SODA CAN MYTHBUSTING

Joseph F Dues, Jr.
jdues@purdue.edu
Purdue University
College of Technology at New Albany

ABSTRACT

Examining the mechanics of a soda can is an exciting way to get students interested in strength of materials by relating classroom concepts to everyday objects. A soda can containing a carbonated drink is a thin wall pressure vessel. The geometry of the soda can is optimized to minimize the amount of aluminum required. The wall thickness is very thin and is subject to an appreciable amount of stress and strain. By mounting a strain gage to the can, and then relieving the stress by opening the can, the change in strain from the pressurized to unpressurized condition can easily be measured. This change in strain can be used to calculate the level of stress in the can before it was opened as well as the original pressure of the soda.

This lab was planned as an informal experiment and once the principle concepts had been investigated; the students were encouraged to try their own tests with the can. Initially, they shook the can to observe the pressure rise associated with the agitation. They quickly then began sharing and testing methods for preventing or reducing the explosion when a shaken soda is opened. The students then tried a series of pressure reducing tests they labeled "MythBusters" in the spirit of TV shows and internet sites that attempt to expose urban legends.

Given the opportunity to do their own experimenting, the students were much more enthusiastic about the lab. By testing their own theories for reducing the pressure in the soda can, they could clearly show if their method for preventing the explosion of a dropped can had any effect. This resulted in the students continuing to experiment long after they had fulfilled the required tasks of the lab experiment.

I. INTRODUCTION

This lab exercise has two purposes; to expose the students to the topics of stress and strain with a familiar object and to provide the students with an opportunity to devise and implement their own experiments.

Strain can be hard to visualize for the beginning engineering student since it typically is so small in metallic structures. One method of reinforcing the idea that strained structures surround our everyday life is to investigate the strain to which a soda can is subjected. Due to the optimization of the amount of material used to make the can, this strain turns out to be rather significant. Measurements Group, a division of Vishay, manufactures strain gages and has published a series of experiments using strain gages on soda cans. Their first experiment simply determines the internal pressure in the soda can by measuring the change in strain in the soda can as it is opened [1]. This experiment has been used to introduce freshman to engineering concepts [2] as well as a component of a capstone course in experimental concepts for engineering seniors [3]. Measurements Group has also used the soda can experiment to investigate failure modes of a soda can [4] and to analyze modern soda cans that are a 30-sided polygon instead of a perfect cylinder [5]. Thus the first task in this experiment is to measure the strains found in a soda can. The second purpose of the experiment is to encourage the students to design their own experiments. To do this, the students were instructed to try some "MythBusting" – to demonstrate whether some popular methods for preventing a shaken can from exploding actually worked. "MythBusters" is a TV series on the Discovery Channel that uses science and experiments to demonstrate if common myths are true or false. The myths or "urban legends" are usually stories or scenarios that are plausible and familiar but not necessarily based on facts or true events. The students were asked to adopt the premise of the show and investigated methods to reduce the pressure in a shaken can to prevent it from exploding when opened.

II. LABORATORY SETUP

Equipment and Supplies

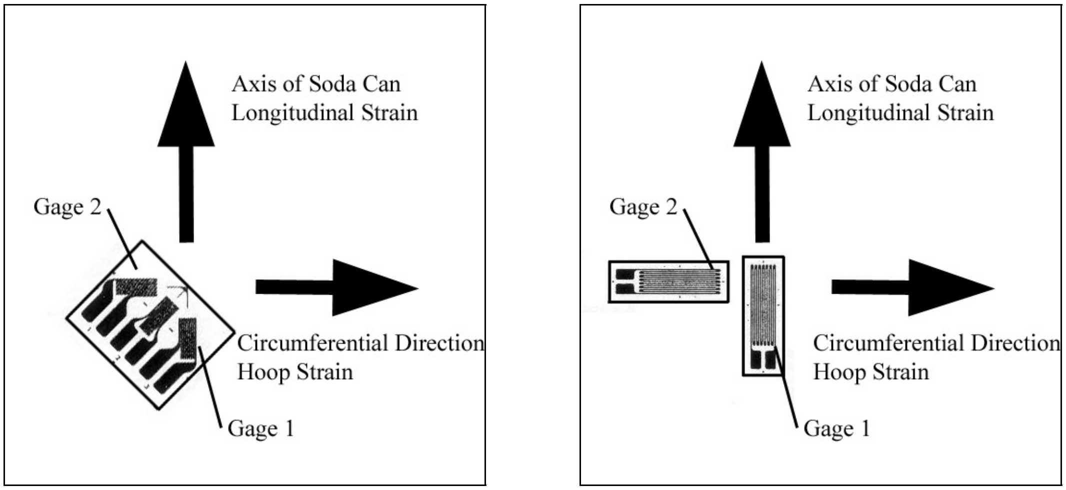
- Soda Can
- Rosette Strain Gage or two Uniaxial Strain Gages
- Measurement Group P-3500 Strain Indicator or similar
- Measurement Group Strain Gage Switch Box
- Strain Gage Mounting Supplies – Glue, etc.
- Strain Gage Lead Wires

