SOLUTIONS MANUAL FOR

MEASUREMENT AND DATA ANALYSIS FOR ENGINEERING AND SCIENCE

THIRD EDITION

by

Patrick F. Dunn

CRC Press
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Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper
Version Date: 20140408

International Standard Book Number-13: 978-1-4665-9507-1 (Ancillary)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

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Third Edition, Taylor & Francis / CRC Press, ©2014

Review and Homework Problem Solutions

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March 2014

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Chapter 2

Experiments Solutions

Homework Problem 2.9

Statement: Consider an experiment where a researcher is attempting to measure the thermal conductivity of a copper bar. The researcher applies a heat input q'' to a copper bar and uses four thermocouples to measure the local bar temperature $T(x)$. The thermal conductivity, k_{th}, can be calculated from the equation

$$q'' = -k_{th}\frac{dT}{dx}.$$

Variables associated with the experiment are the (a) thermal conductivity of the bar, (b) heater input, (c) temperature of points 1, 2, 3, and 4 from the thermocouples, (d) pressure and temperature of the surrounding air, (e) smoothness of copper bar at the interfaces with the heaters, and (f) position of the thermocouples. Determine whether each variable is dependent, independent, or extraneous. Then determine whether each variable is a parameter or a measurand.

Solution:

Analysis:

(a) Dependent, Parameter

(b) Independent, Parameter

(c) Dependent, Measureand

(d) Extraneous, Parameter

(e) Extraneous, Parameter

(f) Independent, Parameter

Comments:

Often, a specific variable can fall into more than one category.

Homework Problem 5.6

Statement: A voltage-sensitive Wheatstone bridge (refer to Figure 5.4) is used in conjunction with a hot-wire sensor to measure the temperature within a jet of hot gas. The resistance of the sensor (in Ω) is $R_1 = R_o[1 + \alpha_T(T - T_o)]$, where $R_o = 50$ Ω is the resistance at $T_o = 0$ °C and $\alpha_T = 0.00395$/°C. For $E_i = 10$ V and $R_3 = R_4 = 500$ Ω, determine (a) the value of R_2 (in Ω) required to balance the bridge at $T = 0$ °C. Using this as a fixed R_2 resistance, further determine (b) the value of R_1 (in Ω) at $T = 50$ °C, and (c) the value of E_o (in V) at $T = 50$ °C. Next, a voltmeter having an input impedance of 1000 Ω is connected across the bridge to measure E_o. Determine (d) the percentage loading error in the measured bridge output voltage. Finally, (e) state what other electrical component, and in what specific configuration, could be added between the bridge and the voltmeter to reduce the loading error to a negligible value.

Solution:

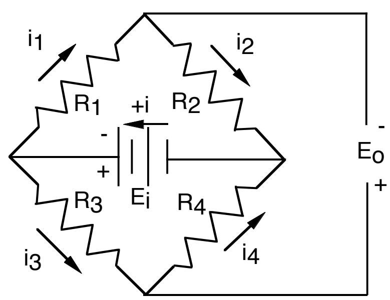

Figure 5.4: The Wheatstone bridge configuration.

Analysis:

(a) When a bridge is balanced $R_1R_4 = R_2R_3$.

Since $R_3 = R_4$, then $R_1 = R_2$.

Now, at $T = 0°C$ (when the bridge is balanced),

$R_1 = R_o[1 + \alpha_T(0 - 0)] = R_o = 50\ \Omega.$

So, $R_2 = R_1 = R_o = 50\ \Omega.$

(b) From the equation in the problem statement, $R_1 = 50[1+0.00395(50-0)] = 59.88\ \Omega.$

(c) $E_o = E_1\left(\frac{R_1}{R_1+R_2} - \frac{R_3}{R_3+R_4}\right)_{T=50\ °C}.$

Homework Problem 6.3

Statement: A first-order system with a time constant equal to 10 ms is subjected to sinusoidal forcing with an input amplitude equal to 8.00 V. When the input forcing frequency equals 100 rad/s, the output amplitude is 5.66 V; when the input forcing frequency equals 1 000 rad/s, the output amplitude is 0.80 V. Determine (a) the magnitude ratio for the 100 rad/s forcing case, (b) the roll-off slope (in units of dB/decade) for the $\omega\tau = 1$ to $\omega\tau = 10$ decade, and (c) the phase lag (in degrees) for the 100 rad/s forcing case.

