Past Paper Tutorial 2016 – covering sensors, error reduction and signal & noise

Q1 **(a)** In the context of a mechanical element subject to an applied force define the following:

i) Stress
ii) Strain
iii) Poissons's Ratio

[2,2,2]

(b) You are tasked with the construction of a load cell to measure a maximum load of 10^4 kg. The following components are available. (please refer to the data at the end of the question).

- A steel pillar of cross sectional area 10 cm^2.
- 4 strain gauges
- A 5V supply
- A variable gain amplifier
- A digital data display unit.

[3]

i) Calculate the strain induced in the pillar when the maximum rated load of 10^4 kg is applied. [6]

ii) Sketch how the gauges are to be applied to the pillar to obtain optimum results and indicate how the gauges are to be connected into a bridge circuit. [4]

iii) Using the component values prescribed, calculate the voltage output from the bridge circuit of part (b)ii) corresponding to maximum load. [6]

iv) The load cell is to be completed by the addition of the the amplifier and data display unit specified below, estimate the highest sensitivity and best mass resolution which can be obtained from this system while retaining the 10^4 kg max load.

[25]

Component Specifications:

Steel Pillar:

- Area : 10×10^{-4} m^2,
- Young's Modulus : 2×10^{11} Nm^{-2}

Strain Gauges :

- Gauge factor : 2.0
- Unstrained resistance at 20°C : 120 Ω

Power Supply

- 5 Volts DC

Variable Gain Amplifier:

- Gain Selectable: 10,20,50,100,200,500,1000
- Max o/p : 13 V DC

Data Display Unit:

- Input range : 0-1 V DC
- Input voltage resolution : 0.1 mV

[25]

Q2 **(a)** i) The thermal voltage noise from a resistive component when passed through a bandpass filter is given by:

$$\overline{v^2} = 4\,kT\,R\,\mathrm{NEB}\,.$$

Outline the origin of thermal noise and identify each of the terms used in the equation.

ii) Similarly the shot noise current, associated with a mean current I, measured after a bandpass filter is given by:

$$\overline{i^2} = 2\,I\,e\,\mathrm{NEB}$$

Outline the origin of shot noise and identify each of the terms used in the equation.

[4,4]

(b) An instrument supplies a mean current of 100 nA to a current to voltage converter with a load resistance of 1MΩ and a N.E.B. of 100 Hz. You may assume that the ambient temperature is 25ºC.

Calculate the total noise voltage (r.m.s.) at the output of the device.

$k = 1.38\times10^{-23}$ J K^{-1} **[7]**

$e = -1.6\times10^{-19}$ C

(c) The spectral density of noise at the output of an amplifier with a voltage gain of 10 is illustrated in Figure Q5. It is intended to measure a sinusoidal input signal which has an amplitude of 1.4 mV and a frequency of 1.5 kHz .

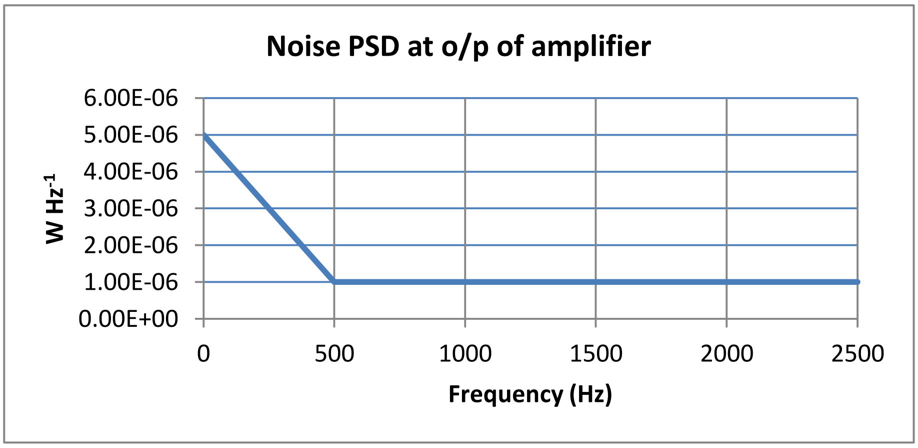

Figure Q2

i) Assuming the output of the amplifier is connected to an ideal low-pass filter with a cut-off frequency equal to 2 kHz, calculate the signal to noise ratio (dB).

ii) Assuming that the output of the amplifier is connected to an ideal bandpass filter of bandwidth 10 Hz, and adjustable centre frequency, calculate the highest value of signal to noise ratio achievable.

iii) Comment on the practicality of the approach proposed in part ii) above and suggest an alternative approach, stating the assumptions which you have made.