Experimental Steps

1. <u>Prepare for mounting the strain gage(s)</u>. The gage or gages should be mounted near the middle of the can. Ideally orient a rosette gage so that one element is oriented axially and one element is oriented circumferentially. This gage orientation is shown in Figure 1 and will result in the simplest calculations. Alternatively, the rosette gage can be mounted in an arbitrary direction as shown in Figure 2 and an additional calculation of the principal strains can be made. By performing the addition calculations of the principal stresses, precise alignment of the rosette gage is not required. If using two uniaxial gages, then you must mount one gage axially and one gage circumferentially as also shown in Figure 1.
2. <u>Clean Can</u>. Remove the surface coatings to reveal the bare aluminum. The can wall is extremely thin, so for most accurate results, be careful not to remove too much of the aluminum wall. Using a very fine grit carbide strip will help

minimize the amount of material removed. Following the recommendations of the glue manufacturer, clean, etch and neutralize the aluminum surface.

3. Glue strain gage to can. Carefully orient the gage and glue the gage in place following the procedure recommended by the glue manufacturer. Usually a catalyst is used to speed curing of the glue as well as pressure and heat from the experimenter's finger.
4. Solder lead wires to gage. Carefully solder lead wires to each gage. Attach both the black wire and the white wire to one solder tab of each gage and the red wire to the other solder tab. Figure 3 shows the wires for each gage that are needed to connect to the strain indicator circuits. When using rosette gages, if the rosette has been carefully aligned such that the #1 element is parallel to the axis of the can, then only the #1 and #2 strain indicator circuits are needed. If the rosette is located in an arbitrary direction, then all three strain indicator circuits are needed in order to calculate the principal stresses.
5. Connect wires to strain indicator and balance the system. Use the wiring diagram from the strain indicator to attach leads from each gage as shown in Figure 3 to a switch box or individual strain indicator. The switch box allows the attachment of all the gages to a single strain indicator and then the sequential reading of each gage. Alternatively, if sufficient strain indicators are available, each leg of the rosette (or each uniaxial gage) can be attached to a separate strain indicator for simultaneous readings of the strain in each gage. Figure 4 shows separate strain indicators; one for the longitudinal strain and one for the circumferential strain. Balance the system so that each strain indicator displays zero strain.
6. MythBusters - Experiment with increasing and decreasing pressure in can. Shake the can to increase the pressure and observe and record the resulting increase in strain. Experiment with methods to reduce the pressure (i.e. tapping on can, etc.) by observing the increase or decrease in strain. Record your observations.
7. Measure strains due to original pressure. After letting the can sit for at least 15 minutes after shaking, or using a can that hasn't been shaken, balance the strain indicator back to zero and then open the can to release the pressure. Observe and record the resulting negative strain.



Rosette Strain Gage 2 Uniaxial Strain Gages

Figure 1 – Possible Gage orientations for direct measurement of longitudinal and circumferential strain. Gage 1 measures longitudinal strain, Gage 2 measures hoop strain.

Figure 2 – Rosette strain gage mounted on a soda can with an arbitrary alignment. Principal strains must be calculated to determine the hoop and longitudinal strains.

