REPORT
as a partial requirement for
the course on
ENGINEERING EXPERIMENTATION

DETERMINATION OF PRESSURE WITHIN A THIN WALLED CYLINDER
USING AN EXTERNALLY APPLIED STRAIN GAGE

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ABSTRACT:

        The ASME boiler codes requires continuous monitoring of pressure in thin walled pressure vessels. Unfortunately 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. A strain gage was mounted externally in the circumferential direction of a test pressure vessel to measure the hoop stress. The pressure within the vessel is directly related to the hoop stress. It was determined that the pressure was 52.3 psig +/- 12%. The external strain gage is insensitive to the fowling problems experienced with more traditional pressure measuring devices. This pressure monitoring system is recommended for our full product line.

INTRODUCTION:

        The ASME boiler codes requires 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.
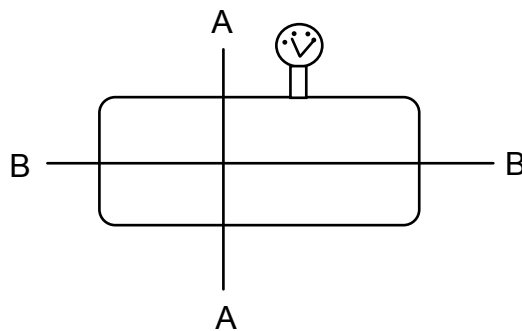

Figure 1: Thin wall cylinder schematic with cross sectional
lines A---A and B---B indicated.

The hoop stress can be determined from a stress analysis of the tank cross section, such as along line A--A of figure 1 and is shown in Fig. 2.[1]
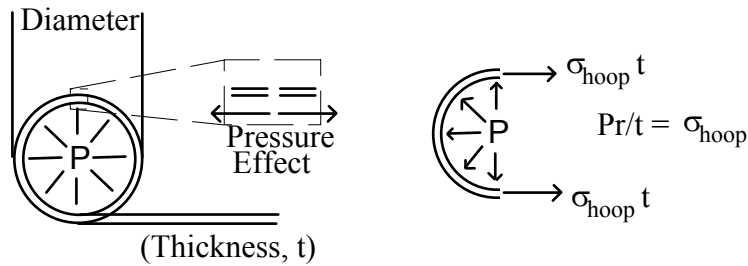
$$\sigma_{Hoop} = \frac{Pr}{t} \qquad (1)$$

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).

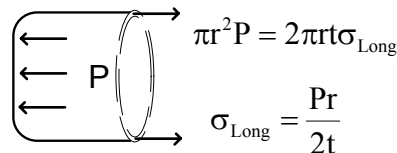$$\sigma_{Loop} = \frac{Pr}{2t} \qquad (2)$$

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:

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

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

$$P = E\, t\, \varepsilon\, /[\, r\, (1 - \nu/2)] \qquad (4)$$

where Poisson's ratio $v = 0.30$ and elastic modulus $E = 12.7 \times 10^6$ psi for our test pressure vessels. Consequently, a strain gage mounted externally in the circumferential direction of the vessel can be directly related to the pressure within the tank.

PROCEDURE:

A 120 Ω strain gage (R1) was mounted on the test pressure vessel (a 12 oz Diet Coke Can) while the soda can was unopened. The diameter of the can was measured with a vernier caliper. The vessel surface was prepared according to the specifications listed in the strain gage installation manual.[2] A second 120 Ω strain gage (R2) was mounted on a flat stock of aluminum which is used as the matching resistor in the strain circuit bridge. The NI Terminal module (1322) contained the other half of the bridge circuit shown in figure 4 (R3 and R4).
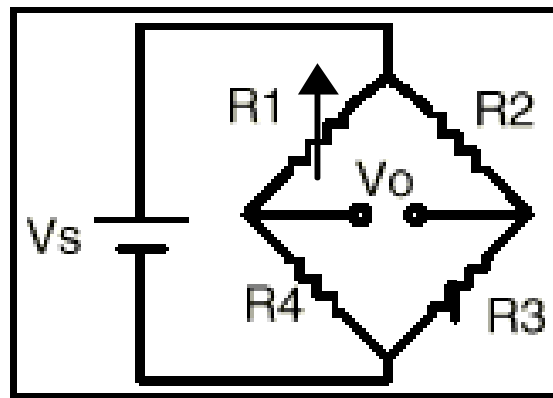

Figure 4: Wheatstone bridge configuration with R1 acting as strain gage.

