WORCESTER POLYTECHNIC INSTITUTE
MECHANICAL ENGINEERING DEPARTMENT

Engineering Experimentation
ME-3901, D'2012

Laboratory #3: Part 3 of 3

General information

Office hours

Instructors: **Cosme Furlong**

Office: HL-151

Everyday:

9:00 to 9:50 am

Christopher Scarpino

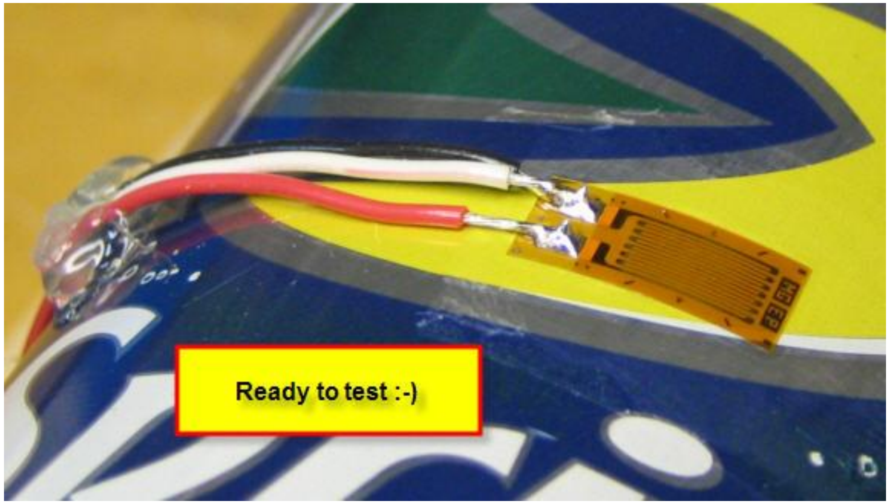
Office: HL-153

During laboratory sessions

Teaching Assistants: **During laboratory sessions**

General information

Please refer to handout:
"Laboratory 3: Strain Measurements"



(consider doing "screenshots" of the experiment for your report)

Hoop stress: $\sigma_{Hoop} = \frac{P \cdot r}{t}$

Longitudinal stress: $\sigma_{Long} = \frac{P \cdot r}{2t}$

Stress-strain relationship:

$$\varepsilon_{Hoop} = \frac{\sigma_{Hoop} - \nu \cdot \sigma_{Long}}{E}$$

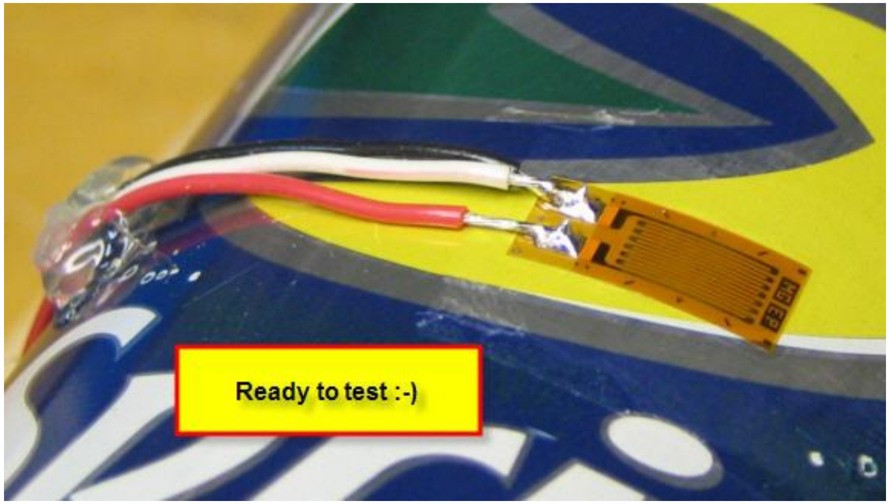
Internal pressure of "can":

$$P = \frac{E \cdot t}{\left[r \cdot \left(1 - \frac{\nu}{2} \right) \right]} \cdot \varepsilon_{Hoop}$$

