SensitiviT Industries, Ltd.

February 1, 2017
A. Engineer, B. Engineer
SensitiviT Industries Ltd
Nowhere, YS 66666

Dear Andrea and Bill,

As we discussed in our face-to-face meeting, we want to review our methods for determining the thermal time constant, τ, of our temperature sensors in water. We subject the sensors to a step temperature change by taking them from boiling water to an ice bath and the reverse step. We currently define the time constant as the time it takes to reach 63.2% of the final temperature difference between the initial bath and the final bath.

You have presented arguments that, even though we move the temperature sensor assemblies quickly between the baths, the variation in time for the process has a significant effect on our final estimate of the time constant. You have also proposed that fitting the entire temperature vs. time curve to an exponential would result in a smaller confidence interval for the time constant estimate.

We currently define the onset of the event by finding the time corresponding to when the temperature deviates 5 standard deviations from the baseline established before transitioning. You argue that the temperature changes significantly while it is in the air between baths. Since the heat transfer coefficient in air is lower than that for water and the initial cooling is fastest, you proposed that the time corresponding to the maximum absolute slope in the temperature vs. time curve is when the thermocouple actually is in the new bath and the temperature at that time should correspond to $T_{initial}$. We want you to develop the data analysis program to find the time and temperature corresponding to the maximum absolute slope use those values as t = 0 and $T_{initial}$. Use the 0.632 method and fitting the entire temperature vs. time curve to determine the time constant for both onset methods.

Use both of the onset and time constant determination methods to analyze the dynamic response of a bare wire thermocouple and thermocouples embedded in 0.5 inch diameter, 2 inch long rods of 6061 aluminum and 304 stainless steel by alternating between the ice water and boiling water baths. Determine which method give the most accurate time constant estimate by comparing the data to the prediction, by comparing the standard errors of the fit and by plots of the residuals vs. time.

Since this is the first report you have written for our company, I have taken the liberty of providing a detailed outline of what should be included in the report. While the order makes sense to me as I constructed the outline, you may find it necessary to make some modest adjustments in order of presentation to improve the flow of information. However, you must include all of the information requested in the outline. You may choose to add a few tables or figures but don't go overboard.

Regards,
Pat A. Cake
Pat A. Cake
Manager of Systems Level Modeling Effort

i. Cover letter – Even though this is an internal report, you are transmitting the report and it needs a cover letter that is meaningful for me (Mr. Cake) and for other engineers who may be using your data. This letter should briefly restate what was requested and what is provided in the report. You do not need to state detailed results. You may want to present an important conclusion e.g. Our results show that…is a good/bad assumption.
ii. Cover page that includes a title, the authors, their affiliation, and the date
iii. Executive Summary – *<u>This section may be all that people read so it is extremely important to do this well.</u>* This can be as long as one page, single spaced. It describes what the report contains including the motivation, methods, and major results.
   a. What did you do and why?
      i. Evaluated different methods of determining time constants for different thermocouples.
   b. How did you do it?
      i. Measured temperature vs. time when transitioning between fixed temperature baths.
      ii. Used three different fitting strategies and determined the residual error.
   c. What were your main conclusions? This can contain qualitative and quantitative conclusions.

I. Introduction - Be direct, clear, and succinct. Don't foreshadow or withhold information. The purpose of this report is information transfer, not to entertain or interest the reader. But, don't present results here.
   a. (Re)State the purpose of your report (Paraphrase and expand on the purpose at the beginning of the assignment. This paragraph should let the reader know what information they will obtain in the report.
   b. Briefly describe your strategies to achieve the goals without going into details like the specific equipment. This is where you can describe analytical methods.
      i. Summarize the three proposed methods for determining time constant. This can be done with a single schematic and a few equations. Using an example dataset would be useful.
      ii. Summarize how you evaluated the accuracy of the different methods.
   c. Summarize the structure of the rest of the report.

II. Experimental methods
   a. Describe your temperature measurement setup/sensors
      i. Thermocouples
         1. Briefly but accurately describe each type.
         2. State how you processed and recorded the thermocouple output.
         3. Provide a schematic/block diagram of the thermocouple, the amplifier, and the A-to-D converter.
      ii. Thermistor
         1. State that the thermistor is the calibration standard for the thermocouples and that the interchangeability is ±0.2^{o}C with proper reference.
         2. State that you calibrated the thermistor using two fixed point baths.
         3. Provide β and R_o value for the thermistor based on the two point calibration.
   b. Describe the temperature baths.
   c. Describe what you used for your fixed point baths and how accurate they are
      i. Ice water – you may state without attribution that you are assuming that the purity of town water is such that the freezing point is 0^{o}C ±0.1^{o}C

ii. Boiling water – You will be given a student's Honors project that describes how to estimate the effect of barometric pressure on the boiling point. Look up the minimum and maximum barometric pressure for NH (make sure you properly reference it in the reference section) and estimate the maximum change in boiling point. Make a statement that the water bath reference is within ±x.x^{o}C of 100^{o}C.

d. Data analysis methods

   i. Describe how you determined static sensitivity and the methods you used to determine the confidence intervals for the temperature measurement. This can be a straightforward statement or two. Refer to the data and the plot in appendix. **Don't put them here.**

   ii. Describe how you determined the time constants.

