ME220 Introduction to Sensors Homework #3, due 5:00 pm, **Wednesday** 5/7/08

1. Force Sensor + Circuit Calculations

A resistive contact force sensor has a response given by:

$$R = R_0\left(1 + \frac{F}{\beta}\right)$$

where R_0 = 1000 Ω, β = 200N, F is the applied force (in Newtons), and R is the resistance of the sensor.

This sensor is to be used for measuring forces ranging from 0 to 50N.

Please design a measuring circuit that will produce an output voltage that ranges from 0V to 4V as the applied force ranges from 0 to 50N. Please design this circuit so that the nonlinearity in the relationship between force and voltage is less than 1% of the full scale output.

You are allowed to use operational amplifiers, resistors, and circuit examples from the lectures, handouts, and reading from the book.

2. Smart Home Thermostat

Heating and cooling of a building can be one of the largest sources of energy consumption in a residence (just look at the power meter the next time your A/C comes on). In an effort to save energy, a "smart home" heating and air conditioning thermostat allows for the variation of the room temperature based on a variety of factors such as time of day, season, and heating load (i.e., orientation of the room with respect to the sun).

You are trying to design a retrofit system to a classic bimetallic unit and need to pick the temperature sensor (don't worry about the "smarts" - that is for another day).

   A. Amount of Expansion and Hysteresis
      The classic mechanical thermostat (shown in figure 1) uses a bimetallic strip. Calculate difference in the lengths of the materials for a 1 meter long strip of copper and iron for a temperature change of 5°C (thermal expansion coefficients can be found in the textbook or elsewhere)?

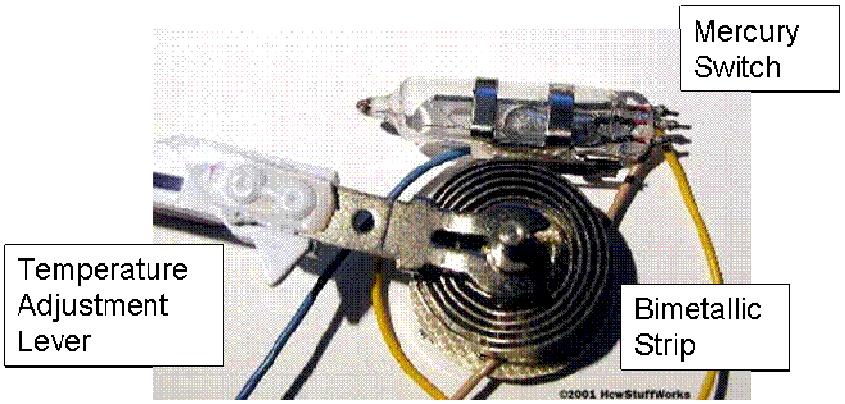


Figure 1. Picture of mechanical thermostat (source: http://home.howstuffworks.com)

Assume that the copper and iron were bonded together to form a cantilever beam that was 1 meter long, and flat at room temperature, and the copper and iron layers were each 1 mm thick. When the temperature changes by 10°C, how much does the end of the cantilever deflect? Again, the textbook may be some help here.

B. RTD
It is possible to replace this with a Resistance Temperature Detector (RTD). Calculate and plot as a function of temperature the resistance for room temperatures from 15°C to 30°C for Copper, Nickel, and Platinum. See course website or http://www.omega.com/temperature/Z/ResistanceElements.html for specs. Assume International Electrotechnical Commission IEC standard for nominal resistance (it's in the file referenced above). Choose a material for your design and explain why it was selected. Using this material, design a circuit that gives a 0-5V output over the aforementioned range.

C. Thermocouple
Instead of the RTD, you consider using a Thermocouple. What thermocouple voltages are produced by a J-type and K-type thermocouple over the 15°C to 30°C temperature range? What is the linearity of this sensor? For this question, look around for information and cite your source.

3. You are asked to design a garden hose with an integral flow sensor. Suppose the normal inside diameter of a garden hose was 2 cm, and a special restrictor has been inserted with a diameter of 1 cm. When water flows through this element, there is a pressure difference between the narrow and wide sections of the hose. For normal garden hose applications, there is interest in measuring flow velocities from 1 cm/sec to 1 m/sec through the end of the hose.

A. Calculate the pressure differences for the cases of 1cm/s and 1m/sec.

B. Select the 4 parameters that you think are the most important to specify for this pressure sensor to guarantee that it will function in this application. State the numerical requirements for these parameters.

