Laboratory: Strain and Pressure Measurement
(Soda can experiment)

INTRODUCTION

The ASME boiler codes require continuous monitoring of pressure in thin walled pressure vessels. A thin walled cylinder has a wall thickness < r/10, with r being the radius of the cylinder. In this situation only the membrane stresses are considered and the stresses are assumed to be constant throughout the wall thickness, t.

Our product lines contain highly viscous fluids which have fowled mechanical and electrical pressure gages and transducers repeatedly. The viscous fluids experience dramatic fluctuations in temperature, and hence pressure, during the curing stage of the process. Unfortunately, the diaphragm within the mechanical pressure gages becomes encrusted with cured products within 10-15 cycles. Electrical pressure transducers have experienced similar problems. The man-hour effort to clean and/or replace the fowled gages has reduced the profit margin by 6%. Consequently, a new method of measuring pressure is required.

Consider a thin-walled pressure vessel as shown in Fig. 1.

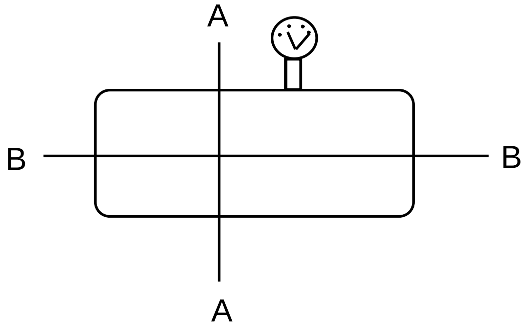


Figure 1: *Thin wall* cylinder schematic with cross sectional lines A---A and B---B indicated.

The hoop stress can be determined from a stress analysis of the tank's cross section, such as along line A--A of figure 1 and is shown in Fig. 2 [1-4],

$$\sigma_{\text{Hoop}} = \frac{Pr}{t} \tag{1}$$

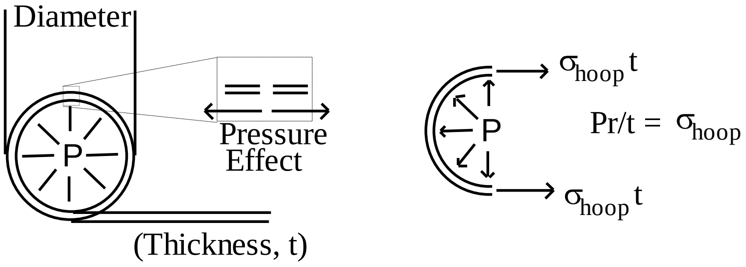


Figure 2: Cross section A--A showing that hoop wall stress must balance internal pressure.

Similarly, figure 3 illuminates the analysis methodology for determining the longitudinal stress (along cross section B---B of Figure 1).

$$\sigma_{Long} = \frac{Pr}{2t} \tag{2}$$

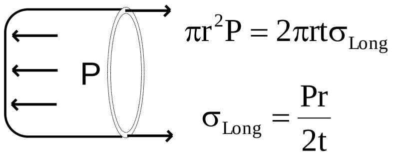


Figure 3: Cross section B--B showing that axial wall stress must balance internal pressure.

Recall that the strain is related to stress in this situation via:

$$\varepsilon_{\text{Hoop}} = (\sigma_{\text{Hoop}} - \nu\ \sigma_{\text{Long}})/E \tag{3}$$

which can be rearranged for pressure by substituting Eqs. 1 and 2 into 3:

$$P = E\ t\ \varepsilon_{\text{Hoop}} /[\ r\ (1 - \nu/2)]. \tag{4}$$

Using Eq. 4, a strain gage mounted in the **circumferential direction** will provide the greatest strain signal to measure the pressure.