General information

Please refer to handout:

"Laboratory 3: Strain Measurements"



(consider doing "screenshots" of the experiment for your report)

Make sure to:

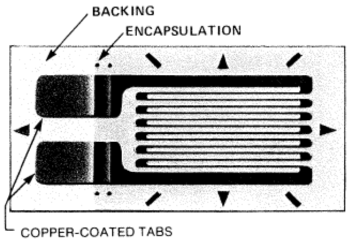
- Estimate maximum strain level to expect (use [30-50] psi as initial values). Are gain and excitation levels appropriate? What measurement resolution is expected?
- Start with a balanced bridge
- Verify output with shunt resistors
- Using shunt resistors, write data into file (are pressure and stress levels appropriate)?
- Do your tests

Strain gages

Definition of gage factor: $$F = \frac{dR/R}{\varepsilon_a}$$

(From lecture notes) $$\Rightarrow \quad F = 1 + 2\mu + \frac{1}{\varepsilon_a}\frac{d\rho}{\rho}$$

2D view of a strain gage



If <u>resistivity</u> does not change $$\Rightarrow \quad F = 1 + 2\mu$$

And strain with change of resistance is: $$\Rightarrow \quad \varepsilon_a = \frac{1}{F}\frac{\Delta R}{R}$$

A typical strain gage has a gage factor $\approx 2.095 \pm 0.5\%$.
Why? How is this possible? Open for discussions

Strain gages and a Wheatstone bridge

Recall from previous discussions:

(Changes in resistance & output voltage)

$$\frac{\Delta E_g}{E} \approx \frac{\Delta R_4}{4R} = \frac{\Delta R}{4R}$$

And strain with change of resistance is:

$$\Rightarrow \quad \varepsilon_a = \frac{1}{F}\frac{\Delta R}{R}$$

We want to recover strain from voltage measurements.
Combine previous equations:

$$\Rightarrow \quad \varepsilon_a = \frac{1}{F}\frac{4\Delta E_g}{E}$$

Strain gages and a Wheatstone bridge

We need to amplify output signal: **determine gain**

Re-write previous equation as:

$$\Delta E_g = \frac{F}{4} \cdot E \cdot \varepsilon_a$$

Assume the following values:
(based on an actual setup)

$$E = 10 \pm 0.005\,V$$

$$F = 2.095 \pm 0.5\%$$

Also, assume the measurement of only 1 μstrain (εμ):

$$\varepsilon_a = 1\,\mu\text{strain} = 1 \times 10^{-6}$$

Using these values leads to:

$$\Delta E_g = 5.238 \times 10^{-6}\,V$$

Is it possible to measure this voltage level in HL-031?
Open for discussions

Strain gages and a Wheatstone bridge
We need to amplify output signal: **determine gain**

Assume that measurement resolution of DAQ system is:
(please, update accordingly, while taking into account max./min. voltages allowed in the DAQs input)

$$1 \times 10^{-3}\,V$$

(i.e., 1 mV per 1 μstrain)

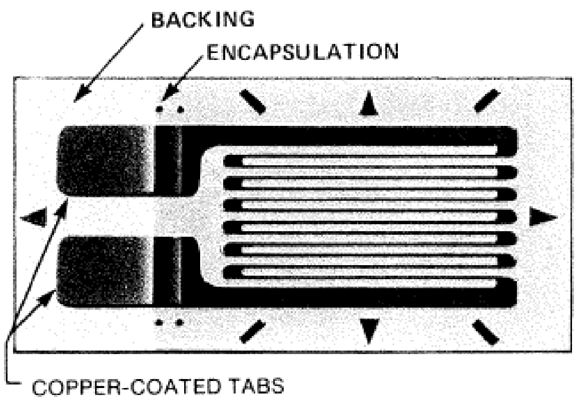
Gain for the output signal should be:

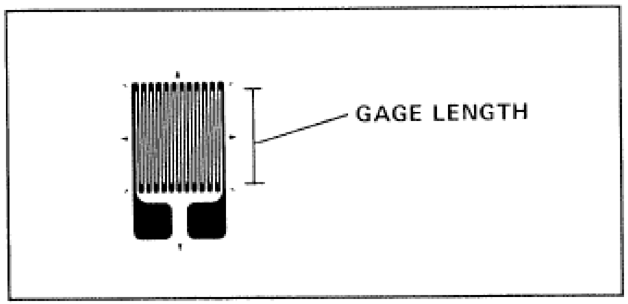
$$Gain = \frac{1 \times 10^{-3}\,V}{5.238 \times 10^{-6}\,V} \approx 191$$

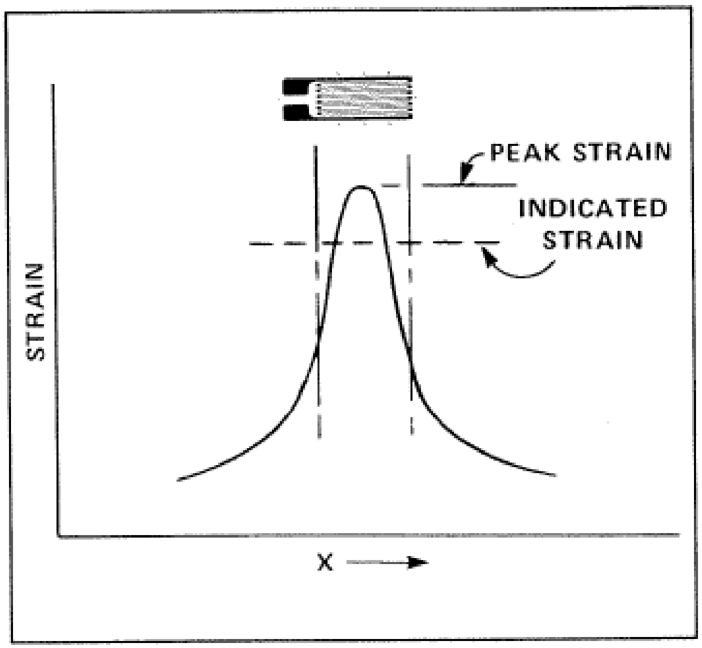
If we use full range resolution of DAQs in HL-031, what is the range of strain values that can be measured?

Open for discussions

Note on strain gages design (typical: 0.001" thick)







$$\text{Gage factor} = F = \frac{dR/R}{\varepsilon_x}$$

$$\text{Resistance} = R = \rho \frac{L}{A}$$

resistivity

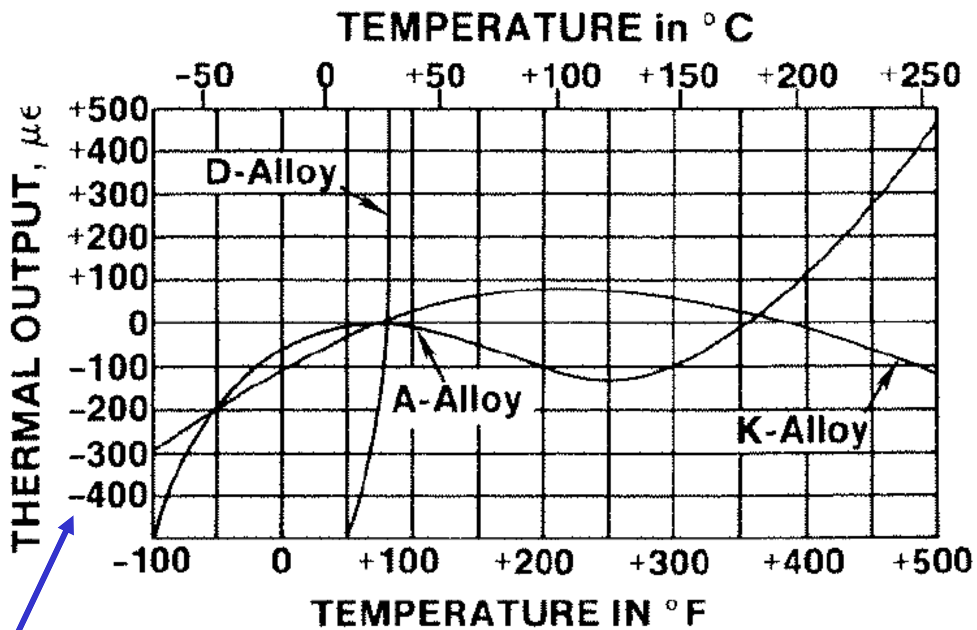
$$\varepsilon_x = \frac{1}{F}\frac{\Delta R}{R}$$

