# Laboratory: Strain and Pressure Measurement

## 1. OBJECTIVES

The objectives of this laboratory include:

- Perform characterization of internal pressure in a thin-walled tank by measurements of mechanical strains;
- Perform uncertainty analysis of characterized internal pressures with respect to parameters involved;
- Identify, in order of importance, percentage contribution of all uncertainties to the overall uncertainty in pressure characterizations;

## 2. BACKGROUND

A thin walled cylinder has a wall thickness smaller than 1/10 of the cylinder's radius. In this case, only the membrane stresses are considered and the stresses are assumed to be constant throughout the wall thickness.

The ASME boiler codes require continuous monitoring of pressure in thin walled pressure vessels. In certain processes, use of mechanical pressure gauge or electrical pressure transducer to monitor the pressure is unpractical, as the diaphragm can become encrusted with chemical products quickly. Therefore, a new method is required.

### 2.1 Piezoresistive Pressure Sensor

As shown in figure below, a pressure transducer consists of a diaphragm and four strain gages installed on the metal film attached to the diaphragm. Note that strain gauges $R_1$ and $R_3$ are in the radial direction and strain gauges $R_2$ and $R_4$ are in the direction transversal to the radius. Therefore, when pressure increases, the resistance of $R_1$ and $R_3$ increases and $R_2$ and $R_4$ decreases. The four strain gages form a Wheatstone bridge, as shown in figure below. The change in output voltage of a pressure transducer is directly proportional to the change in pressure. The relationship between output voltage ( $V_{out}$) and the excitation voltage ($V_{in}$) is shown equation 1.

$$V_{out} = V_{in}\left(\frac{R_1}{R_1 + R_4} - \frac{R_2}{R_2 + R_3}\right) \qquad \text{Eq.1}$$

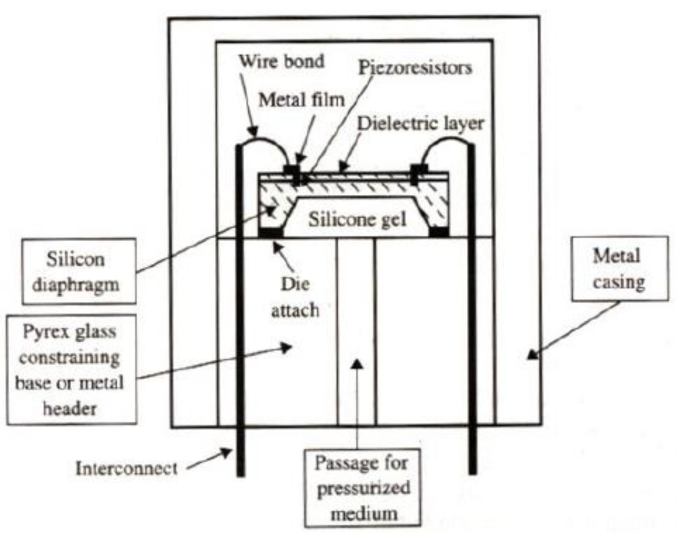



Figure 1a Cross Section of a Pressure Transducer

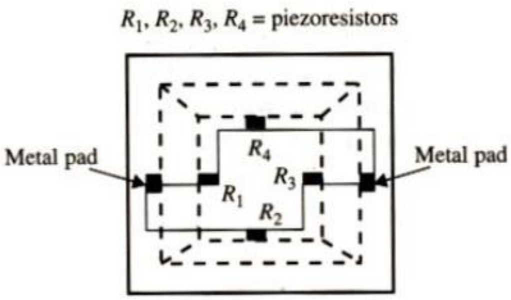



Figure 1b Top View of a Pressure Transducer

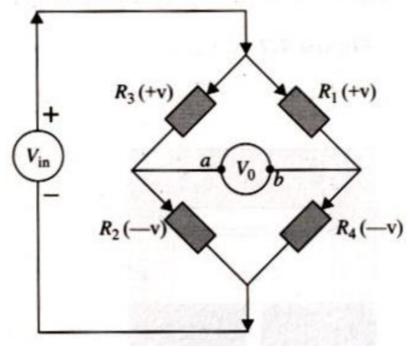



Figure 1c Circuit Diagram of a Wheat Stone Bridge

## 2.2 Stress and Strain in a Thin-Wall Cylinder

For vessels with a wall thickness of no more than one-tenth of its radius, the wall can be treated as a surface. The law of LaPlace holds for fluid or gas filled hollow objects with radius r. For cylinders, the internal pressure acts on them to develop a force along the axis of the cylinder.

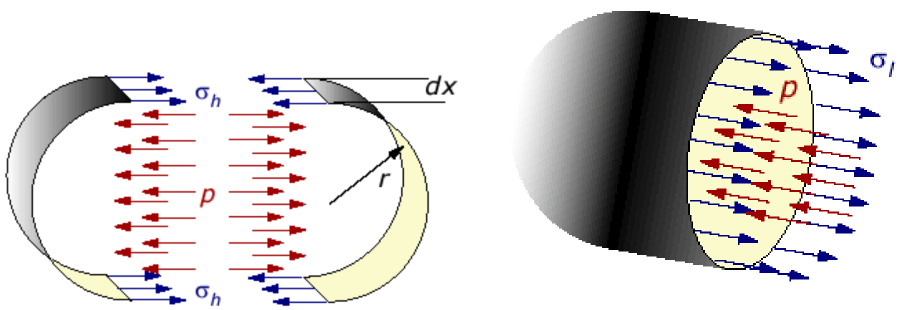



Figure 2 Static equilibrium in cross-sections of a thin-walled cylinder

To determine the hoop stress$\sigma_{\text{hoop}}$, equilibrium in the radial direction should be examined. As illustrated in figure 2, the pressure acts to "pull the two halves apart", while the hoop stress balances the effect. The hoop stress yields,

$$2\sigma_{\text{hoop}} t \, dx = P \, 2r \, dx \qquad \textbf{Eq.1}$$

Therefore,

$$\sigma_{hoop} = \frac{Pr}{t} \qquad \textbf{Eq.2}$$

Similarly, in the axial direction, the pressure acts to push the two halves apart, while axial stress balances the effects, as shown in figure 3. The axial stress yields,

$$2\pi r * \sigma_{axial} * t = P * \pi * r^2 \quad \textbf{Eq.3}$$

$$\sigma_{axial} = \frac{Pr}{2t} \quad \textbf{Eq.4}$$

The Hooke's Law states that stress in the can is proportional to the strain. The relationship in this case can be expressed as:

$$\varepsilon_{Hoop} = \frac{\sigma_{hoop} - \nu * \sigma_{axial}}{E} \quad \textbf{Eq.5}$$

where E is Elastic Modulus of the material, and $\nu$ is Poisson's ratio of the material.

With Eq.2, Eq.4, and Eq.5, the relationship between pressure and strains can be derived as:

$$P = \frac{Et\varepsilon_{hoop}}{r(1 - \nu/2)} \quad \textbf{Eq.6}$$

## 2.3 Basics of Strain Gages

### 2.3.1 Operating Principle and Application of Strain Gages

Strain-gauge sensor is one of the most commonly used means of load, weight, and force detection. Strain gauges are frequently used in mechanical engineering research and development to measure the stresses generated by machinery, and in Aircraft component testing to structural measure stress of members, linkages, and any other critical component of an airframe.

A strain gauge operates on the principle that the electrical resistance of a wire changes when the length of the wire varies. It is used for measuring deformations in solid bodies. The strain experienced by the sensor is directly proportional to the change in resistance of the gauge used, as shown in Eq 7.When unstressed, usual strain gauge resistances range from 30 Ohms to 3 kOhms.

$$R = \rho\frac{L}{A} \quad \textbf{Eq.7}$$

An ideal strain gage is small in size and mass, low in cost, easily attached, and highly sensitive to strain but insensitive to ambient or process temperature variations. The ideal strain gauge would undergo change in resistance only because of the deformations of the surface to which the sensor is coupled. However, in real applications, there are many factors which influence detected resistance such as temperature, material properties, the adhesive that bonds the gage to the surface, and the stability of the metal.

The strain sensitivity, which is also known as the gage factor (GF) of the sensor, is given by:

$$F = \frac{dR/R}{\varepsilon_x} \quad \textbf{Eq.8}$$

where R is the resistance of the gauge without deformation, dR is the change in resistance caused by strain, and $\varepsilon_x$ is the strain to be measured. Therefore, the strain can be expressed as:

$$\varepsilon_x = \frac{1}{F}\frac{dR}{R} \quad \textbf{Eq.9}$$

### 2.3.2 Materials and Selection of Strain Gauges

Typical materials for strain gages include: constantan (copper-nickel alloy), nichrome v (nickel-chrome alloy), platinum alloys (usually tungsten), isoelastic (nickel-iron alloy), karma-type alloy wires (nickel-chrome alloy), foils, and semiconductor materials. The most popular alloys for strain gages are copper-nickel alloys and nickel-chromium alloys.

