SensitviT Sensors Inc.

February 1, 2019

A. Engineer, B. Engineer, QC Engineers

SensitiviT Sensors

Quality Control

Hottimes, 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. Our customers have provided feedback that our published time constant value does not lead to accurate descriptions of the process variables.

We currently estimate the time constant by subjecting the sensors to a step temperature change by taking them from boiling water to ice water and the reverse because these are fixed temperature baths. Previously, we determined the time constant from the time it takes to reach 63.2% of the final value and we define the beginning of the transition by the time where the temperature has changed by five standard deviations from the average of the baseline data obtained well before the transition.

We showed in a recent study that this method leads to time constant estimates that do not accurately describe the performance of our sensors. In that study, we showed that the sensor temperature significantly changes during the time it is in the air between the baths. We showed that defining the initial time as the time corresponding to the maximum rate of temperature change corresponds to the time it entered the second bath. The slope is maximum at this point because the heat transfer coefficient in water is much greater than the heat transfer coefficient in air. We also showed that using all of the data instead of a single point leads to lower standard error of the fit when we estimated the time constant from a fit of lnΓ vs. t.­­­

While we are happy with the improvements in the accuracy of our time constant estimates, a recent upgraded uncertainty analysis of the measurement suggests that we might get even better accuracy if we restrict the range of the fit to 0.2<Γ<0.7. We want you to verify if this is correct by repeating the measurements and comparing the standard error of the fit for both fitting methods.

Also, as you know, some of our thermocouples are embedded in a metal sleeve to protect the thermocouple. We would like to select different materials to have lower time constants but want to make intelligent selections before changing the material. We want you to evaluate whether the lumped capacitance method for predicting time constants is consistent with the observations for the thermocouples embedded in stainless steel and aluminum. The best way would be to compare the predicted time constant ratio to the observed time constant ratio.

Your experimental plan should consist of:

* Calibration of a bare wire thermocouple against a thermistor that has an interchangeability of ±0.2°C. Calibrate the thermistor using the two fixed point baths. Use a series of temperature baths between ice and boiling water to determine the linearity, uncertainty of the fit, and uncertainty of the measurement for the temperature calibration.
* Measure the dynamic response of the bare wire thermocouple and the 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.

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,

Urfirst Boss

Quality Control Manager

1. 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. Boss) 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.
2. Cover page that includes a title, the authors, their affiliation, and the date
3. Table of contents
4. Executive Summary – *This section may be all that people read so it is extremely important to do this well.* This can be as long as one page, single spaced. It describes what the report contains including the motivation, methods, and major results.
   1. What did you do and why?
      1. Compared two methods for determining time constants two types of our sensors.
   2. How did you do it?
      1. Measured temperature vs. time when transitioning between fixed temperature baths.
      2. Evaluated two different fitting strategies. Used residuals and standard error of the fit to compare the quality of the different methods.
   3. What were your main conclusions? This can contain qualitative and quantitative conclusions.

Watch and be consistent with your tense. In most cases, past tense is the most appropriate because you are describing what you did. The introduction may refer to something later in the report using future tense.

1. 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.
   1. (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.

We will deduct 10% off the top for an introduction that does not follow the premise of the report which is an internal report to answer a specific question that you describe in the introduction. If we see “The purpose of this lab is to…….”, you will get a 10% deduction.

* 1. Briefly describe your strategies to achieve the goals/answer the questions without going into details like the specific equipment. This is where you can describe analytical methods.
     1. Assumed that the thermal sensor – amplifier measurement system follows first order measurement system response to a step change in input. Summarize the expected response for step function input to a first order system.
     2. Summarize the impact of the time in air on the T vs. t curve when attempting to make a step change in temperature. Show an actual plot (one of your own) and label the important parts. State that you define Tinitial and t = 0 as the point where the slope is greatest because this is where the sensor actually enters the new bath.
     3. State that previous work showed the value of determining the time constant from the fit of lnΓ vs. t instead of probing the data to find the time where the temperature has reached 63.2% of the final value. You can reference me.
     4. Summarize the motivation for the new proposed method for the fits to determine the time constant should be performed. (The program that plots uτ/τ vs. τ will be provided.)
     5. Summarize the different quantitative methods (residuals and syx) you will use to evaluate the accuracy of the different methods.
  2. Summarize the structure of the rest of the report.

