GATE

MADE EASY
Workbook 2025

Detailed Explanations of Try Yourself *Questions*

Instrumentation Engineering
Sensors and Industrial Instrumentation

MADE EASY PUBLICATIONS

1 Introduction to Transducers

Detailed Explanation of Try Yourself Questions

T1. Sol.

$\theta_F = 100 - 30 = 70°C$

We can write

$66.5 = 70(1 - e^{-30/\tau})$

$\Rightarrow \quad \tau = 10$ sec.

For second condition

$68 = 70\,(1 - e(-^{t/10}))$

by solving $t = 36.5$ sec.

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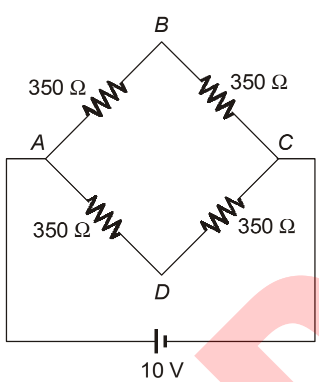
2 Resistive Transducers

Detailed Explanation of Try Yourself Questions

T1. Sol.



Given, $G_f = 2.03 \quad Vs = 10\text{ V}$

$\in = 1430 \times 10^{-6}$

Strain gauge in BC subjected to strain of 1450 μm/m.

$$V_{\text{bridge}} = \frac{V_o}{4} \times \frac{\Delta R}{R + 2\Delta R}$$

$$\Delta R = G_r \times \in \times R$$

$$= 2.03 \times 1450 \times 10^{-6} \times 350$$

$$V_{\text{bridge}} = 7.314 \times 10^{-3} = 7.31\text{ mV}$$

T2. Sol.

$$\frac{R_o}{R_t} = \frac{d_i}{d_t}$$

$$\frac{6000}{20\text{ k}\Omega} = \frac{d_i}{100\text{ mm}}$$

$$d_i = 30\text{ mm},$$

$$\frac{R_D}{R_t} = \frac{d_i}{d_t}$$

$$\frac{15000}{20\text{ k}\Omega} = \frac{d_i}{100\ mm}$$

$$d_i = 75\text{ mm}$$

T3. Sol.

$$\because \quad \in_o = \frac{E\, G_F \in}{4}$$

$$= \frac{2}{4} \times 10(10 + 20\sin 314t) \times 10^{-6}$$

$$= [50 + 100\sin 314t]\ \mu\text{V}$$

T4. Sol.

$$\because \quad \Delta R = R_o\, G_F \in$$

$$\in = \frac{\Delta R}{R_o\, G_F} = \frac{0.52}{100 \times 2} = 0.0026$$

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3 Capacitive Transducers

Detailed Explanation of Try Yourself Questions

T1. Sol.

$$C_1 = \frac{\epsilon_o \epsilon_r \times l \times \omega}{d}$$

$$C_2 = \frac{\epsilon_o \epsilon_r \times X \times \omega}{d} + \frac{\epsilon_o \times \epsilon_r \times (l - X)\,\omega}{d}$$

Given $2C_1 = C_2$

$$\frac{2\,\epsilon_o \cdot \epsilon_r \times l \times \omega}{d} = \frac{\epsilon_o \times \epsilon_r \times X \times \omega}{d} + \frac{\epsilon_o\,\epsilon_r\,(l - X)\,\omega}{d}$$

$$X = \frac{L}{2}$$

T2. Sol.

$$V_o = -\frac{C_i\,d}{\epsilon_A} v_e$$

$$\frac{\partial V_o}{\partial d} = -\frac{C_i\,v_e}{\epsilon\,A}$$

$$= \frac{-10 \times 10^{-12} \times 10}{8.854 \times 10^{-12} \times 800 \times 10^{-6}}$$

$$= 1.1412 \times 10^{4}\ \text{V/m}$$

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4 Inductive Transducers

Detailed Explanation of Try Yourself Questions

T1. Sol.

Voltage produced in the stator of the transmitter

$$V_r \cos\theta = 5\cos 60° = 5 \times \frac{1}{2} = 2.5 \text{ Volts}$$

T2. Sol.

$$L = 6 \text{ mH} \quad ; \quad d = 2\text{mm}$$

Towards the coil

$$\frac{6 \text{ mH}}{L} = \frac{2 - 0.035}{2 \text{ mm}}$$

$$L = 6.10 \text{ mH}$$

Away from coil

$$\frac{6 \times 10^{-3}}{L} = \frac{2 + 0.035}{2}$$

$$L = 5.896 \text{ mH}$$

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5 Piezo-electric Transducers

Detailed Explanation of Try Yourself Questions

T1. Sol.

