Bank of questions

Measurement and Instrumentation

EXERCISES

1.1 List the elements that are used in an instrumentation system.

1.2 Give an example of an electronic instrumentation system employed in engineering analysis.

1.3 Give an example of an electronic instrumentation system employed in process monitoring.

1.4 Give an example of an electronic instrumentation system employed in process control.

1.5 Why is it frequently necessary to conduct an experimental program in conjunction with an analytical engineering analysis?

1.6 Why is a combined analytical/experimental approach preferred for an engineering analysis?

1.7 Explain the difference between open-loop and closed-loop control.

1.8 List several sources of error that must be considered in the design of an instrumentation system.

1.9 A recorder is specified accurate to ± 2 percent of full scale and full scale is set at 50 mV. Determine the deviation that can be anticipated. Compute the probable percent error when the instrument is used at $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ scale. State the conclusion that can be drawn from the results of your computation.

1.10 An instrumentation system that is composed of a transducer, power supply, signal conditioner, amplifier, and recorder will exhibit what accumulated error $\mathscr{E}$ if the accuracies of the individual elements are:

	Case 1	Case 2	Case 3	Case 4
Transducer	0.01	0.01	0.02	0.05
Power supply	0.01	0.01	0.02	0.01
Signal conditioner	0.02	0.01	0.05	0.01
Amplifier	0.02	0.01	0.02	0.01
Recorder	0.03	0.01	0.02	0.01

1.11 Define range and span of an instrument.

1.12 Determine the error produced by a zero offset Z_o if it is not taken into account in determining the output quantity Q_o.

1.13 Determine the error produced if an instrument sensitivity is S_1 instead of the anticipated sensitivity S.

1.14 Determine the error produced if an instrument sensitivity is S_1 instead of the anticipated sensitivity S and if a zero offset Z_o is not taken into account in determining the output quantity Q_o.

1.15 Give an example of a transducer that produces error because of its influence on the quantity being measured.

1.16 Give an example of an instrument with dual sensitivity and explain how it may produce unanticipated error in a measurement.

1.17 An amplifier in an instrumentation system exhibits a zero drift of 1 percent of full scale per hour. Determine the error if the measurement of Q_o is taken 2.4 hours after the initial zero was established and if the amplifier is operated at one-half of full scale.

1.18 A pressure transducer exhibits a temperature sensitivity of 0.1 units per degree Celsius and a pressure sensitivity of 2.5 units per megapascal. If the temperature changes 20°C during a measurement of a pressure of 120 MPa, determine the error due to the dual sensitivity of the transducer.

1.19 The sensitivity of an electrical resistance strain gage is defined as

$$S = \frac{\Delta R/R}{\varepsilon}$$

Where ΔR is the resistance change of the gage due to an applied strain ε.
R is the resistance of the gage.

If the sensitivity $S = 2.0$ for a gage with a resistance of 120 Ω, compute the sensitivity if the gage is connected to the instrument system with lead wires having a total resistance of 12 Ω.

1.20 Determine the apparent strain indicated by the strain gage lead-wire system described in Exercise 1.19 if the lead wires are subjected to a temperature change of 16°C after the initial zero is established for the system. Note that the lead wires change resistance with temperature according to:

$$\Delta R = R \gamma \Delta T$$

where γ is the temperature coefficient of resistance (0.0039/°C for copper).

1.21 Describe a suitable transducer for measuring pressure in a shock tube.

1.22 Place a weight limit on a transducer used to determine the natural frequency of a clamped circular plate fabricated from aluminum and having a diameter of 250 mm and a thickness of 1 mm.

1.23 Describe calibration procedures for:
(a) A power supply
(b) A pressure transducer
(c) A Wheatstone bridge
(d) An amplifier
(e) A voltmeter

1.24 Describe a calibration procedure to check the entire instrumentation system if the quantity being measured is:
(a) Strain
(b) Pressure
(c) Temperature
(d) Displacement
(e) Acceleration

Questions on Sensors and Transducers

3.1 Briefly describe the difference between a transducer and a sensor.

3.2 A slide-wire potentiometer having a length of 200 mm is fabricated by winding wire having a diameter of 0.25 mm around a cylindrical insulating core. Determine the resolution limit of this potentiometer.

3.3 If the potentiometer of Exercise 3.2 has a resistance of 1000 Ω and can dissipate 4 W of power, determine the voltage required to maximize the sensitivity. What voltage change corresponds to the resolution limit?

