LABORATORY NUMBER 5

MEASUREMENT OF TEMPERATURE AND PRESSURE

1.0 Introduction

The purpose of this laboratory is to introduce the student to two common devices used to measure temperature and pressure: the thermocouple and the pressure transducer. In addition, the student will use the computerized data acquisition system to measure the response of a simple thermal transient system.

2.0 Measurement of Temperature

2.1 Experimental Equipment

The apparatus consists of two thermocouples connected in standard reference junction configurations, a hot plate, a container of water, a mercury-in-glass thermometer and a voltage-temperature conversion table for type-K thermocouples.

2.2 Experimental Procedures

Write down your answers to each of the questions asked in the sections below so that they may be reported in your technical memorandum.

1) Connect the thermocouples to the DMM. Wave the thermocouples around in the air for a minute or so and then record the voltage. Look up the temperature in the table. The temperature should be close to zero (at least under a degree). What does the temperature you measured represent? It should be noted that this is not quite the correct use of the tables since the tables assume one junction is at 0 °C and the calibration will be slightly in error at the higher room temperature reference temperature.

2) Grip on of the junctions in one hand for a minute or so. Record the voltage. Is the voltage positive or negative? What does the sign of the voltage mean here?

3) Prepare the ice bath by mixing crushed ice and water. A correctly prepared ice reference bath must be a slushy mixture of water and ice and the ice must extend all the way to the bottom of the container. If the ice floats on some water, the water below the ice may have a temperature greater than 0 °C since water is most dense at a temperature of 4 °C.

4) Place one of the junctions in the ice bath (select the one that causes the DMM to read positive). Prepare a data sheet with the following columns:

<table>
<thead>
<tr>
<th>Run No.</th>
<th>TC mVOLTS</th>
<th>TC Temp</th>
<th>Hg Temp</th>
</tr>
</thead>
</table>

Place a container of cold water on the hot plate and insert the other junction into it. Place the mercury-in-glass thermometer in the water. Turn on the hot plate. About every two minutes, read the...
DMM and the thermometer and record the data. It is best if you use the thermometer to stir the water every thirty seconds or so. Continue for about 10 minutes. Compute the thermocouple temperatures from the tables, and compute the % difference between the thermocouple temperature and the mercury-in-glass thermometer temp. What do you think about the agreement?

3.0 Measurement of a Temperature Transient

3.1 Experimental Equipment

The apparatus consists of the computer data acquisition system (DAS), an ice reference bath, and two sets of thermocouples connected in the standard reference configuration. The difference between the two thermocouple sets is the diameter of the junction probes. In one case, they are 1/8-inch diameter and in the other they are 1/16-inch diameter. The output of each thermocouple pair is connected to the DAS.

3.2 Experimental Procedure

Both reference junctions (labeled “ICE”) should be placed in the ice bath and the other two junctions should be at room temperature. Connect the 1/8-inch diameter thermocouple set to Channel A0 on the data acquisition input box; connect the 1/16-inch diameter thermocouple set to Channel A1 on the data acquisition input box.

The transient we are studying is simple. At the start of the experiment, both sensing thermocouples will be placed into the ice bath. They will then proceed to cool down to the temperature of the ice bath. The smaller diameter thermocouple should respond more rapidly.

Open the folder titled ‘ENGR 300 Labs’ on the Desktop. Double click on the LabVIEW VI titled ‘Lab 5’. When you are ready to begin collecting data, hit the run button on the toolbar (○) while simultaneously inserting both thermocouple sensing junctions into the ice bath (the reference junctions should already be in the ice bath and have had time to equilibrate to the ice-bath temperature). The LabVIEW VI will collect data and save a file titled ‘Lab_5_data.xls to the Desktop. IMPORTANT: if you run the VI multiple times, the file will be overwritten.

The data file will show two columns. The first column is the output of the 1/8-inch thermocouple; the second column is the output of the 1/16-inch thermocouple (assuming you have connected the thermocouples to the data acquisition box properly). Each subsequent data point in a column represents measurements taken at 10 Hz (i.e., there is 0.1 s between each point).