0.0193

T2. Sol.

$$V_o = gpt$$

$$300 = 0.65 \times \frac{f}{36 \times 10^{-6}} \times 2 \times 10^{-3}$$

$$F = 8.3\ N$$

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6 Measurement of Flow

Detailed Explanation of Try Yourself Questions

T1. Sol.

$$\frac{Q_1}{Q_2} = \sqrt{\frac{P_1}{P_2}}$$

$$\frac{80}{Q_2} = \sqrt{\frac{15}{25}}$$

$$Q_2 = 103.27\ l/\text{min}$$

T2. Sol.

$$Q = \frac{C_d A_2}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}}\sqrt{\frac{2\Delta p}{\rho}}$$

$$\rho = \frac{M}{Q}$$

$$1000 = \frac{4}{Q}$$

$$A_2 = \left(\frac{3.5}{2}\right)^2 = 9.62\times 10^{-4}$$

$$Q = 4\times 10^{-3}\ \text{m}^3/\text{sec}$$

$$4\times 10^{-3} = 0.95\times\frac{9.62\times 10^{-4}}{\sqrt{1-\frac{1}{4}}}\times\sqrt{\frac{2\Delta p}{1000}}$$

$$\Delta p = 8.9\ \text{kN/m}^2$$

T3. Sol.

Given $\omega = 4.5\times 10^4\,Q$

$\beta = 0.88,\ n = 4,\ Q_{max} = 3.15\times 10^{-3}\ \text{m}^3\text{s}^{-1}$

Now maximum amplitude

$= \omega_{max}\times\beta\times n$

$= 4.5\times 10^4\times 3.15\times 10^{-3}\times 0.88\times 4$

$= 498.96$

Maximum frequency, $f_{max} = \dfrac{\omega_{max}\times n}{2\pi}$

$$= \frac{4.5\times 10^5\times 3.15\times 10^{-3}\times 4}{2\pi}$$

$= 90.2$ kHz

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7 Measurement of Pressure

Detailed Explanation of Try Yourself Questions

T1. Sol.

$$\Delta p = 9.81 \text{ Pa}, \quad d_t = 2 \text{ mm} = 0.002 \text{ m}$$
$$d_w = 0.02 \text{ m}$$
$$d = 4 \text{ mm}, \quad \text{specific gravity} = 0.864$$
$$\rho = 0.864 \times 1000$$

We know,

$$\Delta p = \left(\sin\theta + \frac{\alpha_L}{\alpha_\omega}\right) d\rho g$$

$$\sin\theta = \frac{\Delta p}{d\rho g} - \left(\frac{dt}{d\omega}\right)^2$$

$$= \frac{9.81}{(0.0104) \times (0.864 \times 1000)\,(9.81)} - (0.1)^2$$

$$\theta = \sin^{-1}(0.2793°) = 16.22°$$

T2. Sol.

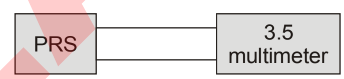
$$\Delta p = \rho g h$$
$$1 = 13600 \times 9.8 \times h$$
$$h = 7.5 \times 10^{-3} \text{ mm}$$

$$\% \text{ error} = \frac{-a}{a + A} \times 100$$

$$= -\frac{(1)^2}{(1)^2 + (15)^2} \times 100 = -0.44$$

$$= -0.5\% \text{ approx.}$$

T3. (10)



$$\text{Total count} = 2000 \text{ counts}$$
$$\text{Max voltage} = 200 \text{ mV}$$

$$\text{Sensitivity} = \frac{1 \text{ mV/V}}{1\text{k pascal}}$$

$$\text{Input voltage} = 10 \text{ V}$$
$$\text{Full scale output} = 200 \text{ mV}$$

$$\text{Sensitivity} = \frac{200 \text{ mV}/10 \text{ V}}{P_{in}}$$

$$\Rightarrow \quad \frac{\frac{1 \text{ mV}}{\text{V}}}{1\text{k pascal}} = \frac{\frac{200 \text{ mV}}{10 \text{ V}}}{P_{in}}$$

$$\Rightarrow \quad P_{in} = 20 \text{ k pascal}$$

$$\text{Resolution} = \frac{20 \text{ k pascal}}{2000 \text{ counts}} = 10\, P_a$$

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8 Measurement of Temperature

Detailed Explanation of Try Yourself Questions

T1. Sol.

Sensitivity of each thermopile 60 μV/°C

10 junction sensitivity = 10 × 60 μV/°C

Resolution of AC is given as $\frac{V_{ref}}{2^n - 1}$

$$= \frac{6\,V}{2^{10} - 1} = 5.86 \text{ mV}$$

Resolution of system $= \frac{5.86 \text{ mV}}{6 \text{ mV/°C}} = 0.977°\text{C}$

T2. Sol.

