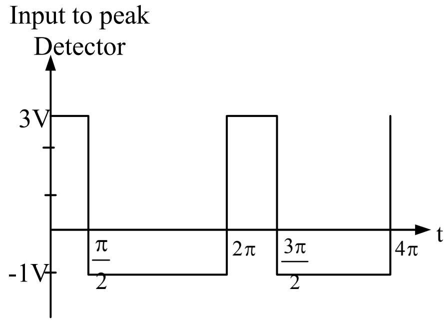
$V_{rms(ind)} = 1.11 \times 1.5$ V $= 1.665$ V

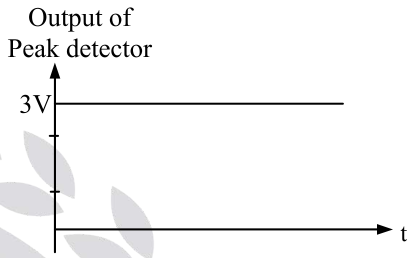
(iii) Reading of "peak measuring" – "rms indicating" meter:

This meter consists of a peak detector at the primary stage whose output is fed to DC voltmeter and the scale is calibrated to read rms of sine wave

$\therefore$ reading = 0.707 V_{dc}

Where, V_{dc} is average voltage of output of peak detector for given input





DC voltmeter measures "V_{dc} of output of peak detector"

$V_{dc} = 3V$

$V_{rms(ind)} = 0.707 \times 3V = 2.121V$

02.

Sol: Advantages of Electronic Voltmeters:

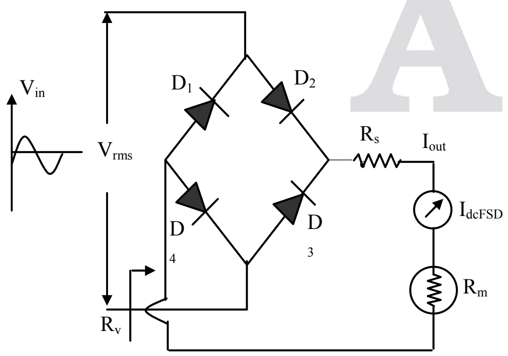
1. Electronic voltmeters offer very high input resistance in the order of MΩ
2. Electronic voltmeters cause minimum loading on the circuit under test because of their high input resistance and in turn provide accurate reading.
3. Electronic voltmeters offer better accuracy
4. Electronic voltmeters offer very high sensitivity
5. Electronic voltmeters can detect or sense low level input signals because of their high sensitivity

6. Electronic voltmeters offer improved dynamic input range
7. Electronic voltmeter take less power from circuit under test as the power required for deflection is provided from the external circuit using amplifiers but not from circuit under test. As such, their power consumption is low.
8. Electronic voltmeters offer faster response
9. Frequency range of operation of electronic voltmeters is high
10. Electronic voltmeters are compact in size and are more portable.

Electronic Voltmeter using Bridge Circuit for Full Wave Rectification

A full wave bridge rectifier type AC voltmeter consists of full wave bridge rectifier at primary stage whose output is fed to PMMC indicating meter and the scale of PMMC is calibrated to read rms voltage of input sine wave

Circuit diagram:

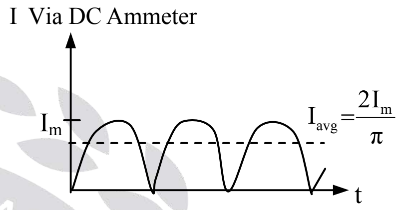


Available PMMC ammeter ratings:

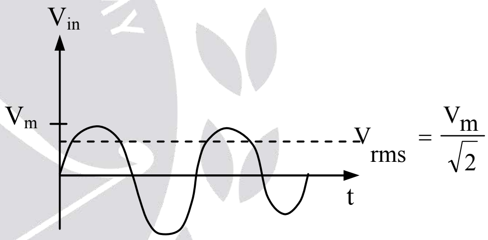
0 - I_{dcFSD}, R_m.

Required AC voltmeter range: 0 - V_{rmsFSD}

The sinusoidal input voltage whose rms value is to be measured is first fed to full wave bridge rectifier. During the half cycle of input, D_2 & D_4 conduct and current passes through ammeter. Similarly during –ve half cycle of input, D_1& D_3 conduct and current passes through ammeter (in same direction)



But the design requirement is " V_{rms} of V_{in} "



$$V_{rms} = \frac{1}{\sqrt{2}} V_m = \frac{1}{\sqrt{2}} R_v \times I_m$$

$$= \frac{1}{\sqrt{2}} R_v \times \frac{\pi}{2} I_{avg}$$

$$\Rightarrow V_{rms} = \frac{\pi}{2\sqrt{2}} R_v \times I_{avg}$$

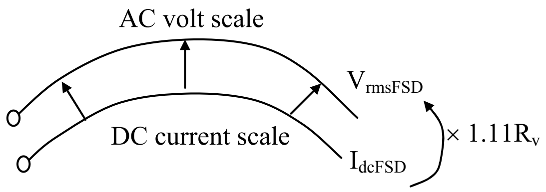
$\Rightarrow V_{rms} = 1.11 R_v \times I_{avg}$–scale calibration relation

Where,

R_v = input resistance of FWBR voltmeters

$= 2R_d + R_{se} + R_m$

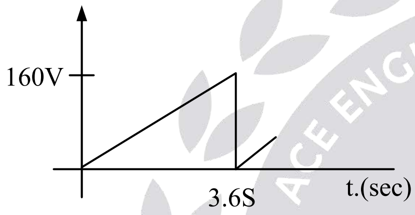
This relation is used to calibrate the DC current scale in terms of AC volts (rms volts)



$\therefore$ This voltmeter internally measures average value but indicates rms value.

Solution to the problem

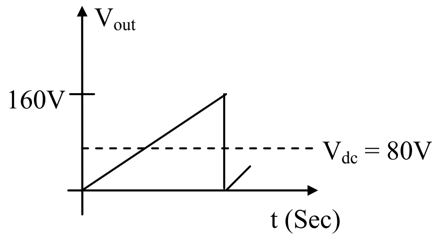
For given voltage waveform,



$$V_{rms(true)} = \sqrt{\frac{1}{3.6}\int_0^{3.6}\left(\frac{160V}{3.6}t\right)^2 dt}$$

$$= \sqrt{\frac{1}{3.6}\int_0^{3.6}(44.4tV)^2 dt} = 92.3V$$

This voltage is input to FWBR. As such, the output of FWBR:



$V_{rms(ind)}$ = 1.11 V_{dc} = 1.11 × 80V = 88.8V

% error in measurement

$$= \frac{88.8V - 92.3V}{92.3V} \times 100 = -3.8\%$$

Chapter 11 Q-Meter

Objective Practice Solutions

01. Ans: (a)

Sol: $C_1 = 300pF$ $\quad C_2 = 200$ pF

$Q = 1/(\omega C_1 R)$

$= 120 = 1/(C_2 + C_x)R$

$C_1 = C_2 + C_X$

$\therefore C_x = 100$ pF

02. Ans: (b)

Sol: $\%error = -\dfrac{r}{r+R}\times 100$

$$= -\frac{0.02}{0.02+10}\times 100 = -0.2\%$$

03. Ans: (c)

Sol: Q-meter consists of R, L, C connected in series.

$\therefore$ Q-meter works on the principle of series resonance.

04. Ans: (b)

Sol: Given data: $C_d = 820$ pF,

$\omega = 10^6$rad/sec & C = 9.18nF

We know, $L = \dfrac{1}{\omega^2[C + C_d]}$

$$= \frac{1}{(10^6)^2[9.18nF + 820pF]} = 100\mu H$$

The inductance of coil tested with a Q-meter is 100μH.

05. Ans: (b)

Sol: A series RLC circuit exhibits voltage magnification property at resonance. i.e., the voltage across the capacitor will be equal to Q-times of applied voltage.

