Experiment A3
Sensor Calibration
Procedure

Deliverables: Checked lab notebook, Brief technical memo

Recommended Reading: Chapters 2 and 9 of the textbook

Part I: Pressure Transducer and Pitot Probe

In this lab, you will perform a multipoint calibration of a capacitive pressure transducer using an inclined manometer as the 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.

Background

Shown in Fig. 1 is the *pinout* for the capacitive pressure transducer. This analog sensor outputs a DC voltage V_{out} that is linearly related to the *differential* pressure $\Delta P = P_2 - P_1$.

In this exercise, you will experimentally determine the calibration curve

$$\Delta P = aV_{out} + b, \tag{1}$$

where a is the inverse of the sensitivity coefficient and b is the offset. The sensitivity coefficient is then $k = 1/a$, and has units of volts/Pa. You will perform a multi-point calibration using an inclined manometer and precision digital multimeter (DMM) to determine a, b, and k.

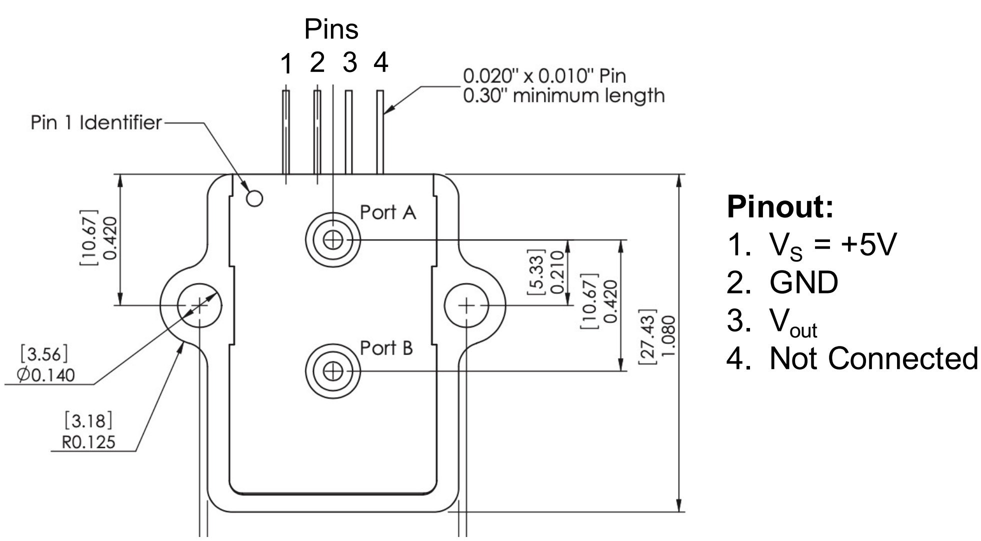

Figure 1 – The pinout for the capacitive pressure transducer shows where to connect the pins. Note that the pin numbers go left to right when looking at the side with the pressure ports with the "Pin 1 Identifier" in the upper left corner.

Measuring Airspeed

Shown in Figure 2 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

$$\langle u \rangle = Q/A, \tag{2}$$

where A is the cross sectional area of the nozzle outlet. 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

$$u = \sqrt{\frac{2\Delta P}{\rho_A}}, \tag{3}$$

where ρ_A is the density of air.