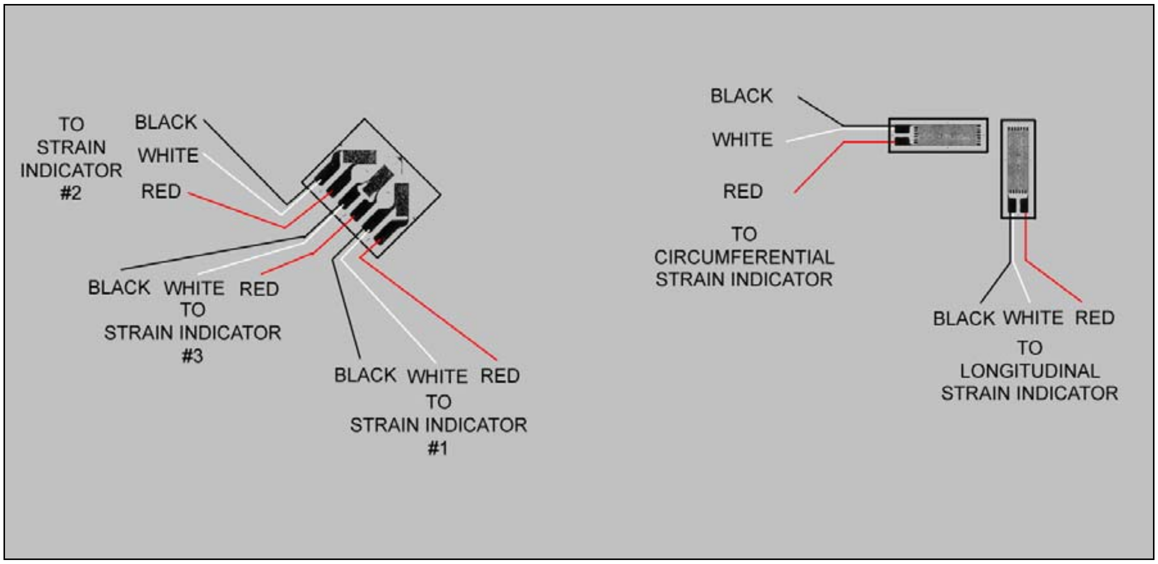


Figure 3 – Rosette strain gage and uniaxial strain gage wiring diagrams.

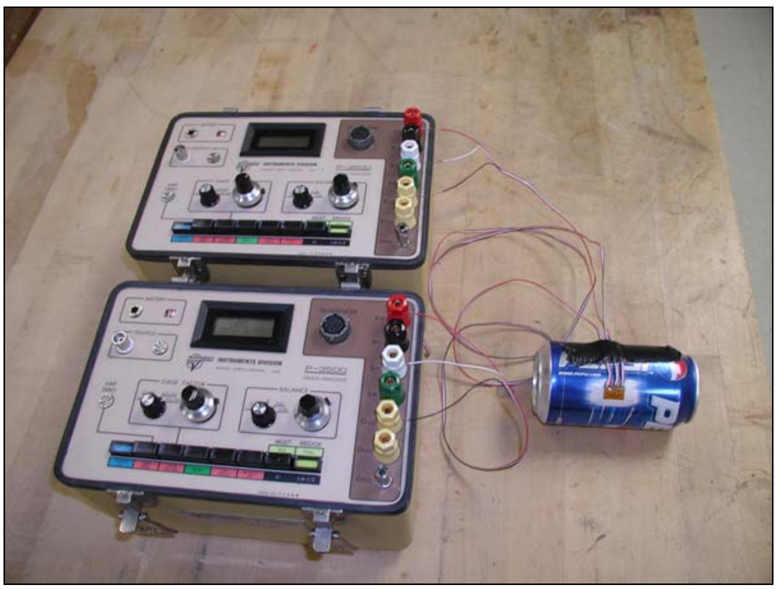


Figure 4 – Strain Gage connected to strain indicator and ready for testing.

III. THEORY

The soda can is analyzed as a thin wall pressure vessel. In a thin wall pressure vessel, two significant stresses exist: the longitudinal stress and the hoop stress. The longitudinal stress is a result of the internal pressure acting on the ends of the cylinder and stretching the length of the cylinder as shown in Figure 5. The hoop stress is the result of the radial action of the internal pressure that tends to increase the circumference of the can. Figure 6 illustrates the direction of the hoop stress [1].