Temperature change can affect the internal structure of strain-sensing material, and also can amend properties of the material of the surface the strain gage is attached to. When there is a temperature change while a measurement is being made, the effects can cause large errors in data unless proper precautions are taken.

Each material has unique reaction to temperature change, as illustrated in figure below. Variation in expansion coefficients between the gage and base materials may cause dimensional changes in the sensor element. Therefore, it is a good practice to select strain gauge made of same type of material as the base structure.

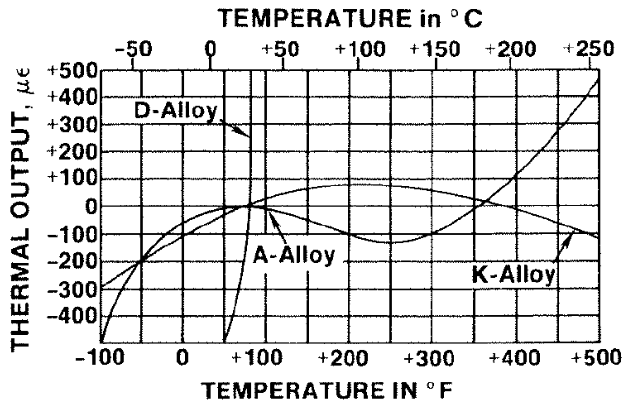



Figure 3 Temperature Effects on Thermal Output of Strain Gauges

Strain gauge's product name contains all critical information needed to select appropriate gauge. The meanings of each part of the name are shown in Figure 4 below. While Figure 5 shows key information of the type of strain gauge selected for this experiment.

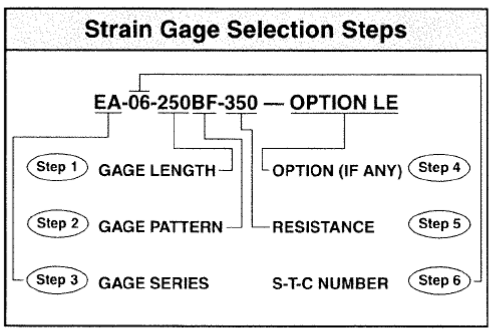
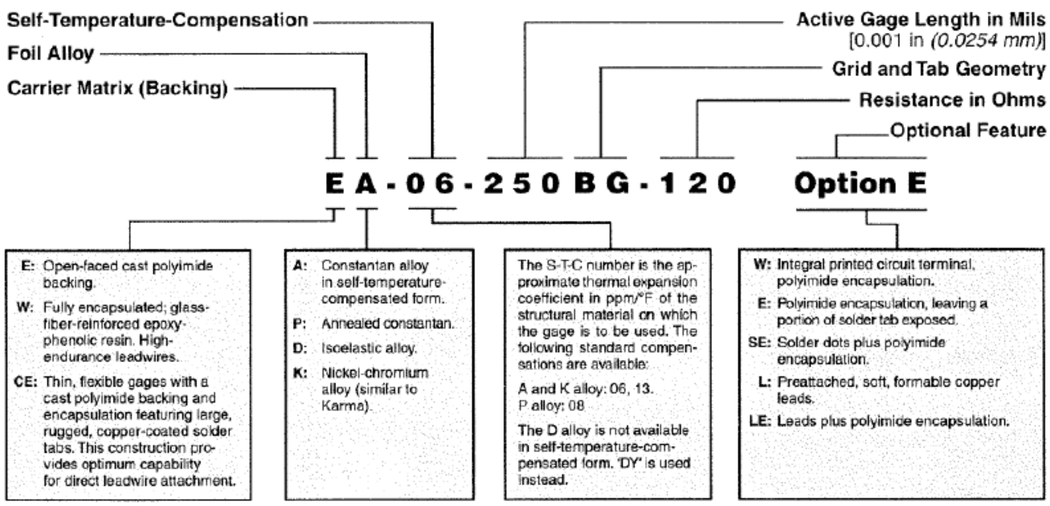



Figure 4 Strain Gage Selection Steps




| GAGE SERIES | DESCRIPTION AND PRIMARY APPLICATION | TEMPERATURE RANGE | STRAIN RANGE | FATIGUE LIFE | |
|---|---|---|---|---|---|
| | | | | Strain Level in $\mu\varepsilon$ | Number of Cycles |
| EA | General-purpose static and dynamic stress analysis. Wide range of options available. | Normal: –100° to +350°F (–75° to +175°C)<br>Special or Short Term:<br>–320° to +400°F (–195° to +205°C) | ±3% for gage lengths under 1/8 in (3.2 mm)<br>±5% for 1/8 in & over | ±1800<br>±1500<br>±1200 | $10^5$<br>$10^6$<br>$10^8$ |

Figure 5 Crucial Information of Strain Gauge Selected

## 2.4 Basics of Wheatstone bridge

A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance (from 1 Ω to 1MΩ) by balancing two legs of a bridge circuit, one leg of which includes the unknown component. A circuit diagram of Wheatstone bridge is shown in figure below, where the battery (symbol "E" serves as an excitation source, and the output is measured by a potentiometer "G").

A "balanced" bridge is one with potential difference between B and D is equal to zero. Balance is sensed by closing switch S2 and measuring output current and voltage – to be near zero. Voltage drop across R2 is equal to voltage drop across R1, since voltage difference between B and D is equal to zero. Therefore,

$$R_x = \frac{R_1 R_3}{R_2} \quad \textbf{Eq.10}$$

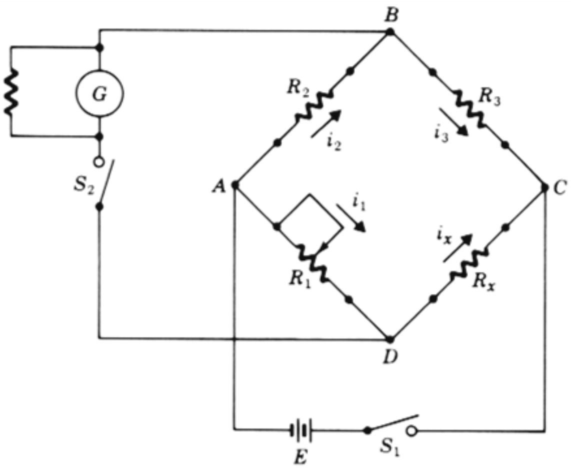



Figure 10 circuit diagram of Wheatstone bridge

When the bridge is unbalanced, equivalent resistance of the circuit is,

$$R = \frac{R_1 * R_4}{R_1 + R_4} + \frac{R_2 * R_3}{R_2 + R_3} \qquad \textbf{Eq.10}$$

When the circuit is viewed as a circuit divider, the output voltage is,

$$E_g = \left(\frac{E}{R_1 + R_4}\right) * R_1 - \left(\frac{E}{R_2 + R_3}\right) * R_2 = E * \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_4)(R_2 + R_3)} \qquad \textbf{Eq.11}$$

When the resistance of $R_4$ changes by a small amount($\Delta R_4$), the new output voltage is,

$$E_g + \Delta E_g = E * \frac{R_1 R_3 - R_2(R_4 + \Delta R_4)}{(R_1 + R_4 + \Delta R_4)(R_2 + R_3)} = E\left(\frac{1 + \frac{\Delta R_4}{R_4} - \frac{R_3 R_1}{R_4 R_2}}{\left(1 + \frac{R_1}{R_4} + \frac{\Delta R_4}{R_4}\right)\left(1 + \frac{R_3}{R_2}\right)}\right) \qquad \textbf{Eq.12}$$

If the bridge was originally balanced ($E_g = 0, R_1 = R_2 = R_3 = R_4$), then we have,

$$\Delta E_g = \frac{E * \frac{\Delta R_4}{R_4}}{4 + 2\left(\frac{\Delta R_4}{R_4}\right)} \qquad \textbf{Eq.13}$$

Since change in resistance is really small($\Delta R_4 \ll 1$), the change in output voltage is,

$$\Delta E_g = \frac{E * \Delta R_4}{4 R_4}$$

or,

$$\Delta E_g = \frac{E * \Delta R}{4R} \qquad \textbf{Eq.14}$$

# 3. PROCEDURES

In order to estimate the internal pressure of soda cans, the procedures of this experiment include research for relevant data, hardware set-up, construction of LabVIEW program, signal conditioning, taking measurements, and data analysis. The measurements should be repeated on 3 soda cans.

The information acquired from research and part of the measurement process should also be used to produce uncertainty analysis and the contribution of each parameter to total uncertainty.

## 3.1 Preparation

### 3.1.1 Research for Relevant Parameters

Research for the parameters below, and provide references:

a. Standard dimension of soda cans: diameter and thickness.

b. Material property of soda cans: material type, elastic modulus, and Poisson's ratio.

c. Common internal pressure range of soda cans.

Document 1 includes relevant data and some information on the materials of soda cans.