Solution:

Known:

Input amplitude = 8.00 V = A_i

At $\omega = 100$ rad/s, $A_0 = 5.66$ V $\Rightarrow \omega\tau = 1$

At $\omega = 1\ 000$ rad/s, $A_0 = 0.80$ V $\Rightarrow \omega\tau = 10$

$\tau = 10$ ms

Analysis:

(a) $M(\omega = 100 \text{ rad/s}) = 1/\sqrt{(\omega\tau)^2 + 1} = 1/\sqrt{2} = 0.707$

(b) $M(\omega = 1000 \text{ rad/s}) = 1/\sqrt{10^2 + 1} = 1/\sqrt{101} = 0.10$

$$\frac{\text{dB}}{\text{decade}} = 20\log_{10}(0.10) - 20\log_{10}(0.707)$$

$$= -20 - (-3)$$

$$= -17 \text{ dB/decade}$$

(c) $\phi = -\tan^{-1}(\omega\tau) = -\tan^{-1}(1)$

$$= -45°$$

Homework Problem 7.12

Statement: Pete thinks that he is too dense (physically, that is). To address his concern, he wants an unbiased engineering student to determine (a) his mass on the moon (in kg), (b) the density of his body (in kg/m^3), and (c) its overall uncertainty at 95 % confidence. For simplicity, assume that Pete is a cylinder, having an 8 in. diameter (±2 %) and a 2 m height (±1 %). Further, his SI-challenged uncle estimates that Pete would weigh 32.3 lbf (±0.2 lbf) on the moon, where g (±0.01 %) is one-sixth that of earth.

Solution:

(a) Determine m: $\frac{W_{\text{on moon}}}{g_{\text{moon}}} = m_{\text{on moon}} = m_{\text{on earth}}$

Now, $W = \frac{m \cdot a}{g_c} = m\frac{(32.2 \text{ ft/s}^2)}{g_c}$

$\Rightarrow m = \frac{W g_c}{32.3 \text{ ft/s}^2}$

$$\text{On moon: } W = m\frac{\frac{32.2}{6} \text{ ft/s}^2}{g_c} = m\frac{5.37 \text{ ft/s}^2}{g_c}$$

$\Rightarrow m = \frac{W g_c}{5.37 \text{ ft/s}^2}$

In the Technical English system, $g_c = 1 \ \frac{\text{slug} \cdot \text{ft}}{\text{lbf} \cdot \text{s}^2}$

In the English Engineering system, $g_c = 32.2 \ \frac{\text{lbm} \cdot \text{ft}}{\text{lbf} \cdot \text{s}^2}$

Using Technical English:

$$m_{TE} = \frac{(32.2 \text{ lbf})(1 \ \frac{\text{slug} \cdot \text{ft}}{\text{lbf} \cdot \text{s}^2})}{5.37 \text{ ft/s}^2} = 6 \text{ slug} = (6 \text{ slug})(14.6 \ \frac{\text{kg}}{\text{slug}}) = 87.6 \text{ kg}$$

Using English Engineering:

$$m_{EE} = \frac{(32.2 \text{ lbf})(32.2 \ \frac{\text{lbm} \cdot \text{ft}}{\text{lbf} \cdot \text{s}^2})}{5.37 \text{ ft/s}^2} = 193.2 \text{ lbm} = 6 \text{ slug}$$

Review Problem 13.5

Statement: A test engineer performs a first-run experiment to measure the time required for a prototype car to travel a fourth of a mile beginning from rest. When the car begins motion, a green light flashes in the engineer's field of vision, signaling him to start the time count with a hand-held stopwatch. Similarly, a red light flashes when the car reaches the finish line. The resulting times from four trials are 13.42 s, 13.05 s, 12.96 s, and 12.92 s. Outside of the test environment, another engineer measures the first test engineer's reaction time to the light signals. The results of the test show that the test engineer over-anticipates the green light and displays slowed reaction to the red light. Both reaction times were measured to be 0.13 s. Compute the average travel time in seconds, correcting for the systematic error in the experimental procedure.

Solution: 12.83 s

Feedback: The experimentalist's reaction time creates a systematic error in the experiment because it affects the accuracy of the measurements. To correct for this, subtract the reaction time from each of the four measurements and then compute the average.

Homework Problem 14.1

Statement: Prove that a least-squares linear regression analysis fit always goes through the point $(\bar{x},\bar{y})$.

Solution:

Known:

$y = a_0 + a_1 x$

Analysis:

We need to show that $\bar{y} = a_0 + a_1\bar{x}$

The proof follows directly from the first of the two "normal" equations.

$\frac{\partial D}{\partial a_0} = 0 = \frac{\partial}{\partial a_0}\Sigma_{i=1}^{N}[y_1 - (a_0 + a_1 x_i)^2]$

$= -2\Sigma_{i=1}^{N}[y_1 - a_0 - a_1 x_i]$

$\Rightarrow \Sigma_{i=1}^{N} y_i = N a_0 + a_1 \Sigma_{i=1}^{N} x_i$

$\Rightarrow \frac{1}{N}\Sigma_{i=1}^{N} y_i = a_0 + a_1 \frac{1}{N}\Sigma_{i=1}^{N} x_i$

or $\bar{y} = a_0 + a_1\bar{x}$ Q.E.D.