Given that V = applied voltage and

V_0 = Voltage across capacitor

There fore, $Q = \dfrac{V_{c\,max}}{V_{in}}$

$\Rightarrow Q = \dfrac{V_0}{V}$

06. Ans: (b)

Sol: $f_1 = 500$ kHz ; $\quad f_2 = 250$kHz

$C_1 = 36$ pF ; $\quad C_2 = 160$ pF

$n = \dfrac{250\,kHz}{500\,kHz}$

$\Rightarrow n = 0.5$

$$C_d = \frac{36pF - (0.5)^2 160pF}{(0.5)^2 - 1}$$

$= 5.33pF$

07. Ans: (c)

Sol: $Q = \dfrac{\text{capactor voltmeter reading}}{\text{Input voltage}}$

$= \dfrac{10}{500\times 10^{-3}}$

$= 20$

08. Ans: i → (c), ii → (a)

Sol: (i) $C_d = \dfrac{C_1 - n^2 C_2}{n^2 - 1}$

$= \dfrac{360 - 288}{3}$

$= 24$ pF

(ii) $L = \dfrac{1}{\omega_1^2[C_1 + C_d]}$

$$= \frac{1}{\left[2\pi\times500\times10^3\right]^2\left[24+360\right]\times10^{-6}} = 264\mu H$$

09. Ans: (b)

Sol: $Q_{true} = Q_{meas}\left(1+\dfrac{r}{R_{coil}}\right)$

$Q_{actual} = Q_{observed}\left[1+\dfrac{R}{R_s}\right]$

10. Ans: (c)

Sol: $1+\dfrac{C_d}{C} = \dfrac{Q_{true}}{Q_{measured}}$

$\Rightarrow \dfrac{C_d}{C} = \dfrac{245}{244.5} - 1$

$= 2.044\times10^{-3}$

$\Rightarrow \dfrac{C}{C_d} = 489$

11. Ans: (b)

Sol: Q-meter works on the principle of series resonance

$V_c = Q\times V_{in}$

∴ Both A & R are individually true but R is not the correct explanation of A.

Conventional Practice Solutions

01.

Sol: Given that: f_1 = 3 MHz & C_1 = 251pF

f_2 = 6 MHz & C_2 = 50pF

$\therefore n = \dfrac{f_2}{f_2} = \dfrac{6MHz}{3MHz} = 2$

After inserting the test coil into socket of Q – meter, the resonance is obtained for the first time at 3 MHz with tuning capacitance set to 251pF. Then, the frequency is doubled (i.e., n = 2) and, the resonance is obtained for the second time at 6 MHz with tuning capacitance set to 50pF.

We know: $C_d = \dfrac{C_1 - n^2C_2}{n^2 - 1}$

$= \dfrac{251pF - (2)^2 50pF}{(2)^2 - 1}$

$= \dfrac{251pF - 200pF}{3}$

$\Rightarrow C_d = 17pF.$

∴ The self capacitance or distributed capacitance of coil is found to be 17pF.

02.

Sol: The effective Q-of the coil, $Q_t = \dfrac{1}{\omega CR}$

$$= \frac{1}{2\pi\times1\times10^6\times60\times10^{-12}\times10}$$

$= 265.258$

The indicated or calculated Q-of the coil

$Q_{ind} = \dfrac{1}{2\pi\times1\times10^6\times60\times10^{-12}\times(10+0.02)}$

$= 264.729$

$$\% \text{ error} = \frac{Q_{ind} - Q_t}{Q_t} \times 100$$

$$= \frac{264.729 - 265.258}{265.258} \times 100$$

$$= -0.19943\%$$

03.

Sol: Refer previous Q for working of Q – meter

given that: f_1 = 1MHz & C_1 = 1530 pF

f_2 = 3 MHz & C_2 = 162 pF

$$n = \frac{f_2}{f_1} = \frac{3\text{MHz}}{1\text{MHz}} = 3$$

After inserting the test coil into socket of Q – meter, the resonance is obtained for the first time at 1MHz with tuning capacitor adjusted to 1530PF. Then the frequency is tripled (i.e.,n = 3) and the resonance is obtained for the second time at 3MHz with tuning capacitor adjusted to 162 pF.

We know: $C_d = \frac{C_1 - n^2 C_2}{n^2 - 1}$

$$= \frac{1530\text{pF} - (3) \times 162\text{pF}}{(3)^2 - 1}$$

$$= \frac{1530\text{pF} - 1458\text{pF}}{8}$$

C_d = 9 pF

∴ The self capacitance of the coil is 9 pF.

04.

Sol: Given distributed capacitance

C_d = 20PF

Tuning capacitance at first resonance =

C_1 = 200pF

Tuning capacitance at second resonance =

C_2 = ?

First resonance frequency occurs at

$$f_1 = \frac{1}{2\pi\sqrt{L(C_d + C_1)}}$$

$$= \frac{1}{2\pi\sqrt{L(220)}}$$

Second resonance frequency will be double the first resonance frequency

$f_2 = 2f_1$

$$f_2 = \frac{1}{2\pi\sqrt{L(C_2 + C_d)}} = \frac{2 \times 1}{2\Pi\sqrt{l(C_1 + C_d)}}$$

$$\Rightarrow \frac{1}{2\pi\sqrt{L(C_2 + C_d)}} = \frac{2 \times 1}{2\pi \times \sqrt{L(C_1 + C_d)}}$$

By cross multiplying and squaring

$$(C_1 + C_d) = 4 \times (C_2 + C_d)$$

By solving

$$C_2 = \frac{C_1 - 3C_d}{4} \text{ .... (1)}$$

By substituting values of C_d and C_1 in (1) then

$$C_2 = \frac{200 - 3 \times 20}{4} = \frac{200 - 60}{4}$$

= 35pF

Tuning capacitance at second resonance

C_2 = 35pF and

Second resonance frequency will be double the first resonance frequency

$f_2 = 2f_1$

05.

Sol: $Q = \frac{\omega L}{R}$

$$Q = \frac{X_L}{R}$$

$$Q = \frac{100}{10} = 10$$

06.

Sol: Given that: f_1 = 1MHz, C_1 = 210 pF,

Q_1 = 100 and f_2 = 2 MHz, C_2 = 45 pF

$$n = \frac{2\text{MHz}}{1\text{MHz}} = 2$$

$$C_d = \frac{210\,\text{pF} - 2^2 \times 45\,\text{pF}}{2^2 - 1}$$

$$= \frac{210\text{pF} - 4 \times 45\text{pF}}{3} = 10 \text{ pF}$$

$$L = \frac{1}{(2\pi \times 1\text{MHz})^2 [210\text{pF} + 10\text{pF}]}$$

$$= 1.15 \times 10^{-4} \text{ H}$$

$$R_{coil} = \frac{2\pi \times 1\text{MHz} \times 1.1513 \times 10^{-4}}{100}$$

$$= 7.245\Omega$$

Chapter 12 Basics of Transducers

Objective Practice Solutions

01. Ans: (d)

Sol: Piezo electric transducer is an active transducer.

02. Ans: (c)

Sol: Active transducers do not require an auxiliary power source to produce their output. From given options thermocouple & solar cell pair transducers are active transducers as they produce output with no auxiliary power source.

03. Ans: (d)

Sol: Pressure → Piezoelectric crystal

Temperature → Thermistor

Displacement → Capacitive transducer

Stress → Resistance strain gauge

04. Ans: (d)

Sol: Thermocuple → Cold junction compensation

Strain gauge → DC bridge

Piezoelectric crystal → Charge amplifier

LVDT → Phase sensitive detector

05. Ans: (b)

Sol: Usually from transducers we get small output which is not sufficient for further processing, so in order to amplify that output we require signal conditioning circuit. finally to read the output we require recorder.