### 3.1.2 Understand the Effect of Gain in Signal Conditioners

Calculate the amplifier gain required to amplify the output of the Wheatstone bridge so that you get 1 mV/micro-strain.

Recall Gage factor defined in eq.8,

$$\mathrm{F} = \frac{\mathrm{dR/R}}{\varepsilon_{\mathrm{x}}}$$

Measured strain can be expressed as

**Eq.15**

$$\varepsilon_x = \frac{\Delta R}{F R_x}$$

Recall the expression of change in bridge output voltage caused by a small change in resistance from eq.14,

$$\Delta E_g = \frac{E\ \Delta R}{4R}$$

From eq.15 and eq.14, the relationship between measured strain and change in output can be found as,

**Eq.16**

$$\Delta E_g = \frac{F}{4} E\varepsilon_x$$

To achieve an output signal of 1mV per με, the gain (G) needs to satisfy:

$$\frac{G\Delta E_g}{\varepsilon_x} = \frac{1\times 10^{-3}V}{1\times 10^{-6}} = 1\times 10^3 V$$

Therefore,

**Eq.17**

$$G = 1\times 10^3 V \times \frac{4}{EF}$$

For this experiment, gage factor (F) is 2.095±0.5%.

### 3.1.3 Calculate Strain Simulated by Shunt Resistors

Calculate the strain simulated by shunt resistors.

The connected shunt resistors are parallel to the gage, the equivalent resistance is:

**Eq.18**

$$R_{eq} = \frac{R_x R_{cal}}{R_x + R_{cal}}$$

Therefore,

**Eq.19**

$$\varepsilon_{eq} = \frac{\Delta R}{F * R_x} = \frac{R_{eq} - R_x}{F * R_x} = \frac{R_x}{F(R_x + R_{cal})}$$

Gage factor is 2.095 ± 0.5% for the gauge chosen for this experiment. Resistance without deformation is 120Ω.

## 3.2 Setup

For measurement of strain via a bonded resistance strain gage, it must be connected to an electrical measuring circuit which can accurately measure changes in resistance. Strain-gage transducers usually employ four strain elements electrically connected to form a Wheatstone bridge. This bridge circuit compensates for temperature effects. Quarter bridge strain gauge circuits are appropriate for this purpose.

### 3.2.1 Hardware setup

1. Prepare 3 cans of sodas; they should be of the exact same brand and product.
2. Strain gauges should be mounted in hoop direction of the soda can.

Besides strain gauge and the cans, material needed for attaching the gauge to a surface include: sand paper,  degreaser/alcohol, conditioner, neutralizer solutions, cotton balls & swabs, one-side sticky tape , adhesive , low-impedance strain gage wire (about 15 “) , and soldering material. The steps of are explained below.

1) Degreasing: wipe the surface with degreaser or alcohol to remove oil, grease, organic taminants and soluble chemical residues.
2) Surface abrading: sand the surface with sand paper, in order to remove loosely bonded adherents (scalc, rust, paint, coating, oxides, etc.) and develop a surface texture suitable for bonding.
3) Mark layout lines: mark the planned positions to attach strain gauges.
4) Apply neutralizer to the surface, alcohol works as well.
5) Mount on tape: secure strain gauge to the surface with tape, before applying adhesive. When mounting the gauge to the tape, make sure that the side of the gage with soldering terminals should be facing the tape, or “facing up” from the surface.

   Carefully remove the strain gauge from its package with tweezers, make sure the strain gauge stay chemically clean. Attach one end of a 4-to-6 inch tape to the surface, carefully attach the strain gage to the tape with tweezers, then pick the gage up by lifting the tape at a shallow angle until the tape comes free with the gage and terminal attached. See figure below for illustration of this step.

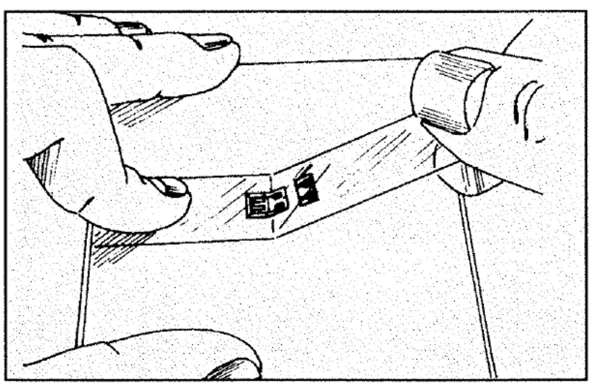


Figure 6 Mount the strain gauge on tape

6) Position the tape: position the gauge/tape assembly so the gauge is over previously marked layout line. Gently apply the assembly onto surface. If the assembly is misaligned, lift the tape again at a shallow angle until the assembly is free from the surface. Reposition.

7) Lift tape: prior to applying adhesive, lift the end of tape opposite the solder tabs at a shallow angle, until the gauge and terminal is free from the surface. Tack the loose end of the tape under and press to the surface, so the gage lies flat with the bonding side exposed.

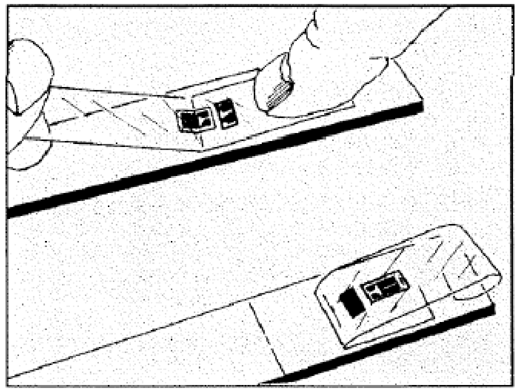


Figure 7 Lift tape

8) Apply adhesive and attach: apply a drop of adhesive to the gage's bonding side, attach the gauge and the surface by pressing on the tape for a minute. Wait two minutes before making a firm wiping stroke over the tape.

9) Remove the tape and clean the terminals with alcohol and a cotton swab.

10) Soldering and stress relief: mask the gage grid area with drafting tape before soldering. After soldering the wires to the terminals, tape or hot gluing the lead-in wires to the surface to prevent the wires from being accidentally pulled from the tabs.

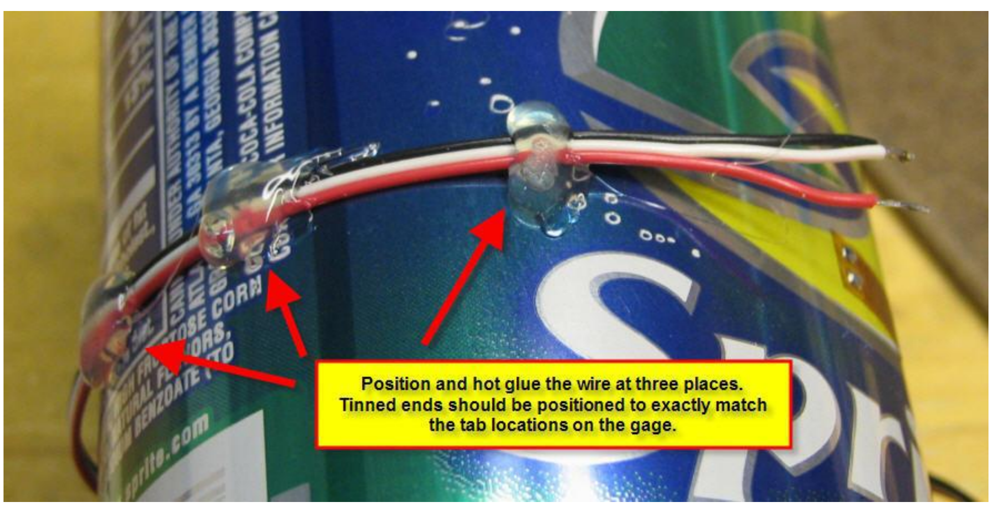



Figure 8 hot gluing the positioned wires at 3 locations

11) Protecting the gage: apply a protective coating over the entire gage and terminal area.

12) Measure the base resistance of the unstrained strain gage after its proper mounting but before complete wiring. Check for surface contamination by measuring the isolation resistance between the gauge grid and the stressed force detector specimen by means of an ohmmeter, if the specimen is conductive. This should be done before connecting the lead wires to the instrumentation.

13)

14) Strain gage will be connected to a Wheatstone bridge with quarter bridge set-up.

15) Connect the signal conditioner properly to provide power to the bridge and amplify the signal. For set-up procedures, refer to Document 2.

16) Connect the inputs from the signal conditioner to the NI DAQ device with a BNC cable, use channel AI0.

### 3.2.2 Construct the LabVIEW program

Refer to Document 3 for the tutorial to construct a basic VI program for this laboratory.

### 3.2.3 Verify the Set-up

Before starting the measurements, the strain gauge installations needs to be verified, the following steps should be followed:

a. Run the VI program to monitor the readings.

b. Check for irrelevant induced voltages in the circuit by reading the voltage when the power supply to the bridge is disconnected. Ensure that bridge output voltage readings for each strain-gage channel are practically zero.

c. Connect the excitation power supply to the bridge and verify both the correct voltage level and its stability.

d. Test out the strain gage bond by applying pressure to the gage. The reading should not be affected.