Make a plot of voltage versus time. Put both sets of data on the same scatter plot - the large-diameter TC data and the small-diameter TC data.

You should now evaluate the time constant for the temperature response of each thermocouple. It is expected that the temperature will drop according to:

\[ \Delta T = \Delta T_i e^{-t/\tau} \]
Where $\Delta T$ is the measured temperature difference, $\Delta T_i$ is the initial temperature difference, $t$ is time and $\tau$ is the time it takes the temperature to decrease to 1/e of its initial value (the time constant). The temperature differences are relative to the $t\to\infty$ temperature, which in our case is 0 °C.

The above equation is for temperature. In fact, the temperature is not a linear function of voltage and before we examine temperature response, we should convert our data from mV to degrees. However, for the limited range of temperatures in this problem (~20 °C to 0 °C), temperature is approximately a linear function of voltage and so we can evaluate the time constants using the voltage data directly [i.e., we assume for the sake of our time constant calculation that $T = (\text{constant}) \cdot (\text{output voltage})$].

Pick a point in time on the graph close to time zero but after the $v$ has started to drop. Call this $t_i$ and $T_i$. Find, at a later time the value of time, $t_f$, where the temperature is 1/e (i.e. 0.36788) times $T_i$. The time constant is $(t_f - t_i)$. Evaluate $\tau$ for the large and small thermocouples from the computer plot. Are the results as expected?

Alternatively (or in addition), note that you may determine the time constant by taking the log of both sides of the above equation, which gives:

$$\log \Delta T = \log \Delta T_i - (1/\tau)t$$

Therefore, plotting $\log \Delta T$ vs. $t$ should give you a line with intercept $\log \Delta T_i$ and slope $-(1/\tau)$. You may find this procedure simpler and more accurate than plotting the exponentially varying data.

### 4.0 Measurement of Pressure

#### 4.1 Experimental Equipment

In this experiment, you will measure pressure using three devices: a pressure transducer connected to the data acquisition system, a mercury manometer and a dial pressure gage. Most dial pressure gauges are Bourdon-tube gauges. The particular gage used in this experiment is actually a diaphragm type which is more expensive and generally more accurate. All three of these instruments are connected together and sense the same pressure. The pressure is supplied by a hand-operated inflation bulb from a blood pressure set (the mercury manometer and pressure gage also come from blood pressure sets).

The most inherently accurate instrument in this setup is the mercury manometer. Its accuracy is only dependent on the measurement of the length of the mercury column and the density of the mercury. The pressure difference required to support the column is:

$$\Delta P = \rho g H$$
Where $\Delta P$ is the pressure difference in Pascals, $\rho$ is the density of mercury ($\text{kg/m}^3$), $H$ is the height of the column in meters and $g$ is the acceleration of gravity (9.8 m/s$^2$). The pressure gage also reads in mm of mercury. This is not a normal unit for a pressure gage but this is a special gage intended for a blood pressure set.

The pressure transducer has an output in mV. The pressure transducer (described in the attached data sheet) is an inexpensive one and although it should be repeatable and linear in output, its calibration is not claimed to be better than $\pm 5\%$. The output is specified as 79 mV for a 30 psi (206,850 Pa) pressure differential with a 10 volt power supply. This 30 psi pressure corresponds to 1551 mm Hg. Expressed in a different way; the pressure transducer should have an output of $5.09 \times 10^{-3}$ mV/mmHg-Volt of the power supply.