06. Ans: (d)

Sol: Bolometer

→ measurement of power at 500 MHz

Hot wire anemometer

→ measurement of flow of air around an aeroplane.

C-type bourdon tube

→ measurement of high pressure

Optical pyrometer

→ measurement of temperature of furnace.

07. Ans: (d)

Sol: Charge amplifier with very low bias current and high input impedance → piezoelectric sensor for measurement of static force

Voltage amplifier with low bias current and very high input impedance → Glass electrode PH sensor

Voltage amplifier with very high CMRR sensing applications → strain gauge in unipolar DC wheatstone bridge.

08. Ans: (b)

Sol: Mcleod gauge → Pressure

Turbine meter → Flow

Pyrometer → Temperature

Synchros → Displacement

09. Ans: (a)

Sol: Variable capacitance device

→ Pressure transducer

Orifice meter → Flow measurement

Thermistors → Temperature measurement

10. Ans: (b)

Sol: From given options diaphragm and pivot torque are employed for displacement measurement while thermistor and thermocouple not related to displacement measurement.

11. Ans: (a)

Sol: Instrumentation amplifier is used to amplify signals from transducer.

12. Ans: (a)

Sol: LVDT gives linear output & also very accurate compare to any other transducer given in options.

13. Ans: (b)

Sol: The lower limit of useful working range of a transducer is determined by transducer error and noise.

14. Ans: (d)

Sol: From given options, thermocouple and thermopile, piezoelectric pick-up, photovoltaic cellare a self generating type transducers.

Conventional Practice Solutions

01.

Sol: Transducers can be classified

- Based upon transduction principle
- as primary and secondary transducers
- as passive and active transducers
- as analog and digital transducers
- as transducers and inverse transducers

Based upon transduction principle

The transducers can be classified on the basis of principle of transduction as resistive, inductive, capacitive etc., depending upon how they convert the input quantity into resistance, inductance or capacitance respectively.

02.

Sol: Primary and Secondary Transducers:

The first transducer which converts physical phenomenon into displacement, pressure, velocity etc. which is to be accepted by next stage is known as "**Primary Transducer**". The output of the primary transducer is converted subsequently into a usable output by a device called "**Secondary Transducer**"

Passive and Active Transducers:

Passive transducers: They derive the power required for transduction from an auxiliary power source.

Eg: Resistive, inductive and capacitive transducers.

Active transducers: They do not require an auxiliary power source to produce their output. They are also known as self - generating type since they develop their own voltage or current output.

Eg: piezoelectric, photovoltaic etc.

Analog and digital Transducers:

Analog transducers: These transducers convert the input quantity into an analog output which is a continuous function of time.

Eg: LVDT, thermocouple etc.

Digital Transducers:-These transducers convert the input quantity into an electrical output which is in the form of pulses.

Transducers & Inverse Transducers

Transducer: A transducer can be broadly defined as a device which converts a non – electrical quantity into an electrical quantity.

Inverse transducer: An inverse transducer is defined as a device which converts an electrical quantity into a non – electrical quantity.

03.

Sol: In the direct method of measurement, the physical quantities like length or mass are measured directly by the measuring instruments. The indirect method of measurement comprises of various stages for the measurement of the physical quantity like temperature, pressure, force etc, since they cannot be measured by the direct instruments. In this method, the transducer is used which is connected to a host of other instruments to convert one form of energy that cannot be measured into the other form that can be measured easily. The input and the output values are calibrated so that for all the value of output the value of the input can be calculated.

Transducer:

The transducers that convert the mechanical input signals into electrical output signals are called as electrical transducers. The output obtained from the electrical transducers can be read by the humans or it can given as input to the controllers.. The input given to the electrical transducers can be in the form of the displacement, strain, velocity, temperature, flow etc and the output obtained from them can be in the form of current, voltage and change in resistance, inductance and capacitance. The output can be measured easily and it is calibrated against the input, thus enabling the measurement of the value of the input.

1. **Potentiometers:** They convert the change in displacement into change in the resistance, which can be measured easily.
2. **Variable Capacitance Transducers:** These comprise of the two parallel plates between which there is dielectric material like air. The change in distance between the two plates produced by the displacement results in change in capacitance, which can be easily measured.
3. **Variable Resistance Transducers:** There is change in the resistance of these sensors when certain physical quantity is applied

to it. It is most commonly used in resistance thermometers or thermistors for measurement of temperature.

4. **Magnetic sensors:** The input given to these sensors is in the form of displacement and the output obtained is in the form of change in inductance or reluctance and production of the eddy currents.

5. **Piezoelectric transducers:** When force is applied to these transducers, they produce voltage that can be measured easily. They are used for measurement of pressure, acceleration and force.

6. **Strain gauges:** When strain gauges are strained or stretched there is change in their resistance. They consist of the long wire and are able to detect very small displacements produced by the applied force or pressure.

7. **Photo electric transducers:** When the light is applied to these transducers, they produce voltage.

8. **Linear variable differential transformer (LVDT):** LVDT is the transformer consisting of the primary and the secondary coil. It converts the displacement into the change in inductance.

9. **Ultrasonic Transducers:**
These transducers use the ultrasonic or ultrasound waves to measure parameters like fluid level, flow rate etc.

Apart from these, there are some more electrical type of transducers like moving coil type, changing dielectric type, changing core positions type etc.

i) Inductive transducer:

The inductive transducers work on the principle of the magnetic induction of magnetic material. Just as the resistance of the electric conductor depends on number of factors, the induction of the magnetic material depends on a number of variables like the number of turns, of the coil on the material, the size of the magnetic material, and the permeability of the flux path. In the inductive transducers, the magnetic materials are used in the flux path and there are one or more air gaps. The change in the air gap also results in change in the inductance of the circuit and in most of the inductive transducers; it is used for the working of the instrument.

ii) Capacitive transducer. The capacitive transducer or sensor is nothing but the capacitor with variable capacitance. The capacitive transducer comprises of two parallel metal plates that are separated by the material such as air, which is called as the dielectric material. In the typical capacitor, the distance between the two plates is fixed, but in variable capacitance transducers, the distance between the two plates is variable.

In the instruments using capacitance transducers, the value of the capacitance changes due to change in the value of the input quantity that is to be measured. This change in capacitance can be measured easily and it is calibrated against the input quantity, thus the value if the input quantity can be measured directly.

The capacitance C between the two plates of capacitive transducers is given by:

$C = \varepsilon_o \times \varepsilon_r \times A/d$

Where C is the capacitance of the capacitor or the variable capacitance transducer

ε_o is the absolute permittivity

ε_r is the relative permittivity

The product of ε_o and ε_r is also called as the dielectric constant of the capacitive transducer.

A is the area of the plates

d is the distance between the plates

It is clear from the above formula that capacitance of the capacitive transducer depends on the area of the plates and the distance between the plates. The capacitance of the capacitive transducer also changes with the dielectric constant of the dielectric material used in it.

Thus, the capacitance of the variable capacitance transducer can change with the change of the dielectric material, change in the area of the plates and the distance between the plates.

iii) Strain gauges: Strain gauges are devices whose resistance changes under the application of force or strain. They can be used for measurement of force, strain, stress, pressure, displacement, acceleration etc It is often easy to measure the parameters like length, displacement, weight etc that can be felt easily by some senses. However, it is very difficult to measure the dimensions like force, stress and strain that cannot be really sensed directly by any instrument. For such cases, special devices called strain gauges are very useful.