      1. Display and describe a typical T(t) curve and schematically show the limiting values, $T_{initial}$ and T_{final}.
      2. Provide the expression for the error fraction, $\Gamma(t)$ you use to obtain τ.
      3. Display and describe a typical $\ln(\Gamma(t))$ vs. t curve indicating how you obtain τ, the time constant. Point out you force the intercept to zero and that you truncate the fit for small values of Γ.
      4. Refer to the figure in the Introduction for the 0.632 method and the initial slope method.

III. Experimental results and discussion

a. Dynamic response characterization of thermocouples

   i. Show plots of temperature vs. time for each thermocouple type (bare, embedded) for one transition.

      1. Indicate the time corresponding to the beginning of the transition using both methods.
      2. State which appears to be more accurate.

   ii. Describe how well each time constant determination method describes the data for each thermocouple type, each temperature bath, and each onset method.

      1. Provide representative plots comparing the fit to the T vs. t data for the two time constant estimation methods, the two onset methods and the two thermocouple types (bare, embedded). List the time constant on the plot and a vertical dashed line at $t = \tau$. The captions should clearly indicate which method is being used. There should only be four plots for each thermocouple type.
      2. Provide representative plots of residuals vs. time for all four methods for each thermocouple type. List the value of s_{yx} on each plot.
      3. Use the above information to show which method is the most accurate method to determine the time constants.

   iii. Provide a table showing the time constant and s_{yx} for each method, for each thermocouple, and for each temperature transition. Organize the data in the order you intend to discuss it. Include all relevant units.

   iv. Discuss and propose explanations for any trends in the time constants that you observe.

      1. Consider the effect of bath-fluid velocity on the heat transfer coefficient. (There is a clear effect. You need to recognize it and describe it.)

2. An expression for the time constants using the lumped capacitance model was presented in class and is given in Example 3.3 in the book. Summarize the derivation and provide a prediction for the ratio of time constants for the aluminum and stainless steel under equivalent heat transfer conditions. Does the relevant ratio for the different materials agree with the observations?

IV. Summary and conclusions - Summarize what you determined in your experiments and the subsequent analysis. Don't summarize things you did not prove or show.

a. What is the confidence limit for your thermocouple temperature measurements?
b. Which time constant method was most accurate and why?
c. Does the lumped capacitance measurement describe the trends in material properties for the two embedded thermocouples in similar heat transfer conditions?

V. Appendix

a. Static sensitivity determination
   i. Data table with clear description and units in table headings.
   ii. Provide the static sensitivity plots of amplified voltage for the bare thermocouple vs. temperature from the thermistor. Use symbols for the discrete data points you obtained but do not connect them with lines.
      1. Show the best fit line <u>with the equation</u> on the plot using appropriate symbols and units.
      2. Convert the amplified voltage to temperature and replot the temperature based on thermocouple output vs. temperature based on the thermistor. Show the confidence limit of the fit for 95% confidence using $\pm t_{\nu,P} s_{yx} \sqrt{\frac{1}{N} + \frac{(x-\bar{x})^2}{\sum_{i=1}^{N}(x_i-\bar{x})^2}}$ On the same plot, Show the 95% confidence level of the measurement using $\pm t_{\nu,P} s_{yx} \sqrt{1 + \frac{1}{N} + \frac{(x-\bar{x})^2}{\sum_{i=1}^{N}(x_i-\bar{x})^2}}$.
      3. State the confidence limits as $T \pm \Delta T$ at the middle of the measurement range and at the extremes.
      4. Provide a magnified plot in the region near 0°C comparing the 95% confidence level of the measurement to your 25 repetitive measurements of ice water temperature using the bare wire thermocouple. Comment on whether the above confidence limit is effective in predicting the value of the next measurements.
      5. The figure captions should summarize the fit and point out how to locate the confidence lines.
   iii. State the static sensitivity equation in the text and explain and describe the confidence limit lines on your figure.
b. Show the plot of temperature vs. time for the bare wire thermocouple transitioned from boiling water to air with the room temperature value indicated on the plot as a horizontal dashed line. Comment on the result.
c. Anything else you feel is necessary.