# Experiment A4
# Sensor Calibration
Procedure

Deliverables: Checked lab notebook, Brief technical memo

**Safety Note:** Heat gloves and lab coats must be worn when dealing with boiling water. Open-toed shoes are strictly prohibited.

## Overview

In this lab, you will learn how to implement modern electronic transducers. In the first part, you will perform a 2-point calibration of a resistive temperature device (RTD). In the second part, you will perform a multipoint calibration of a capacitive pressure transducer using a manometer as a calibration standard. You will also use a Pitot probe to measure the velocity of a jet of air and a flowmeter or "rotameter" to measure flow rate..

## Part 1: RTD Calibration

As discussed in lecture, the resistivity of a metallic strip increases with temperature, and this phenomenon can be exploited to create an electronic transducer known as a resistive temperature device (RTD). In this exercise, you will calibrate a resistive temperature device (RTD) probe. The tip of the RTD probe contains a thin strip of platinum wire, and the resistance of the platinum probe wire $R_S$ is related to temperature by

$$R_S(T) = R_0\left[1+\alpha_T\left(T-T_0\right)\right], \tag{1}$$

where $\alpha_T$ is the temperature coefficient of resistance and $R_0$ is the resistance of the probe at a temperature $T_0$ = 0°C. Please follow the steps listed below to experimentally determine $R_0$ and $\alpha_T$.

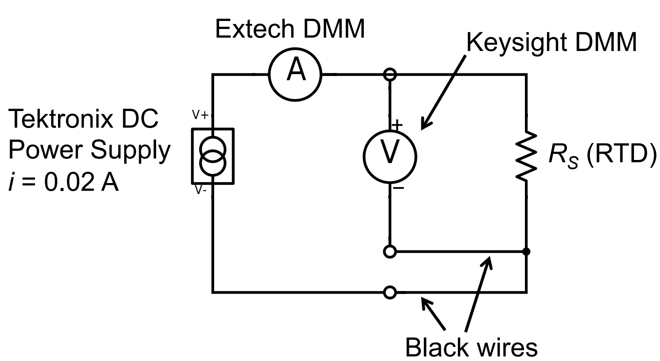


**Figure 1** – A schematic of the RTD circuit.

1. **Make sure the RTD is not yet connected.**
2. Turn on the Tektronix DC power supply, and **turn *both* the current knobs as low (counterclockwise) as they will go**, then turn *both* the voltage knobs as high as they will go.
3. Construct the circuit shown in Fig. 1.
    - **a.** Connect one of the black wires on the RTD to the negative terminal of the DC power supply with a black banana-to-grabber cable.
    - **b.** Connect the positive terminal of the DC power supply to the "V•Ω•mA" receptacle on the Extech DMM with a red banana-to-banana cable.
    - **c.** Connect the red wire on the RTD to the COM receptacle on the Extech DMM with a red banana-to-grabber cable.
    - **d.** Set the Extech DMM to 200mA mode.
    - **e.** Connect the HI (red) cable of the Precision DMM to the red wire of the RTD with a red banana-to-grabber cable.
    - **f.** Connect the LO (black) cable to the *other* black wire of the RTD with a black banana-to-grabber cable.
4. Compare the circuit you constructed to Figure 1 to make sure it is correct. Ask the instructor to check if you are unsure.
5. Turn on the Keysight Precision DMM and press the "DCV" button to measure DC voltage.
6. Slowly turn up the ***fine*** current knob on the DC power supply until you get close to 20 mA on the Extech DMM. **CAUTION: If you turn up the current to high, it will burn out the probe!**
7. Record the current on the Extech DMM and the voltage on the Keysight Precision DMM in your lab notebook. The measured resistance of the RTD at any given temperature can be calculated by dividing the voltage $V$ by the current $i$, i.e. $R_S = V/i$.
8. Fill a beaker with ice water. Mount the RTD probe in the beaker clamp and dangle it in the ice water. You should notice a change in the voltage. After the voltage reaches steady state, record it in your lab notebook.
9. Fill another beaker with about an inch of distilled water and place it on the hot plate. Turn on the hot plate and allow the water to reach a slow boil.
10. Put on the heat gloves, remove the RTD probe from the ice bath, and submerge it in the boiling water. You should notice a change in the voltage. After the voltage reaches steady state, record it in your lab notebook.
11. **Turn off the hot plate.**
12. **Turn off the DC Power supply. Turn all four knobs as low as they will go (counterclockwise).**

13. Using the voltage you measured in the ice bath, calculate the resistance $R_0$ at $T_0$ = 0°C by dividing the measured voltage $V$ by the measured current $i$, i.e. $R_S(0°C) = V/i$.
14. Using the voltage you measured in the boiling water, calculate the resistance at $T$ = 100°C by dividing the voltage $V$ by the current $i$, i.e. $R_S(100°C) = V/i$.
15. Then, use your value for $R_0$, your resistance at 100°C, and Eq. (1) to determine the temperature coefficient of resistance $\alpha_T$. (Note: $\alpha_T$ should have units of 1/°C.)
16. Compare your values for $R_0$ and $\alpha_T$ with the values given on the RTD data sheet and Omega website. (The exact part number for the RTD can be found in the appendix of this handout.)