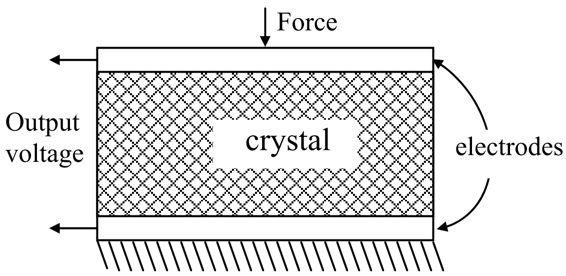
There are some materials whose resistance changes when strain is applied to them or when they are stretched and this change in resistance can be measured easily. For applying the strain you need force, thus the change in resistance of the material can be calibrated to measure the applied force. Thus the devices whose resistance changes due to applied strain or applied force are called as the strain gauges

When force is applied to any metallic wire its length increases due to the strain. The more is the applied force, more is the strain and more is the increase in length of the wire. If L_1 is the initial length of the wire and L_2 is the final length after application of the force, the strain is given as:

$\varepsilon = (L_2 - L_1)/L_1$

Further, as the length of the stretched wire increases, its diameter decreases. Now, we know that resistance of the conductor is the inverse function of the length. As the length of the conductor increases, its resistance decreases. This change in resistance of the conductor can be measured easily and calibrated against the applied force. Thus, strain gauges can be used to measure force and related parameters like displacement and stress. The input and output relationship of the strain gauges can be expressed by the term gauge factor or gauge gradient, which is defined as the change in resistance R for the given value of applied strain ε.

iv) Piezoelectric transducers



Piezo-electric transducer

Piezo-electricity represents the property of a number of crystalline materials that cause the crystal to develop an electric charge or potential difference when subjected to mechanical forces or stresses along specific planes. Conversely, the crystal would undergo change in thickness (and thus produce mechanical forces) when charged electrically by a potential difference applied to its proper axis. Elements exhibiting piezo-electric qualities are sometimes known as electro restrictive elements.

A typical mode of operation of a piezo electric device for measuring varying force applied to a simple plate is shown in the fig. Metal electrodes are attached to the selected faces of a crystal in order to detect the electrical charge developed. The magnitude and polarity of the induced charge on the crystal surface is proportional to the magnitude and direction of the applied force and is given by

$Q = KF$

Where Q is the charge in coulomb, F is the impressed force in Newton's and K is the crystal sensitivity in C/N;

Chapter 13 Resistive, Inductive & Capacitive Transducers

Objective Practice Solutions

01. Ans: (b)

Sol: For resistive potentiometer

output E_0 $= K \times E_i$

Where E_0 = output of the potentiometer

E_i = input of the potentiometer

02. Ans: (b)

Sol: In a resistance potentiometer, non linearity decreases with increase of load to potentiometer resistance because the output equation for potentiometer under loading condition is

$$E_0 = \frac{K}{1 + K(1-K)\times\left(\frac{R_p}{R_m}\right)}$$

R_p = resistance of the potentiometer

R_m = resistance of the meter

03. Ans: (a)

Sol: In a resistance potentiometer high value of resistance lease to high value of sensitivity.

04. Ans: (c)

Sol: Total temperature of POT = $T_{ambient} + T_{pot}$

$$T_{pot} = 30\left(\frac{°C}{W}\right)\times P$$

$$P = \frac{V^2}{R} = \frac{(10)^2}{100} = 1W$$

$$T_{pot} = 30\left(\frac{°C}{W}\right)\times 1W$$

$= 30$ °C

Total temperature of POT = 40 + 30

= 70°C

05. Ans: (a)

Sol: Semiconductor strain gauge has a much higher gauge factor then that of a metal wire strain gauge because of piezo resistive effect.

06. Ans: (b)

Sol: We for quarter bridge strain measuring circuit the output $V_0 = \frac{V_i}{4}\times G_F \times \varepsilon$

Here, V_0 = 1 mV

Strain (ε) = 500×10^{-6}

V_i = 4 V

Now $G_F = 2$

07. Ans: (a)

Sol: For the given bending force we can say that configuration P is subjected to more tension compare to other two configurations.

08. Ans: (d)

Sol: $G_f = 1+2\times0.35 = 1.70$

09. Ans: (c)

Sol: For sinusoidal input output should have to be sinusoidal.

10. Ans: (c)

Sol: Gauge factor $\frac{0.150/250}{1.5\times10^{-4}} = 4$

11. Ans: (b)

Sol: A gauge factor is a ratio of per unit change in resistance to per unit change in length $G.F = \frac{\Delta R / R}{\Delta L / L}$.

12. Ans: (b)

Sol: To receive the optimum output signal for shear strain, all the gauges should be placed at a position that is 45° in with respect to the longitudinal axis.

13. Ans: (c)

Sol: A strain gauge bridge sometimes excited with ac to avoid the power frequency pick-up.

14. Ans: (b)

Sol: GF = 2

$\varepsilon = 1 \times 10^{-6}$

$R = 120\Omega$

We know = $\frac{\Delta R}{R} = GF\varepsilon$

$\Delta R = GF\,\varepsilon\,R$

$= 2 \times 1 \times 10^{-6} \times 120$

$\Delta R = 240 \times 10^{-6}\,\Omega$

15. Ans: (c)

Sol: The piezoresistive effect is a change in the electrical resistivity of a semi conductor or metal when mechanical strain is applied. Semiconductor strain gauges have higher piezoresistive coefficient so higher gauge factor.

16. Ans: (a)

Sol: In given diagram of LVDT, two secondary coils are so connected that output will always be added. So output is constant voltage graph.

17. Ans: (d)

Sol: LVDT has one primary coil and two secondary coils are connected in opposition , so that output must difference between two secondary output voltage.

18. Ans: (a)

Sol: LVDT is an inductive transducer which translates the linear motion into electrical signals.

19. Ans: (b)

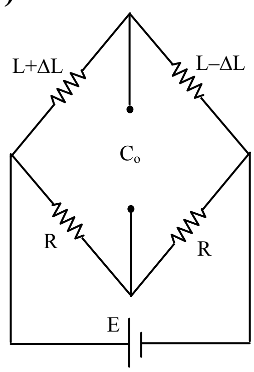
Sol: Air cored inductive transducers are suitable to use at higher frequencies.

20. Ans: (d)

Sol: Inductive transducer in differential configuration of output is unaffected by External magnetic field temperature changes, variation of supply voltage & frequency.

21. Ans: (b)

Sol:



For push pull arrangement for L change of inductance exhibited at output
$= L + \Delta L - (L - \Delta L) = 2\Delta L$

22. Ans: (d)

Sol: An LVDT exhibits linear characteristics up to a displacement of ± 5mm, linearly of 0.05 % has an infinite resolution and high sensitivity of the order of 40 V/mm.

23. Ans: (a)

Sol: To avoid the effect of fringing, the potential of the guard ring of a capacitance transducer hold at circuit potential. Ground is supposed to be a conduit to remove extraneous noise from the circuit.

24. Ans: (b)

Sol: The transfer function of capacitive transducer is given as

$$\frac{Xo(s)}{X_i(s)} = \frac{1}{\sqrt{1+\left(\frac{1}{\tau\omega}\right)^2}}$$

So this resembles a high pass filter.

25. Ans: (a)

Sol: A strain gauge is an example of an electromechanical transducer in which displacement is used to vary the resistance. So we can say that both statement I & II are true as well as related.

26. Ans: (c)

Sol: Incase of strain gauge
Statement –I is true but
Statement –II is false.

Conventional Practice Solutions

01. Question not clear.

02.

Sol: Given data:
Gauge factor of given soft iron wire = 5.2
We know the relationship between gauge factor and Poisson's ratio
$G_f = 1 + 2\nu$

$$\nu = \frac{G_f - 1}{2} = \frac{5.2-1}{2} = \frac{4.2}{2} = 2.1$$

03.

Sol: Given data:
Conductor length $\ell = 24$ mm
Charge in length of conductor $\Delta\ell = 1$ mm
Diameter of the conductor D = 1.5 mm
Charge in diameter of conductor ΔD = 0.02 mm

$$\text{Poisson's ratio } \nu = \frac{\text{lateral strain}}{\text{longitudinal strain}}$$

$$= \frac{\Delta D/D}{\Delta\ell/\ell}$$

$$= \frac{0.02/1.5}{1/24}$$

$\nu = 0.32$

Gauge factor = 1 + 2ν
$= 1 + (2 \times 0.32) = 1.64$

04.