## 3.3 Taking Measurements

**a.** Before connecting the can, measure the can diameter. Record uncertainty. The middle part of the can has the largest diameter, make sure to capture the diameter from the middle.

**b.** Enter relevant information into VI’s front panel, use standard thickness obtain from research as initial value. Press the can or slightly shake the can and observe the measured strains react as expected. Let the can settle (strains and pressure approach zero) before starting measurement.

**c.** Run the VI for 10 seconds, then open the can, keep recording for another 10 to 20 seconds. Press “stop” button to make sure the data is recorded. Data will be saved in csv file in the same directory VI is saved.

**d.** Measure thickness of the can after drinking the beverage; adjust the calculation results if there is significant deviation from the initial value used. The middle part of the can has the lowest thickness, make sure to capture the thickness from the middle.

## 4. DATA ANALYSIS & DISCUSSION

With the results acquired with three soda cans, estimate the range of internal pressure of similar soda cans. Compare with the pressure value obtained through research.

Conduct uncertainty analysis on the pressure measurements and Poisson's ratio measurements. Assume 3% of uncertainty in strain measurements. Refer to provided sample uncertainty analysis.

Identify, in order of importance, percentage contribution of all uncertainties to the overall uncertainty in pressure characterizations and Poisson's ratio measurements.

*For optional activities during this laboratory, refer to Document 4.

## ATTACHMENTS

- Sample VI
- Sample Lab Report
- User Manual of Signal Conditioner Used in the Experiment

## Document 1: Soda Can Parameters and Uncertainty Estimation as a Reference

### a. Standard dimension of the soda can (diameter and thickness) and the uncertainties associated

The standard values and factors contributing to uncertainty for can diameter and thickness of a soda can are listed in table below. [1]

| | Standard | | Resolution | Repeatability (Assumed) | Standard Deviation (Assumed) |
|---|---|---|---|---|---|
| | Metric | English | | | |
| Diameter | 6.6 cm | 2.6 in | 0.001 in | 0.005 in | 0.0001in |
| Thickness | 0.013cm | 0.005in | 0.0001 in | 0.0001in | negligible |

Table 1 Standard values and factors contributing to uncertainty for can diameter and thickness

According to the table above, for diameter, the uncertainty caused by resolution is $(\mathrm{u_{res}})_\mathrm{d} = 0.0005$ in, the uncertainty caused by repeatability is $(\mathrm{u_{rep}})_\mathrm{d} = 0.0025$ in, uncertainty caused by standard deviation is $(\mathrm{u_{sd}})_\mathrm{d} = 0.0001$ in. Therefore, uncertainty in diameter is calculated as:

$$(u_d)_d 0. = \sqrt{(u_{res})_d^2 + \left(u_{rep}\right)_d^2 + (u_{sd})_d^2} = 0.0025 \text{ in} \quad \textbf{Eq.14}$$

Similarly, for thickness, the uncertainty caused by resolution is $(\mathrm{u_{res}})_\mathrm{t} = 0.0005$ in, the uncertainty caused by repeatability is $(\mathrm{u_{rep}})_\mathrm{t} = 0.0005$ in. Therefore, uncertainty in thickness is calculated as:

$$(u_d)_t = \sqrt{(u_{res})_t^2 + \left(u_{rep}\right)_t^2} = 0.000071 \text{ in} \quad \textbf{Eq.15}$$

Same approach can be applied to uncertainty of strain measurement.

Resolution of strain measurements can be extracted by plotting the measurements data points and identifying the smallest increment.

When gain=192, resolution is 0.325 με and uncertainty caused by resolution is 0.325 με . Therefore, repeatability is 0.163 με, and uncertainty caused by resolution is 0.163 με. The strain gauge chosen for this experiment has a gauge factor of 2.095 $\pm$ 0.5%. Therefore, when measuring strain of 1000 με, the uncertainty caused by gauge factor is 5 με.

**Eq.16**

[1] Berlage, R. (2001). *Strain Measurements of a Soda Can.* Northern Illinois University.

$$(u_d)_\varepsilon = \sqrt{(u_{res})_\varepsilon^2 + \left(u_{rep}\right)_\varepsilon^2 + \left(u_{gf}\right)_\varepsilon^2} = 5.0132\ \mu\varepsilon$$

The beverage can lids are usually made from AA5182 H48, while bodies are usually made from AA 3004 or AA 3104 in the H 19 temper. This specification is sufficiently wide to permit suppliers to offer versions with higher formability or higher strength properties. Increase in material strength has been achieved by gradually increasing the magnesium content from the nominal 0.9% of 10 years ago, to nominal 1.1% today, and copper from nominal 0.06 to 0.15%. In addition to magnesium and copper, manganese (up to 1.5%) is the principal alloying element for increasing strength. Careful control of the level of iron, and the iron/silicon ratio, assists in reducing the level of earing; it also assists in controlling the grain size, which is beneficial to formability. 2

## b. Material property of soda cans (material type, elastic modulus, and Poisson's ratio) and uncertainty associated.

AA3004-H19's mechanical properties and significant digits of the data are shown in table below.

| Mechanical Properties | Metric | | English | |
|---|---|---|---|---|
| | Value | Significant Digits | Value | Significant Digits |
| Modulus of Elasticity | 69.0 GPa | 3 | 10000ksi | 3 |
| Poisson's Ratio | 0.35 | 2 | 0.35 | 2 |

Table 2 AA3004-H19's mechanical properties

In Aluminum alloys, the compressive modulus is typically 2% greater than the tensile modulus. Provided value is an average of modulus of elasticity during tension and compression.3 Therefore, since strain gauge is in tension during our experiment, the corrected modulus of elasticity should be 68.3 GPa and 9900ksi, uncertainty of modulus of elasticity should be approximately 1%. And uncertainty of Poisson' ratio is about 3%.

[2] Wootton, E. (n.d.). *Case study on Can Making*. Retrieved 2012, from Training in Aluminum Application Technologies: http://core.materials.ac.uk/repository/eaa/talat/3710.pdf

[3] Ibid.

## c. Common internal pressure range of soda cans

Gases exert a pressure on any surface with which they are in contact. The amount of pressure exerted by the molecules of a gas depends on the force and frequency of the molecules towards the walls of its container. The pressure of gases is therefore dependent upon temperature and volume. The Third Gas Law states that when the volume of a fixed mass of gas is maintained constant, pressure is directly proportional to absolute temperature.

Soda manufacturers often inject cold liquid with pressurized carbon dioxide, then bottle the drink under high pressure. This is due to the fact that more gas will dissolve in a cold liquid that's under a high pressure than in a warm liquid that is not under pressure. The carbon dioxide in the soda forms carbonic acid, which alleviates the sweet taste of the drink. The carbon dioxide also serves an anti-microbiological purpose.

Each type of soda drink contains a different amount of carbon dioxide, and thus has varying amounts of pressure. On average, the 12 ounce soda cans sold in the US tend to have a pressure of roughly 120 kPa (17psi) when canned at 4 °C, and 250 kPa (36 psi)when stored at 20 °C.

Specifically, a refrigerated can of 7UP® contains 210 kPa (31 psi) of pressure. On the other hand, Pepsi-Cola® contains 276 kPa (40 psi) at approximately 16 °C. Lastly, a can of Coca-Cola Classic® at 34 °C has an internal pressure of approximately 380 kPa (55 psi).4

[4] *Pressure in a can of soda*. (n.d.). Retrieved Dec 2012, from The physics fact book: http://hypertextbook.com/facts/2000/SeemaMeraj.shtml

## Document 2: Set-Up Procedure for Signal Conditioner (Tacuna)

### a. Connection

Connect the wires as indicated in Figure 3.

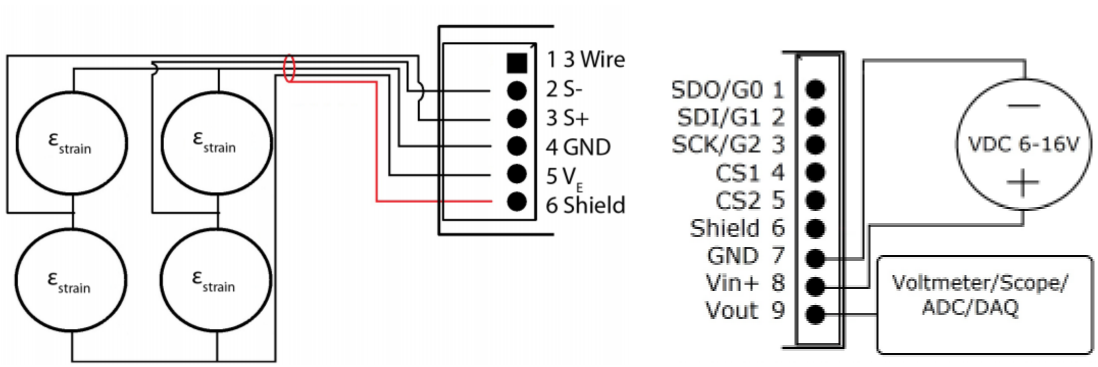



Figure 9 Connections for Tacuna Systems Strain Gauge or Load Cell Amplifier/Conditioner Interface Manual

### b. Gain Setting

To get a gain of 220, make sure the switches (location shown in Figure 4) are set as indicated in Table 7.