## Part II: Pressure Transducer and Pitot Probe

In this exercise, you will *simultaneously* calibrate a capacitive pressure transducer using a manometer and use a pitot probe to determine the speed of an air jet.

### Theoretical Background

*Calibrating the Pressure Transducer*

Shown in Fig. 2 is a schematic of the capacitive pressure transducer. This "analog" sensor outputs a DC voltage $V_{out}$ that is linearly related to the *differential* pressure $P = P_2 - P_1$, such that

$$V_{out}(P) = k \cdot P + V_0 \qquad (2)$$

where $k$ is the sensitivity coefficient and $V_0$ is the offset voltage. In this exercise, you will experimentally determine the calibration curve, which is the *inverse* of Eq. (2).

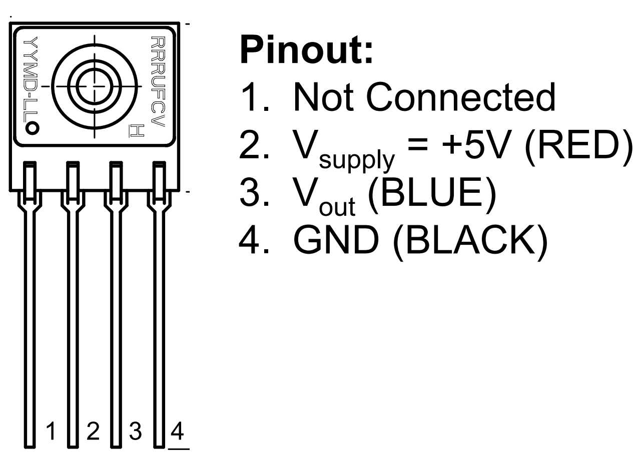


**Figure 2** – The pinout for the capacitive pressure transducer. Note that the pin numbers go left to right when looking at the side with letters printed on it.

*Measuring Airspeed*
Shown in Figure 3 is a schematic of the overall experimental set-up. As you calibrate the pressure transducer, you will simultaneously measure the airspeed of a jet as a function of flow rate. Theoretically, the average velocity $\langle u \rangle$ is related to the flow rate $Q$ by the equation

$$\langle u \rangle = Q/A, \tag{3}$$

where $A$ is the cross sectional area of the nozzle. You will measure the airspeed using a Pitot Static Probe, which measures pressure using the Bernoulli effect. Bernoulli's equation says that the airspeed $u$ is related to the pressure differential $\Delta P = P_2 - P_1$ via

$$u = \sqrt{\frac{2\Delta P}{\rho_A}}, \tag{4}$$

where $\rho_A$ is the density of air.

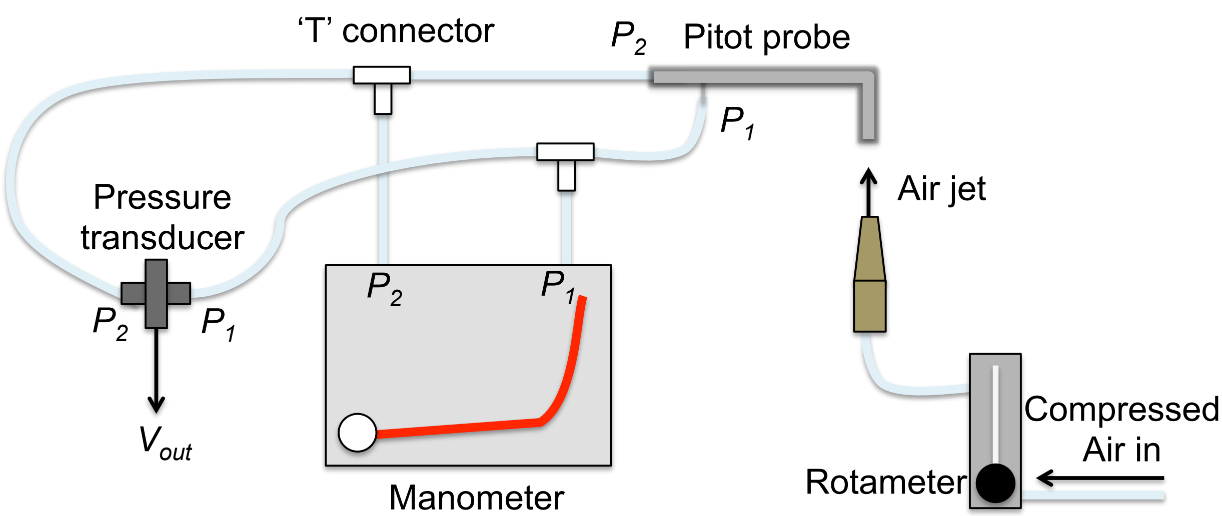


**Figure 3** – A schematic of the experimental setup for calibrating the capacitive pressure transducer and measuring airspeed with the Pitot probe.