3.4 A 10-turn potentiometer with a calibrated dial (100 divisions/turn) is used as a balance resistor in a Wheatstone bridge. If the potentiometer has a resistance of 10 kΩ and a resolution of 0.1 percent, what is the minimum incremental change in resistance ΔR that can be read from the calibrated dial?

3.5 Why are potentiometers limited to static or quasi-static applications?

3.6 List several advantages of the conductive-film type of potentiometer.

3.7 A new elevator must be tested to determine its performance characteristics. Design a displacement transducer that utilizes a 20-turn potentiometer to monitor the position of the elevator over its 50-m range of travel.

3.8 Compare the potentiometer and LVDT as displacement sensors with regard to the following characteristics: range, accuracy, resolution, frequency response, reliability, complexity, cost.

3.9 List the basic elements of the electronic circuit associated with an LVDT.

3.10 Prepare a sketch of the output signal as a function of time for an LVDT with its core located in a fixed off-center position if:

(a) The demodulator is functioning
(b) The demodulator is removed from the circuit

Signal conditioning circuits

4.1 A strain gage with $R_g = 350\ \Omega$ and $S_g = 2.00$ is used to monitor a sinusoidal signal with an amplitude of 1500 μin./in. and a frequency of 200 Hz. Determine the output voltage E_o if a constant-voltage potentiometer circuit is used to convert the resistance change to voltage. Assume $E_i = 22$ V and $r = 5$.

4.2 Determine the magnitude of the nonlinear term η for the data of Exercise 4.1.

4.3 If the strain gage described in Exercise 4.1 can dissipate 0.5 W, determine the input voltage E_i required to maximize the output voltage E_o.

4.4 Determine the circuit sensitivity S_{cv} for the constant-voltage potentiometer circuit described in Exercise 4.1.

4.5 Determine the load error $\mathcal{L}$ if the output voltage E_o of Exercise 4.1 is monitored with:

(a) An oscilloscope having an input impedance of $10^6\ \Omega$
(b) An oscillograph having an input impedance of $350\ \Omega$

4.6 If a constant-current potentiometer circuit was used in Exercise 4.1 in place of the constant-voltage potentiometer circuit, determine the output voltage E_o if $I = 5$ mA.

4.7 Determine the magnitude of the nonlinear term η for the data of Exercise 4.6.

4.8 If the strain gage described in Exercise 4.1 can dissipate 0.5 W, determine the current I that should be used with a constant-current potentiometer circuit to maximize the output voltage E_o.

4.9 Determine the circuit sensitivity S_{cc} for the constant-current potentiometer circuit of Exercise 4.6.

4.10 Determine the circuit sensitivity S_{cc} for the constant-current potentiometer circuit of Exercise 4.8.

4.11 Determine the load error $\mathcal{L}$ if the output voltage E_o of Exercise 4.6 is monitored with:

(a) An oscilloscope having an input impedance of $10^6\ \Omega$
(b) An oscillograph having an input impedance of 350 Ω

4.12 A constant-voltage Wheatstone-bridge circuit is employed with a displacement transducer (potentiometer type) to convert resistance change to output voltage. If the displacement transducer has a total resistance of 1000 Ω, then $\Delta R = \pm 500\ \Omega$ if the wiper is moved from the center position to either end. If the transducer is placed in arm R_1 of the bridge and, if $R_1 = R_2 = R_3 = R_4 = 500\ \Omega$:

(a) Determine the magnitude of the nonlinear term η as a function of ΔR.
(b) Prepare a graph of η versus ΔR as ΔR varies from $-500\ \Omega$ to $+500\ \Omega$.

4.13 Determine the output voltage E_o as a function of ΔR for the displacement transducer and Wheatstone bridge described in Exercise 4.12 if $E_i = 12$ V.

4.14 The nonlinear output voltage of Exercise 4.13 makes data interpretation difficult. How can the Wheatstone-bridge circuit be modified to improve the linearity of the output voltage E_o?

