MAE 3340 *INSTRUMENTATION SYSTEMS*

Laboratory Exercise 8: Using Thermocouples for Temperature and Heat Flux Measurements

NAME: ____

SECTION ____

1. Introduction:

This week we are going to work with thermocouples (TCs). The Objectives of this lab are:

-- *Understanding Type J, K Thermocouples and the Seebeck Effect*
-- *Examination of Thermocouple Signal Output Levels*
-- *Amplifying the Thermocouple Output*
-- *Measurement Curve Fitting and Confidence Level Analysis*
-- *Reference Temperatures Software Compensation*
-- *End-to-End Temperature Calculations*
-- *Calculating Lumped-Mass Time Constant of a Thermodynamic System*

This lab will have two parts. In part (1) you will build an amplifier circuit for the TC output, and then calibrate both unamplified and amplified type "J" thermocouple outputs against reference temperature measurements. These calibrations allow absolute temperatures to be derived from the TC outputs. In part (2) will use the calibrated thermocouples to indirectly measure the convective heat transfer to a penny immersed in a beaker of hot water.

2. Required Equipment:

-- MyDAQ with Attached Breadboard and USB cable
-- Two Type "J" TCs with stripped wire ends
-- Digital Multimeter (DMM) with Type "K" TC sensor
-- Hand Held Glass Thermomoter
-- Pyrex Beaker
-- Corning electrical resistance laboratory hotplate
-- TI 741 Op Amp
-- *100 and 2500 Ω* resistors
-- Assorted Jumper wires

Type "J" thermocouples use *(Iron/Constantan)* lead pairs and *Type K TCs use Chromel/Alumel* leads. By convention the (+) lead on the *Type J* TC uses white wire-shielding, and the (-) lead used red wire-shielding. The (+) lead on the *Type K* TC used yellow wire-shielding, and the (-) lead used red wire-shielding. See Slide 58 of Appendix II for the lab 8 lecture notes.

3. Part 1 Setup and Lab Procedure:

Based on the Type J calibrations as presented in class, at 100 deg. C, the anticipated output is only approximately 4.25 mVolts. Since we are using the MyDAQ to measure this output voltage, it is useful to compare the level against the values of the least significant bit. The AI channels on the MyDAQ are fixed over a range of $\pm$10 V, and the resolution is 16 bits. This as calculate on slide 9 of the lecture notes, the LSB value is $\pm$0.3052 -- or about 7.2% of the total TC output. Thus the unamplified measurement is going to be very noisy.

a) Verify this fact by connecting the TC to channel zero of the MyDAQ breadboard, and using the VI developed for Lab 2 to display the output voltage. Heat the sensor bead with the heat gun set on low. Observe the voltage display response on your VI.

Describe the response, and note the measurement noise level as compared to the signal.

b) Clearly, the signal must be amplified to increase the measurement sensitivity and reduce the effects of the measurement resolution error. As described by the lab 8 lecture notes slide 10, build the amplifier circuit. Use R_1 of at least 100 Ohms and R_2 to give an output gain value of 20 minimum. Note the resistor values and calculate the anticipated gain.

R_1 Value: ____________________ R_2 Value: ________________________ Gain: ______________________

Once the circuit is completed, set up the experiment as shown by slides 13-17 of the section 8 notes. Make sure DMM is set to measure the TC output in deg. C.

c) Program the VI for reading both TC channels as shown by slides as shown by slides 18 to 23 of the lecture notes. Both TC voltage outputs should be displayed on the front panel. Now hold the two TC beads closely together and heat simultaneously with the heat gun on low.

Describe both responses, and note the measurement noise levels compared to the signal levels.

d) Fill Beaker with tap water and insert all three TC's

-- *"K" from multimeter*
-- *"J" unamplified*

-- "J" Amplified

and the manual thermometer into the water. Place beaker onto Corning Lab Heater, turn set point to "high." Run VI and as water heats up, Read Multimeter Temperature Output and Thermometer Value, and mVolt outputs from TC'sa connected to MyDAQ. Log calibration data points as water warms from tap temperature to just below boiling. Populate student-generated spreadsheet file according to the format of Table 1 below. Log at least 10 data points.