**Experimental Procedure**

1. Make sure the breadboard is turned off.
2. Plug the pressure transducer into the breadboard such that each wire is in a separate row. Make sure the tubes are securely fastened to the barbed connectors on the transducer.
3. Refer to the pin-out in Figure 2. Use the breadboard's built-in +5V DC power supply to connect Pin 2. Pin 4 should be connected to ground.

**CAUTION: Make sure the sensor is properly connected before you turn on the power supply. If you are unsure, ask the lab instructor for help. Mixing up +5V DC with ground will burn out the sensors!**

4. Turn on the breadboard.

5. Using the Keysight Precision DMM, measure the voltage difference between Pin 3 $V_{out}$ and ground.
6. The tubes from the transducer should be connected to a couple of 'T's, which split the gas flow between the Pitot probe and manometer. Connect the other tubes from the 'T' to the manometer and Pitot probe, as shown in Fig. 3.
7. Ask the Lab Instructor for a pair of dial calipers. Use them to measure the diameter of the brass nozzle $D$. Use this to then calculate the area of the nozzle $A$.
8. Mount the nozzle to the lab stand using the beaker clamp, such that it is facing upward.
9. Mount the Pitot probe above the nozzle using the other beaker clamp, such that it is directly facing the nozzle.
10. Use the knob on the manometer to "zero" the fluid level. (Turn the knob until the red line of fluid ends at zero.) Note that the manometer measures pressure in units of "inches of water".
11. Slowly open the needle valve on the rotameter. You should hear air flow, see the bead begin to levitate, the fluid level in the manometer should change, and the voltage from the transducer should change. Once you have confirmed this, close the needle valve on the rotameter.
12. Gradually open the needle valve and record the flow rate, manometer pressure in inches of water, and transducer voltage in a table in your lab notebook. (The flow rate should be measured from *the center of the bead*. Use the flowmeter calibration sheet to convert the bead height to a flow rate in L/min.) Do this for at least 8 different flow rates. Be sure to include units!
13. Make a calibration plot of the differential pressure $P$ in units of Pascal as a function of the output voltage $V_{out}$. Apply a linear curve fit to determine the calibration equation.
14. Use Bernoulli's Eq. to calculate the velocity of the air jet based on the measured pressure differential. Make a plot of the velocity in m/s as a function of the flow rate in $m^3$/s. (Double check that your units are correct!)

## Data Analysis and Deliverables

Create plots and other deliverables listed below. Save the plots as PDFs, import them into either Microsoft Word or LaTeX, and add an intelligent, concise caption. Make sure the axes are clearly labeled with units. Plots with multiple data sets on them should have a legend. **Additionally, write 1 – 3 paragraphs describing the items below. Any theoretical formula you used in your analysis should be included as a numbered equation within these paragraphs.**

1. Make a table containing the voltage, current, and RTD resistance you measured for both of the temperatures, 0 °C and 100 °C.

2. Make a table including the parameters $R_0$ and $\alpha_T$ that you measured for the RTD probe compared with the values reported by the manufacturer.

3. Make plot of the measure differential pressure $P$ (in units of Pa) as a function of the transducer voltage $V_{out}$ with a linear curve fit.

4. Report the calibration equation determined by from the linear curve fit from the previous deliverable. The Equation should be of the form $P = aV_{out} + b$.

5. What is the sensitivity coefficient $k = dV_{out}/dP$?

6. Make a plot of the measure velocity of the air jet $u$ in m/s as a function of the flow rate $Q$ in $m^3/s$. The *measured* velocity should be determined from the manometer pressure using Eq. (4). Plot the *theoretical* curve for the average velocity given by Eq. (3) on top of your data.

# Appendix A

## Equipment

**Part I – RTD Calibration**

- Omega General Purpose RTD probe (PR-10-2-100-1/4-6-E)
- Keysight 34465A Precision Digital Multimeter (DMM)
    - One red banana-to-grabber cable
    - One black banana-to-grabber cable
- Extech Handheld Digital Multimeter
    - One red banana-to-banana cable
    - One red banana-to-grabber cable
- DC power supply
    - One red banana-to-grabber cable
    - One black banana-to-grabber cable
- Hot plate
- Lab coats
- Heat gloves
- 2x 100mL beakers
- Ice bath (solid water floating in liquid water)
- Lab stand with one beaker clamp

**Part II**

- Calipers
- Pitot probe
- Capacitive pressure transducer (Honeywell HSCSAAN010NDAA5)
- Keysight 34465A Precision Digital Multimeter (DMM)
    - One red banana-to-grabber cable
    - One black banana-to-grabber cable
- DC power supply
- Inclined manometer
- Rotameter (0 – 24,000 L/min)
    - Long tube with quick-connect going to drop-down compressed air
    - Short tube with nozzle
- Two 'T's with tubes connected
- Lab stands with two beaker clamps