4.15 A strain gage with $R_g = 120\ \Omega$, $P_T = 0.2$ W, and $S_g = 2.00$ is used in arm R_1 of a constant-voltage Wheatstone bridge. Determine:

(a) Values of R_2, R_3, and R_4 needed to maximize E_o if the available power supply is limited to 36 V
(b) The circuit sensitivity of the bridge of Part (a)

4.16 If the strain gage of Exercise 4.15 is subjected to a strain of 900 μin./in., determine the output voltage E_o.

4.17 Four strain gages are installed on a cantilever beam as shown in Fig. E4.17 to produce a displacement transducer.

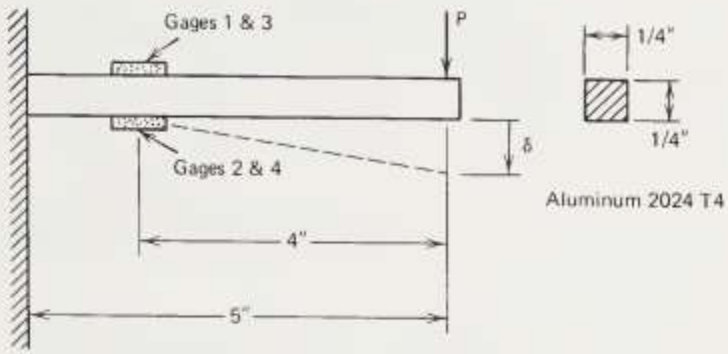

Figure E4.17

(a) Indicate how the gages should be wired into a Wheatstone bridge to produce maximum signal output.
(b) Determine the circuit sensitivity if $R_g = 350\ \Omega$, $P_T = 0.10$ W, and $S_g = 2.00$.
(c) Determine the calibration constant $c = \delta/E_o$ for the transducer.

4.18 If the cantilever beam of Exercise 4.17 is used as a load transducer, determine the calibration constant $C = P/E_o$.

4.19 A strain gage with $R_g = 120\ \Omega$, $P_T = 0.2$ W, and $S_g = 2.00$ is used in arm R_1 of a constant-current Wheatstone bridge. Determine:

(a) Values of R_2, R_3, and R_4 needed to maximize E_o if the available power supply can deliver a maximum of 20 mA.
(b) The circuit sensitivity of the bridge of Part (a)
(c) The output voltage E_o if the gage is subjected to a strain of 900 μin./in.

4.20 If the displacement transducer of Exercise 4.12 is used with a constant-current Wheatstone bridge:

(a) Determine the magnitude of the nonlinear term η as a function of ΔR.
(b) Prepare a graph of η versus ΔR as ΔR varies from $-500\ \Omega$ to $+500\ \Omega$.

4.21 Determine the output voltage E_o as a function of ΔR for the displacement transducer and Wheatstone bridge described in Exercise 4.20 if $I = 20$ mA.

4.22 Use an op-amp with a gain of 100 dB and $R_a = 7$ MΩ to design an inverting amplifier with a gain of 20.

4.23 Use an op-amp with a gain of 100 dB and $R_a = 7$ MΩ to design a noninverting amplifier with a gain of 20.

Resistance type strain gages

5.1 A strain gage is to be fabricated from Advance wire having a diameter of 0.001 in. and a resistance of 25 Ω/in. The gage is to have a gage length of $\frac{1}{4}$ in. and a resistance of 200 Ω. Design a grid configuration.

5.2 Plot a family of curves showing bridge voltage E_i as a function of r for a Wheatstone bridge with a single active 350-Ω gage on a material with $P_D = 0.002$ W/mm^2. Use the area of the gage as a parameter and vary A in increments between 0.0005 mm^2 to 0.5 mm^2. From these results, indicate the value of r that should be used in the design of the bridge.

5.3 Repeat Exercise 5.2 for a 120-Ω gage.

5.4 Determine the system sensitivity for a bridge with a single active gage having $R_g = 350$ Ω and $S_g = 2.05$, if $r = 4$ and if the bridge voltage is 6 V.

5.5 If the gage in Exercise 5.4 can dissipate 0.05 W, is the bridge voltage correct? If not, what is the correct voltage?

5.6 Determine the voltage output from a Wheatstone bridge if a single active gage is used in an initially balanced bridge to measure a strain of 600 μm/m. Assume that a digital voltmeter will be used to measure the voltage and that $S_g = 2.06$, $r = 1$, and $E_i = 9$ V.

5.7 Determine the loading error produced by connecting an oscilloscope with an input impedance of 10^6 Ω to a Wheatstone bridge with one active gage. Use $R_g = 350$ Ω, $r = 5$, and $q = 1$.

5.8 The bridge in Exercise 5.7 is powered with a 9-V constant-voltage supply and the strain gage has a gage factor $S_g = 3.35$. If the gage responds to a dynamic strain pulse having a magnitude of 1200 μm/m, determine the sensitivity setting on the oscilloscope that will give a trace deflection of four divisions.

5.9 If the bridge and gage of Exercise 5.8 respond to a strain of 1000 μm/m, determine the trace deflection if an oscilloscope having a sensitivity of 1 mV/div is used for the measurement.

