Wright State University, Department of Mechanical and Materials Engineering

ME 4610: THERMAL-FLUID SCIENCES LABORATORY

Thermocouple Calibration

Objectives: Learn how to calibrate thermocouples using a precision resistance temperature detector and a constant-temperature recirculating chiller bath.

Method:

1. Calibrate thermocouples using a constant-temperature recirculating chiller bath and platinum resistance temperature detector. The data acquisition system will collect thermocouple data and RTD data using LABVIEW virtual instruments.

Data to be collected:

1. Transient RTD temperature from the F250 precision thermometer showing the bath temperature from one steady state to another.
2. Steady state thermocouple temperatures and the corresponding RTD temperatures. At each steady state, collect 500 readings for each thermocouple and 100 RTD readings.

Calculations:

1. Determine the mean, standard deviation and confidence interval at a confidence level of 99% for the RTD readings.

Report:

1. Title page
2. A plot of the transient RTD temperature from one steady state to another.
3. A plot of the time derivative of the RTD temperature (with and without 60-second averaging) showing that steady state was achieved.
4. Plots of the steady state RTD temperatures versus the Type E thermocouple temperatures (One plot for each thermocouple, *x*-axis = Type E temperatures, *y*-axis = RTD temperatures). Use a regression analysis to fit a straight line to the data for each thermocouple. Show the equation of the line on your plot.
5. A plot of the calibration uncertainty of the thermocouple versus temperature for each thermocouple. This must account for the uncertainty of the RTD (±0.0043°C), the confidence interval of the bath temperature as read by the RTD at a confidence level of 99%, and the difference between the actual RTD data and the prediction using the line.
6. A discussion of the results:
   - How does a thermocouple work? Where is the extra junction and how is it compensated for using the data acquisition board and thermocouple module?
   - How much time was required to reach steady state? Refer to the transient plot in your quantitative discussion.
   - What is the actual temperature and uncertainty of each thermocouple when they both read 24.72ºC with a standard deviation of 0.17ºC over 250 data points at a confidence level of 99%? Use the regression equations and show your work.

Nominal Bath Setpoint (ºC)	RTD (ºC)	TC01 (ºC)	TC02 (ºC)
15			
20			
25			
30			
35			

References:

An excellent description of how thermocouples work is given in the following websites:
http://www.omega.com/temperature/Z/pdf/z019-020.pdf
or http://www.cs.wright.edu/people/faculty/sthomas/z019020.pdf
http://www.omega.com/temperature/Z/pdf/z021-032.pdf
or http://www.cs.wright.edu/people/faculty/sthomas/z021032.pdf

Operator's manual for the Lauda Recirculating Chiller:
http://www.cs.wright.edu/people/faculty/sthomas/lauda.pdf

F250 precision thermometer handbook:
http://www.isotechna.com/Articles.asp?ID=133
or http://www.cs.wright.edu/people/faculty/sthomas/f250.pdf

Primer for using SCC-68 DAQ Board and SCC-TC01 Modules for collecting thermocouple data:
http://www.cs.wright.edu/people/faculty/sthomas/temperaturedaq.doc

Primer for using the LABVIEW Virtual Instrument for Resistance Temperature Detector (RTD) temperature collection:
http://www.cs.wright.edu/people/faculty/sthomas/labviewrtd.pdf

Discussion

Thermocouples are rugged, reliable electronic temperatures sensors that are used in many industrial and experimental applications where the temperature of a device must be continuously monitored and the data stored using a data acquisition system. Thermocouples operate over a very wide range of temperatures, but the type of thermocouple chosen depends upon the expected temperatures. Calibration of thermocouples is relatively easy, and consists of comparing the thermocouple output to the output of a NIST-traceable device, such as a platinum resistance temperature detector (RTD). The two devices are immersed in a constant temperature bath, and the bath temperature is allowed to reach steady state. At that point, the data acquisition system is started, and thermocouple and RTD data are collected. Enough data is collected to ensure a valid statistical sample. The bath temperature is raised, allowed to reach steady state, and data is again collected. This process is continued over the range of temperatures expected. The average RTD values are plotted against the average thermocouple values and a linear curve is computed, which is the calibration equation.