PROCEDURE

Hardware Configuration: Your strain gage will be connected to an amplifier (Measurements Group Model 2310 Strain Gage Conditioning Amplifier). The amplifier will provide the circuitry to complete a 1/4-arm Wheatstone bridge, provide power input to the bridge, bridge balance, and signal amplification. You will compute the amplifier gain required to amplify the output of the Wheatstone Bridge so that you get 1 (One) mV/micro-strain.
(Volts/Engineering Unit = V/EU = 0.001 V/ 0.000 001 Strain = 1,000 Volts/Strain
Or 1 volt = 1,000 micro-strain)

LabVIEW VI. Configure the National Instruments hardware with the Measurements & Automation software to measure voltage. Create a VI to provide simultaneous readouts of :

1. Strain in units of [micro-strain]. The front panel should also have a graph of strain vs. time with a horizontal axis having a time span of about 10 seconds. **Fix** the vertical axis to cover a strain range from –2,000 to +2,000 micro-strain.
2. Pressure in the can [lb/in^2] (This is a computed value based upon the can geometry) Note that strain will be negative when the can is opened.
3. Hoop stress lb/in^2
4. Longitudinal stress lb/in^2

Values for the parameters in Eq. 4 (E, ν and t) should be inputs on the front panel of your VI. **Show Units with the labels. Set up the display to appropriate numeric formats.**

The output from the VI should include strain vs. time with at least 10 readings before and after the can is opened. In addition, values for thickness, diameter, Modulus and Poisson's ratio should be recorded. This represents raw data. The front panel displays of pressures and stresses are computed from the raw data.

Set the measurement rate of the VI so that at least 10 strain measurements are taken before and after each "event" and written to a text file. You will want the strain levels before and after opening the can recorded and saved to a file. Remember, it is the difference in strain that represents the pressure release.

Prepare **three** soda cans for the experiment. The goal is to get at least two good tests per group.

Measure the can dimensions. The diameter can be measured with a vernier caliper or by carefully measuring the circumference. The thickness can be measured with a micrometer by sacrificing one can and cutting it in half. The cans will be very close in thickness. Read and note the micrometer "zero" in order to correct the readings of the can thickness. Make all readings to ± 0.0001 inches (this is 1/10th of the finest division on the micrometer.) at eight (8) equally spaced locations around the circumference of the can. (Make sure you do this carefully and correctly. This dimension is the greatest source of error in the experiment.)

Mount a strain gage (T1 on the attached schematic) aligned with the ***circumferential*** direction on each of three unopened soda cans. Place the gage mid-way between the ends to avoid the influence of the end geometry. (See photos on the web for details.)

Prepare the three conductor strain gage wire (use about 3 ft of wire) by tinning the ends of the wires. Also tin the pads on the gage with a small dot of solder. Hot glue the wires in place prior to soldering to the gage to assure that they do not pull on the gage. Solder the wires to the gage using the three wire configuration. Black and white are the common wires. Next electrically check the gage installation with the instruments provided. This will verify (a) that the wiring is not shorted to ground and (b) that the gage resistance is within specification.

Connect the gage to the Measurements Group Model 2310 Strain Gage amplifier as a ¼ bridge, 3-wire connection, using a terminal strip to interface the strain gage wires to the amplifier cable. The wiring connections are provided with the attached data sheet.

Amplifier settings (modify to suit specific excitation source).

1. Compute and set your computed **GAIN** on the front panel of the amplifier using the combination multi-turn pot and the multiplier buttons. Note that the pot provides values from 1.00 to 11.00. It does not start at zero.
2. **EXCITATION**: Select **10 Volts** and turn **ON**.
3. **FILTER 10 (Hz)**
4. **AC IN** Button in **OUT** position.
5. **AUTO BAL** Momentarily Switch to **RESET,** release to **ON. Wait for about 5 seconds. If the yellow HI light is flashing you have connected the wiring wrong or there is a bad connection to the gage. Adjust the Trim knob to extinguish both LED's**. The output from the amplifier should now be very close to zero.

Calibrate the strain gage setup using an internal **CAL A+ and B+ switches.** Compute the strain simulated by these internal shunt resistors (A2 = 59.94 KΩ, and B2 = 174.8 KΩ; please verify these values) Check the attached schematic to determine how these are connected to the bridge. Do they simulate positive or negative strain?