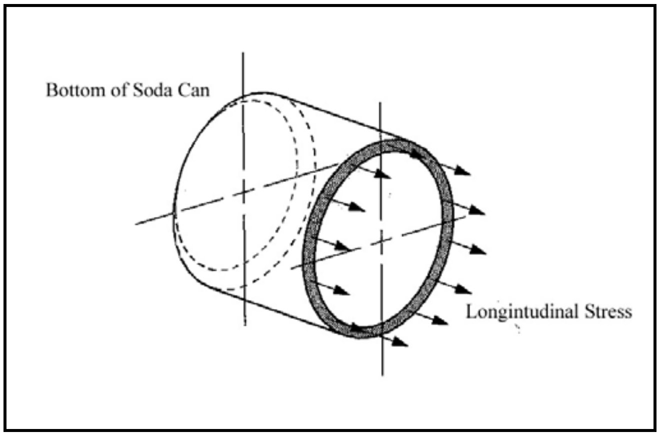


Figure 5 – Longitudinal Stress.

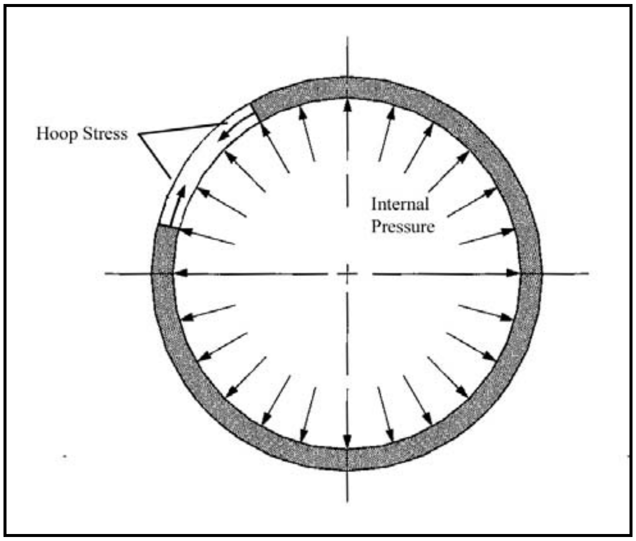


Figure 6 – Hoop Stress.

The longitudinal stress in a thin walled cylinder can be calculated from:

$$\sigma_L = \frac{pD}{4t} \qquad (1)$$

where:

p – internal pressure (psi)
D – mean diameter of cylinder (in.)
t – wall thickness (in.)

Likewise, the hoop stress for the thin walled cylinder is calculated from:

$$\sigma_H = \frac{pD}{2t} \qquad (2)$$

using the same variables.

This means that:

$$\sigma_H = 2\sigma_L \tag{3}$$

Assuming that:

- The material is homogeneous and isotropic,
- The can is loaded only within its elastic range,
- A biaxial state of stress exists in the can,

Then Hooke's law states that stress in the can is proportional to the strain. For a biaxial state of stress, this proportionality can be expressed as:

$$\sigma_L = \frac{E(\varepsilon_L + \nu\varepsilon_H)}{(1-\nu^2)} \tag{5}$$

And

$$\sigma_H = \frac{E(\varepsilon_H + \nu\varepsilon_L)}{(1-\nu^2)} \tag{6}$$

where:

E – modulus of elasticity or Young's modulus (psi)
ν – Poisson's ratio
ε_H – hoop strain (in./in.)
ε_L – longitudinal strain (in./in.)

Using equations 5 and 6 with equation 3, and simplifying results in:

$$\sigma_L = \frac{E(\varepsilon_H)}{(2-\nu)} \tag{7}$$

And

$$\sigma_H = \frac{E(\varepsilon_L)}{(1-2\nu)} \tag{8}$$

Thus the pressure can be calculated directly from the measured strains by substituting equations 7 and 8 back into equation 1 to get:

$$p = \frac{4tE\varepsilon_H}{D(2-\nu)} \tag{9}$$

And

$$p = \frac{4tE\varepsilon_L}{D(1-2\nu)} \tag{10}$$

Once we have equations 9 and 10, then the internal pressure in the can may be directly calculated from the measured longitudinal and hoop strains.

IV. MYTHBUSTING

A shaken can will explode when opened because the shaking of the can causes some of the dissolved carbon dioxide to come out of the liquid solution and form gas bubbles on the interior of the soda can. This increases the pressure in the can. When the can is opened, the gas rushes to the opening to escape to the lower pressure surroundings and takes along some of the liquid with it. This results in foam spraying from the can opening.