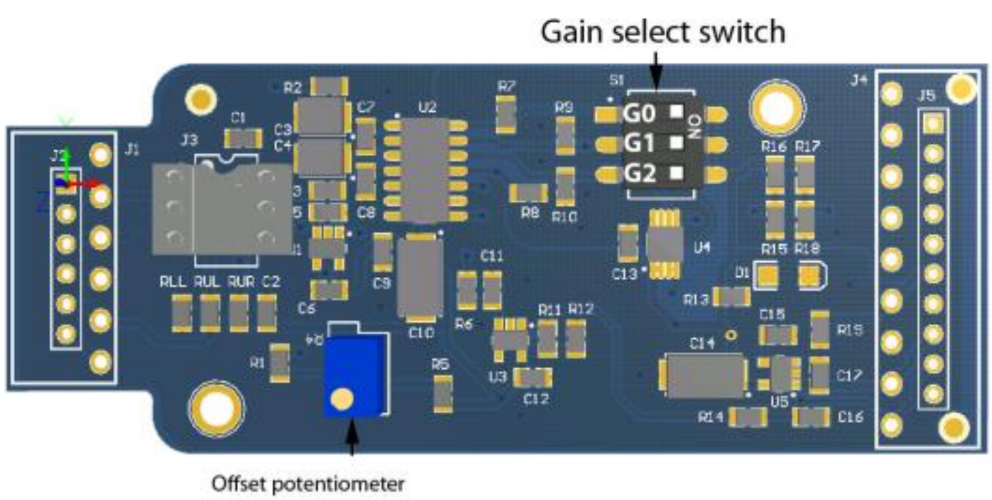



Figure 10 Location of Gain select switch and offset potentiometer

| G0 | G1 | G2 |
|---|---|---|
| ON | OFF | OFF |

Table 1 Switch settings for Tacuna for 220 Gain

### c. Bridge Balance

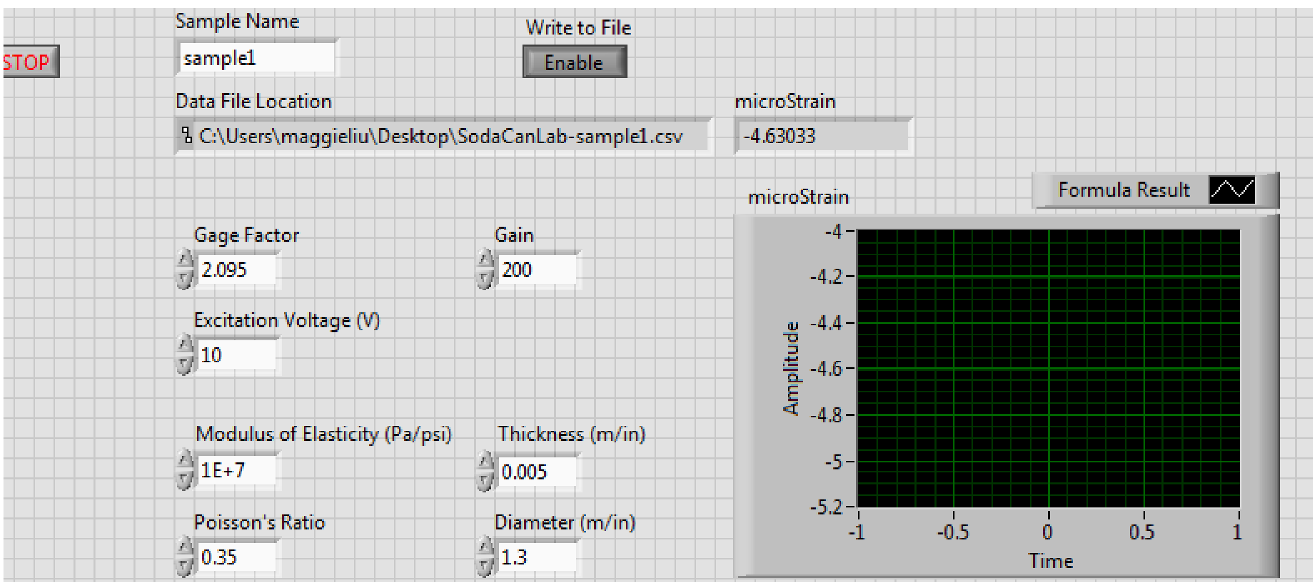
Use the offset potentiometer to adjust the output voltage to 2.5V, which is half of the output range.

It is required to open the enclosure to adjust the gain switches but not the offset potentiometer. The wire connections are located outside of the enclosure.

## Document 3: Tutorial for LabVIEW Program

This sample LabVIEW program for the Strain and Pressure Laboratory acquires the voltage input from connected NI DAQ device, calculates and indicates real-time strains experienced by the strain gauge, then calculates and saves dynamic values of internal pressure of the can, stress in both circumferential and axial directions of the can to a .csv file in the same folder where the LabVIEW program is saved, along with the micro strain readings. Around 30 sets of readings are taken each second.

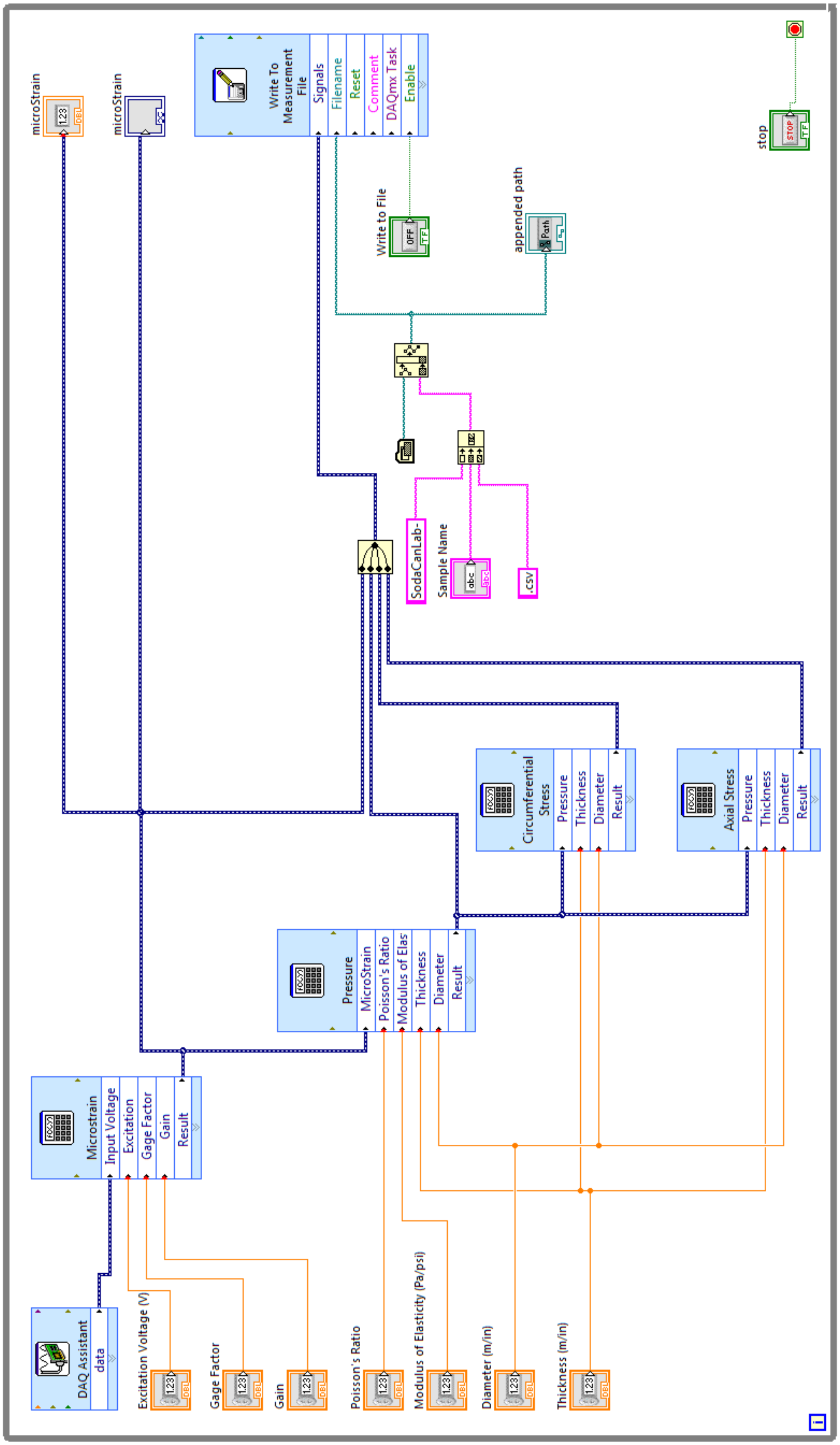
The front panel of the program is shown below. The block diagram is shown on page 2. This document walks through the steps of constructing this program.