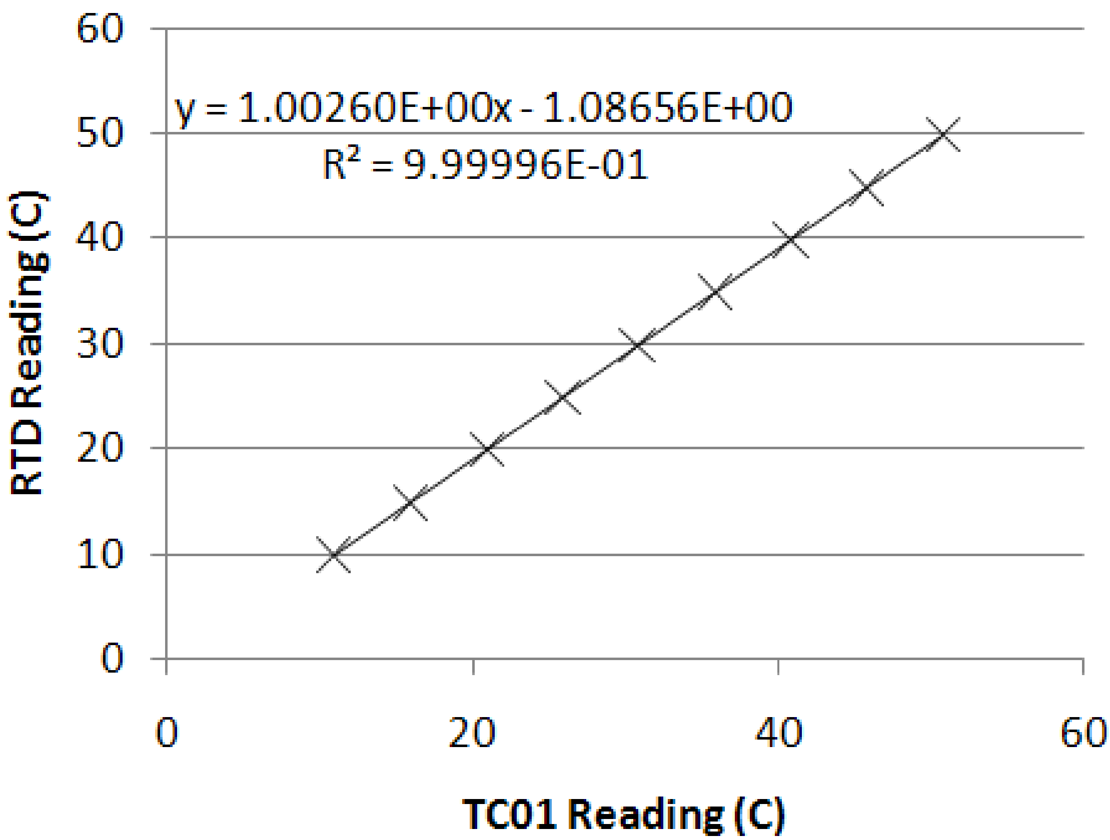

Figure 1: Typical calibration equation for a thermocouple.

The calibration uncertainty of the thermocouple is simply the summation of the stated NIST uncertainty of the RTD, the confidence interval of the bath temperature as read by the RTD, and the difference between the actual RTD temperature and that predicted by the calibration equation.

Once the thermocouple is calibrated, it is ready for use. The uncertainty of the temperature measurement can be estimated to be the sum of the calibration uncertainty discussed above and the confidence interval of the data set collected. To be conservative, the maximum uncertainty shown in the plot in #5 above would be appropriate.

Two Type-E, 1/16-inch-diameter thermocouple probes (TC01 and TC02) are to be calibrated using a recirculating chiller bath and the platinum resistance temperature detector (PRTD as follows:

1. A recirculating chiller bath (Brinkmann-Lauda, Model RC20) was filled with water. Adjust its set-point to a nominal temperature value of 15°C. Place the PRTD probe (ASL, Model F250 Mk II) in the bath such that the immersion depth

of the probe is approximately 100 mm. Place the two thermocouple probes to be calibrated in the bath in close proximity to the PRTD.