Resistance of RTD at 1°C

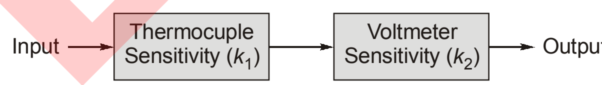
$$R_1°\text{C} = R_o(1 + \alpha\Delta t)$$
$$= 100\,[1 + 0.00392\,(1)]$$
$$= 100.392$$

$$V_o = \frac{10(100.392)}{1010.392} - \frac{10}{1010} \times 100$$
$$= 0.384 \text{ mV/°C}$$

$$g = \frac{10 \text{ mV}}{0.384 \text{ mV}} = 26/°\text{C}$$

T3. Sol.

Block diagram representation of the given problem shown below:



Here, $k_1 = 4.8$ mV/°C

$$k_2 = 1°/\text{mV} = \left(1° \times \frac{\pi}{180} \times 30\right)\frac{\text{mm}}{\text{mV}}$$

Overall sensitvity

$$k_1 \times k_2 = 4.8\frac{\text{mV}}{°\text{C}} \times \left(1° \times \frac{\pi}{180} \times 30\right)\frac{\text{mm}}{\text{mV}}$$
$$= 2.5 \text{ mm/°C}$$

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9 Measurement of Force

Detailed Explanation of Try Yourself Questions

T1. Sol.

Consider 1 kN is applied on load cell stress

$$= \frac{1 \times 10^3}{\frac{\pi}{4} \times (10^{-3} \times 50)^2}$$

$$= 0.5095 \times 10^6 \text{ N/m}^2$$

$$\text{Strain} = \frac{\text{Stress}}{E} = \frac{0.5095 \times 10^6}{200 \times 10^9}$$

$$= 2.5475 \times 10^{-6}$$

Fractional change in resistance

$$\frac{dR}{R} = F\epsilon = 2 \times 2.5475 \times 10^{-6}$$

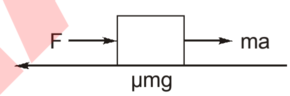
$$= 5.095 \times 10^{-6}$$

$$\text{Output voltage} = 2(1+\mu)\left(5.095 \times 10^{-6} \times \frac{6}{4}\right)$$

$$= 19.87 \times 10^{-8}$$

Gauge sensitivity = 19.87 μV/kN

T2. Sol.



$$F = \mu mg + ma$$

$$4.9 = mg$$

$$m = 0.5 \text{ kg}$$

$$F = 0.5 \times 0.5 \times 9.8 + 0.5 \times 4$$

$$= 4.5 \text{ N.}$$

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10 Measurement of Torque, Vibration & Shock

Detailed Explanation *of* Try Yourself Questions

T1. Sol.

$$\frac{y}{x} = \frac{r^2}{\sqrt{(-r^2)^2 + (5\xi r)^2}}$$

At 30 kHz

$$r = \frac{\omega}{\omega_n} = \frac{30}{20} = 1.5 \qquad \xi = 0.7$$

$$\frac{y}{x} = \frac{1.5 \times 1.5}{\sqrt{(1 - 2.25) + (2 \times 0.7 \times 1.5)^2}} = 0.92$$

For 1 kHz

$$r = \frac{1000}{20} = 50$$

$$\frac{y}{x} = \frac{50 \times 50}{\sqrt{(1 - 50 \times 50)^2 + (2 \times 0.7 \times 1.5)^2}} = 1$$

T2. Sol.

$$a_{peak} = x_m \omega^2$$
$$= 10 \times 10^{-3} \times (2\pi \times 100)^2$$
$$= 10^{-2} \times 10^4 \times 39.4384$$
$$= 3943.84$$

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11 Measurement of Velocity

Detailed Explanation of Try Yourself Questions

T1. Sol.

$$\text{Speed} = \frac{6000}{10} = 600$$

Since points appear to be revolving once in 12 seconds or 5 times in 1 minute, we have

Slip = 5 rpm

Possible shaft speed = 600 ± 5

= 605, 595 rpm

T2. Sol.

(i) $$n = \frac{f}{m} = \frac{4000}{10}$$

= 400 rpm

(ii) 400 + 20 = 420 rpm

Shaft speed + disc speed.

T3. Sol.

Frequency of AC voltage, $f = m \times f_r$

m = Number of teeth

f_r = Rotation speed (rps)

f = 25 × 100 = 2.5 kHz

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12 Measurement of Humidity, Viscosity & pH Value

Detailed Explanation of Try Yourself Questions

T1. Sol.

$$\frac{\mu_A}{\mu_B} = \frac{V_B}{V_A}$$

$$\frac{12 \times 10^{-3}}{\mu_B} = \frac{0.003}{0.06}$$

$$\mu_B = 0.24 \text{ m}^2/\text{sec.}$$

T2. Sol.

pH change 7.8 – 6.5 = 1.3

at 25°C slope factor = 59.1 mV/pH unit

$$= 59.1 \times 1.3 \times 100$$

$$= 7.683 \text{ V}$$

Loading condition

$$V_L = \frac{V_o}{R_o + R_L} \times R_L$$

$$= \frac{7.683}{10^{10} + 10^{11}} \times 10^{11} = 6.9 \text{ V}$$

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