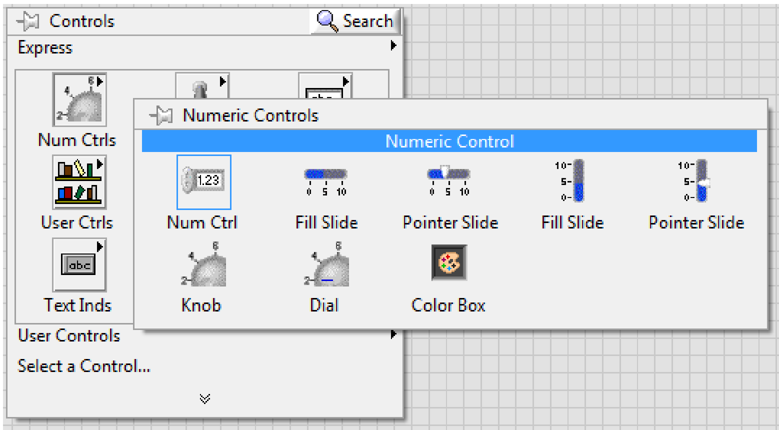

**Part 1: Building the Front Panel**

Before opening LabVIEW program, make sure that the NI DAQ device is probably connected to the desktop and turned on.

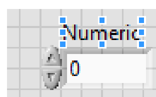
On *Tools Palette*, make sure that *Automatic Tools Selection* is enabled (the box/button on top of the palette). This setting automatically selects the appropriate pointer tools from the palette based on the mouse- over object.


DAQ Assistant
data
Microstrain
Input Voltage
Excitation
Gage Factor
Gain
Result
Excitation Voltage (V)
Gage Factor
Gain
Poisson's Ratio
Modulus of Elasticity (Pa/psi)
Diameter (m/in)
Thickness (m/in)
Pressure
MicroStrain
Poisson's Ratio
Modulus of Elas
Thickness
Diameter
Result
Circumferential Stress
Pressure
Thickness
Diameter
Result
Axial Stress
Pressure
Thickness
Diameter
Result
microStrain
microStrain
Write To Measurement File
Signals
Filename
Reset
Comment
DAQmx Task
Enable
Write to File
appended path
SodaCanLab-
Sample Name
.csv
stop

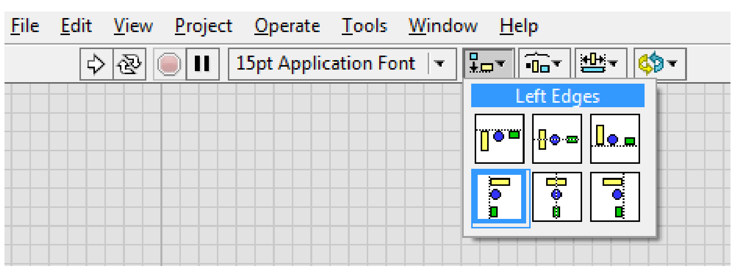
On *Front Panel*, right click on a blank location and access the *Controls Palette*, under *Express* menu find *Numeric Controls*, then select a *Num Ctrl* by left clicking. The control can also be found through *Search* tool in the *Controls Palette*. After selecting the icon, move the pointer to desired location and left click to position the control on front panel.



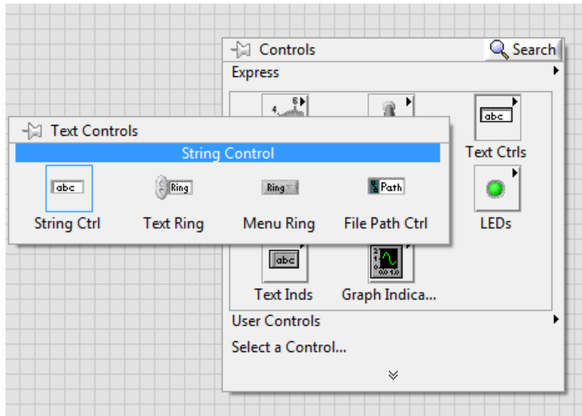

Then, click on the text above the control and edit the name of the control.




In the same way, create all the numeric controls needed for this program. The objects can be arranged with the tools on the top tool bar, alignment, distribution and resizing tools can be used on selected objects.




Add the String Control for Sample Name. The control is located at *Control Palette* ➔ *Express* ➔ *Text Controls*➔ *String Control*.



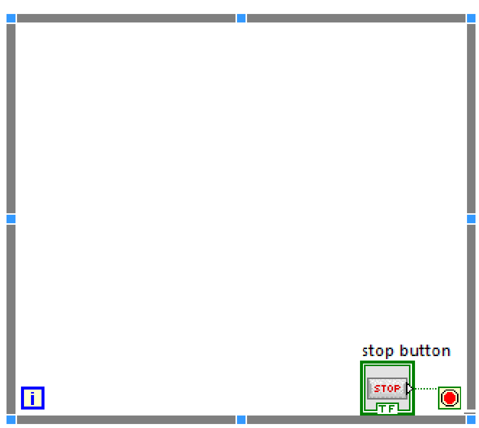

Add *Numeric Indicator* and *Waveform Graph* for Micro Strain readings. The path for *Numeric Indicator* is *Control Palette* ➔ *Express* ➔ *Numeric Indicators* ➔ *Numeric Indicator*. The path for *Waveform Graph* is *Control Palette* ➔ *Express* ➔ *Graph Indicators* ➔ *Graph*.

Add Path Indicator for Data File Location (*Control Palette* ➔ *Express* ➔ *Text Indicators* ➔*File Path Indicator*), *Text Button* for Enable Write to File (*Control Palette* ➔ *Express* ➔ *Buttons* ➔ *Text Button*), and *Stop Button* to end the program (*Control Palette* ➔ *Express* ➔ *Buttons* ➔ *Stop Button*).

After arranging the objects for a desirable layout, the front panel is completed.

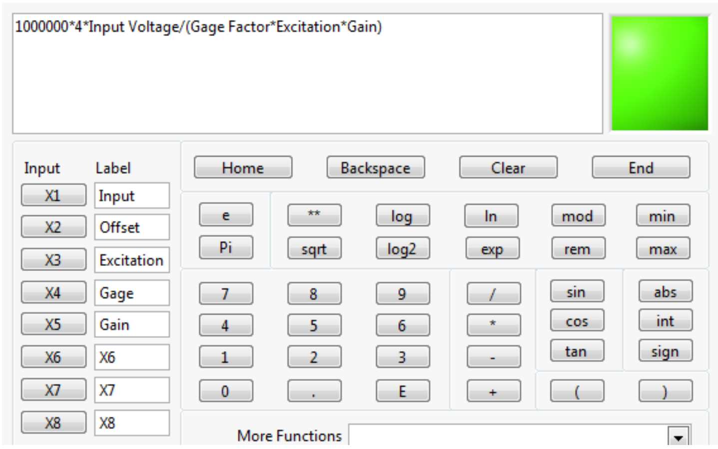
**Part 2: Building the Block Diagram**

Add a *While Loop* and connect the (already created) *Stop Button* with the *Loop Condition* icon. (*Functions Palette* ➔ *Programming* ➔ *Structures* ➔*While Loop*).