Sol: Given data:
$G_f = 2$
Stress = 1000 (kg/cm^2)
E = 2×10^6 (kg/cm^2)

Percentage change in Resistance of the strain gauge

$= \frac{\Delta R}{R} \times 100$

$= \frac{G_f \times \text{stress}}{E} \times 100$

$= \frac{2 \times 1000}{2 \times 10^6} \times 100$

$= 0.1\%$

We know the relationship between gauge factor and Poisson's ratio

$G_f = 1 + 2\nu$

$\nu = \frac{G_f - 1}{2} = \frac{2-1}{2} = 0.5$

05.

Sol: Air gap after displacement of the armature

$= 1.00 - 0.025 = 0.975$ mm

Since inductance is inversely proportional to the length of air gap, inductance with new gap would be $= \frac{1950}{0.975} = 2000\ \mu H$

Change in inductance = 2000 – 1950 = 50 μH

$\text{Ratio} = \frac{\text{change in inductance}}{\text{orginal inductance}} = \frac{50}{1950} = 0.0256$

$\text{Ratio} = \frac{\text{displacement}}{\text{original gap}} = \frac{0.025}{1.0} = 0.025$

Since the two ratios are equal, we can say that the change in inductance is linearly proportional to the displacements.

06.

Sol: Given data:

LVDT rms output voltage = 2.6 V

LVDT displacement = 0.4 μm

Sensitivity of LVDT is

$S = \frac{\text{LVDT rms output voltage}}{\text{LVDT displacement}}$

$= \frac{2.6}{0.4}\left(\frac{V}{\mu m}\right)$

$= 6.5\left(\frac{V}{\mu m}\right)$

07.

Sol: Given data:

Sensitivity of given LVDT $= 60\left(\frac{V}{mm}\right)$

Bellow deflection = 0.15 mm for given pressure of $1.2 \times 10^6\ (N/m^2)$

Given output voltage = 4.5 V

Sensitivity of LVDT in $\left(\frac{V}{N/m^2}\right)$

$= 60\left(\frac{V}{mm}\right) \times 0.15(mm) \times \frac{1}{1.2 \times 10^6\left(\frac{N}{m^2}\right)}$

$= 7.5\left(\frac{\mu V}{N/m^2}\right)$

Pressure when output voltage is 4.5 V is

$= \frac{\text{output voltage}}{\text{sensitivity of LVDT}}$

$= \frac{4.5(V)}{7.5\left(\frac{\mu V}{N/m^2}\right)}$

$= 6 \times 10^5 (N/m^2)$

08.

Sol: Given data:

LVDT output voltage in rms = 6(V) for displacement of 0.4×10^{-3}(mm)

Voltmeter specification: 10 V voltmeter

Scale divisions = 100

Division can be estimated = $\frac{2}{10}$th division

Sensitivity of the given LVDT

$$= \frac{\text{Voltage output}}{\text{input displacement}}$$

$$= \frac{6}{0.4\times10^{-3}}\frac{(V)}{(mm)}$$

$$S = 15000\left(\frac{V}{mm}\right)$$

Resolution of voltmeter

$$= \frac{\text{voltmeter range}}{S\times\text{scale division}}\times\frac{2}{10}$$

$$= \frac{10(V)}{15000\left(\frac{V}{mm}\right)\times100}\times\frac{2}{10}$$

$$R = 1.333\times10^{-6}(mm)$$

09.

Sol: Given data:

Plate separation (x) under static condition

= 0.05 mm

C_{static} capacitance under static condition

= 5×10^{-12}(F)

Change in capacitance due to axial displacement = 0.75×10^{-12}(F)

We know the relationship between capacitance (C) and plate separation (x)

$$C \propto \frac{1}{x}$$

$$\frac{C_{static}}{C_{static}+\Delta C} = \frac{x_1}{x}$$

$$x_1 = x\times\frac{C_{static}}{C_{static}+\Delta C}$$

$$= 0.05\times10^{-3}\times\frac{5\times10^{-12}}{(5\times10^{-12})+(0.75\times10^{-12})}$$

x_1 = 43.478 μm

axial displacement = $x - x_1$

= $(0.05\times10^{-3}) - (43.478\times10^{-6})$

= 0.006522 mm

10.

Sol: Given data:

Area of quarts diaphragm = 750 mm^2

t_1 = separation distance between quartz diaphragm = 3.5 mm

C = 370 pF with no pressure with separation distance 't_1'

Δt_2 = deflection due to applied pressure

Δt_2 = 0.6 mm for the applied pressure of $900\left(\frac{km}{m^2}\right)$

We know the relationship between Capacitance (C) and separation distance (t) between the plates is

$$C \propto \frac{1}{t}$$

$t_2 = t_1 - \Delta t_2$

= 3.5 mm – 0.6 mm

t_2 = 2.9(mm)

$$\frac{C_1}{C_2} = \frac{t_2}{t_1}$$

$$C_2 = C_1\frac{t_1}{t_2} = 370\times10^{-12}\times\frac{3.5\times10^{-3}}{2.9\times10^{-3}}$$

C_2 = 446.552 pF

11.

Sol: Given data:

Capacitor overlapping area = $5\times10^{-4}(m^2)$

C = 9.5 (pF)

$\varepsilon_r = 81$

$\varepsilon_0 = 8.854\times10^{-12}$ (pF/m)

We know that

$$C = \frac{\varepsilon_0\varepsilon_r A}{d}$$

$$d = \frac{\varepsilon_0\varepsilon_r A}{C}$$

$$= \frac{8.854\times10^{-12}\times81\times5\times10^{-4}}{9.5\times10^{-12}} = 0.03775\ (m)$$

d = 37.75 (mm)

$$\text{sensitivity } S = \frac{\partial C}{\partial d} = -\frac{\varepsilon_0\varepsilon_r A}{d^2}$$

$$= -\frac{8.854\times10^{-12}\times81\times5\times10^{-4}}{(37.75\times10^{-3})^2}$$

$S = -0.025\times10^{-8}$ (F/m)

12.

Sol: Given data:

Separation distance (t_1) between diaphragm = 4 mm

For separation distance t_1 capacitance is 300 pF & oscillator frequency of 100 kHz.

P = applied pressure = 500 (kN/m^2)

Δt_2 = average deflection for pressure

P = 0.28 mm

t_2 = separation distance after application of pressure P

$t_2 = t_1 - \Delta t_2$

= 4 mm – 0.28 mm

= 3.72 mm

Now we know the relationship between C and t

$$C \propto \frac{1}{t}$$

$$\frac{C_1}{C_2} = \frac{t_2}{t_1}$$

$$C_2 = C_1\frac{t_1}{t_2} = 300\times10^{-12}\times\frac{4\times10^{-3}}{3.72\times10^{-3}}$$

C_2 = 322.58 (pF)

We know the relationship between frequency (f) & capacitance (C)

$$f \propto \frac{1}{C}$$

$$\frac{f_1}{f_2} = \frac{C_2}{C_1}$$

$$f_2 = \frac{f_1C_1}{C_2} = 100\times10^3\times\frac{300\times10^{-12}}{322.58\times10^{-12}}$$

f_2 = 93 kHz

Chapter 14 Piezo Electric Transducers

Objective Practice Solutions

01. Ans: (a)

Sol: For piezo electric transducer

$$\text{frequency} \propto \frac{1}{\text{cable length}}$$

$$f_{new} = \frac{f_{old}}{2} = \frac{1000}{2} = 500\text{Hz}$$

02. Ans: (a)

Sol: The output piezo electric transducer is a zero for static pressure.