To be measured (use a bridge circuit)

Strain gage: temperature effects

Recall Lab #1: resistance as a function of temperature. **Open for discussions**

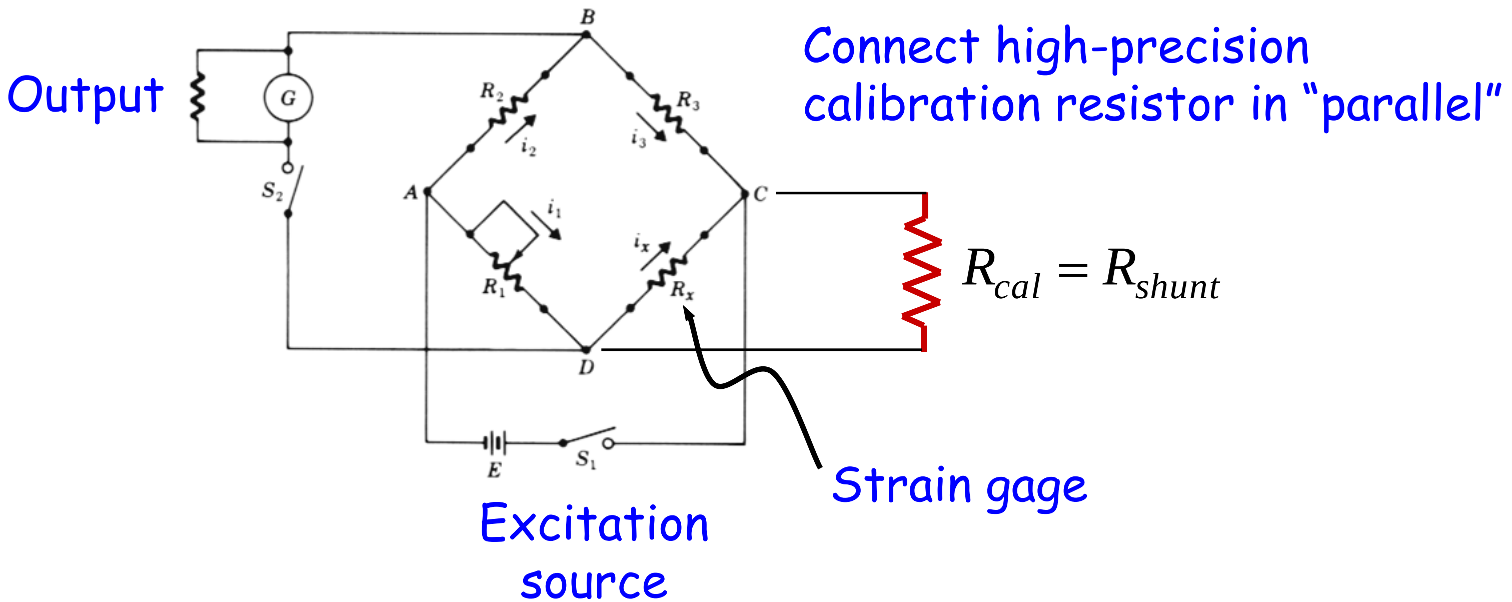
Note units



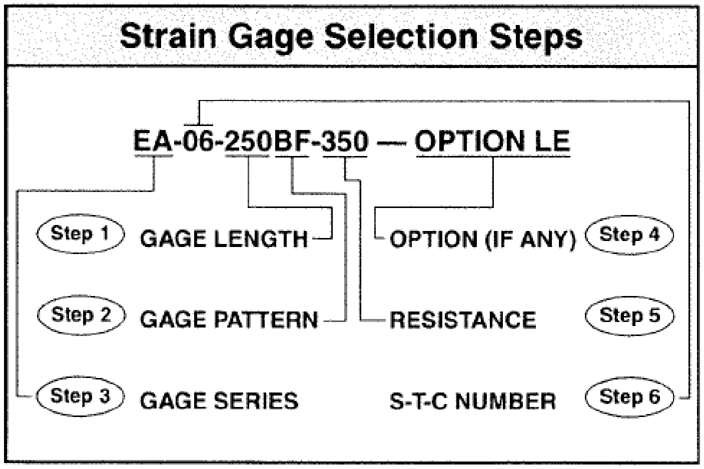
Note signs

Strain gages and a Wheatstone bridge: gain

Calibration by use of shunt resistors



Strain gage selection



CONSIDERATIONS FOR PARAMETER SELECTION

Selection Step: **1**
Parameter: **Gage Length**

- ☐ strain gradients
- ☐ area of maximum strain
- ☐ accuracy required
- ☐ static strain stability
- ☐ maximum elongation
- ☐ cyclic endurance
- ☐ heat dissipation
- ☐ space for installation
- ☐ ease of installation

Selection Step: **2**
Parameter: **Gage Pattern**

- ☐ strain gradients (in-plane and normal to surface)
- ☐ biaxiality of stress
- ☐ heat dissipation
