Familiarization Experiment 5a
Pressure Measurement in a Thin-Wall Cylinder

Overview

Thin-walled pressure vessels are very common engineering components with many different uses. A typical kind of pressure vessel is the oxygen tank used by a scuba diver. A more sophisticated and much larger kind is the fuselage of a modern passenger aircraft (" ... for your comfort and safety, this aircraft is pressurized during flight ... ")

All pressure vessels have to be properly designed to support the stresses induced by the internal pressures. This experiment investigates the behaviour of a thin-walled pressure vessel in terms of the induced stresses and strains. The particular thin-walled pressure vessel considered here is the familiar pop can. These cans are made by the billion and are remarkable for their low manufacturing cost and efficient use of material. In the experiment, you will use strain gauges to measure the strains in the material of the can. In this Familiarization Experiment 5a you will attach strain gauges to your can and test their operation using an axial load applied to the can. In the subsequent Exploration Experiment 5b you will then use your strain gauges to estimate the internal pressure.

In this Familiarization Experiment 5a the steps you will take are:

1. (Prelab) Read about strain gauges and how they work. Review the instructions for how to install strain gauges.

2. Attach an orthogonal pair of strain gauges on an unopened pop can.

3. Connect your strain gauges to a strain gauge indicator and zero the readings.

4. Stand your can upright and measure the strain changes caused by adding a series of weights up to 20kg on top of the can. Evaluate the expected strains. Compare the measured strains with the expected strains. Are you satisfied that your strain gauges are working properly ?

5. Carefully preserve your instrumented can for use in your Exploration Experiment 5b.

6. (In preparation for Experiment 5b) Formulate and design an experiment to investigate the research objective you have identified. Assemble/build the needed apparatus.

Objectives

- To become familiar with working with strain gauges and associated instrumentation
- To test your experimental setup to confirm proper functionality

Prelab Preparation

To prepare for the lab, complete the following tasks.

1. Review the theory for the stresses and diameter change a of a thin-walled cylindrical pressure vessel.
2. Learn about strain gauges, see https://en.wikipedia.org/wiki/Strain_gauge
3. Read and understand instructions for installing strain gauges. See Appendix A or http://www.vishaypg.com/docs/11127/11127B127.pdf
4. Learn about 3-wire strain gauge connection www.vishaypg.com/docs/11092/tt612.pdf
5. Bring a can of (non-alcoholic) carbonated beverage to the lab. Select a can that is in good condition, without dents or other defects. Allow the can to stabilize to room temperature ahead of time. Do not use a refrigerated can because the condensation that forms on the surface compromises the strain gauge installation.
6. Answer the questions in the prelab quiz on Canvas.

Theory -- Stress Calculation

The stresses σ_θ and σ_a can be determined from the measured strains ε_θ and ε_a can using Hooke's Law. Assuming that the material is isotropic :

$$\epsilon_\theta = \frac{\sigma_\theta}{E} - \frac{\nu\sigma_a}{E} \qquad (1)$$

$$\epsilon_a = \frac{\sigma_a}{E} - \frac{\nu\sigma_\theta}{E} \qquad (2)$$

where,

ϵ_θ = circumferential strain

ϵ_a = axial strain

σ_θ = circumferential stress

σ_a = axial stress

E = Young's modulus

ν = Poisson's ratio

On inversion, Equations (4) and (5) give:

$$\sigma_\theta = \frac{E(\epsilon_\theta + \nu\epsilon_a)}{(1-\nu^2)} \qquad (3)$$

$$\sigma_a = \frac{E(\epsilon_a + \nu\epsilon_\theta)}{(1-\nu^2)} \qquad (4)$$

Experimental Procedure – Strain Gauge Operational Check

1. Follow the instructions in http://www.vishaypg.com/docs/11127/11127B127.pdf or Appendix A. Install two strain gauges adjacent to each other, one aligned circumferentially and one axially, on the cylindical surface of the can, approximately midway along the length.
2. Do an initial operation check on your strain gauge installation. Balance the channels to achieve zero indicated readings. Gently push on the can near the gauges to confirm that the readings change and then return to zero after you let go.
3. Do a further operation check on your strain gauge installation. Stand your can upright and sequentially add weights up to 20 kg on top of the can. Plot strains vs. added weight and find the gradients. Check that the results conform to your expectations.

Lab Report

In your memo style report, briefly describe what you did so that the reader can generally understand your procedure. Be sure to mention any particular features or circumstances that may have impacted your data or results. There is no need to give details of the strain gauge installation because this is a standard process.

Summarize your measurements and results. Comment on your findings, particularly unexpected ones. Suggest possible causes of discrepancies and explain your reasoning, don't just cite "experimental error". Suggest possible changes in the experimental procedure to rectify the issues that you identify.