03. Ans: (a)

Sol: For signal conditioning of piezo electric type transducer we require a charge amplifier.

04. Ans: (d)

Sol: Piezoelectric transducers is used to measure dynamic pressure measurement while for static its output is zero millivolts.

05. Ans: (a)

Sol: t = 2.5mm

$$G = 0.05 \times \frac{V_m}{N}$$

$P = 1.6 \times 10^5$ N/m^2

We know

$\varepsilon = gtp$

$= 0.05 \times 2.5 \times 10^{-3} \times 1.6 \times 10^6$

$e_0 = 200$ V

06. Ans: (c)

Sol: The piezoelectric transducers vibrate at ultrasonic frequencies. Piezoelectric material is a type of electro acoustic transducer that converts electrical energy into mechanical and vice versa.

07. Ans: (a)

Sol: Piezoelectric crystal can be shown as electrical equivalent circuit in interms L and C. Quartz, Rochelle salt, tour maline are piezoelectric crystal. Also piezoelectric crystal exhibits the reverse effect of electrostriction.

08. Ans: (c)

Sol: Piezoelectric transducer used for dynamic displacement only and it is useless for static displacement. Piezoelectric materials have low dielectric constant.

Quartz dielectric constant is 4.2

09. Ans: (a)

Sol: $BaTiO_3$ used in record player. Mechanical stress in piezoelectric material producer on electric polarization and application of electric field produces a mechanical strain.

Conventional Practice Solutions

01.

Sol: Given t = 2 mm

$g = 0.05$ Vm/N

$\frac{F}{A} = 15\times10^5$ N/m^2

We know

$$g = \frac{E_0/t}{F/A}$$

So $E_0 = g\times\frac{F}{A}\times t$

$= 0.05$ Vm/N $\times 15\times10^5$ N/m$^2 \times 2\times10^{-3}$

$= 150$ V

02.

Sol: Given data:

Area of given crystal = 36 mm^2

Thickness of given crystal = 1.5 mm

$g = 0.012\left(\frac{Vm}{N}\right)$

$\varepsilon_r = 1400$

$E = 120\times10^{10}$ (N/m^2)

F = 10 N

(i) Output voltage $e_0 = gtp$

$$= g\,t\frac{F}{A}$$

$$= 0.012\times1.5\times10^{-3}\times\frac{10}{36\times10^{-6}}$$

$e_0 = 5V$

(ii) Charge sensitivity $d = g\,\varepsilon_0\,\varepsilon_r$

$= 0.012\times8.854\times10^{-12}\times1400$

$$d = 148.75\left(\frac{pC}{N}\right)$$

(iii) strain $\varepsilon = \frac{\text{stress}}{E} = \frac{F}{AE}$

$= 0.2315\times10^{-6}$

$= 0.2315$ μstrain

(iv) charge generated Q = dF

$= 148.75\times10^{-12}\times10$

Q = 1487.5 (pC)

(v) Capacitance of pick up $C = \frac{Q}{V}$

$$= \frac{1487.5\times10^{-12}}{5} = 297.5\text{(pF)}$$

03.

Sol: Charge sensitivity $d_{33} = d = 150\times10^{-12}$ C/N

$C_{pz} = 25\times10^{-12}$ F

$R_{pz} = 10^{10}\,\Omega$

Input force = 2N u(t) (step force)

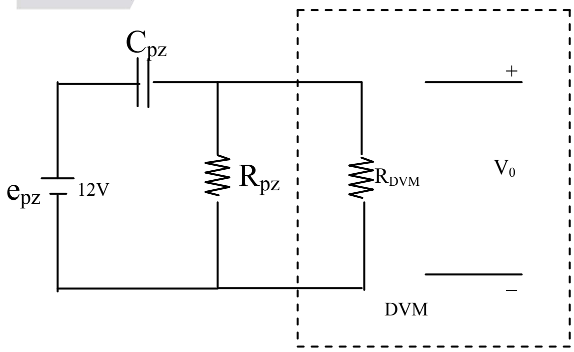
The Voltage generated

$$= \frac{\text{Charge Generated}}{C_{pz}}$$

$$e_{PZ} = e_0 = \frac{d\times F}{C} = \frac{q}{c}$$

$$e_{PZ} = \frac{150\times10^{-12}\,C/N\times2N}{25\times10^{-12}} = 12V$$

The equivalent circuit under the given condition is



$$\frac{V_0(S)}{e_{pz}(S)} = \frac{\tau s}{\tau s + 1}$$

$\tau = C_{pz}(R_{pz} \,||\, R_{DVM})$

$\tau = 20PF\ (10^{10}\Omega \,||\, 10^{13}\Omega)$

$\tau = 25 \times 10^{-12} \times 999 \times 10^{9}\,\Omega$

$\tau = 0.25$ sec

$V_0(t) = e_{pz} \times e^{-t/\tau}$

Where $V_0(t)$ is voltage across the Dvm .

Drop allowed from peak value i.e, 12 v is no more than 0.12v. Time at which V_0 falls to 11.88 V must be calculated.

Assigning $V_0(t) = 11.88$v

$11.88 = 12 \times e^{\frac{-t}{\tau}}$

$$\frac{11.8}{12} = e^{\frac{-t}{\tau}}$$

$$\Rightarrow \ln\left(\frac{11.88}{12}\right) = \frac{-t}{\tau}$$

$$\Rightarrow \frac{t}{\tau} = \ln\left(\frac{12}{11.88}\right)$$

$$\Rightarrow t = \tau \times \ln\left(\frac{12}{11.88}\right)$$

$$= 0.025 \ln\left(\frac{12}{11.88}\right) \text{seconds}$$

$\Rightarrow t = 2.512$ m Seconds

Chapter 15 Measurement of Temperature

Objective Practice Solutions

01. Ans: (a)

Sol: Platinum resistance thermometer used to measure temperature in the range –200° C to 1000°C

Material	Minimum temperature	Maximum temperature
Platinum	–200°C	1000°C
Copper	–200°C	150°C
Nickel	–70°C	150°C
Tungsten	–200°C	850°C

02. Ans: (d)

Sol: RTD material must have

(i)High temperature coefficient of resistance

(ii) Higher resistivity

(iii) Linear relationship between R and T

(iv) Stability of the electrical characteristics of the material

03. Ans: (d)

Sol: Platinum has a constant volume of temperature coefficient in 0 to 100°C range.

Resistivity of platinum tends to increase less rapidly at higher temperatures.

Platinum has stability over higher range of temperature.

04. Ans: (b)

Sol: $$\alpha_{45°C} = \left(\frac{R_2 - R_1}{T_2 - T_1}\right)\frac{1}{R_{45°C}}$$

$$R_{45°C} = \frac{R_1 + R_2}{2} = \frac{5 + 6.5}{2} = 5.75\Omega$$

Here $R_1 = 5\Omega$ at $T_1 = 30°C$

$R_2 = 6.5\Omega$ at $T_2 = 60°C$

$$\alpha_{45°C} = \left(\frac{6.5 - 5}{60 - 30}\right)\times\frac{1}{5.75} = 0.0087\ (1/°C)$$

05. Ans: (d)

Sol: The resistance temperature characteristics of a temperature transducer is related to positive temperature coefficient thermistor.

06. Ans: (d)

Sol: Thermistors are well suited to precision temperature measurement. It is used in range of –100°C to 300°C. It has higher negative temperature coefficient of resistance.

07. Ans: (c)

Sol: A thermistor can exhibit either a negative change of resistance (NTC) or positive change of resistance (PTC) with increase of temperature depending upon the type of material used.

08. Ans: (b)

Sol: $R = 5000\ \Omega$ at $T = 25°C$, $\alpha = 0.04\ (1/°C)$

$R_{lead} = R\ [1+\alpha\ (T_{lead} - T)]$

$10 = 5000\ [\ 1+ 0.04\ (T-25)]$

$T = 0.05°C$

09. Ans: (b)

Sol: Thermistors are essentially semiconductor devices that behaves as resistors with high negative temperature coefficient and are atleast 10 times as sensitive as the platinum resistance thermometer.