- ☐ space for installation
- ☐ ease of installation
- ☐ gage resistance availability

Selection Step: **3**
Parameter: **Gage Series**

- ☐ type of strain measurement application (static, dynamic, post-yield, etc.)
- ☐ operating temperature
- ☐ test duration
- ☐ cyclic endurance
- ☐ accuracy required
- ☐ ease of installation

Selection Step: **4**
Parameter: **Options**

- ☐ type of measurement (static, dynamic, post-yield, etc.)
- ☐ installation environment — laboratory or field
- ☐ stability requirements
- ☐ soldering sensitivity of substrate (plastic, bone, etc.)
- ☐ space available for installation
- ☐ installation time constraints

Selection Step: **5**
Parameter: **Gage Resistance**

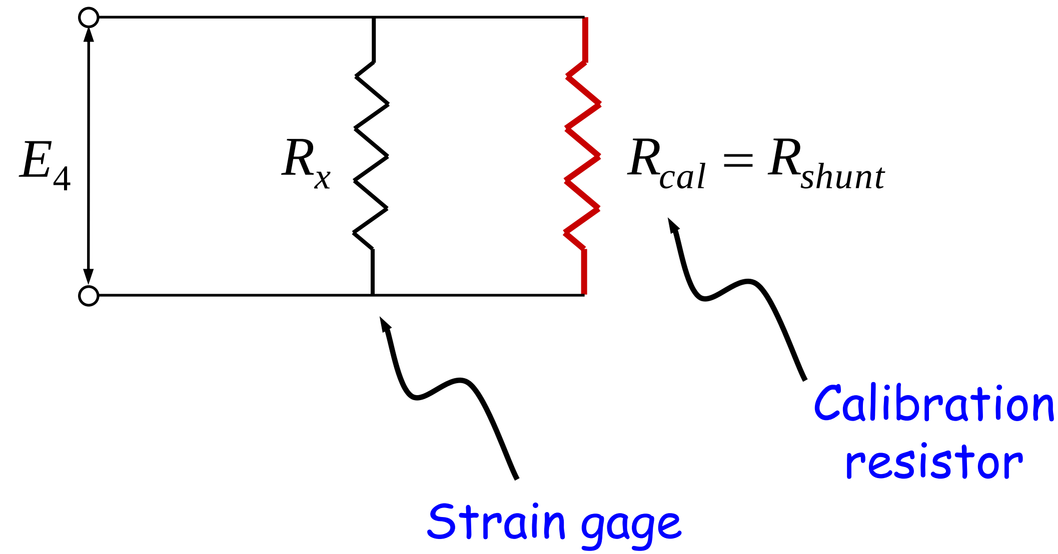
- ☐ heat dissipation
- ☐ leadwire desensitization
- ☐ signal-to-noise ratio