5.10 If the bridge, gage, and oscilloscope of Exercise 5.9 record a trace deflection of 3.7 divisions, determine the strain at the gage location.

5.11 Determine the sensitivity of a gage–bridge–galvanometer system if a four-equal-arm bridge ($R_1 = R_2 = R_3 = R_4 = R_g$) is used and if $R_g = 350$ Ω, $S_g = 2.07$, $P_g = 0.1$ W, $R_G = 100$ Ω, and $S_G = 0.003$ mm/μA.

5.12 Would the sensitivity of the system described in Exercise 5.11 be improved by replacing the 350-Ω gage with a 120-Ω gage? Explain.

Force, Torque and Pressure Measurements

6.1 Determine the sensitivity of a load cell–Wheatstone bridge combination if $S_g = 2$, $\nu = 0.30$, $E_i = 6$ V, $A = 0.5$ in.^{2}, and $E = 30{,}000{,}000$ psi.

6.2 The sensitivity of the transducer of Exercise 6.1 can be increased if the input voltage E_i is increased. If each gage in the bridge can dissipate 0.5 W of power, determine the maximum sensitivity that can be achieved without endangering the strain-gage ($R_g = 350\ \Omega$) sensors.

6.3 Determine the voltage ratio E_o/E_i for the load cell of Exercise 6.1 if the fatigue strength of the elastic member is 75,000 psi.

6.4 If the load cell of Exercise 6.3 is used in a static load application, what maximum load could be placed on the transducer? What voltage ratio E_o/E_i would result?

6.5 The calibration constant of a transducer procured from a commercial supplier is listed as 2 mV/V. Determine the sensitivity S of the transducer if $P_{max} = 40{,}000$ lb and $E_i = 10$ V.

6.6 Design a beam-type load cell with variable range and sensitivity. Use aluminum ($E = 10{,}000{,}000$ psi, $\nu = 0.33$, and $S_f = 20{,}000$ psi) as the beam material and four electrical resistance strain gages ($S_g = 2$ and $R_g = 120\ \Omega$) as the sensors. Design the load cell to give the following sensitivities and corresponding range:

$(E_o/E_i)^*$ (mV/V)	Range (lb)
1	1000
2	500
5	200

6.7 Design a ring-type load cell with a linear-variable-differential-transformer (LVDT) sensor. The load cell should have a capacity of 2000 lb. The radius to thickness ratio of the ring R/t should be 10. Select an LVDT for this application from Table 3.1. Use steel ($E = 30{,}000{,}000$ psi and $\nu = 0.30$) for the ring. Determine the sensitivity S_t for your transducer.

6.8 For the transducer designed in Exercise 6.7, determine $(E_o/E_i)^*$ if the fatigue strength of the steel $S_f = 60{,}000$ psi.

6.9 Show that the torque cell shown in Fig. 6.6 is insensitive to both axial load P and moments M_x and M_y.

6.10 Determine the sensitivity of a torque cell if $E = 30{,}000{,}000$ psi, $\nu = 0.30$, $E_i = 8$ V, $D = 1$ in., $S_g = 2$, and $R_g = 120\ \Omega$.

6.11 The sensitivity of the torque cell described in Exercise 6.10 can be increased if the input voltage E_i is increased. If each gage in the bridge can dissipate 0.8 W of power, determine the maximum sensitivity that can be achieved without endangering the strain-gage sensors.

6.12 Determine the sensitivity of the torque cell of Exercise 6.11 if strain gages having $R_g = 500\ \Omega$ are used in place of the 120-Ω gages.

6.13 A torque cell with a capacity of 500 ft · lbs is supplied with a calibration constant of $(E_o/E_i)^* = 4$ mV/V and a recommendation that the input voltage $E_i = 10$ V. If the cell is used with $E_i = 8$ V and a measurement of E_o yields 24 mV, determine the torque T.

6.14 Determine the sensitivity of the torque cell described in Exercise 6.13.

6.15 Why are at least four slip rings used to transmit the voltages associated with a torque cell on a rotating shaft?

6.16 Outline the advantages associated with the use of telemetry for data transmission from a rotating shaft.

6.17 A solid circular shaft having a diameter of 2 in. is rotating at 800 rpm and is transmitting 100 hp. Show how four strain gages can be used to convert the shaft itself into a torque cell. Determine the sensitivity of this shaft–torque transducer if the shaft is made of steel having $E = 30{,}000{,}000$ psi and $\nu = 0.30$.