The two strain gages were connected to the data acquisition system as shown in figure 5. Strain gage R1 used a 3 wire lead whereas the balancing resistor (R2) used a 2 wire lead configuration as shown in figure 5.[3]
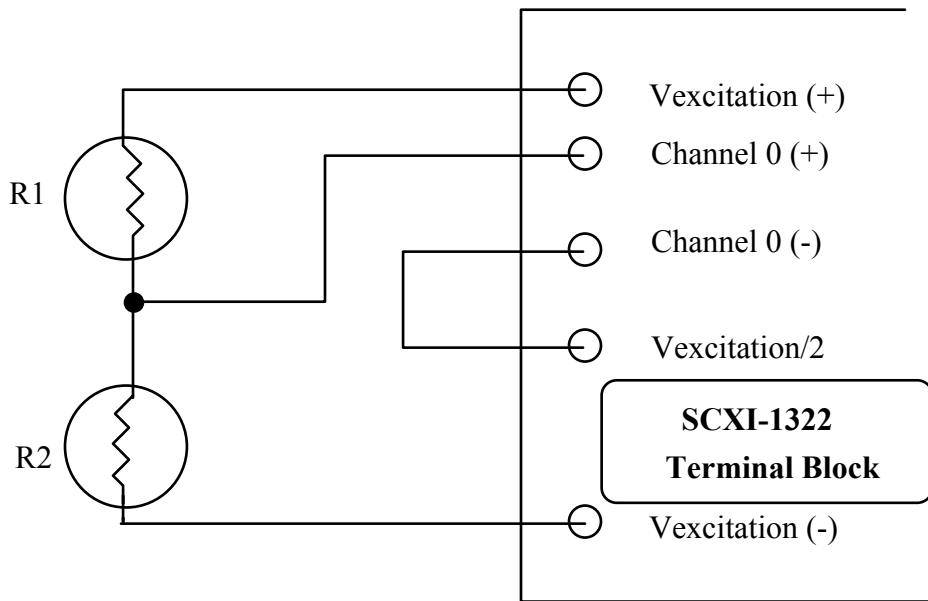
Figure 5: Connecting a Quarter-Bridge strain gage to channel 0.

A vi to measure strain was created (strain.vi) and its front panel is presented in figure 6. This virtual instrument had an internal potentiometer balance which was used to balance the bridge shown in figure 4 at the start of the experiment.
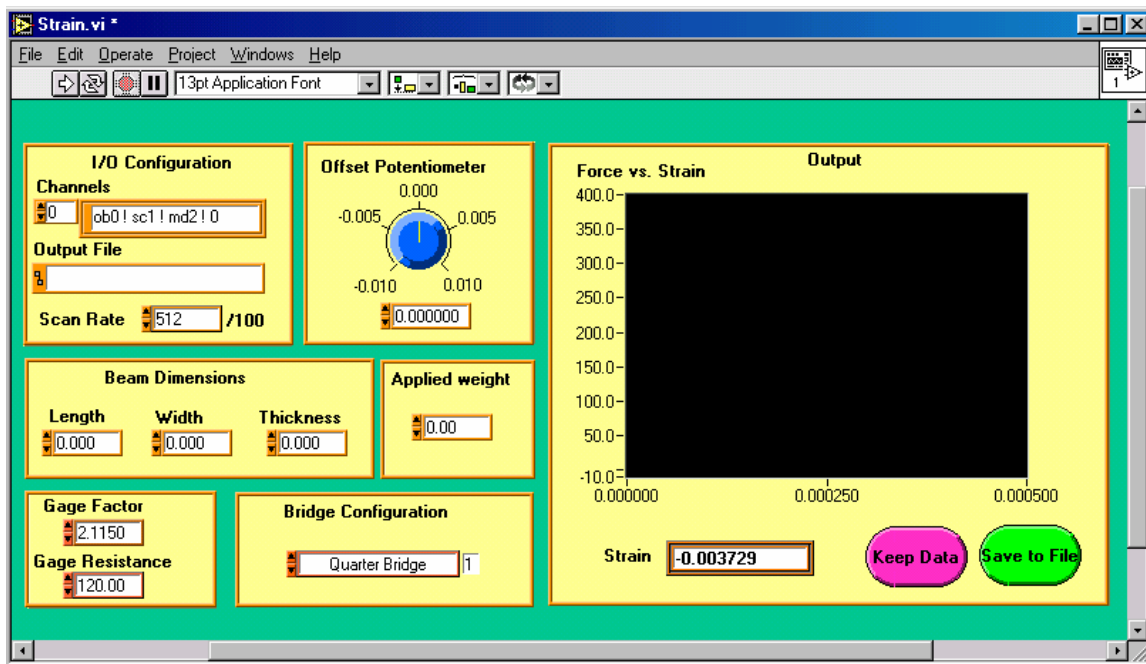

Figure 6: Strain.vi front panel showing required input parameters.