4. A hot-wire anemometer consists of a miniature thermistor that is mounted sticking up from a surface as shown in the figure below. This thermistor has resistance of 1000Ω at 20°C (ambient temperature) and a positive Temperature Coefficient of Resistance (TCR) of 0.2%/°C. The thermistor is mounted in an electrical circuit as shown in the figure below with a load resistor of 9 K and a Vin of 10V. The thermal conduction from the thermistor is a function of the airflow velocity according to

$$G = \frac{\alpha(\beta + v)}{\beta}$$

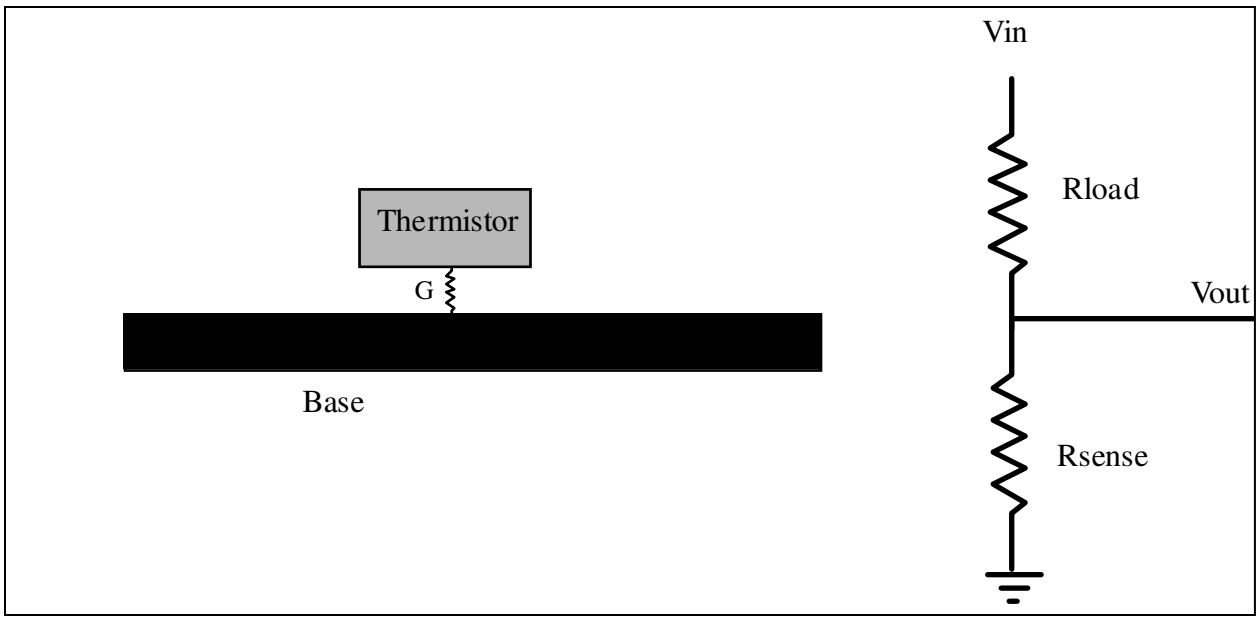
where α = 1 mW/C, β = 1 m/s, and v is velocity {m/s}.

A. If the airflow velocity is 0 m/s, what is the temperature of the thermistor? What is the resistance of the thermistor?

B. What is the output voltage of the circuit in this case? How much does this voltage change if the airflow is increased to 1m/s?

C. Write an algebraic expression for the sensitivity of this flow sensor. (in this expression, use symbols for all the quantities, rather than a numerical expression. This expression should include Vin, Rload, etc as variables)

D. In the expression above, the bias voltage Vin should be present, suggesting that the sensitivity of this system can be improved by increasing the bias voltage. Please comment on how large this voltage can be increased before bad things start to happen.



5. A round steel bar with modulus of elasticity 200 GPa and diameter 1 cm is loaded in tension with an axial load of 50 kN. A strain gauge with a gage factor of 2.5 and resistance of 120 Ω (in the unloaded state) is mounted on the bar in the axial direction

    A. What is the change in resistance of the gauge from the unloaded state to the loaded state?
    B. If the strain gauge is placed in one leg of a Wheatstone bridge, with 120 Ω resistors in the other 3 legs, what is the output voltage of the bridge in the strained state?
    C. What is the stress in the bar?
    D. If we assume that the maximum strain of a Steel beam is 1%, and we were interested in measuring strains all the way to this level, what would the corresponding axial load be?
    E. What changes to the design of the bridge are necessary to allow 0.2% accuracy (as compared to a linear estimate for sensor output) for signals all the way to the 1% strain level?