Problem Set #2 Solutions ME220 Introduction to Sensors

1. Strain Gauge Load Sensor

Q: What is the resistance of the strain gauge when an added load of 1 kg is applied to the end of the beam?

<u>Solution</u> (15 points): The strain on the upper surface of a beam with a load at the end is

NOTE: the 4 in the strain equation could be replaced with a 6, if you calculated for the maximum strain.

$$\varepsilon = \frac{4LF}{Ewt^2} = \frac{(4)(0.1m)(10N)}{(7.3x10^{10} N/m^2)(0.04m)((0.02m)^2)} = 3.4x10^{-6}$$

$$\Delta R = R_o K\varepsilon = (1000\Omega)(3)(3.4x10^{-6}) = 0.01\Omega$$

Q: The Wheatstone bridge is biased with a 5V Vin. What is the voltage difference between the sense and reference terminals of the bridge?

<u>Solution</u> (5 points):

$$\Delta V = \frac{VinR_S}{R_L + R_S} - \frac{Vin}{2} \sim \frac{5V(0.01\Omega)}{4000\Omega} = 12.5\mu V$$

2. Thermometer Noise Calculation

Q: If you connected the output of this sensor to a low pass filter with a cutoff at 100 Hz, and made sure that there were no temperature changes, what would the amplitude of the RMS noise be?

<u>Solution (5 points) :</u>

$$V_{RMS} = NSD * (\sqrt{bandwidth}) = (10\mu V/\sqrt{Hz})(\sqrt{100Hz}) = 100\mu V$$

Q: If the filter cutoff frequency were changed to 1 Hz, what would the RMS noise amplitude be?

<u>Solution</u> (5 points): 10 µV

3. Cantilever beam with strain gauges

Solution (10 points):

The output of the voltage divider with for this circuit is

$$Vout = \frac{VinR2}{R1+R2} = \frac{Vin(1000\Omega)(1-F/100)}{(1000\Omega)(1+F/100)+(1000\Omega)(1-F/100)}$$

$$Vout = \frac{Vin(1-F/100)}{2}$$

Important point – this expression is exactly linear. Therefore, the second and all higher derivatives are equal to zero. The taylor series expansion reduced exactly to the expression above. There are no error terms.

This is a significant advantage, and is the reason that positive and negative strain gauges are often arranged together in this manner – the nonlinearities that come from a typical voltage divider are eliminated completely in this case.

4. Thermostat near lamp

a) What effect does the lamp have on the thermostat temperature?

b) The thermistor has a nominal resistance of 1000 ohms, and is measured with a current of 0.2 mA. How much effect does this have on the measured temperature?

c) What can you do to minimize these effects?

Solutions:

a) (10 points) The lamp causes an increase in temperature, and an oscillation in temperature. To find out how much, we need to calculate the amount of power that hits the thermometer, and then work out the response of the sensor to this power.

Since the sensor takes up 1mm x 1mm area at a distance of 10cm, the fraction of the power is:

$$Fraction = \frac{10^{-6} m^2}{4\pi 10^{-2} m^2} = 8x10^{-6}$$

Therefore, the power at the sensor is P = 8x10^{-6}(P = 100W + (100W)(cos(2π*60*t)))

The Sensor has DC and AC response given by

$$T_{DC} = T_o + \frac{P_{DC}}{G} = 20C + \frac{8x10^{-4}}{2x10^{-4}}$$

So, there is a static temperature rise of about 4 degrees.

There is also an oscillation, given by

$$T_{AC} = \frac{P_{AC}}{j\omega C + G} = \frac{8x10^{-4}}{(j)(120\pi)(10^{-3}) + (2x10^{-4})}$$

$$|T_{AC}| = \frac{8x10^{-4}}{\sqrt{((120\pi)(10^{-3}))^2 + (2x10^{-4})^2}} = 0.002$$

So, the lamp increases the temperature by about 4 degrees and also causes a 2 milli-degree oscillation.

b) **(5 points) The measurement power is : 40 microW, and this causes a temperature rise of :**

40 µW/(0.2 mW/degree)= 0.2 degrees temperature rise.

c) **(5 points) We need to reduce the heat flow from the lamp, which could be accomplished by moving the lamp away, putting a reflective shield over the sensor, or increasing the thermal conductance in the wires. The problem with this last option is that the sensitivity to air temperature would also be affected. A shield is the best idea.**

5. Clothes Dryer

a) If the unloaded length of the "foot" is 1 cm, what is the length when the entire machine is assembled and mounted upright on the ground? What is the resistance of the strain gauge in this situation?

Solution (10 points):

$$\Delta X = F / k = (12.5kg * 9.8) / 1e6 = 1.2e-4m$$

$$\Delta R = R(1 + g\varepsilon) = 1k\Omega(1 + 2.5 * \frac{1.2e-4}{1e-2}) = 1030\Omega$$

b) After adding a load of wet clothing, what is the possible range of resistance values?

Solution (5 points):

Adding wet clothes will increase the weight on a foot by at least 2.5 kg. This is about 1/5 of the weight of the dryer, so the increase will be more than 6 ohms.

c) When the clothes are dry, what is the possible range of resistance values?

Solution (5 points):

The dry clothes weigh less than 5 kg, which is less than half the wet weight, so the resistance increase would be less than 3 ohms.

d) The Laundry Room environment can have large temperature variations – leading to resistance variations as large as 4%. Is this a problem for this application? If so, what can be done in the design of a circuit to reduce or eliminate the effect of temperature on the sensor output?

Solution (5 points):

It can be a problem. The best thing is to make a wheatstone bridge circuit that has unstrained resistors with the same temperature and same TCR. A possibility is mounting them on the same legs but rotated 90 degrees so that the compression of the legs does not produce a strain signal, but they are subjected to the same temperature variations.