Instrumentation and Measurements

PRACTICE PROBLEMS

Indicator Diagrams

1. Diesel engines in a waste-to-energy plant are powered by a gaseous mixture of methane and other digestion gases. The combustion conditions in each cylinder are continuously monitored by pressure and temperature transducers. A particular cylinder’s indicator diagram is shown. The scale selected in the monitoring software is set to 111 kPa/mm. Most nearly, what is the mean effective pressure in the cylinder?

![Indicator Diagram](image)

- (A) 7.7 kPa
- (B) 15 kPa
- (C) 360 kPa
- (D) 850 kPa

Variable Inductance Transformers

2. Which of the statements regarding the linear variable differential transformer (LVDT) shown is true?

![LVDT Diagram](image)

- (A) The LVDT is a variable reluctance transducer, and its output voltage is directly proportional to its core movement.
- (B) The LVDT is a variable reluctance transducer, and its output current is directly proportional to its core movement.
- (C) The LVDT is a variable capacitance transducer, and its output current is directly proportional to core movement.
- (D) The LVDT is a variable inductance transducer, and its output voltage is directly proportional to core movement.

Resistance Temperature Detectors

3. A resistance temperature detector (RTD) measures temperature in a bridge circuit. The resistances of resistors 1, 2, and 3 are 100 Ω, 200 Ω, and 50 Ω, respectively. The power supply voltage is 10 V. The reference resistance of the RTD is 100 Ω at 0°C. The alpha value for the RTD is 0.00392 1/°C. The variation of RTD resistance with temperature is linear. What is most nearly the temperature of the RTD when the voltmeter reads 4.167 V?

![RTD Diagram](image)

- (A) 130°F
- (B) 210°F
- (C) 260°F
- (D) 330°F
4. The temperature of a steel girder during a fire test is measured with a type 404 platinum RTD and a simple two-wire bridge, as shown. The characteristics of the RTD are: resistance, $R$, 100 $\Omega$ at 0°C; temperature coefficient, $\alpha$, 0.00385 $1/^{\circ}C$. The values of the bridge resistances are $R_1 = 1000 \Omega$, and $R_3 = 1000 \Omega$. When the meter is nullled out during a test, $R_2 = 376 \Omega$. The lead resistances are each 100 $\Omega$. Most nearly, what is the temperature of the beam during the test?

(A) 130°C  
(B) 175°C  
(C) 200°C  
(D) 450°C

Piezoelectric Transducers

5. A compression-style crystal piezoelectric accelerometer has a sensitivity of 2.0 mV/g. It falls to the floor from a height of 3 ft and comes to rest 0.02 sec after contact with the floor. What is most nearly the average voltage output of the accelerometer during impact?

(A) 21 mV  
(B) 32 mV  
(C) 43 mV  
(D) 57 mV

6. A piezoelectric transducer is connected to a charge amplifier as shown. What is the purpose of capacitor $C_i$?

(A) $C_i$ biases the transducer output.  
(B) $C_i$ isolates the transducer from inadvertent amplifier transients.  
(C) $C_i$ rectifies the transducer output.  
(D) $C_i$ prevents DC voltages from being passed to the amplifier.

Photosensitive Conductors

7. A velocity indicating system attached to a machine consists of a light source, a light sensor, a disk that rotates with the machine’s rotation, and a counting circuit. There are 12 reflective strips around the periphery of the disk. As a machine starts up, the disk spins, and the sensor detects the pulses reflected back by the reflective strips. Given the numbers of counts per minute recorded by the sensor, what is most nearly the average angular acceleration of the disk between 2 sec and 4 sec?

<table>
<thead>
<tr>
<th>time (sec)</th>
<th>counts (min)</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>1200</td>
</tr>
<tr>
<td>4</td>
<td>10,800</td>
</tr>
</tbody>
</table>

(A) 3.5 rad/sec$^2$  
(B) 21 rad/sec$^2$  
(C) 42 rad/sec$^2$  
(D) 84 rad/sec$^2$
21. Two iron-constantan thermocouples are wired in series to monitor the cylinder head temperature in an aircraft engine. The voltage across the thermocouples is read in the cockpit as 16.52 mV. The cockpit temperature is 70°F. What is most nearly the average temperature of the cylinder head?

(A) 290°F

(B) 330°F

(C) 350°F

(D) 380°F

22. A copper-constantan thermocouple is used with an ice bath to measure the temperature of waste sludge during digestion. The voltage is proportional to the difference in temperature between the junctions. When the thermocouple is calibrated, it generates a voltage of 5.07 V when the temperature of the hot junction is 108.9°C and the reference temperature is at 0°C. Most nearly, what is the temperature of waste sludge when the voltage is 1.83 V?

(A) 40°C

(B) 45°C

(C) 50°C

(D) 55°C

**Solutions**

1. The average height of the pressure plot is

\[ \bar{h} = \frac{A}{w} = \frac{490 \text{ mm}^2}{64 \text{ mm}} = 7.656 \text{ mm} \]

The average pressure is

\[ \bar{p} = k\bar{h} = \left( \frac{111 \text{ kPa}}{\text{mm}} \right) (7.656 \text{ mm}) \]

\[ = 849.8 \text{ kPa} \left( \frac{850 \text{ kPa}}{100 \text{ kPa}} \right) \]

The answer is (D).

2. A coil of wire, particularly a coil with an iron core, behaves as an inductor in an AC circuit. In an LVDT, the movable transformer core changes the inductance between the primary and secondary windings. The transformer is constructed so that the output voltage of the LVDT is directly proportional to the movable core position. A linear variable differential transformer (LVDT) is a variable inductance transducer.

The answer is (D).