4.2 Experimental Procedure

Measure the voltage of the power supply battery with a multimeter while it is connected to the transducer. Open the valve on the bulb so that the pressure is zero. Check to see that the pressure gage and the manometer read zero. If either shows a substantial discrepancy, show the instructor. It is possible that a technician can adjust them. **Note: When increasing the pressure, pump the bulb slowly. If the mercury column rises too rapidly, it can leak out.**

Open the LabVIEW VI entitled ‘Lab 5P’ from the ‘ENGR 300 Labs’ folder on the desktop. Pump the manometer to 280 mm Hg. Type this value into the appropriately labeled box, then hit the ‘RECORD DATA’ button to store the pressure transducer output voltage. Also note the reading from the dial pressure gage. The data from the pressure transducer is an average of 100 samples taken at 1000 Hz. Repeat the procedure for manometer readings of 200, 100, 50, 25, and 0 mm Hg. For the 0 mm Hg reading, leave the valve of the bulb open regardless of the manometer reading. The pressure transducer data is saved to the Desktop as ‘Lab5P_data.xls’, with the first column representing your manometer reading and the second column representing the pressure transducer output voltage in mV (not V). **IMPORTANT:** if you run the VI multiple times, data will continue to be appended to the data file; delete the file if you wish to clear previously stored data.

One problem with pressure transducers like the one we are using is that while the slope of the voltage output will remain quite stable with time, the reading with zero applied pressure may change. i.e., there is a drift in the zero offset. We need to correct the pressure transducer output for this zero offset. Use your data to determine the zero offset and the experimentally determined calibration constant (slope of the data) for the transducer. Use the calibration to determine the pressures in mmHg as determined by the pressure transducer. Compare your results from the transducer and dial pressure gage to the manometer readings (treat the manometer as the primary measurement), and determine the percentage error for the transducer and pressure gage.
5.0 Required Results

Your data sheet and question answers from Part 2.

Your plot from Part 3 and on a separate, identified sheet of paper, your calculations and the two values of $\tau$, the thermocouple time constants. Your table of pressures and percent errors from Part 4.0. On a separate sheet, your response to the following questions

1) Do you think your electrical measurements for part 2 would have produced significantly different temperatures if you had used an RTD or a thermistor device? What about part 3? Why?

2) Which thermocouple responds more quickly? Can you give some reasons why?

3) What can you say about the accuracy of the pressure transducer? The dial pressure gage? What can you say about the linearity of the pressure transducer and the dial pressure gage?
SUPPLEMENTARY INFORMATION FOR LABORATORIES 5 AND 6

MEASUREMENT OF TEMPERATURE AND PRESSURE

1.0 TEMPERATURE MEASUREMENTS

1.1 INTRODUCTION

There are four main types of devices with electrical output which are used for measuring temperatures in the moderate temperature regime. These are Thermocouples, Resistance Temperature Detectors (RTD’s), Thermistors and other Semiconductor Devices. As temperatures become very high, these devices are damaged or destroyed and other methods must be used, radiation pyrometers being common.

In selecting a temperature measuring device, the user must consider a number of factors such as durability, stability (i.e. its temperature-voltage characteristic remains constant over time), transient response time, physical size, level of output voltage, purpose of the output etc. Often, more than one of the devices will be appropriate.

1.2 THE THERMOCOUPLE

When two different metals are brought into intimate contact (as by welding for example), a voltage difference will be created across the junction as a result of the Seebeck Effect. The voltage that is developed is a function of the temperature of the junction and so this simple device is a temperature sensor.

Different combinations of metals produce different voltage levels and different temperature coefficients (mV/C etc.) but certain metal combinations have been found to work best and are sold commercially. The voltage characteristics of some of these are shown in Figure 5.1. Some examples of are Platinum/Platinum-Rhodium, Iron/Constantan, Copper/Constantan and Chromel/Alumel. Most of these metals are alloys. Generally, a high temperature of these metals are alloys. Generally, a high temperature coefficient is wanted but the thermocouple must survive in the measurement environment. For example, copper/constantan has a high voltage output but will be destroyed at high temperatures or in chemically harsh environments. Platinum/Platinum-Rhodium has a rather low voltage output but is stable in some rather active chemical environments.

With the restricted combinations of metals used, it is possible to standardize thermocouples. Companies that manufacture thermocouple junctions and lead wires take great care to control the composition of the materials. It is thus possible to purchase thermocouples and wire, use standard tables to convert voltage to temperature and have a high confidence that the temperature measurement is accurate. At San Francisco State, virtually all the thermocouples...
are of the Chromel/Alumel type. This type, often called "Type K", is durable at temperatures up to 1300°C, and has a fairly high temperature coefficient.