Selection Step: **6**
Parameter: **S-T-C Number**

- ☐ test specimen material
- ☐ operating temperature range
- ☐ accuracy required

Strain gages and a Wheatstone bridge: gain
Calibration by use of shunt resistors

Measuring arm of the bridge



Strain gages and a Wheatstone bridge: gain

Calibration by use of shunt resistors

Equivalent resistance

$$\frac{1}{R} = \frac{1}{R_x} + \frac{1}{R_{cal}} \quad \Rightarrow \quad R = \frac{R_x \cdot R_{cal}}{R_x + R_{cal}}$$

Strain gages and a Wheatstone bridge: gain

Calibration by use of shunt resistors

Change in resistance is

$$\Delta R = R - R_x = \frac{R_x \cdot R_{cal}}{R_x + R_{cal}} - R_x$$

$$= -\frac{R_x^2}{R_x + R_{cal}}$$

Strain gages and a Wheatstone bridge: gain

Calibration by use of shunt resistors

Using the definition of a gage factor:

$$\varepsilon_{cal} = \frac{\Delta R}{F\ R_x} \quad \Rightarrow \quad \varepsilon_{cal} = -\frac{R_x}{F\,(R_x + R_{cal})}$$

Indicates compression

Strain gages and a Wheatstone bridge: gain
Calibration by use of shunt resistors

Example

If: $R_{cal} = 878{,}000\ \Omega\,;\qquad R_x = 120\ \Omega$ with $F = 2.095$

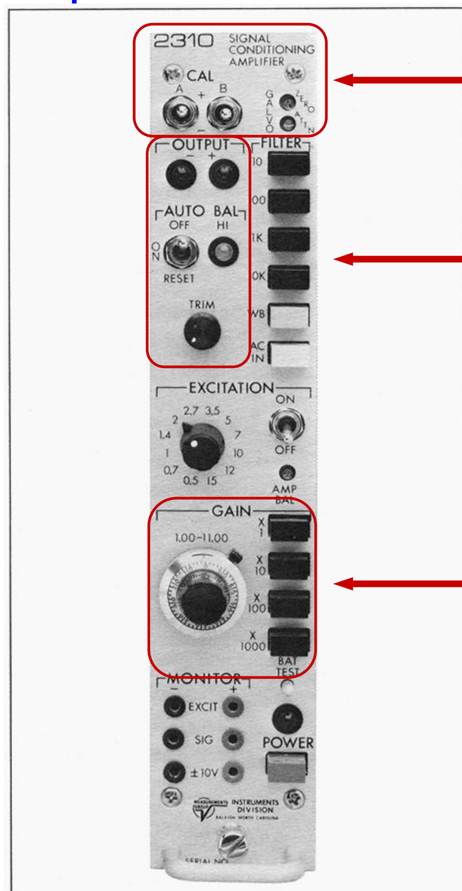
$$\Rightarrow\quad \varepsilon_{cal} = -\frac{R_x}{F\,(R_x + R_{cal})} = -\frac{120}{2.095(120 + 878{,}000)} = -65.2\times 10^{-6}$$

$$= -65.2\ \mu\text{strain (compression)}$$

Strain gages and a Wheatstone bridge

Calibration by use of shunt resistors

Amplifier model 2310



2310 Front Panel

Internal calibration resistors

Internal variable resistor (bridge calibration)

