ME310 – Instrumentation and Theory of Experiments

Lab 4: Temperature Calibration and Measurement

CONCEPTS: temperature measurements, RTDs, thermistors, digital data acquisition, LabVIEW GUIs

DELIVERABLES: Full lab report (**with** full uncertainty analysis) document, due in 2 weeks, in lab.

1. Introduction

Two important aspects of temperature measurement are choosing the measurement device, and obtaining an accurate calibration. Different devices, such as thermistors and resistance temperature detectors each offer advantages and disadvantages in measuring temperature, in the response time and the response function, as well as variations between the many different types of each device that are available. Choosing the appropriate instrument can be a significant factor in obtaining valid results.

Equally important is the ability to accurately determine the temperature being measured. Each of the devices mentioned above measures changes in properties other than temperature that can in turn be related to a change in temperature. To measure temperature effectively, an accurate calibration is necessary between the change in properties actually measured and the associated change in temperature.

In this lab you will use constant temperature baths to investigate variations in the capabilities and properties of two different temperature measurement devices. You will also calibrate each of the three devices using physical ice points. A pdf of both types instruments can be found on the course website, since they look similar in appearance.

2. Theory

Thermistors and resistance temperature detectors (RTDs) measure properties that can be used to determine the temperature of a substance. Whereas thermocouples (discussed in class) use as their thermometric property the voltage that is created between two different metals when two bimetal junctions are at different temperatures, RTDs and thermistors use the fact that as temperature changes, the electrical resistance of materials change (thermistor = thermal + resistor…). In the sections that follow each of these devices is explained briefly.

2.1. Thermistors & RTDs

As mentioned above, thermistors and RTD's rely on the fact that the resistivity of a substance changes as its temperature does. The main difference between thermistors and RTD's is the material from which they are made. Another difference (actually a function of the material and the implementation) is that the response of an RTD is more linear than a thermistor, while the thermistor is more sensitive.

RTD's are generally made of a conductive metal. In a conductor the atoms can be thought of being in a regular lattice. The metal's conduction properties are a result of the lattice: an irregular lattice is a poor conductor compared to a more regular one. As temperature increases the atoms in the lattice shake more, making it more irregular, thus scattering more of the conduction electrons, not allowing them to conduct current. The decrease in the ability to conduct current is seen as an increase in the metal's resistivity.

Thermistors are generally made from a semi-conducting material, such as a ceramic material. Semiconductors are characterized by having two energy bands (in their electron cloud) separated by an energy gap. The band with a lower energy is called the valence band, while the band with higher energy is called the conduction band. The population of the conduction band of a semi-conductor determines its resistivity. Electrons from the valence band can jump to the conduction band, across the energy gap, if they acquire enough energy. Energy can be added to electrons in the valence band by increasing the temperature. As temperature increases, resistivity goes down, because the population of the conduction band increases.

RTD's have a relatively slow response time. With this in mind, they are not usually used for applications in which the temperature varies quickly. Thermistors have a relatively quick response time, and are not as delicate as RTD's, so they can be used in applications that have harsh environmental conditions. Thermistors can be easily packaged in a manner that will allow them to be flat mounted to a device. The use of these devices relies on a calibration of the device, usually obtained by measuring the output of the system as the temperature is varied in a known controlled fashion.

2.2. Data Acquisition

This lab uses a National Instruments PCI-6221 data acquisition board (the same board as lab 3 and the design project). The input range that the board is set to for this lab is ±1 V.

3. Procedure

NOTE: Each student should bring a USB flash drive to the lab to obtain their own set of the computer data. Before beginning the lab, be certain you can identify thermistor and RTD devices.

<u>Spot check thought questions:</u> Read through & think about the questions in Section 5.

<u>Constant Temperature Baths</u>

Portions of this section may already be in progress at the time you start your lab. Check with the TF to determine the state of each temperature bath.

Note that the immersion heaters draw a lot of current to produce the heat, and may cause a ground loop in the form of the 60-Hz AC voltage in conjunction with the rest of the measurement devices. Since the water isn't deionized, the thermocouples, which act as antennas, can pick up this signal and disrupt their voltage output that you're seeking to measure (consider the role that the pre-amps play here!). Avoid this problem by making sure that the immersion heaters are plugged into the **same** power strip as the rest of the equipment used in the lab.

Set the temperature of the five temperature baths as follows:
1. Fill the 0ºC bath approximately 50% full from a cold water tap. Empty two 5lb bags of ice into the bath.

2. Fill the 15ºC bath to approximately 70% of capacity from a cold water tap. Empty one 5lb bag of ice into the bath in a controlled manner until the temperature drops slightly below 15ºC. Allow the temperature to slowly rise to 15ºC. Once at 15ºC, continue to monitor the temperature and add ice as necessary to maintain that temperature.