Thermocouple junctions can be made in very small sizes - as small as 0.0005 inches is measure time-varying temperatures to 0.1 seconds or better.

![Figure 5.2 – Thermocouple connected DVM](image)

![Figure 5.3 – TC with ice reference](image)

Reliability and relatively low cost have made thermocouples extremely popular as temperature measuring devices. However, they do have some complications. In Figure 5.2, a copper-constantan thermocouple is shown connected to a voltmeter to measure the temperature at J1. A problem becomes immediately apparent. While there is a copper-constantan junction at J1, there is also a copper-constantan junction at J2. The secondary junction at J2 also produces a voltage and so the measured voltage is not simply the voltage change at J1. It can be demonstrated that the measured voltage is directly related to the temperature difference \( T_{J1} - T_{J2} \). To make this system work, an independent measurement of the temperature at J2 is required.

A better way to measure temperature J1 is shown in Figure 5.3. In this case, the point J2 is known as a reference junction. The junction at J2 is normally maintained at a relatively easily controlled temperature, the temperature of melting distilled water being most common. This is called an "Ice Reference Junction" or simply and "Ice Reference". In the labs at SFSU, these are normally made of crushed ice and water in a thermos bottle. Commercial devices are available which will simulate an Ice Junction without the need to maintain an ice bath.

In the example above, the thermocouple metals were copper and constantan so the junctions at the voltmeter were copper-copper. If the thermocouple were chromel-alumel, the junctions at the voltmeter would be copper-alumel or copper-chromel so there would be voltages generated. If both terminals are kept at the same temperature, these voltages cancel out.

In data acquisition systems, an alternate method of compensation may be used. As shown in Figure 5.4, all the thermocouples are directly connected to the data acquisition system terminal strip. The reference junction is also connected to the terminal strip. The terminal strip is insulated so that all the terminals are at the same temperature. The reference junction voltage is then arithmetically subtracted from the voltage of each of the sensing junctions to arrive at the correct voltage. Alternatively, a semiconductor temperature measuring device is used to determine the temperature of the terminal strip.

5.7
Thermocouples have some other difficulties also (but share these with some of the other devices). The output is in the millivolt range and hence the signals can be contaminated by electrical noise. The voltage output is also not generally a linear function of temperature and so tables or curve fits must be used to convert voltages to temperature.

1.3 RESISTANCE TEMPERATURE DETECTORS

It was mentioned in the discussion of strain gages that strain gages have to be compensated for the effects of temperature. Many Resistance Temperature Detectors (RTD's) take advantage of this effect to create a temperature sensor. Some designs in fact look a bit like small strain gages. In other cases, the sensor is a coil of wire. In any case, an RTD is a device for which the resistance is a direct function of its temperature. The resistance of these devices can be measured with a Wheatstone Bridge. The resistance is normally a nonlinear function of temperature so a calibration curve is required to convert resistance to temperature. The output of the measuring bridge is in the millivolt range so there can be some problems with electrical noise. The voltage supply to the bridge must also be kept to a minimum since $I^2R$ losses in the sensor can heat the sensor and cause temperature errors. There is no need for a reference junction with these devices. They are not normally quite as small as the minimum size possible for thermocouples and do not give such good spatial resolution. They can be made of thin foils, however, and the time response can be quite rapid.

1.4 THERMISTORS

Thermistors are generally made of semiconductor materials devices which have a negative coefficient of resistance with temperature (i.e. the resistance goes down as the temperature increases). These devices are much more sensitive to temperature changes than are RTD's - the resistance can change on the order of 1% for each 1 C change in temperature. The output can be sensed with a Wheatstone Bridge but the change in resistance is so large that multimeters and other devices to measure resistance are often adequate. The output is not in general linear with temperature. Thermistors are often used to measure water temperature in automobiles. Thermistors are generally larger than the largest of thermocouple junctions and have poorer spatial resolution and somewhat slower time response. They also do not survive at very high temperatures (greater than about 300 C).