To prevent an explosive spray, one of two things needs to happen. Either the gas must go back into solution thus reducing the pressure and the tendency to explode, or the gas must be concentrated at the end of the soda can to be opened so that only the gas rushes out and not the liquid. Obviously, monitoring the pressure in the can is only a judge of the relative amount of gas in solution and not a measure of the location of the gas that is not in solution. Thus this experiment is a good judge of methods to reduce the pressure in the soda cans but not necessarily a good judge of whether there will be a foam explosion when a shaken can is opened.

The results reported here are for Pepsi soda cans at room temperature. Rosette gages were mounted near the midpoint of the cans. Figure 2 shows a gage oriented with the #1 element at 45 degrees to the axis of the can and the #2 gage in the hoop direction. Since a gage was not oriented in the longitudinal direction, the principal strains were calculated and used to determine the longitudinal and hoop strain.

The three most common experiments the students performed are discussed here. Before testing each myth, the students shook each can for 5 seconds. Shaking the can had the effect increasing internal pressure 10% to 20% above the pressure calculated once the can was opened.

<u>Myth 1 – Tapping on Top of Can</u>

The first myth experiment was to tap on the top surface of the can for 5 seconds after shaking the can for 5 seconds. Table 1 shows the change in strain measured by students when testing the effects of tapping on the top of the can.

Table 1. Strain effects of tapping on top of can.

Group	Strain Direction	Strain (x 10^{-6} in/in) After Shaking 5 sec	Strain (x 10^{-6} in/in) After Tapping 5 sec	% Reduction
1	Longitudal	42	40	-5%
	Hoop	293	291	-1%
2	Longitudal	11.3	11.1	-1%
	Hoop	322	320	-1%
3	Longitudal	49.2	49.9	+1%
	Hoop	185	173	-7%
4	Longitudal	13.8	12.9	-6%
	Hoop	34.1	32.1	-6%
5	Longitudal	46	46	0%
	Hoop	298	288	-4%

Tapping on the top of the can was not reported to be very successful. In general, shaking the can raised the pressure 10% to 20% above the room temperature pressure in the can while tapping on the top of the can had a negligible effect on reducing it (average of only 3% reduction of pressure). However, tapping on the can will be most likely to only concentrate gas at the top end by dislodging bubbles from the sides and bottom. This is not going to reduce the pressure although it may prevent a foam explosion.

<u>Myth 2 – Tapping on Bottom of Can</u>

The second myth tested was to shake the can for 5 seconds, turn it over and then tap on the bottom surface of the can for 5 seconds. Student's measured results are shown in Table 2, as seen below.

Table 2. Strain effects of tapping on bottom of can.

Group	Strain Direction	Strain (x 10^{-6} in/in) After Shaking 5 sec	Strain (x 10^{-6} in/in) After Tapping 5 sec	% Reduction
1	Longitudal	7.7	7.6	-2%
	Hoop	233	204	-12%
2	Longitudal	19.8	17.1	-13%
	Hoop	242	217	-10%
3	Longitudal	47	44	-7%
	Hoop	262	266	+1%
4	Longitudal	49.5	45.0	-9%
	Hoop	331	293	-11%
5	Longitudal	10.5	10.6	+2%
	Hoop	132	128	-3%

Like Myth 1, tapping on the bottom also had little effect once the can was turned over. However, the students noticed that the process of turning the can over did seem to reduce the longitudal and hoop strains. Turning the can over was observed to contribute to the average pressure reduction of 6%. This effect led to the tests of Myth 3.

Myth 3 – Repeated Turning Can End Over End

The last myth tested was to turn the can end over end for two complete revolutions after shaking the can for 5 seconds. Table 3 shows the student's experimental results from testing this myth.

Table 3. Strain effects of repeated turning can end over end.

Group	Strain Direction	Strain (x 10^{-6} in/in) After Shaking 5 sec	Strain (x 10^{-6} in/in) After Rotating Twice	% Reduction
1	Longitudal	65.7	8.3	-87%
	Hoop	225	16.4	-93%
2	Longitudal	15.1	0.6	-95%
	Hoop	68.9	10.7	-84%
3	Longitudal	21.3	1.6	-93%
	Hoop	88.7	2.6	-97%
4	Longitudal	36.3	6.4	-82%
	Hoop	259	67	-74%
5	Longitudal	26	4	-84%
	Hoop	276	9.5	-97%

Turning the can end over end was observed to have a large effect on the apparent pressure in the can. Turning the can over twice reduced the pressure about 90% and repeated turning was reported to reduce the pressure nearly back to that of an unshaken can. Students theorized that the turning end over end mixed the liquid and the gas and caused the gas bubbles to go back into solution.