Gain (note resolution in gain settings)

Strain gages and a Wheatstone bridge
Calibration by use of shunt resistors

Amplifier model 2310 in ¼ bridge configuration

+ A: 59.94 kΩ ⇒ ≈ 954 μstrain

+ B: 174.8 kΩ ⇒ ≈ 328 μstrain

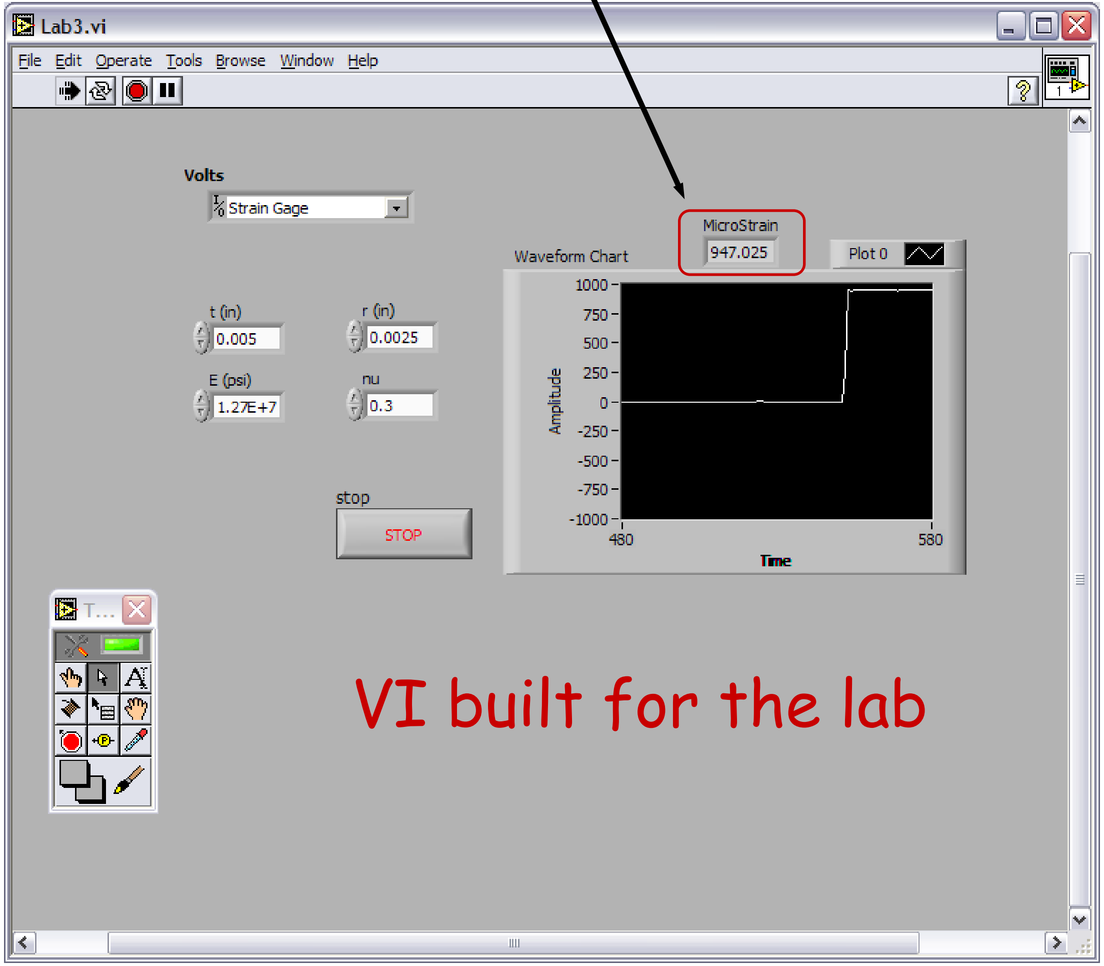
(Make sure to verify these results)

