LULEÅ UNIVERSITY OF TECHNOLOGY
Dept. of Computer Science and Electrical Engineering

Course	E0004E (SME101)
Date	2008-01-16
Time	9.00–13.00

Exam in: **Measurement & Instrumentation**
Teacher: Johan Carlson, 070-580 82 52
Problems: 5 (5 points per problem)
Tools allowed: BETA (Mathematics Handbook), Physics handbook,
Language dictionary, calculator
Text book: Principles of Measurement Systems, by John Bentley

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1. An electronic differential transmitter gives a current output of 4 to 20 mA linearly related to a differential pressure input of 0 to 10^4 Pa. The Norton impedance of the transmitter is 10^5 Ω. The transmitter is connected to an indicator of impedance 250 Ω via a cable of total resistance 500 Ω. The indicator gives a reading between 0 and 10^4 Pa for an input voltage between 1 and 5 V.

   (a) Draw a block diagram of the system, with all quantities clearly marked and labeled. (1p)

   (b) Derive a general expression for the system measurement error due to loading. Evaluate this expression for an input pressure of 5×10^3 Pa. (3p)

   (c) How can the system be modified to reduce the error due to loading? (1p)

2. A thermocouple sensor has an electromotive force (e.m.f.) in microvolts (μ V)

$$E(T) = 38.74T + 5.319 \times 10^{-2}T^2 + 1.071 \times 10^{-4}T^3,$$

   for the range 0 to 400 °C. For $T = 0$ °C, $E(T) = 0$ μV and for $T = 400$ °C, $E(T) = 17152$ μV.

   (a) Derive an expression for the ideal straight line relationship, $E(T) = K \cdot T$. (1p)

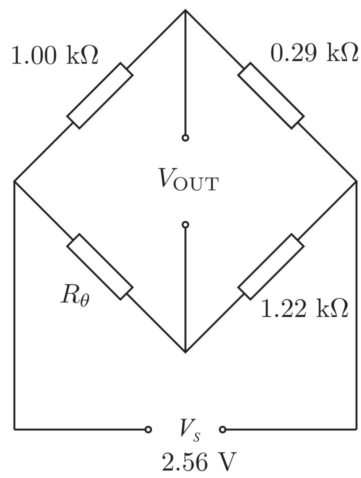
   (b) Determine the sensitivity of the sensor (as a function of the temperature). (1p)

   (c) Determine the magnitude of the maximum non-linearity of the system, as a percentage of the full-scale deflection (400 °C). (3p)

3. The resistance R_θ kΩ of a thermistor at θ K is given by:

$$R_\theta = 1.68 \exp\left[3050\left(\frac{1}{\theta} - \frac{1}{298}\right)\right].$$

   The thermistor is incorporated into the deflection bridge circuit in the figure below.



(a) Assuming V_{OUT} is measured with a detector of infinite input impedance, calculate:

- The range of V_{OUT} corresponding to an input temperature range of 0 to 50 °C.
- The non-linearity at 12 °C as a percentage of the full-scale deflection (2p)

(b) Calculate the effect on the range of V_{OUT} of reducing the detector impedance to 2 kΩ. (3p)

4. A measurement system consists of a chromel-alumel thermocouple (with cold-junction compensation), a millivolt-to-current converter and a recorder. The table below gives the model equations and parameters for each element. Assuming that all probability density functions are normal, calculate the mean and standard deviation of the error probability distribution, when the input temperature is 117 °C. (5p)

	Chromel-alumel thermocouple	e.m.f.-to current converter	Recorder
Model equation	$E = C_0 + C_1T + C_2T^2$	$i = K_1E + K_ME\Delta T_a + K_I\Delta T_a + a_1$	$T_M = K_2i + a_2$
Mean values	$\overline{C}_0 = 0.00$	$\overline{K}_1 = 3.893$	$\overline{K}_2 = 6.25$
	$\overline{C}_1 = 4.017 \times 10^{-2}$	$\overline{\Delta T}_a = -10$	$\overline{a}_2 = 25.0$
	$\overline{C}_2 = 4.66 \times 10^{-6}$	$\overline{a}_1 = -3.864$	
		$\overline{K}_M = 1.95 \times 10^{-4}$	
		$\overline{K}_I = 2.00 \times 10^{-3}$	
Standard deviations	$\sigma_{C_0} = 6.93 \times 10^{-2}$	$\sigma_{a_1} = 0.14$, $\sigma_{\Delta T_a} = 10$	$\sigma_{a_2} = 0.30$
	$\sigma_{C_1} = \sigma_{C_2} = 0$	$\sigma_{K_1} = \sigma_{K_M} = \sigma_{K_I} = 0$	$\sigma_{K_2} = 0$

5. A load cell consists of an elastic cantilever and a displacement transducer. The cantilever has a stiffness of 10^2 N/m, a mass of 0.5 kg and a damping constant of 2 Ns/m. The displacement transducer has a steady-state sensitivity of 10 V/m.

   (a) A package of mass 0.5 kg is suddenly dropped onto the load cell. Use the equation below (same as Eq. (4.31) in the text book) to derive a numerical equation describing the corresponding time variation of the output voltage ($g = 9.81$ m/s^2) (3p)

$$f_o(t) = 1 - e^{\xi\omega_n t}\left[\cos\omega_n\sqrt{(1-\xi^2)t} + \frac{\xi}{\sqrt{1-\xi^2}}\sin\omega_n\sqrt{(1-\xi^2)t}\right]$$

   (b) The load cell is used to weigh packages moving along a conveyor belt at the rate of 60 per minute. Use the results derived in (a) to explain why the load cell is unsuitable for this application. Explain what modifications to the load cell are necessary. (2p)