V. INTERNAL PRESSURE RESULTS

Measured Values

Can thickness:	t	0.005 in	
Can diameter:	D	2.59 in	
Young's Modulus:	E	10 x 10^6 psi	(assumed)
Poisson's Ratio:	ν	0.3	(assumed)

The change in longitudal and hoop strains were measured after the pressure was released from the cans. From these strains, the change in internal pressure of the soda was determined as shown in Table 4. These changes in strain and pressure are shown as negative since the soda can goes from a pressurized and strained condition as an unopened can to the unpressurized and unstrained condition after the soda can is opened.

Table 4. Experimental change in pressure when soda can is opened.

Group	Strain Direction	Strain (x 10^{-6} in/in)	Internal Pressure (psi)
1	Longitudal	-246	-47.5
	Hoop	-1233	-56.0
2	Longitudal	-225	-43.5
	Hoop	-1147	-52.1
3	Longitudal	-241	-46.5
	Hoop	-1085	-49.3
4	Longitudal	-234	-45.1
	Hoop	-962	-43.7
5	Longitudal	-229	-44.2
	Hoop	-1060	-48.2

The average change in strain when the soda can is opened is:
Longitudinal Strain: ε_L -246 x 10^{-6} in/in
Hoop Strain: ε_H -1233 x 10^{-6} in/in

The average gage pressure in an unopened Pepsi soda can then is:
45.4 psi (calculated from Longitudinal Strain)
49.9 psi (calculated from Hoop Strain)

VI. CONCLUSIONS

In the "MythBusters" free experiment portion of this lab, the students tested many ways of reducing the pressure in a shaken soda can. Of the three most common methods, only the repeated turning end over end of the soda resulted in a significant reduction of the indicated internal pressure.

By designing their own experiments, and with the added benefit of being able to potentially discount their friend's theories of opening a shaken soda can, the students were more enthusiastic about the lab than if they had simply followed a list of instructions for performing the lab. While the author doesn't have an objective measure of the amount of knowledge gained during this experiment, based on discussions with the students after the experiment he feels that this lab will be remembered long after some of the other strength of material experiments.

The anecdotal evidence indicates that room temperature soda cans have an internal pressure ranging from about 45 to 55 psi. For this example, the pressure calculated from the longitudal and hoop strains fell in the expected range of pressures. The internal pressures calculated from the two strain directions also are slightly different from each other. The average longitudinal pressure is about 10% less than the pressure calculated from the average hoop strain. This difference turns out to be fairly common and is the major potential source of error in this experiment. The discrepancy in the calculated internal pressures should lead to a discussion of the potential sources for this difference. For example, the assumption that the cylinder was infinitely long, homogeneous and isotropic was made in order to do the analysis. How true are these assumptions? Several measurements could also the source of this difference. Is the thickness uniform throughout the can? How does removing some material from the surface to mount the gage affect the strains?

This experiment allowed the students to design and test their own theories as well as introduced them to the many possible sources of experimental error. Both are skills that will be invaluable later in their careers when they are faced with testing a solution to a problem and then interpreting possibly conflicting results.

[1] "The Real Thing – Experimental Stress Analysis NOTEBOOK", Vishay, October 1985, http://www.vishay.com/brands/measurements_group/guide/notebook/e1/e1.htm.

[2] Lissenden, C. and McNitt, R., "Catastrophic Failures, Designed for Failure and Adventures in Mechanics – One Credit Mechanics Seminars", Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition, Albuquerque, NM, June 2001.

[3] Sawyers, D., and Mirman, C., "Experimental Concepts in a Cross-Disciplinary Capstone Course for Mechanical Engineers", Proceedings of FIE '98, Tempe, AZ, November 1998.

[4] "The Real Thing Revisited – Experimental Stress Analysis NOTEBOOK", Vishay, April 1990, http://www.vishay.com/brands/measurements_group/guide/notebook/e1/e11.htm.

[5] "The Real Thing Revisited (Again) – Experimental Stress Analysis NOTEBOOK", Vishay, April 1995, http://www.vishay.com/brands/measurements_group/guide/notebook/e1/e21.htm.