Note the change in strain readout with and without these resistors switched on and off. If you computed the gain properly, the values should be very close. Make a final adjustment to the gain to agree with the computed strain.

Do an external shunt calibration check using a non-precision resistor R_{CAL}. Measure this resistor using the hp Multimeter. Will this simulate a positive or negative strain?

After the amplifier settings and strain calibration have been performed you now have the strain portion of the setup ready.

Next you must compute the values for the other readouts on the front panel prior to running a test. For initial checkout purposes use the following values:

Can thickness: Approximately 0.0042 inches. Determine corresponding uncertainty.
Can diameter: To be measured. Determine corresponding uncertainty.
Elastic Modulus: $10x10^6$ psi.
Poisson's ratio: 0.3

With the above inputs, use the A+ and B+ switches to see if the computed pressure and stresses match your hand calculations. It is also a convenient time to adjust digits and precision for the digital readouts.

Prior to the third meeting of this lab where the cans will be opened you must have all of the above finished and have looked up final values for material properties.

Look up the properties of the can material (aluminum modulus and Poisson’s ratio) in **at least three text books**. You are trying to establish a typical range of values in order to estimate the total error. Provide references for this information.

You are now ready to test. Do a mock test to coordinate the test sequence of one person running the computer and the other opening the can. Sort of like “start … open … stop”. Submit the pressure results to the instructor who will disseminate the information to all the groups.

Technical Results for the Report:

Can pressures that you measured. Average and standard deviation of all the tests.

An **error analysis of your results.** That is, determine the uncertainty in P. To compute this, assume the uncertainty in strain is +/- 3%. For the other parameters in the equation you will have to come up with your own determination. Refer to the lecture on this calculation.

Make sure to indicate, in order of importance, percentage contribution of all uncertainties to the overall uncertainty. Which parameters have to be more carefully characterized? Discuss your observations and justify them using engineering calculations.

REFERENCES:

1. J. Hall, *Laboratory 3: strain and pressure measurement*, Engineering Experimentation, Worcester Polytechnic Institute, C-Term, 2012
2. Baumeister, T. and L.S. Marks, “Standard Handbook for Mechanical Engineers”, Chapter 5, McGraw-Hill, 1967
3. R. L. Norton, *Machine Design*, 3th Ed., Prentice-Hall, 2006.
4. Measurements Group Model 2310 Strain Gage Conditioning Amplifier Manual.
5. Web site with strain formulas can be found at http://www.measurementsgroup.com/

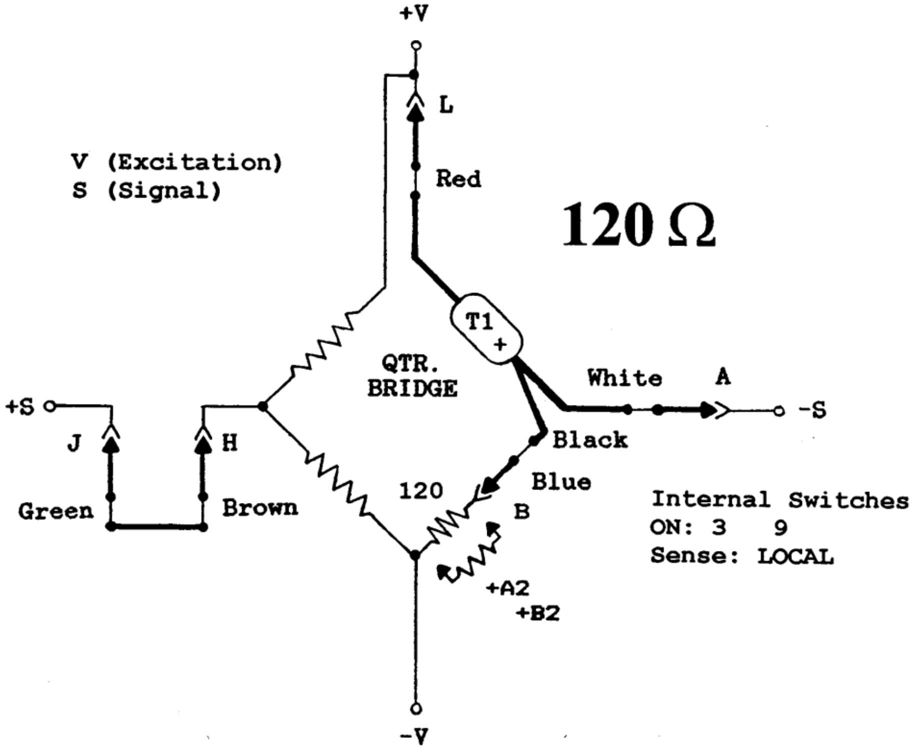
ATTACHMENTS:

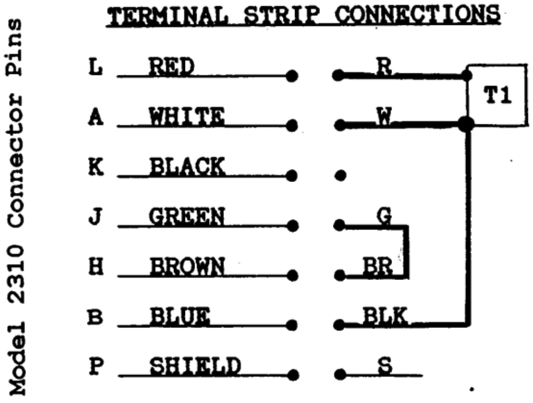
Schematic for Quarter Bridge wiring. 120 Ohms.
Model 2310 Strain Gage Amplifier information.
Strain Gage Photos. (See Web Page of Strain Manufacturers, Reference 5.)

ME 3901 Engineering Experimentation
Laboratory 3: Strain and Pressure Measurement

Measurements Group Model 2310 Strain Gage Amplifier

Quarter Bridge Schematic





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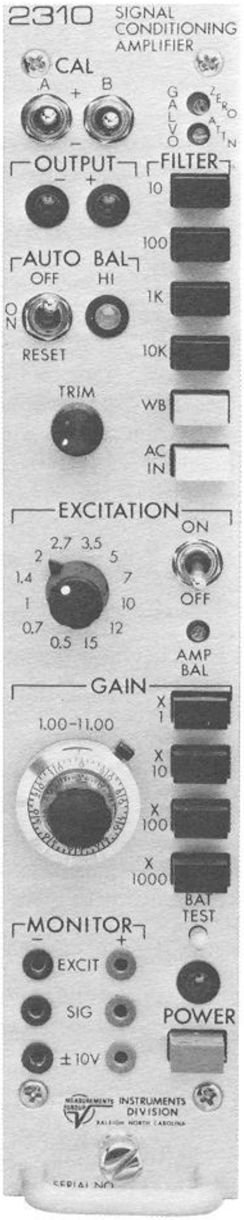
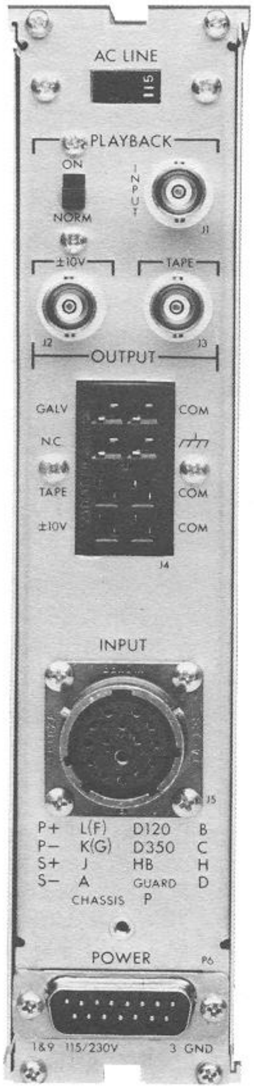


2310 Front Panel



2310 Rear Panel