2. Acquire bath temperature data from the PRTD with a LabVIEW virtual instrument on the personal computer using the RS232 interface.
3. Set the data acquisition system (DAS) to acquire bath temperature data from the thermocouples by opening a LabVIEW virtual instrument on the personal computer. The DAS consists of a data acquisition board (National Instruments, Model SCC-68), four thermocouple modules (National Instruments, Model SCC-TC01) mounted to the DAQ Board, and a data acquisition card (National Instruments, Model PCI-6221) installed in the PC.
4. Monitor the bath temperature using the PRTD until the bath reaches steady state. At this point, record 100 data points at a nominal rate of one data point every three seconds. Also, record 500 data points for each thermocouple at the steady state at a rate of 1 data point every 0.25 second.
5. Increase the set-point temperature of the bath to 15°C after the steady state PRTD and TC data are recorded, and monitor the bath temperature again to determine when steady state is reached. Repeat this process until steady state PRTD and TC data is recorded for bath temperatures of 15, 20, 25, 30, and 35°C.

The calibration uncertainty of a thermocouple is the summation of the stated NIST-traceable uncertainty of the PRTD (0.0043°C), the confidence interval of the well temperature as read by the PRTD at a confidence level of 99%, and the difference between the actual PRTD temperature and that predicted by the calibration curve.

$$\Delta T_{\mathrm{CAL}} = \Delta T_{\mathrm{PRTD}} + \Delta T_{\mathrm{WELL95}} + \Delta T_{\mathrm{BF}}$$

Variation of the well temperature at steady state is unavoidable due to the dead-band of the temperature controller for the well. The behavior of the recirculating chiller is shown in the figures below.

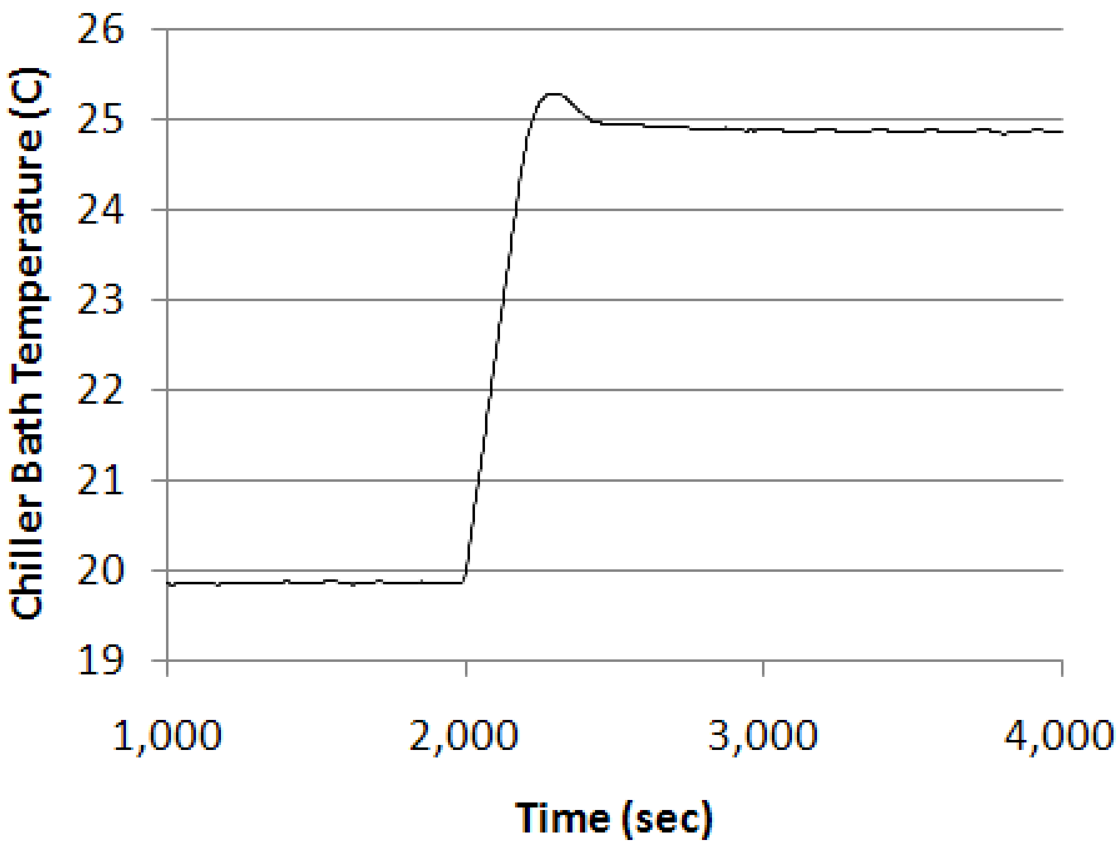

Figure 2: Typical recirculating chiller bath temperature trace measured by the PRTD.