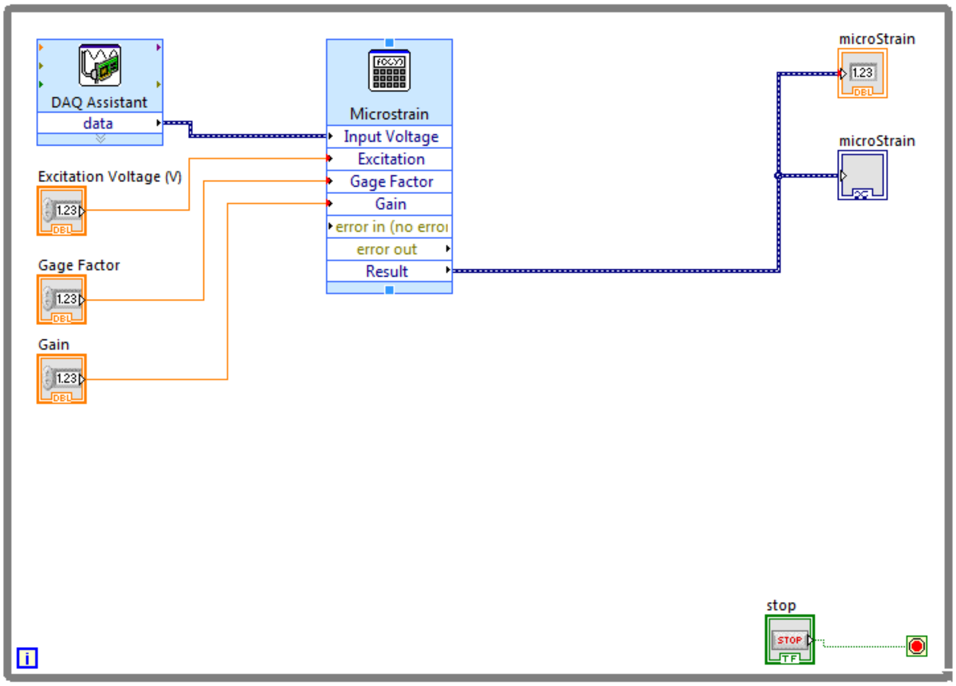


Add a *DAQ Assistant* in the *While Loop* and configure the subVI with the wizard. (*Functions Palette* ➔ *Measurement I/O* ➔ *NI DAQ mx* ➔ *DAQ Assistant*). For the measurement type, select *Acquire Signals* ➔ *Analog Input* ➔ *Voltage*. For the physical channel, select the channel of incoming signal. Since channel AI0 of NI 6229 is connected to the input, select this specific channel. Next, configure the channel settings: input -10V to 10V for input signal range, and *1 Sample (On Demand)* for acquisition mode. Note that the DAQ box needs to be connected to the computer and turned on before starting of LabVIEW program. Save the work and restart the program if the module fails to initialize.

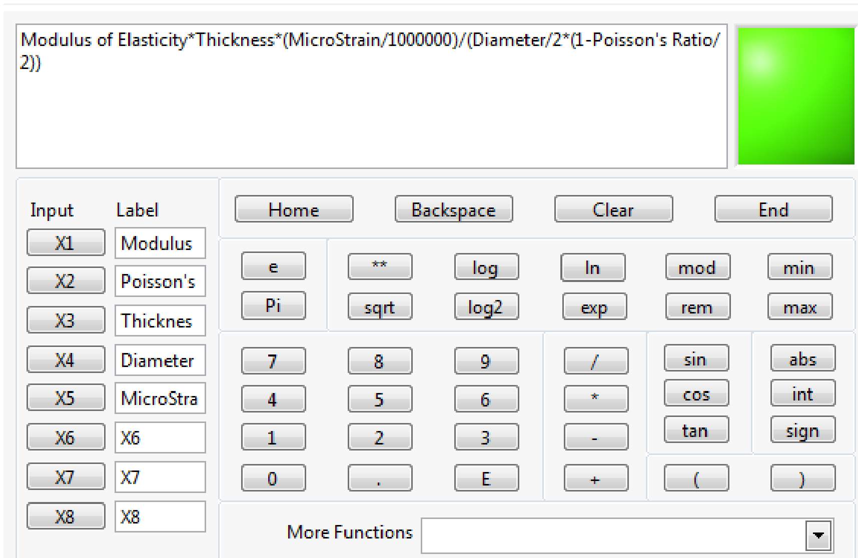

The next step is to transfer the input voltage signal to strain, in the unit of micro strain, and then display it in numerical and graphical form. Create a *Formula* (*Function Palette*➔ *Express*➔*Arithmetic & Comparison*➔*Formula*), set “Input Voltage”, “Excitation”, “Gage Factor” and “Gain” as input labels, then click “OK” to close the configuration wizard. Input the formula as shown in the figure below.

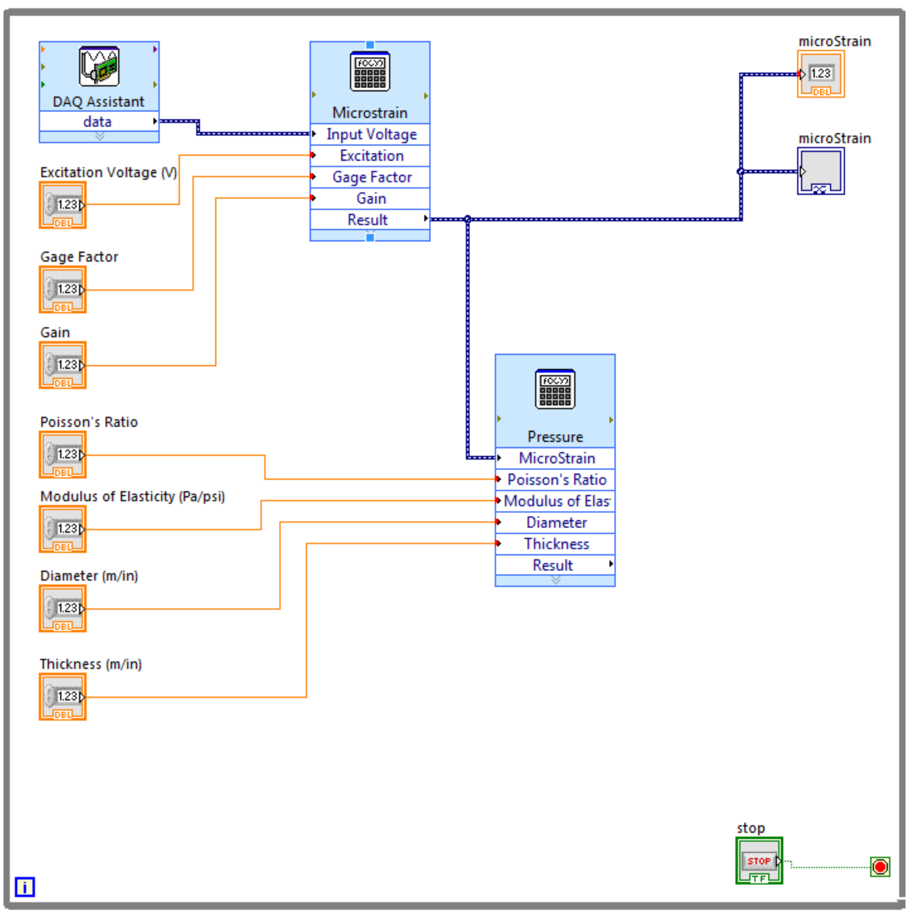


On the block diagram, drag down the arrow on the bottom of the *Formula* icon to expand the input/output menu. To change the order of the elements, right click on an element and select "select input/output", then click on the input/output desired for the position. Connect the *data* output of the *DAQ Assistant*, and the *Numerical Controls* for excitation voltage, gage factor and gain to the corresponding inputs of the *Formula*. Connect the *Numeric Control* and *Wave Graph* for micro strain to the *result* output of *Formula*. Then click on the text under the icon to change the label to "micro strain".

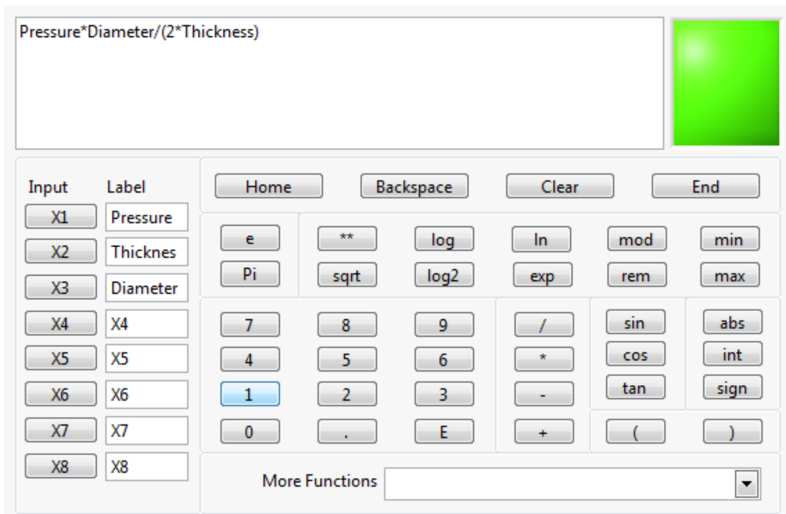


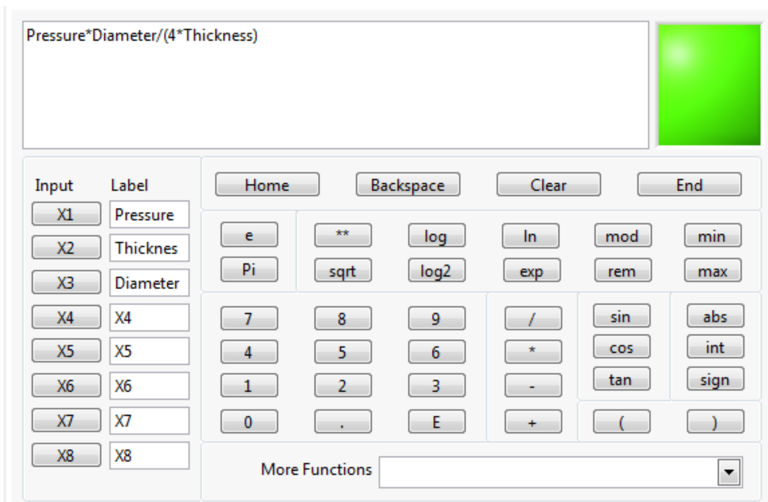

In similar ways, internal pressure can be calculated from strain and other properties of the can. Use *Formula* to calculate internal pressure based on micro strain results from previous *Formula*, inputs from *Numeric Controls* for material's modulus of elasticity, material's Poisson's ratio, thickness of the can wall, and diameter of the can. The formula is shown in the figure below.