1.5 SEMICONDUCTOR TEMPERATURE SENSORS

The voltage across a simple diode is a function of temperature. Resistance varies with temperature. Individual components or integrated circuits can be produced which have an output which is a function of temperature. In many cases the output signal can be high level (on the order of 5 volts) which has little problems with noise. Furthermore, they can often be constructed to have a linear output so that output can be readily converted to temperature (e.g. with a simple meter). Generally, these devices are not as small nor do they have the rapid time response of small thermocouples nor will they survive high temperatures.
PX136 Series
Pressure Transducers
Operator's Manual: M0227/1092

SPECIFICATIONS:
Excitation: 10 Vdc 16 Vdc max
Hysteresis & Repeatability: 0.15%FS
Zero Balance: 1 mV gage models; 2 mV absolute models
Stability: 0.5%FS/year
Storage Temp: -55 to 125°C
Operating Temp.: -40 to 85°C
Compensated Temp.: 0 to 50°C
Thermal Effects (25-0°C/25-50°C):
Zero: 2 mV typ (4 mV max);
Span: 1.5%FS typ (3 %FS max)
Input Resistance: 8.8 K ohms
Output Resistance: 4.0 K ohms
Response Time: 1ms
Gage Type: diffused silicon
Shock: 150g @ 6 ms, half sine
Vibration: 10 to 2000 Hz @ 20g
Wetted Parts:
P1 (absolute): Dry gases only
P2 (gage): Polyester, epoxy adhesive, silicon, borosilicate glass, and silicon-to-glass bond. (not recommended for highly ionic solutions)
Pressure Port: tube type
Weight: 5 g

slope = 5.09E-03 mV/(mmHg-Vsupply)

WARNING!
READ BEFORE INSTALLATION
Fluid hammer and surges can destroy any pressure transducer and must always be avoided. A pressure snubber should be installed to eliminate the damaging hammer effects.
Fluid hammer occurs when a liquid flow is suddenly stopped, as with quick closing solenoid valves. Surges occur when flow is suddenly begun, as when a pump is turned on at full power or a valve is quickly opened.
Liquid surges are particularly damaging to pressure transducers if the pipe is originally empty. To avoid damaging surges, fluid lines should remain full (if possible), pumps should be brought up to power slowly, and valves opened slowly. To avoid damage from both fluid hammer and surges, a surge chamber should be installed, and a pressure snubber should be installed on every transducer.
Symptoms of fluid hammer and surge's damaging effects:
a) Pressure transducer exhibits an output at zero pressure (large zero offset). If zero offset is less than 10% FS, user can usually re-zero meter, install proper snubber and continue monitoring pressures.
b) Pressure transducer output remains constant regardless of pressure.
c) In severe cases, there will be no output.

SOLDERING
Limit soldering to 315°C (600°F), 10 seconds duration, maximum.

CLEANING
Proper cleaning fluids should be selected, based on the type of contaminants to be removed. OMEGA recommends alcohols or fluorinated solvents.

MOUNTING AND INTERFACE
Each sensor is furnished with an unassembled steel locking ring. When mounted through the panel hole, the locking ring is forced onto the mounting and locks the sensor to the panel. Pin have 0.25" square cross section to facilitate wire wrap or solder connect are on .100" centers.

<table>
<thead>
<tr>
<th>PSIG</th>
<th>PSIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output (mV)</td>
<td>20</td>
</tr>
<tr>
<td>Span Tol (mV)</td>
<td>1.5</td>
</tr>
<tr>
<td>Linearity BSFL (%FS)</td>
<td>---</td>
</tr>
<tr>
<td>P2&gt;P1 typical max</td>
<td>1.0</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>P2&lt;P1 typical max</td>
<td>0.1</td>
</tr>
<tr>
<td>Overpressure (PSI)</td>
<td>20</td>
</tr>
</tbody>
</table>

5.9