The programming logic of the potentiometer is shown in the diagram view of the VI in figure 7.

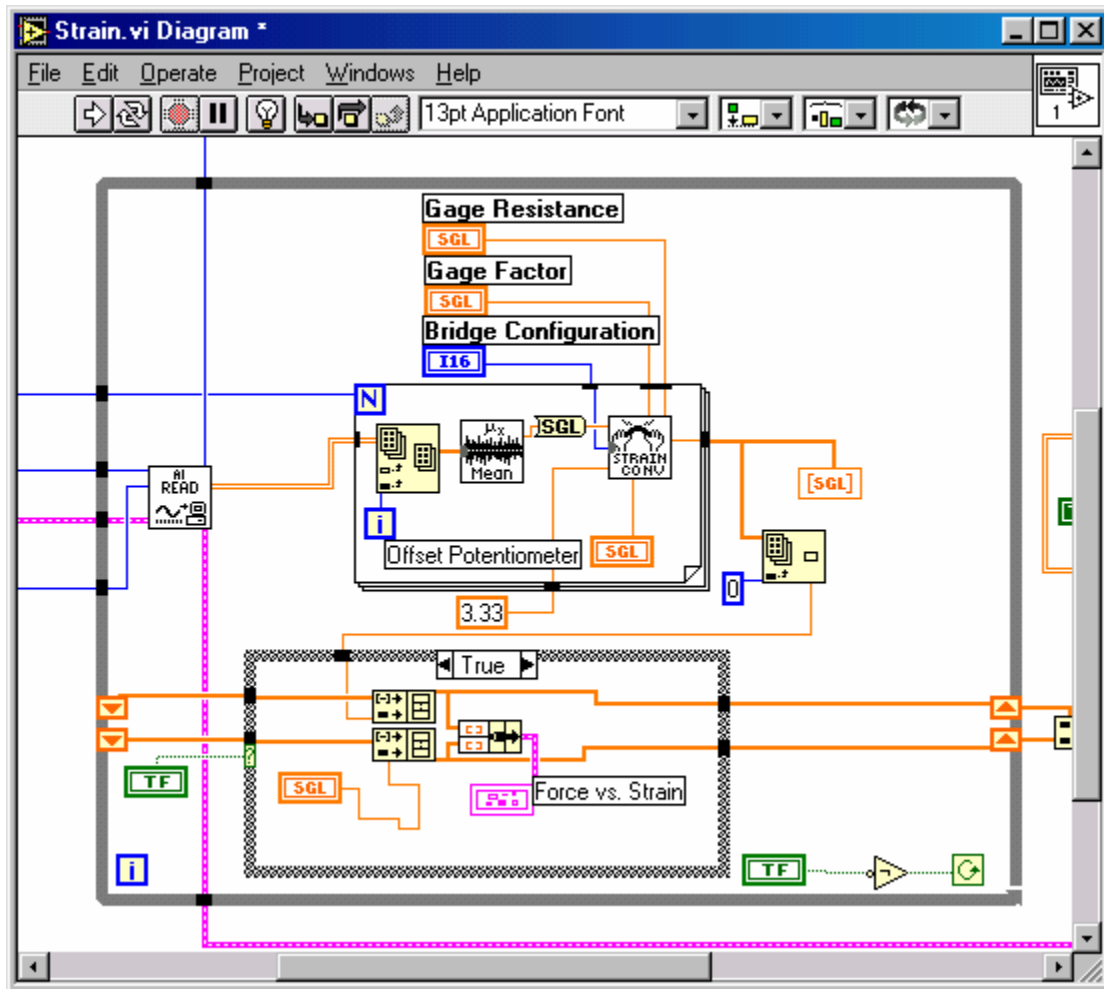Figure 7: Diagram view of strain.vi centered on the offset potentiometer configuration.