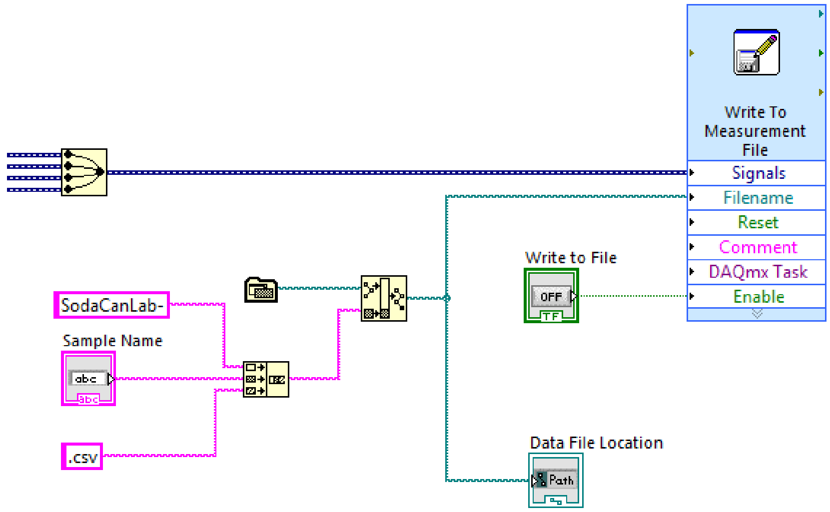




Calculated pressure, diameter and thickness are used to calculate circumferential stress and axial stress. The formulas are shown in the two figures below.

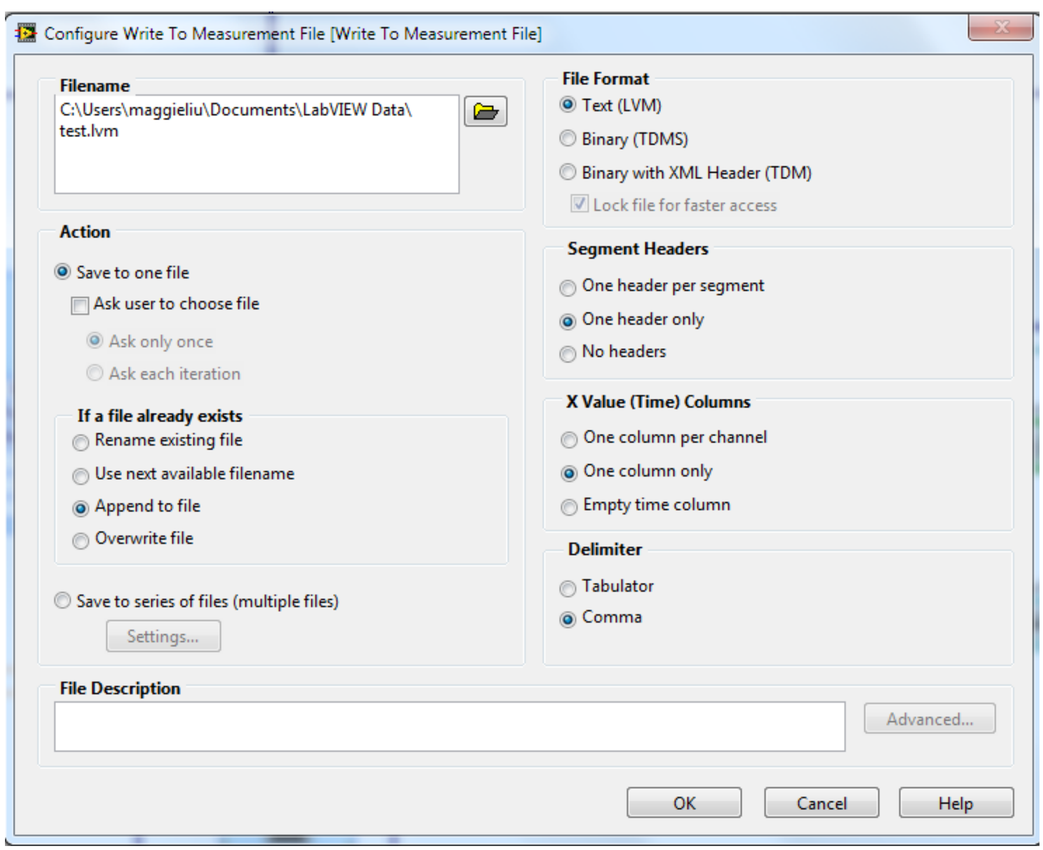


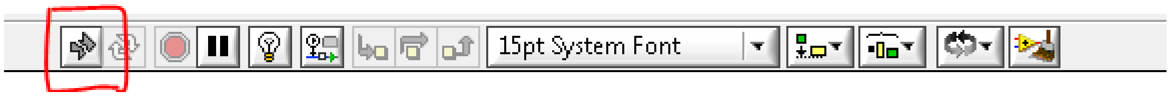

Dynamic data of micro strain, pressure, circumferential and axial stress are then combined with *Merge Signal* function and then written to file with a *Write to Measurement File* function. The merged signal should be connected to *Signal* Input of the *Write to Measurement File* function. The *Filename* can be constructed with *Build Path* function. It builds the file path with an *Application Directory* function, which points to the folder where the VI is saved, and a concatenated string (Use *Concatenate String* function in *String Palette*) which consists of the lab name, the user inputted sample name, and a ".csv" (comma separated values) as file extension, so that the data file can be opened with Microsoft Excel.

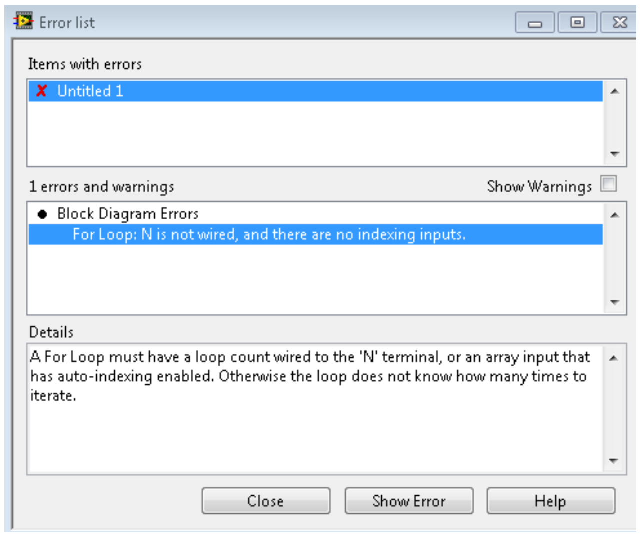



The *Write to Measurement File* should be configured as shown below. The filename in this wizard will be overwritten by the input; it should "save to one file"; the format should be text, with one header only or no headers; there should be only one time column; and the delimiter should be comma.



Now we have completed constructing the VI. If there is any error in the program, the run button will appear "broken" as shown in the figure below. Click on the button to view the error list, the "details" should explain the error. Debug until all errors are resolved; use other debugging functions on the menu bar if needed.




When the run button appears as a rightward arrow, enter appropriate parameters on the *Front Panel*, connect a BNC cable to AI0 of the DAQ device with two idle clips (this will provide some varied voltage inputs), and test run the program. Use *Edit*➔ *Make current values default* to save the entered parameters as default values. If there is no error interrupting the run, we can check the data file under the specified directory for satisfactory results. Trouble shoots until the program is ready for use.

Now the VI is ready for the Soda Can Laboratory. Can you make it better?

## Document 4: Optional Activities in this Laboratory

1. Create a shared data file for the class; consolidate measured internal pressure from all the students. What is the average and standard deviation of the measured value? What are some of the possible causes of these variations?
2. Before opening the can in this experiment, shake the can for 5 seconds, measure the change in internal pressure. What are the possible causes of the change?
3. Before opening the can, take two data recordings, one with the DAQ Assistants' input voltage range set to -10V to 10V, one with it set to -2V to 2V. Analyze the data and find out the resolution of each recording. Why are they different?
4. Read the user manual for the signal conditioner and change the gain setting. Compare the resolutions of strain readings and pressure readings under different gains.