Check + + - and ε_{cal}

Strain gages and a Wheatstone bridge

Calibration by use of shunt resistors

+ A resistor

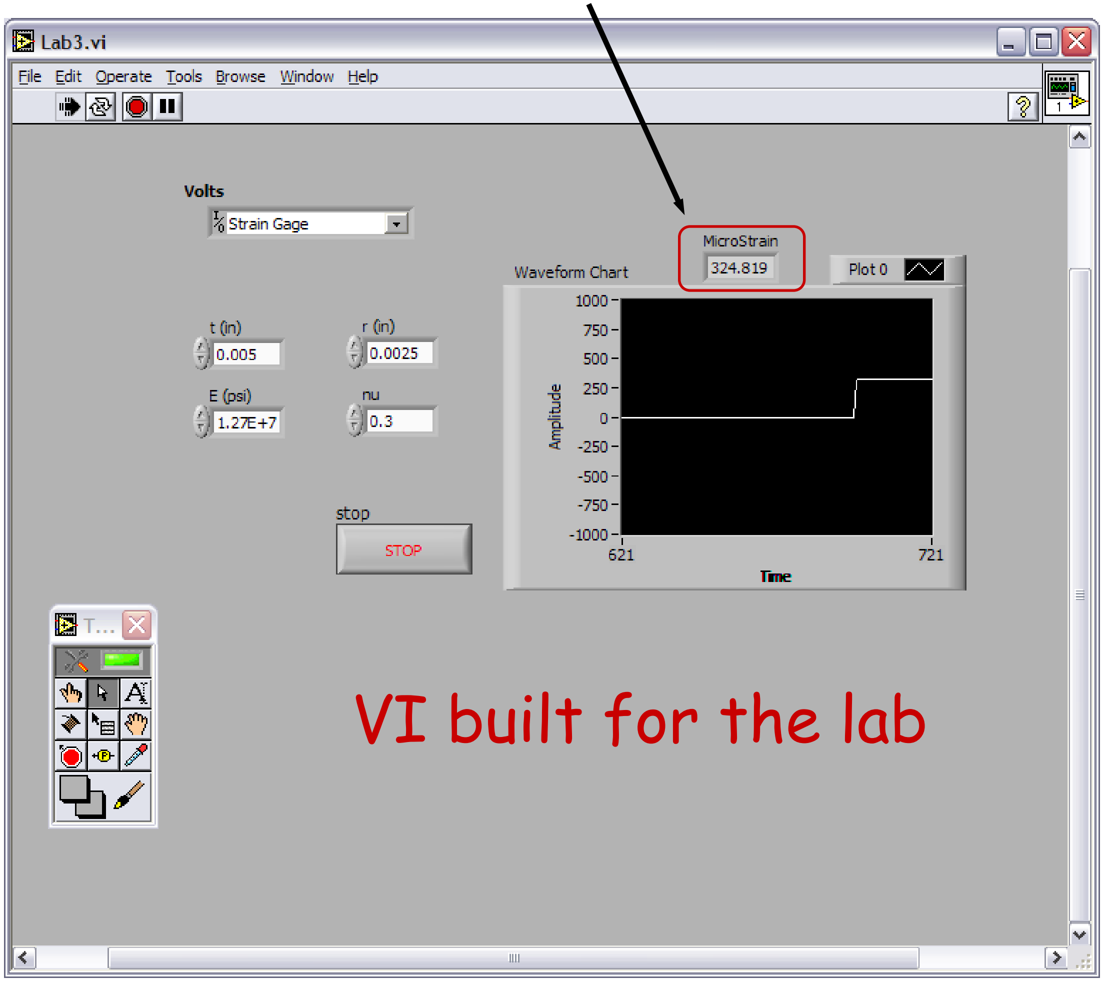


VI built for the lab

Strain gages and a Wheatstone bridge

Calibration by use of shunt resistors

+ B resistor



VI built for the lab

Finish lab

Do not forget to include RSS uncertainty analysis of your pressure measurements