Temperature Measurements

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MECE 3320: Measurements & Instrumentation Lab Exercise

I. Introduction

In this lab exercise, you will determine how various temperature measurement systems respond to different inputs. This analysis will include three different thermocouples.

II. Teaching Objectives and Overview

The purpose of this laboratory is for each student to understand and do the following:

- ➩ Instrument calibration.
- ➩ Measurements with thermocouples.
- ➩ Determination of time constants and comparisons of the dynamic responses of three measuring systems.
- ➩ Application of first-order dynamic behavior to dynamic temperature measurement problems.

In this lab, we will use first-order models to approximate the response of different thermocouples. A thermocouple consists of two wires of different metals joined at one end (the junction). When a voltage is applied across the free ends of the two wires, the differing properties of the wires create an induced voltage that it proportional to the temperature change at the junction.

III. Procedure

A. Part 1: Calibration Curve

You will create a static calibration curve to correlate voltage measurements with temperature readings.

- ➩ Take voltage readings with the thermocouple in ice water and boiling water. Be careful not to allow the devices to come into contact with the hot plate or the bottom of the beaker.
- ➩ Record the voltages measured.
- ➩ Take the temperature of boiling water to be 100degC and ice to be 0degC.
- ➩ In Matlab: Plot the voltages measured on the *x-axis* and the temperatures on the *y-axis*. Create a linear curve fit using the two data points. The linear fit results in an equation that relates the voltage to the known temperature: $T = kV + b$, where "T" is the temperature, "k is the gain (degC/V), "V is the voltage read in to the computer, and "b is the zero-voltage offset. The gain "k is the inverse of the static sensitivity, which has units of V/degC.

- ➩ Repeat the calibration procedure for the other two thermocouples.

B. Part 2: Time Constants

The calibration curves you found represent static calibrations. In the following section, you will consider the dynamic behavior of the sensors. The dynamics of all the temperature sensors used in this lab can be modeled accurately as first-order systems. The natural response of a first-order system can be characterized by a single parameter - the time constant.

Time constants can be found by observing the response of the instrument to a step input in temperature. Note that the second medium governs the physics of the transient response. For each of the sensors, you will determine the time constant for transfers from ambient air to ice water and from boiling water to ambient air. An ice water bath will be provided for your tests.

- ➩ Open the LabView program for temperature measurement (You should have already downloaded the program before coming to the lab). Place the thermocouple in the ice bath.
- ➩ Start the labview program (dont forget to give an appropriate filename).
- ➩ Wait for 10 seconds while the program is running.
- ➩ Now, remove the thermocouple from the water bath and ***very quickly*** transfer it to the ice bath.
- ➩ Wait for about 10 seconds.
- ➩ Stop the labview program.
- ➩ Open the file you saved and check if the data is saved correctly.The first column is the time. The second column is the temperature.
- ➩ Repeat the experiemnt with all the three thermocouples.
- ➩ From the data file you saved, determine the time constant of the thermocouples. The following expression can be used to calculate the time constant τ.

$$e^{-\frac{t}{\tau}} = \frac{T_\infty - T}{T_\infty - T_0} \tag{1}$$

where T_0 is the initial temperature, T_∞ is the final temperature and T is the time required for the sensor to complete 63.2% of the transient from the initial temperature to the final temperature.

C. Part 3: Error Fraction

The equation below gives an expression for the error fraction.

$$\Gamma(t) = \frac{T_\infty - T(t)}{T_\infty - T_0} \tag{2}$$

- ➩ Calculate the error fraction at each instant of time for the data you have gathered.
- ➩ Take the natural log of the error fraction data.
- ➩ Plot the natural log of the error fraction versus time.
- ➩ Find the negative reciprocal of the slope of this curve. This is the time constant.

The error fraction versus time curve provides an easy way to judge the accuracy of a first-order model for the data gathered. If the error fraction plot is linear, then the first-order model is a good approximation of the dynamic behavior of the system.

D. Part 4: Additional Tests

Once you have performed all of the tests outlined above, perform the following tests:

- ➩ Transfer the thermocouple from ice water to room temperature air (21degC). How does the time constant compare with the one obtained from the boiling water-to-ice-water transition? Is it different? Why or why not?
- ➩ Repeat the experiment by transferring the thermocouple from air to ice-water. When calculating the time constant for the thermocouple in transition from air to ice water, you measured the time to go 63.2 percent of the way from the initial temperature (around 21 C) to the final temperature (around 0 C). Using the same graph, recalculate the time constant using 14C as the starting temperature (i.e., what is the time required to go 63.2 percent of the way from 14 C to 0 C?). Is this time constant value significantly different from the initial value you computed? Why or why not?

E. Part 5: Thought Questions

Document your response to these questions in your lab report.

- ➩ How do the time constants of the three thermocouples compare?
- ➩ How do the time constants obtained for air and water compare? Are they significantly different? If so, explain why.
- ➩ Does the instrument need to be at steady state before transferring it to the final medium?
- ➩ How accurate (qualitatively) is the first-order model approximation for the different sensors and media?

F. Part 6: Frequency Response

From the measured time responses, it can be seen that the response time of these sensors is not instantaneous. From this we can infer that these measurement systems may have some difficulty following inputs that change quickly. Frequency response is a means of characterizing the dynamic response capabilities of a system.

The frequency response of a system can be determined by calculating the response of a system to sinusoidal inputs at different frequencies. Two important characteristics are:

- ➩ the magnitude ratio between the output and input waveforms
- ➩ the phase difference between the output and input waveforms

For a first-order system, we can create the frequency response plot using only our knowledge of the system time constant. The magnitude ratio can be calculated from the following expression.

$$M(\omega) = \frac{1}{\sqrt{1 + (\omega tau)^2}} \tag{3}$$

The phase difference is determined from $\Phi(\omega) = -tan^{-1}(\omega\tau)$. In Matlab, create a frequency response plot for the three thermocouples using the time constant from the ice water tests. Plot the magnitude ratio on a log-log scale and the phase difference on a semilog scale (log scale of frequency axis). Consider frequencies from 0.1 rad/s to 1000 rad/s. Your plots will look nice if you use ten points per decade of frequency (i.e., 0.1, 0.2, 0.3, ,1, 2, 3,... , 10, 20, 30,). Overlay the three magnitude responses on one plot and the three phase responses on another. How do the frequency response characteristics of the three thermocouples compare?

G. Part 7: Dynamic Temperature Measurement Problem

Include the analysis for this problem in your lab book.

Assume that the thermocouple you used is placed in a water stream at a point where the temperature varies sinusoidally between 60 C and 80 C at a frequency of 40 rad/s. Assuming that the thermocouple time constant is the same as the value you determined in the ice water case, what will be the range of sinusoidal variation in the temperature readings? Repeat the calculations for a temperature frequency of 2 rad/s. Now assume the thermocouple is in air instead of water. Determine the range of the variation using input frequencies of 10 rad/s and 1 rad/s.

IV. Report

For this lab you will write the Results and Discussion of Results sections of a full report.

References

[1] Luke Graham, Strain Gages and Force Measurement. OpenStax CNX. August 15, 2006 http://cnx.org/contents/da31d8d7-0eb6-4673-94e3-e448c3f59779@1@1.

[2] D. G. Alciatore and M. B. Histand, Introduction to Mechatronics and Measurement Systems, Fourth Edition, McGraw Hill, 2011.