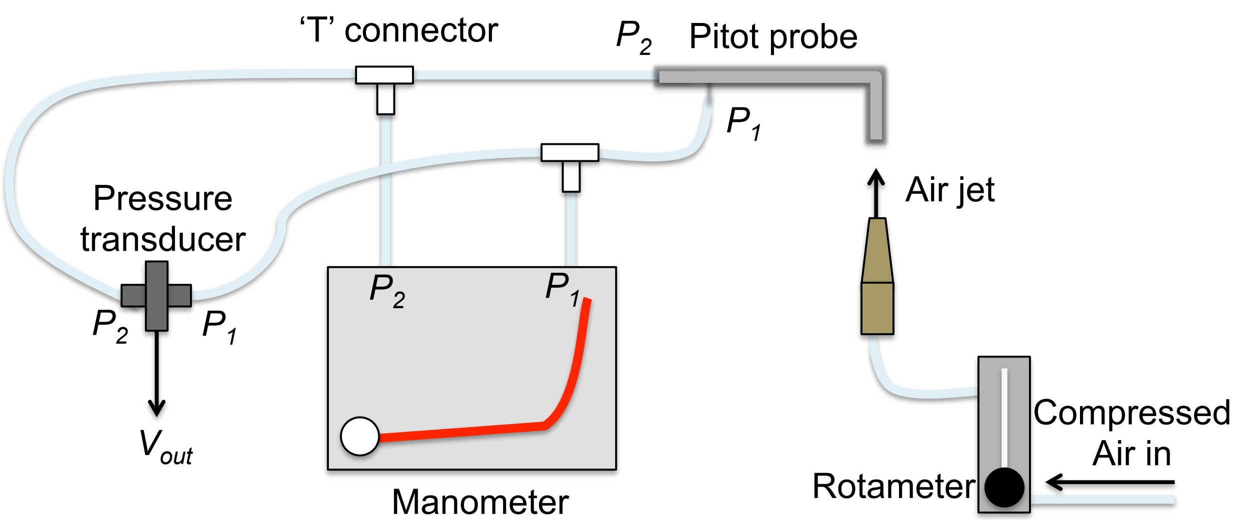

Figure 2 – A schematic of the experimental setup for calibrating the capacitive pressure transducer and measuring airspeed with the Pitot probe.

Experimental Procedure

1. Make sure the breadboard is turned off.
2. The calipers are in a plastic box. Use the calipers to measure the diameter D of the brass nozzle. Use this to then calculate the area A of the nozzle. Which do you think is more relevant to the airflow: the inner diameter or the outer diameter?
3. Sketch the experimental set-up shown in Fig. 2 in your lab notebook.
4. Construct the set-up shown in Fig. 2.
    a. Connect a tube from each of the separate 'T's to each of the ports on the pitot probe.

b. The tubes from the transducer should be connected to a couple of 'T's, which split the gas flow between the pressure transducer and manometer.

5. Sketch the pinout for the pressure transducer shown in Fig. 1 in your lab notebook. Write down the color of the wire connected to each pin.
6. Connect the transducer to 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.
7. Refer to the pin-out in Figure 1. Use the breadboard's built-in +5V DC power supply to connect Pin 1. Pin 2 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!

8. Turn on the breadboard.
9. Using the Keysight Precision DMM, measure the voltage difference between Pin 3 (V_{out}) and ground.
10. Mount the nozzle to the lab stand using the beaker clamp, such that it is facing upward. Focus your engineering awareness on the clamping mechanism and try to think of the best way to clamp the nozzle.
11. Mount the Pitot probe above the nozzle using the other beaker clamp, such that it is directly facing the nozzle. The probe tip should be aligned with the center of the nozzle, about 1 cm away.
12. 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".
13. 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.
14. Make a table in your lab notebook with three columns:

    flow rate, Q (L/min) | pressure, ΔP (in. H2O) | voltage, V_{out} (V)
15. Gradually open the needle valve and record the flow rate, manometer pressure, and transducer voltage in a table in your lab notebook. Do this for at least 8 different flow rates. Be sure to include units!
    a. The pressure transducer has a range of 0 to ±1 inH2O. The 8 data points that you record should span this range.
    b. The 4th and 5th decimal place of the voltage will fluctuate indefinitely. This is called "electronic noise", and it is equivalent to radio static. Only record the digits that are not fluctuating.
    c. 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.

16. Increase the flow rate so the stagnation pressure goes above 1 inH2O. What happens to the sensor voltage when the pressure is above 1 inH2O?
17. Finishing move: return the lab bench to its initial state.
    a. Disconnect all wires and cables from the sensor, breadboard, and DMM.
    b. Turn off the DMM.
    c. Disassemble the nozzle, pitot probe, and beaker clamps.
    d. Disconnect the tubing from the sensor, pitot probe, and manometer. Leave the 3 tubes connected to each 'T'.

Data Analysis and Deliverables

Create the tables, schematics, plots, and other deliverables listed below. Save the plots as PDF or EPS files, import them into either Microsoft Word or LaTeX, and add an intelligent, concise caption. 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.

Please make the following deliverables using the specified units. Report all values rounded to 3 significant digits.

1. 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. (Ignore any data points that are beyond the range of the sensor.)

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

3. What is the sensitivity coefficient $k = dV_{out}/dP$? What is the range of the sensor $|\Delta P_{max}|$? (Be sure to include the correct units!)

4. Make a plot of the measured 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. (3). Plot the *theoretical* curve for the average velocity given by Eq. (2) on top of your data.

Talking Points

- Based on the range of the pressure sensor, what is the maximum airspeed u_{max} that this system could measure?

- Does the measured airspeed vs. flow rate agree with the theoretical curve? If there is a discrepancy, please explain why. (Do *not* use the phrase "human error".)

Appendix A

Equipment

- Breadboard w/ jumper wire kit
- 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
- Analog pressure sensor 1 INCH-D-4V (Digikey Part # 442-1012-ND)
- Inclined manometer – Dwyer (MARK II 25)
- Pitot probe
- Rotameter (0 – 24,000 L/min) – (McMaster Part # 4112K41)
    - Long tube with quick-connect going to drop-down compressed air
    - Short tube with brass nozzle
- Two 'T's with 1/4" OD, 1/8" ID tubes connected
- Lab stands with two beaker clamps
- Calipers