3. Fill the 30ºC bath from a cold water tap. Allow 30-45 min. for the water to reach 30ºC.

4. Fill the 45ºC and 60ºC from a hot water tap. Allow 30-45 min. for the water to reach the proper temperature.

3.1. Thermistor Measurements

Connect the thermistor directly to the DMM and measure its resistance when placed in each of the five baths. Wait for the change in resistance readings to near steady-state. **Discussion question**: Can you estimate the time constant for the thermistor?

Obtain a voltage divider circuit from the GST (diagrammed below). Measure the resistance of the resistor (nominally 1kΩ) in the voltage divider circuit.

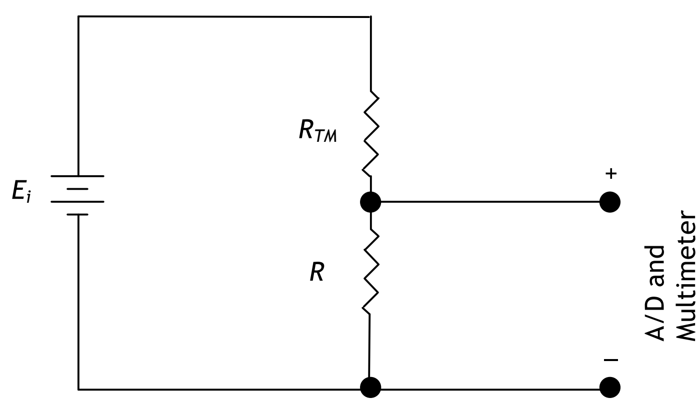

Figure 1: Voltage Divider circuit.

The excitation voltage E_i = 1.5 V is provided by the DC power supply. The voltage divider circuit is built on a breadboard (the board also contains a Wheatstone Bridge circuit which you will use when calibrating the RTD) that has been built so that hooking up the circuit is fairly easy – follow the labels on the breadboard.

For each of the five temperature baths make the following measurements:

Measure the temperature in the bath with a standard thermometer.

Record the voltage indicated on the DMM.

Now switch the BNC cable from the DMM to the A/D breakout box (NI BNC-2090). Execute the LabView VI with a frequency of 10Hz for 10 seconds and **save** the results.

Draw an updated block and wiring diagram.

SPOT CHECKS: For the 0ºC bath, does the experimental voltage you measured match what you would expect from a theoretical calculation of the voltage divider circuit (using your experimental value for the thermistor's resistance)?
Is the thermistor signal impacted by the wind tunnel operation? If possible, try to acquire a data set when the wind tunnel is off or at a low power setting.

3.2. RTD Measurements

You'll need to use the Wavetek model 753A 'Brickwall Filter' unit to amplify the RTD measurement. Make sure it is set to 'DC' and that the lowpass filter is set to 1 kHz.

Connect the RTD directly to the multimeter and measure its resistance when it is placed in each of the five baths. Note the settling time for the RTD to come to steady state, especially compared to the thermistor.

Connect the RTD and power supply (1.5 V) outputs to the bridge circuit (diagrammed below) following the labels on the circuit. The output from the bridge circuit should connect to the BNC input 2 (on the lowpass filter side) of the Wavetek unit. Connect the 'Output 2' of the amplifier to the **A/D board** and to the **multimeter**. In the diagram, R_1 and R_4 are both nominally 100Ω, R_2 is the RTD and R_3 is a 200Ω potentiometer. Set the amplifier gain to 0 dB (no gain). Place the RTD in the 0° bath and balance the bridge using R_3 and the multimeter. Record the voltage from the DMM and A/D board (using the same settings as for the thermistor) for all temperature baths.

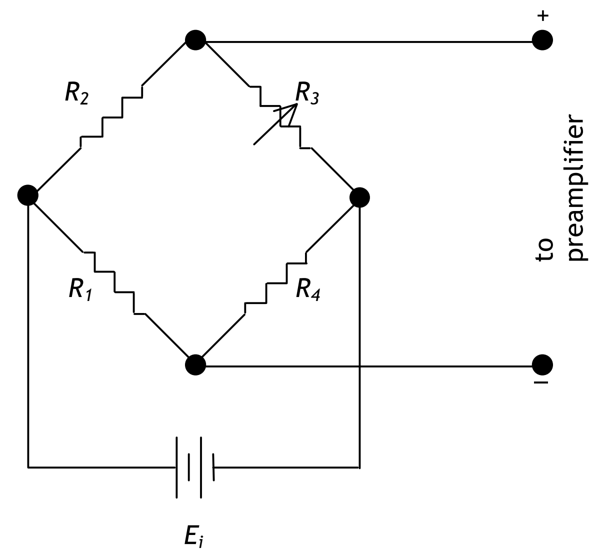

Figure 2: Wheatstone bridge circuit.

Change the amplifier gain to +10 dB. Repeat the temperature measurements made above using both the A/D board and multimeter.