[5,3,2]

Q3 **(a)** i) Explain the terms *active transducer* and *passive transducer*.

ii) For each of the following state whether the transducer is active or passive:

- A platinum resistance thermometer
- A linear potentiometer as a displacement transducer
- A piezoelectric force transducer
- A photovoltaic cell

[4,4]

(b) A common equation relating the resistance of a metallic resistance thermometer to its temperature is:

$$R(T) = R_0\left(1 + \alpha\, \Delta T\right)$$

i) State the exact meaning of each of the terms.

ii) State whether the device described by the above equation is linear or not.

[4,1]

(c) The resistance thermometer of Q3(b) is incorporated in the circuit presented in Figure Q3(c).

If the resistance of the thermometer at 20 ^{o}C is 109 Ω and at 100 ^{o}C is 145 Ω, calculate the output voltage at a temperature of -20 ^{o}C.

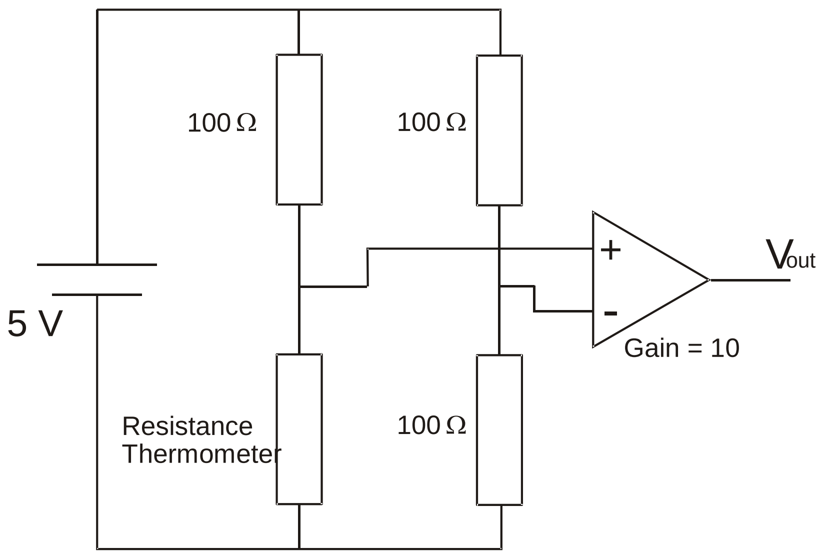

Figure Q3(c)

[6]

(d) The resistance thermometer described in Q3(c) is plunged from room temperature into a bath of boiling water.

i) Sketch the output (Vout) of the system in Q3(c) as a function of time, stating any assumptions made.

ii) State what is meant by the *time constant* and identify the four physical properties of the resistance thermometer that would influence the time constant.

[2,4]

Q4 **(a)** A displacement measuring system may be represented by the following system diagram, Figure Q4(a).

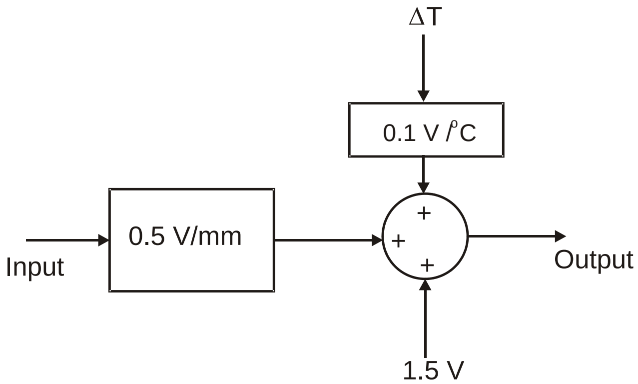

Figure Q4(a)

Where ΔT is the temperature difference determined by subtracting 20 °C from the working temperature of the device.

With reference to Figure Q4(a):

i) Determine the percentage non-linearity of the device.
ii) Determine the sensitivity of the measurement system.
iii) State whether temperature is a modifying or an interfering unwanted input.
iv) Determine the output for an input displacement of 6mm at an ambient temperature of 0 ^{o}C.

[2,2,2,4]

(b) A sinusoidal signal has a frequency of 6 kHz and a peak to peak voltage of 1.5V. The signal is in the presence of white noise of spectral power density $3x10^{-6}$ V^2 Hz^{-1}. The signal and noise are both passed through a band-pass filter which has a Noise Equivalent Bandwidth (NEB) of 15Hz.

i) Identify the optimum central frequency for the band-pass filter.

ii) Calculate the signal to noise ratio in dB.

[2,5]

(c) Explain the process of coherent averaging as a mechanism for improving Signal to Noise ratio. Include in your answer: a key factor that is essential for its use; a quantification of the improvement in signal to noise ratio; and an example of where it could be used to advantage.

[8]