Once the unit was balanced, the flip top of the lid was released and the soda poured out of the container. The strain gage reading on the empty soda can was measured and reported. This procedure was repeated for 4 separate soda cans for statistical confidence.

Each can was cut in half and the wall thickness measured with a micrometer.

FACILITIES:

A 300 MHz Pentium II CPU with 64 Mbytes of RAM and 4 Gbyte hard drive.
LabVIEW version 5.0
NI DAQ Board: AT-MIO-16E-10
NI SCXI 1000:
NI SCXI 1122 module
NI SCXI 1322 terminal strip
Strain gages (R1 and R2): Measurements Groups EA-13-240LZ-120
Strain gage wire: 3 wire, 26 gage, Measurements Groups SS-0326-007.
Solder:
35 Watt Soldering iron:
Micrometer
Vernier caliper
Surface preparation material (emery cloth, glue, solvent cleaners and neutralizers)
12 oz soda cans, unopened

RESULTS:

The wall thickness of the soda cans averaged 0.004 in. +/- .0005 in. The soda can
diameter averaged 2.597 in +/- 0.001 in. The average strain recorded was 0.001137 in/in
+/- 3%. Statistical trials can be found in the Appendix.

The pressure was calculated based on Eq. 4

$$P = E \quad t \quad \varepsilon \quad / [\quad r \quad (1 - \nu/2)]$$
$$P = 12.7 \times 10^6 \ (0.004) \ .001137 \ / \ [2.597in/2)(1-.3/2)]$$
$$P = 52.3 \text{ psi}$$

 The corresponding hoop and longitudinal stresses in the test vessel were:

$$\sigma_{Hoop} = \frac{Pr}{t} = 16.99 \text{ ksi}$$

$$\sigma_{Loop} = \frac{Pr}{2t} = 8.49 \text{ ksi}$$

The uncertainty measurement in P is a function of the strain, radius measurement and wall thickness. Each measurement was done by independent means such that the uncertainty can be expressed as:

$$\omega_P = \sqrt{(\frac{\partial P}{\partial t}\omega_t)^2 + (\frac{\partial P}{\partial r}\omega_r)^2 + (\frac{\partial P}{\partial \varepsilon}\omega_\varepsilon)^2}$$

$$\omega_P = \sqrt{(\frac{P}{t}\omega_t)^2 + (\frac{-P}{r}\omega_r)^2 + (\frac{P}{\varepsilon}\omega_\varepsilon)^2}$$

$$\omega_P = P\sqrt{(\frac{1}{0.004}0.0005)^2 + (\frac{-1}{1.2985}0.001)^2 + (0.03)^2}$$

$$\frac{\omega_P}{P} = 12.86\%$$

This uncertainty is primarily a function of the error in the thickness measurement.

CONCLUSIONS:
 The external strain gage is completely insensitive to the fowling problems experienced with more traditional pressure measuring devices. This system is capable of continuous pressure monitoring. Replacement of the strain gages does not require any significant down time in the process. We recommend this system for all our product line pressure vessels.

REFERENCES:
1. Baumeister, T. and L.S. Marks, Standard Handbook for Mechanical Engineers",
        Chapter 5, McGraw-Hill, 1967.
2. Measurements Group Inc., "Student Manual for Strain Gage Technology", Bulletin
        309B, PO Box 27777, Raleigh, NC, 1983.
3. National Instruments, Getting Started with SCXI, Part No. 320515C-01, June 1996.

APPENDIX:

Wall thickness measurements using a micrometer accurate to +/- 0.0001 in.

Soda Can Thickness (in)	Trial				
	1	2	3	4	5
A	.004	.004	.0041	.0042	.0039
B	.0041	.004	.0042	.0039	.004
C	.0041	.004	.004	.0041	.004
D	.0041	.004	.0041	.0039	.004

Diameter measurements using a vernier caliber accurate to +/- 0.0002 in.

Soda Can Diameter (in)	Trial				
	1	2	3	4	5
A	2.597	2.596	2.597	2.598	2.597
B	2.599	2.599	2.600	2.598	2.599
C	2.597	2.597	2.596	2.596	2.597
D	2.600	2.599	2.600	2.598	2.599

Strain recorded after emptying the soda cans

A	0.001137 in/in
B	0.001142 in/in
C	0.001140 in/in
D	0.001135 in/in