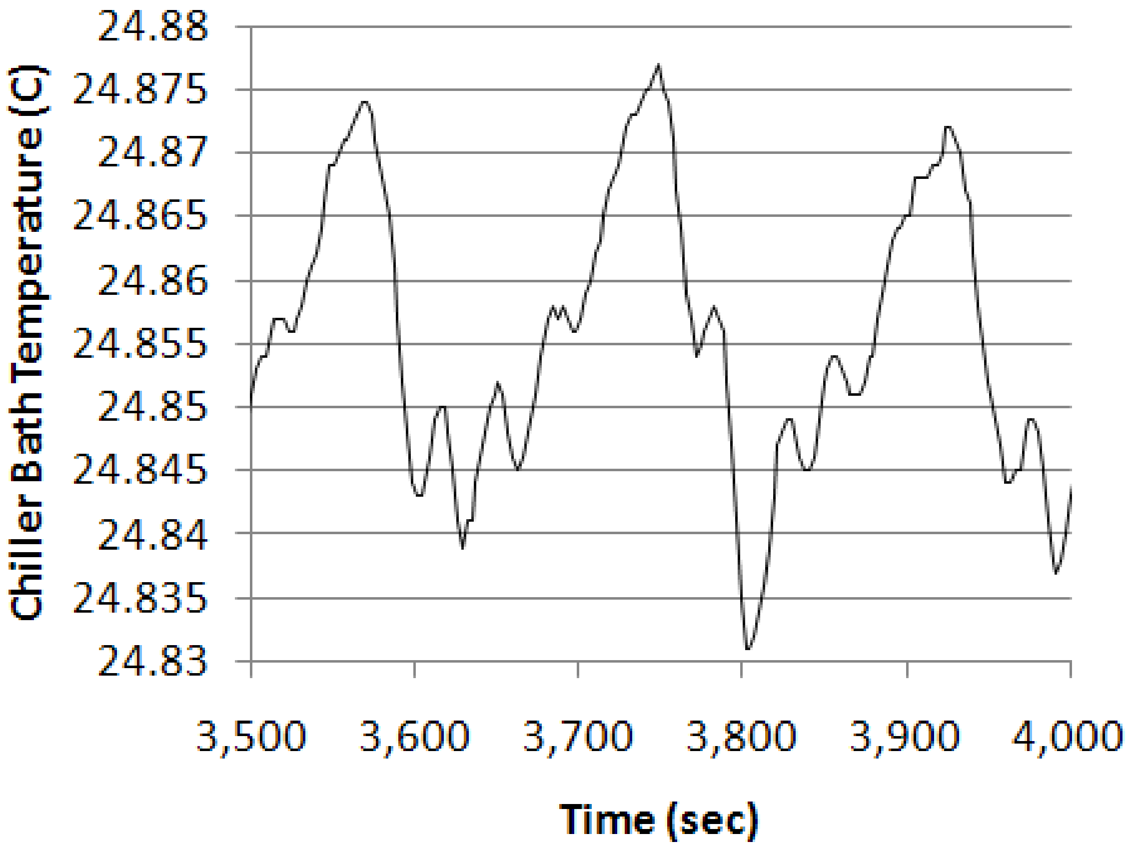

Figure 3: Steady state temperature fluctuations of the recirculating chiller bath measured by the PRTD.

The uncertainty of the temperature measurement is estimated to be the sum of the calibration uncertainty discussed above and the confidence interval of the data set collected at a confidence level of 99%.

$$\Delta T = \Delta T_{\mathrm{CAL}} + \Delta T_{\mathrm{C99}}$$