1. Experimental methods
   1. Describe your temperature measurement setup/sensors
      1. Thermocouples
      2. Briefly but accurately, describe each type.
      3. State how you obtained and processed the thermocouple output.
      4. Provide a schematic/block diagram of the thermocouple, the amplifier, and the A-to-D converter.
      5. 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.** State the average confidence interval of the measurement.
   2. Describe the temperature baths.
      1. Describe the constant temperature baths and how you monitored their temperature with a thermistor.
         1. State that the thermistor is the calibration standard for the thermocouples and that the interchangeability is ±0.2oC with a proper reference.
         2. State that you calibrated the thermistor using two fixed point baths.
         3. Provide β and Ro value for the thermistor based on the two point calibration
      2. Describe what you used for your fixed point baths and how accurate they are
         1. Ice water –you are assuming that the purity of town water is such that the freezing point is 0oC ±0.1oC.
         2. Boiling water – you are assuming that the boiling water bath reference is within ±0.1oC of 100oC. This is not exactly correct because the boiling temperature is a function of atmospheric pressure.
   3. Data analysis methods
      1. Describe how you determined the time constants.
         1. Display and describe a typical T(t) curve and schematically show the limiting values, Tinitial and Tfinal. Indicate that the knee in the curve is when the sensor enters the new bath.
         2. Describe how you used a sliding polynomial fit to determine the maximum  .
         3. Display and describe a typical ln(Γ(t)) vs. t curve indicating how you obtain τ, the time constant. Point out you force the intercept to zero and reference equation in Appendix.
2. Experimental results and discussion
   1. Show a ln(Γ(t)) vs. t curve for one bare thermocouple transition and one embedded thermocouple transition
      1. The plot for each should have captions that summarize what the reader should observe
      2. Each plot should show the fit for both Γ fit ranges and list the τ for each range
   2. Show T vs. t data and the predictions using the τ for each fit method for one bare thermocouple transition and one embedded thermocouple transition List the time constant and the  values on each plot.
   3. Provide a plot of the residuals vs. time for previous plots. Make sure the legend is easy to understand or use labels and arrows to indicate which curve corresponds to which method.
   4. Provide a table showing the time constant using and the  value for each fit method for each thermocouple and each transition (ice-boil, boil-ice).
   5. State whether or not the restricted fit range results in a better prediction (lower syx and residuals that do not depend on time). It may work for some curves and not the others. If the difference between the two syx values is less than the uncertainty of the temperature measurement, then the difference is not significant. If it is greater, then it is significant.
   6. In theory, the time constant for a given sensor should be independent of the temperature transition. Is this consistent with your observations? If not, propose a reason why.
   7. Summarize the lumped capacitance model to predict time constant derivation and provide a prediction for the ratio of time constants for the aluminum and stainless steel under equivalent heat transfer conditions. Does the predicted ratio for the different materials agree with the observations?
3. Summary and conclusions - Summarize what you determined in your experiments and the subsequent analysis. Don’t summarize things you did not prove or show. Don’t discuss things in this section, just succinctly restate your findings.
   1. State the confidence limit for your thermocouple temperature measurements.
   2. State whether restricted fit range to determine time constant resulted in significantly lower standard error of the fit.
   3. State whether the lumped capacitance measurement describe the trends in material properties for the two embedded thermocouples in similar heat transfer conditions?
4. Appendix
   1. Static sensitivity determination
      1. Data table with clear description and units in table headings.
      2. 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 with the equation 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 On the same plot, Show the 95% confidence level of the measurement using  .
         3. State the confidence limits as T±ΔT at the middle of the measurement range and at the extremes.
         4. The figure captions should summarize the fit and point out how to locate the confidence lines.
      3. State the static sensitivity equation.
   2. Anything else you feel is necessary.

Rubric

Cover Letter – 5%

Executive Summary – 20%

Introduction 10%

Experimental Methods 20%

Results and Discussion 35%

Summary and Conclusion 5%

Appendix 5%

Each part will be graded on clarity and organization of the presentation of information, quality of graphical information (when relevant), and completeness.