3. Since the voltage is not zero, the bridge is not balanced. Rearrange Eq. 64.16 to find the RTD resistance.

\[ R_{\text{RTD}} = \frac{V_1R_1R_3 + V(R_1R_3 + R_2R_3)}{V_1R_2 - V(R_1 + R_2)} \]

\[ = \frac{(10 \text{ V})(100 \text{ Ω})(50 \text{ Ω})}{(10 \text{ V})(100 \text{ Ω}) - (4.167 \text{ V})} \]

\[ \times \left( \frac{(100 \text{ Ω})(50 \text{ Ω})}{(200 \text{ Ω})} \right) \]

\[ = 150.0 \text{ Ω} \]

Rearrange Eq. 64.3 to find the temperature. Since temperature varies linearly with resistance, only the alpha-value, \( \alpha \), is required.

\[ T = \frac{R_{\text{ref}}(\alpha T_{\text{ref}} - 1) + R_{\text{RTD}}}{R_{\text{ref}}\alpha} \]

\[ = \frac{(100 \text{ Ω}) \left( \left( \frac{0.00392}{1^\circ C} \right) (0^\circ C) - 1 \right) + 150.0 \text{ Ω}}{(100 \text{ Ω}) \left( \frac{0.00392}{1^\circ C} \right)} \]

\[ = 127.6^\circ C \]
Convert to the Fahrenheit scale.

\[ T_F = 32 + \frac{9}{5}T_C = 32^\circ F + \left(\frac{9}{5}\right)(127.6^\circ C) = 261.7^\circ F \]

The answer is (C).

4. When the meter is nulled out, the resistance of the leg containing the RTD is

\[ R_I = R_{\text{RTD}} + 2R_{\text{lead}} = \frac{R_2R_3}{R_1} = \frac{(376 \Omega)(1000 \Omega)}{1000 \Omega} = 376 \Omega \]

The resistance of the RTD is

\[ R_{\text{RTD}} = R_I - 2R_{\text{lead}} = 376 \Omega - (2)(100 \Omega) = 176 \Omega \]

The relationship between temperature and resistance for an RTD is

\[ R_T = R_0(1 + \alpha T + BT^2) \]

For a platinum RTD with \( \alpha = 0.00385 \, 1/\text{C} \), the resistance is

\[ R_T = R_0 \left(1 + (3.9083 \times 10^{-3})T + (-5.775 \times 10^{-7})T^2\right) \approx R_0 \left(1 + (3.9083 \times 10^{-3})T\right) \]

\[ 176 \Omega \approx (100 \Omega) \left(1 + (3.9083 \times 10^{-3})T\right) \]

\[ T \approx 194.5^\circ C \quad \text{(200.3}^\circ C\text{.)} \]

The answer is (C).

5. The displacement of the falling accelerometer is

\[ x = x_0 + v_0 t - \frac{1}{2}gt^2 \]

The initial displacement and the initial velocity are both zero. The time required to fall a distance of \( x \) is

\[ x = \sqrt{\frac{2x}{g}} \]

The impact velocity is

\[ v = gt = g\sqrt{\frac{2x}{g}} = \sqrt{2xg} \]

\[ = \sqrt{(2)(3 \, \text{ft})(32.2 \, \frac{\text{ft}}{\text{sec}^2})} = 13.9 \, \frac{\text{ft}}{\text{sec}} \]

The average acceleration is

\[ \bar{a} = \frac{v}{\Delta t} = \frac{13.9 \, \frac{\text{ft}}{\text{sec}}}{(0.02 \, \text{sec})(32.2 \, \frac{\text{ft}}{\text{sec}^2-g})} = 21.58 \, \text{g} \]

The average voltage output is

\[ V = k\bar{a} = \left(2.0 \, \frac{\text{mV}}{\text{g}}\right)(21.58 \, \text{g}) = 43.16 \, \text{mV} \quad \text{(43 mV)} \]

The answer is (C).

6. The transducer capacitance, \( C_t \), prevents DC voltages from being passed to the amplifier. The value of \( C_t \) does not influence the amplifier gain.

The answer is (D).

7. Each revolution produces 12 counts. Using Eq. 57.18, the average angular acceleration is

\[ \alpha_{\text{ave}} = \frac{\omega_2 - \omega_1}{t_2 - t_1} \]

\[ = \left(\frac{2\pi \text{ rad}}{\text{rev}}\right) \left(\frac{10,800 \, \text{ counts}}{\text{min}} - 1000 \, \text{ counts} \right) \frac{\text{min}}{4 \, \text{sec} - 2 \, \text{sec}} \left(12 \, \text{ counts} \right) \frac{\text{rev}}{60 \, \text{sec}} \right) \]

\[ = 41.89 \, \text{rad/sec}^2 \quad \text{(42 rad/sec}^2) \]

The answer is (C).

8. The weight of the object is equal to the force on the scale.

\[ F = pA = p\left(\frac{\pi}{4}\right)(D - 2t)^2 \]

\[ = \left(50 \, \frac{\text{lbf}}{\text{in}^2}\right) \left(\frac{\pi}{4}\right)(2 \, \text{ft})(12 \, \text{ in} - 2)(2 \, \text{ in})^2 \]

\[ = 15,708 \, \text{lbf} \quad \text{(16,000 lbf)} \]

The answer is (B).

9. From Eq. 64.11, the strain is

\[ \epsilon = \frac{\Delta R_y}{(GF)R_y} = \frac{100.1 \, \Omega - 100 \, \Omega}{(6.0)(100 \, \Omega)} = 1.67 \times 10^{-4} \]

From Eq. 64.24, the stress is

\[ \sigma = E\epsilon = \left(30 \times 10^6 \, \frac{\text{lbf}}{\text{in}^2}\right)(1.67 \times 10^{-4}) = 5.0 \times 10^3 \, \text{lbf/in}^2 \]