Connect the RTD to the voltage divider circuit in place of the thermistor. Connect the output of the voltage divider circuit to the amplifier and output of the amplifier to the A/D board only. Set the amplifier gain to 0 dB and take data from the A/D board for all baths. Set the amplifier gain to +10 dB and repeat the measurements with the A/D board for all baths. **Discussion question**: What is the effect of the preamplifier on these measurements?

Finally, **turn off** the battery-powered pre-amplifiers that you've used for the lab.

3.4 ***Step-by-step Procedure List*** **(Note: Fill in the blank setting spaces!)**

3.1 Thermistor measurements

- Identify the thermistor and connect it to the DMM;
- For each water bath (5 total):
  - Place thermistor in bath; monitor resistance measurement on DMM and note when value has reached steady state. Record resistance and time required to reach steady state for each bath measurement;
- Obtain voltage divider circuit and measure resistance of circuit resistor (~1kW);
- Power circuit with V_{DC} = 1.5V from power supply and connect thermistor output to voltage divider (as R_{TM});
- Using a BNC T connector, connect circuit output to the ADC breakout box and multimeter;
- Open the LabView wiring diagram for the acquisition VI file, and locate the data acquisition tool. Find the DAQ board information (and FSI) and add to your Equipment List;
- For each water bath (5 total):
  - Measure & record temperature of bath using digital thermometer;
  - Record DMM voltage from voltage divider circuit;
  - Run LabView acquisition program, with ___ Hz sampling rate and ___ s acquisition. Save results;
- Perform first Spot Check;
- Draw block and wiring diagram.

3.2 RTD Measurements

- Locate RTD and connect output to DMM.
- Measure steady state resistance for each water bath; record resistance and settling time;
- Locate Wheatstone Bridge circuit (arms 1,4 = ___Ω, arm 2: RTD output; arm 3: 200Ω potentiometer) and connect output to DC preamplifier;
- Set preamp to unity gain and connect output to multimeter & ADC breakout box;
- Turn Wavetek preamp on and make sure the coupling is set to 'DC' (NOT 'AC');
- Supply bridge circuit with V_{DC} = 1.5 V;
- Place RTD in 0°C bath; balance bridge, using multimeter as a guide;

- Using previous acquisition settings, record DMM and ADC voltage for all baths;
- Change preamp gain to 10 dB;
- Repeat previous acquisition steps for remaining baths;
- Draw block and wiring diagram;
- Turn off bridge power and switch RTD output to voltage divider circuit instead;
- Set preamp gain to 0 dB and connect preamp input to voltage divider output; connect preamp output to the ADC box;
- Once resistance is at steady state, acquire the ADC voltage for each bath;
- Change preamp gain to 10 dB and repeat measurements;
- Power down Wavetek preamp unit;
- Draw new block and wiring diagram.

4. Analysis, Results and Discussion

Note: You should find the data sheets for the relevant instruments on your own, online. Make sure to reference your Equipment List for the necessary information.

1. Thermistor: Using the data files you took in lab, calculate means and standard deviations for the voltages you took at each temperature, and plot mean voltage as a function of control temperature. Convert the voltage to a resistance. Plot the calculated thermistor resistance as a function of control temperature. Compare these calculations with the resistance measurements you took with the multimeter. Can you fit the calibration data using a linear regression? Also plot 1/temperature as a function of ln(resistance), and note the functional form; does degrees centrigrade or Kelvin make more sense? Discuss. No uncertainty analysis is necessary for the thermistor results.

2. RTD: Using the data files you took in lab for the bridge circuit at both gain settings, calculate means and standard deviations for the voltages you took at each temperature. Based on these values and for those obtained using the voltage divider circuit at both gain settings, plot mean voltage as a function of control temperature. Fit the calibration data using a linear regression. Apply a full uncertainty analysis to all results.

3. Comment on the significance and implications of the various spot checks and on the significance and implications of the various results graphs (including comments on sensitivity). Also comment on the advantages and disadvantages of using the different types of input circuits with the different types of measurement devices.

5. Analysis Guidance: Think about these questions *while* you're performing the lab.

What is the title of this lab and what is the ultimate goal of this lab exercise?

a. Is your calibration analysis a calibration of the individual temperature device or of the entire measurement setup? What is the difference between these two distinctions (think applicability of the calibration information) and what related aspects should you consider for the uncertainty analysis?
b. What information do you need for the instruments, regarding their uncertainty sources and associated values?

6. Further Reading

Figliola, Richard S., Donald E. Beasley, Theory and Design for Mechanical Measurements, 4th ed. New York: Wiley, 2000. Chapter 7&8

Moore, John N, C. C. Davis, and M.A. Coplan, Building Scientific Apparatus, 2nd ed. Reading MA: Addison-Wesley Publishing Company, 1989. Chapter 7.

7. Authors

Written by M.S. Isaacson & C. Orison (10/99). Most recent revision: C. Farny (01/16).