10. Ans: (b)

Sol: $\beta = 3000$ K

$R = 1050\Omega$ at $T = 27\ °C$

$= 300$ K

So temperature coefficient of resistances for the thermistor $\alpha = \frac{-\beta}{T^2} = \frac{-3000}{(300)^2}$

$= -0.033\ (\Omega/\Omega/°C)$

11. Ans: (d)

Sol: In case of thermocouple we required a reference junction compensation to get stable and reliable output. Also thermocouple output is very small.

12. Ans: (a)

Sol: V_0 = output of thermocouple = 50 mV

R_t = thermocouple internal resistance = 50Ω

$R_{lead} = 10\Omega$

r = PMMC internal resistance = 120Ω

so output voltage indicated by PMMC V_{PMMC} is

$$V_{pmmc} = \frac{r}{r + R_t + R_{lead}} \times V_0$$

$$= \frac{120}{120 + 50 + 10} \times 50 \times 10^{-3}$$

$$= \frac{120 \times 50 \times 10^{-3}}{180}$$

$= 33.33$ mV

13. Ans: (d)

Sol:

Thermocouple	**Temperature range(in°C)**
Copper-constantan	–200 to 350
Iron - constantan	–200 to 850
Alumel-Chromel	–200 to 1100
Platinum Rhodium	450 to 1500

14. Ans: (b)

Sol: Iron-constantan thermocouple is most suitable for temperature measurement in the range of 700 °C to 800° C.

15. Ans: (a)

Sol: Time to reach equilibrium

Conditions $5T = 10 \Rightarrow T = 2$ sec

$\theta = \theta_0\ [1 - e^{-t/T}]$

$0.5 = [1 - e^{-t/T}]$

$T = 1.39$ sec

Conventional Practice Solutions

01.

Sol: Temperature of thermistor at 2330 Ω is

Here $R_T = 2330\ \Omega$

$R_0 = 1050\ \Omega$

T = unknown temperature at 2330 Ω

$T_0 = 27°C = 300°K$

$$R_T = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)}$$

$$\ell_n\left(\frac{2330}{1050}\right) = 3140\left(\frac{1}{T}-\frac{1}{300}\right)$$

$$0.7971 = 3140\left(\frac{1}{T}-\frac{1}{300}\right)$$

T = 278.77°K

T = 5.77°C

This temperature corresponds to the resistance of 2330 Ω.

$$\text{Sensitivity } S = \frac{dR}{dT} = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)} \times \left(\frac{-\beta}{T^2}\right)$$

$$= \frac{-R_T\beta}{T^2}$$

$$= \frac{-2330\times 3140}{278.77^2}$$

S = –94.144 (Ω/K)

This is the required sensitivity of the given thermistor at a given operating point (2330 Ω and 278.77°C).

02.

Sol: Given data:

Sensitivity of copper with respect to platinum

$$S_{CuPt} = 7.4\left(\frac{\mu V}{^oC}\right)$$

Sensitivity of constantan with respect to platinum

$$S_{CnPt} = -34,4\left(\frac{\mu V}{^oC}\right)$$

Sensitivity of copper with respect to constantan

$S_{CuCn} = S_{CuPt} - S_{CnPt}$

$$= 7.4\left(\frac{\mu V}{^oC}\right) - \left(-34.4\left(\frac{\mu V}{C}\right)\right)$$

$$S_{CuCn} = 41.8\left(\frac{\mu V}{^oC}\right)$$

Now corresponding temperature difference in a thermocouple made up of copper and constantan junction for temperature difference of 250°C is

$= S_{CuCn} \times 250°C$

$$= 41.8\left(\frac{\mu V}{^oC}\right)\times 250^oC = 10.45\ (mV)$$

03.

Sol: Given data:

$$\alpha = 37.5\left(\frac{\mu V}{^oC}\right)$$

$$\beta = 0.0045\left(\frac{\mu V}{^oC}\right)$$

$\theta_{hot} = 200°C$

$\theta_{cold} = 0°C$

Now we know the thermocouple relationship between thermo-emf set up and temperature difference between hot and cold junction is given by

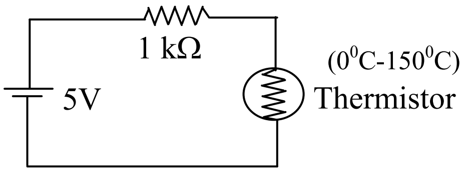
$E = \alpha\,(Q_h - \theta_c) + \beta\left(\theta_h^2 - \theta_c^2\right)$

$= 37.5\times10^{-6}(200–0)+0.0045\times10^{-6}(200^2 –0^2)$

= 7.68 mV

04.

Sol:

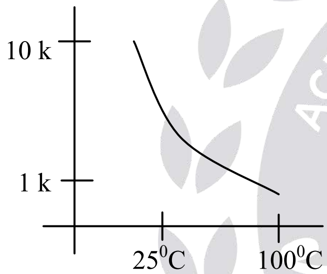


At 25°C the resistance of thermistor is 10kΩ

At 100°C the resistance of thermistor is 1kΩ

This thermistor is used in a temperature range of 0-150°C.

$$P = I^2R = \frac{V^2}{R}$$



$R_T = R_0$

$$\ln\left[\frac{R_T}{R_0}\right] = \beta\left[\frac{1}{T} - \frac{1}{T_0}\right]$$

$T_0 = 25°C + 273 = 293K$ and $R_0 = 10k\Omega$

$T = 100 + 273 = 373K$ and $R_T = 1k\Omega$

$$\ln\left[\frac{1}{10}\right] = \beta\left[\frac{1}{373} - \frac{1}{298}\right]$$

$\beta = 3412.55$ K

Now

$T_0 = 100°C + 273 = 373$ K and $R_0 = 1K\Omega$

$T = 150°C + 273 = 473K$

$$\ln\left[\frac{R_T}{1k\Omega}\right] = 3412.55\left[\frac{1}{423} - \frac{1}{373}\right]$$

$R_T = 339.12\ \Omega$

Thermistor resistor at 150°C

$$I = \frac{5V}{1k + R_T} = \frac{5}{1339.12} = 3.733\times10^{-3}$$

$P = I^2 \times R$

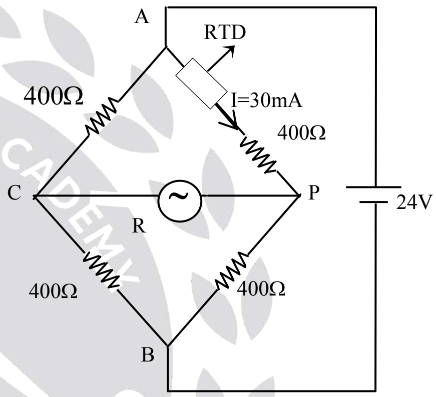
$P = 4.72$ mW

05.