Table 1: TC Calibration Spreadsheet Entries.

Data Point Number	Thermometer Temperature ºC	MultiMeter "K" Temperature ºC	Unamplified Type "J" mVolts	Amplified Type "J" mVolts
1				
2				
3				
...				
9				
10				

e) Plot and Curve Fit the Data. You should produce 4 graphs ...

1) *Hand Held Thermometer Temperature vs Unamplified TC mVolts*
2) *Type "K" Temperature (DMM) vs Unamplified TC mVolts*
3) *Hand Held Thermometer Temperature vs Amplified TC mVolts*
4) *Type "K" Temperature (DMM) vs Amplified TC mVolts*

Curve fit each of the above 4 graph data sets. Examine both first and second order curve fits. Use curve fit RMSE fit and Student –t distribution to assess curve confidence interval to 95% level of confidence. Attach plots for each fit to lab report. Use VI developed for Homework 5 to make this task EASY!

Describe how the RMSE and 95% confidence interval of the unamplified TC calibration compares to the amplified TC calibration.

f) Select Coefficients for "Best fit" for both the unamplified and unamplified type "J" TC's. These coefficients will be your calibrations for the "Installed" TC systems. We will now use these calibration coefficients to scale the mVolts display on VI of front panel to calculate temperature in deg. C.

Following the procedure as described by slides 31 - 36 of the lab 8 lecture notes, add additional stripchart graph and optionally display either or both TC outputs as temperature in T deg. C on the same chart. Run your VI and test for Functionality. Heat both Type "J" TC's with heat gun and compare amplified and unamplified TC temperature outputs

• *Describe the comparative unamplified and amplified TC responses.* Which signal would you rather use for a precise and accurate temperature measurement?

4. Part 2 Setup and Lab Procedure:

a) As shown by Slide 38 of the Lab 8 lecture notes, solder your Amplified TC – tip to a Penny. You might have to clean the penny and sand the surface first to get good contact. The heat gun should provide sufficient heat to allow a decent solder. Allow the penny to cool sufficient to where solder sets. Re-install TC onto the breadboard, once you have a good connection set your display switch appropriately and run your VI to check functionality.

b) Stop your VI, eight click on temperature display graph and select *"Data Operations >> clear chart."* Heat water in beaker to just before boil ~ 90-90 ^{o}C. Immediately immerse penny on bottom of beaker and carefully observe the time response. Run the VI until the temperature stabilizes, then stop VI and right click on Temperature display … *select "Data Operations >> Make Current Value Default" .. Save your VI.*

c) Right click on your your temperature display graph, and select *"Formatting". In the pop-up menu select the "Scales" tab and then for both x and y scales* select *major and minor grids.* This action will add grids that will help you to read your chart accurately. Manually change the graph limits to display the entire temperature response curve. Attach an image of this response curve to your lab report.

d) As described in the lab 8 lecture notes -- slides 40-42 and in Appendix I -- Read T_o and T_{final} (=T_{water}) from your graph, and pull off sufficient intermediate points to plot a log-graph as per slide 56 of Appendix I. In this graph display

$$-\ln\left(\frac{T_{water} - T_p(t)}{T_{water} - T_{p_{(0)}}}\right)$$

on the y axis ... versus time on the x-axis. Calculate the slope of this curve. The reciprocal of this slope is the system time constant.

Attach an image of this curve to the lab report and show your calculations for the curve slope. Show calculations here. You can curve fit the data or use a manual fairing.

e) Considering the lumped mass heat transfer analysis as presented in class, and the material of Appendix I in the Lab 8 Lecture note, calculate the convective heat transfer coefficient and the Biot Number of the penny immersed in the hot water***. Use the Thermodynamic and transport properties of Zinc as given in Appendix I of the Lab 8 lecture notes.***

Show you calculations here.

Based on these results. What can you conclude about the applicability of the “lumped-mass” assumption to this configuration?