Sol: Given data:

$R_1=R_2=R_3=R_4 = 400\Omega$; $\alpha = 0.042\Omega/°C$

$T = 30°C$; $I = 30mA$



Due to temperature rise of 30^0C, increase in the resistance of sensor by $= 0.042 \times 30$

$= 1.26\Omega$

So resistance of sensor branch become

$= 400 + 1.26 = 401.26\Omega$

Current through sensor is restricted is 30mA

Voltage across AB terminals

$=30[400 + 401.26]\times10^{-3}$

$= 24.038 \approx 24V$ (DC supply)

Thevinins equivalent resistance across AB terminals = (400 + 401.26)||(400 + 400)

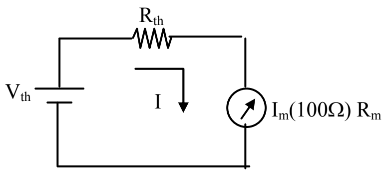
= (801.26)||(800)

$$= \frac{801.26\times800}{801.26+800} = 400.3147\Omega$$

$$V_{th} = 24 \times \left[\frac{400}{800} - \frac{400}{801.26}\right]$$

$= 24[0.5 - 0.499] = 0.0188\text{V}$

$\therefore$ I through the meter



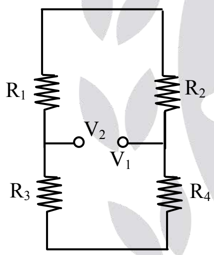
$$I = \frac{V_{th}}{R_{th} + R_m}$$

$$= \frac{0.0188}{400.3147 + 100} = 37.58\mu A$$

Deflection of the meter= 37.58 × 2°= 75.16°

06.

Sol:



Sensitivity 10 mV/ °C means change in 1°C in RTD corresponding to 10 mV change in Bridge output.

$R_T = R_0\,[1+\alpha T]$

$= 100[1+0.00392(1-0)]$

$R_T = 100.392\Omega$

$10\text{ mV} = A_d\,[V_1 - V_2]$

$$V_1 - V_2 = \left(\frac{R_4}{R_2 + R_4}\right)V - \left(\frac{R_3}{R_1 + R_3}\right)V$$

$$= 10\left[\frac{150.392}{100.392 + 10k} - \frac{100}{100 + 10k}\right]$$

$= 0.3842\text{ mV}$

$$A_d = \frac{10}{0.3842} = 26.02$$

Chapter 16 Measurement of Flow, Viscosity, Humidity

Objective Practice Solutions

01. Ans: (d)

Sol: In case of rotameter with increase in the flow rate, the float rises in the tube and there occurs an increase in the annular area between the float and the tube. So we can say that rotameter is a variable area device.

02. Ans: (a)

Sol: Flow rate in pitot tube is

$$Q = AV = A\sqrt{\frac{2P_d}{\rho}}$$

$$\theta \propto \sqrt{P_d}$$

03. Ans: (c)

Sol:

Restrictors	Discharge coefficient
Orifice tube	0.60
Venturi tube	0.98
Flow nozzle	0.80

04. Ans: (b)

Sol: Rotary vane type transducer is an example of positive displacement flow meter.

05. Ans: (b)

Sol: Venturimeter has the lowest pressure drop for a given range of flow because venturimeter has highest coefficient of discharge about 0.98.

06. Ans: (a)

Sol: In Rota meter, flow rate is directly proportional to height.

$$Q \propto h$$

$$\therefore \frac{Q_1}{Q_2} = \frac{h_1}{h_2} = \frac{70\,mm}{20\,mm} = \frac{7}{2} = 3.5$$

07. Ans: (d)

Sol: During the flow through an orifice meter, the fluid jet on leaving the orifice contracts to minimum area at a section called vena-contracta, area of fluid jet at vena contracta is less than areas of the orifice & the two are related as

area at vena contracta = C_d ×orifice area.

$$= 0.6\left(\frac{\pi d^2}{4}\right)$$

C_d of orifice = 0.6

Area of orifice = $\frac{\pi d^2}{4}$

08. Ans: (a)

Sol: Pressure at throat of a venturi tube is lower compare to upstream pressure. While velocity at throat of a venture tube is higher compare to velocity of flow at up stream.

09. Ans: (a)

Sol: In case of rotameter the weight of the float is balanced by the buoyancy and the drag force acting on the float. Volume flow rate sensitive to density changes of the fluid. By using rotameter volume flow rate of gas can be measured.

10. Ans: (c)

Sol: Flowing fluid density affected in orifice plate, rotameter, pitot static tube meter white flowing fluid density is not matter for measurement of flow in non obstruction type meter like electromagnetic flow meter.

11. Ans: (a)

Sol: When an electrically heated wire is placed in a flowing gas stream, heat is transferred from wire to the gas and hence the temperature of the wire reduces and due to this the resistance of the wire also changes. This change in resistance of the wire becomes a measure of flow rate.

12. Ans: (a)

Sol: Hot wire anemometer gives good result when the flowing fluid is exceptionally clean.

13. Ans: (c)

Sol: The turbine type flow meter used to measure totalisation of flow.

14. Ans: (b)

Sol: In case of electromagnectic flow meter the induced voltage is proportional to flow rate

as $e = \frac{B\ell VA}{A} = \frac{B\ell Q}{A}$

$e \propto Q$

Conventional Practice Solutions

01. Repeated, refer second question.

02.

Sol: For ultrasonic flow meter, the guiding equation is

$$\Delta t = \frac{2 d V \cos\theta}{C^2}$$

$$10 \text{ nsec} = \frac{2\times 25\times 10^{-3}\times V\times \cos 60^{\circ}}{1000}$$

Velocity = 0.45 m/sec

03. Ans: 6.0 mV

Sol: Given, $Q_v = \frac{400}{60} = 6.667 \text{ litre/sec}$

l = 8cm = 0.08m, B = 400 gauss

$= 400\times 10^{-4}$ tesla

We know,

$$E = \frac{4B}{\pi l} Q_V \times 10^{-3} V \approx 4.24 mV$$

$$E_{rms} = \frac{2\times 4.24}{\sqrt{2}} mv = 6.0 mV$$

Chapter 17 Intermediate Quantity Measurements

Objective Practice Solutions

01. Ans: (d)

Sol: In seismic vibration sensor for measuring amplitude of vibration $\omega_n << \omega$ & slightly less than 1.

02. Ans: (d)

Sol: $\omega_n = \sqrt{\frac{K}{M}}$

Decreasing the mass in case of a seismic acceleration sensor while keeping all other parameters constant will increase the natural frequency, without affecting steady state sensitivity.

03. Ans: (a)

Sol: $M = 100\ \mu gm$

$F_n = 1kHz$

04. Ans: (a)

Sol: f = 100 Hz

X = 10 mm

Peak acceleration of the seismicmass = $\omega^2 x$

$= (2\pi f)^2 x$

$= (2\pi\times 100)^2 \times 10 \times 10^{-3}$

$= 3947.84\ (m/sec^2)$

05. Ans: (a)

Sol: Accelerometer input range

$= 0\ m/sec^2$ to $98.1\ (m/sec^2)$

F = 30 Hz

M = 0.01 kg

We know acceleration = ω^2 x

$$x = \frac{\text{acceleration}}{\omega^2}$$

$x_1 = 0mm$ to $x_2 = \frac{98.1}{(2\pi\times30)^2}$

$= 2.76$ mm

06. Ans: (b)

Sol: In dc tachogenerators used for measurement of speed of a shaft, frequent calibration has to be done because the strength of permanent magnet decreases with age.

07. Ans: (c)

Sol: In a drag up type ac tachogenerator, the output voltage is modulated waveform.

08. Ans: (b)

Sol: $n_{teeth} = 60$

N = speed of shaft

N = 25 rps

We know

Speed of shaft in rps = $\frac{\text{pulse rate}}{n_{teeth}}$

$$25 = \frac{\text{pulses per second}}{50}$$

Pulses per second = 25×60

= 1500

09. Ans: (b)

Sol: f_r = rotating frequency of motor

$= \frac{1470}{60} = 24.5(\text{rps})$

F_f = stroboscope flashing frequency

= 12.5 (fps)

$F_r - nf_f = 24.5 - nf_f$

$n = 2\,f_r - nf_f = -30$ rpm

So star mark moves at a speed of 30 rpm against the direction of rotation.

10. Ans: (c)

Sol: $\text{rpm} = \frac{\text{pulses per second}}{\text{number of teeth}} \times 60$

$\text{rpm} = \frac{\text{flash per minute}}{\text{number of teeth}}$

$N = \frac{F}{n}$