Exploration Experiment 5b

- **Read the instructions for Exploration Experiment 5b** and prepare a brief proposal as described there. Send it by email to your lab TA within 30 hours of the end of your scheduled Familiarization lab time.
- Discuss your research proposal with your lab TA to get approval of your plans. Make modifications to your plans as needed.
- Prepare any additional needed apparatus so that it is ready for your use on lab day.

Appendix A: Strain Gauge Installation

Bring your own unopened pop can. Get your pop can well before starting the experiment so that it can warm up to room temperature. A chilled can will form condensation on its surface and will prevent you from making a reliable strain gauge installation. Be sure to choose a can that is in good condition, free from mechanical defects such as dents and wrinkles. Make note of the brand, type and temperature of the contents.

Attach two strain gauges in the centre part of the can. Attach them one at a time using the following instructions, which are adapted from Instruction Bulletin B-127-9, "Strain Gage Installation with M-Bond 200 Adhesive", published by Measurements Group, Inc.

a. Before starting, focus your mind on the task at hand. Approach your work with patience and mental calmness. Strain gage installation is a delicate and detailed process and can only be done successfully if you are thoughtful and meticulous while working.

b. Wash your hands. Prepare a clean and uncluttered area in which to work.

c. Select a spot on the can surface. Degrease a work area about 3cm in diameter using alcohol solvent. Moisten a tissue with the solvent and work the spot outward from the center, removing the grease. This outward wiping procedure is required for the subsequent steps of cleaning.

d. Apply Conditioner A to the work area and very gently wet-sand with 600 grit silicon carbide paper to remove surface paint within the marked gage area. Keep the abrading to a minimum so as not to affect the wall thickness (area of interest). Wipe off the conditioner in an outward motion as before.

e. Using a Q-Tip, apply more Conditioner A to the surface and scrub until no residue remains on the Q-Tip. Use a new Q-Tip once the first has been dirtied to see results.

f. Apply Neutralizer 5 to the work area and gently scrub the surface with a new Q-Tip. Wipe off the neutralizer in an outward motion.

g. Prepare a chemically clean surface on the back of the strain gage box as described in steps (a), (c) and (d).

h. Clean the tweezers using a tissue moistened with Neutralizer 5. Use the tweezers to remove the strain gage from the plastic envelope (handle via. the solder tabs). Place the strain gage 'shiny' side up on the chemically clean box.

i. Using the cellophane tape provided, take a 10cm strip and apply it over your strain gage on the chemically clean surface. Ensure that the strain gages make a 90° shape. Lift the tape up at a shallow angle from the chemically neutral surface and tuck one end of the tape under the other end (ensuring gages are 'up'). The TA will assist with this step.

j. Place the tape with the gages down about 2cm from the prepared area of interest. On the underside of the exposed strain gages, apply some M-Bond catalyst. This will help the glue set quickly. Using a very small amount (brush excess from the brush before applying), brush just enough catalyst to ‘wet’ the underside of the gages. Make sure that the application was smooth so that no bubbles occur. Allow one minute for the catalyst to dry.

k. Take a tissue out ready for use. Lift up the tucked-end tape upright to create a fold. Apply two small drops of M-Bond 200 adhesive to the fold crease. Immediately continue folding down the tape to a 30% angle and begin firmly pressing and working the tape flat such that the adhesive spreads flat. Do this with the tissue so that no adhesive gets on your skin.

l. After the tape is flat, apply some Conditioner A to your thumb and press firmly down on the area containing the strain gages for about a minute. The conditioner reduces the chances of your fingers sticking to the can.

m. After the adhesive has settled, pull the tape back off the can as flat as possible. The closer the tape is to the can, the more unlikely the chance a strain gage will pull up with it.

n. With the tap removed prepare a workspace in which you can solder the wires to the tabs on the strain gages. Apply a little flux on the solder tabs. Melt a small amount of solder on each tab to create a spot for the wires to mount. Strip about 1cm of insulation off the connection wires and twist the white and black conductors together. Apply flux and solder the two exposed conductors.

o. Trim the conductors to 2mm in length and solder the red conductor to the right tab and the black/white conductor to the left tab. Tape the wires to the can about 3cm from the connections and then again, with some slack, 3cm from the first tape strip.

p. Measure the strain gauge resistance using a multimeter. The reading should be 120Ω.

q. Brush solvent over the areas containing flux to remove excess flux. Dab a tissue while the area is still wetted with the solvent (do not wipe).

r. Finally, connect the strain gages to the switch and balance unit. The red wires will go into the P+ connections, the white wires to the S- connections and the black wires to the D120 connections. Balance each strain to “zero” by following the instructions on the switch and balance unit.

Exploration Experiment 5b
Pressure Measurement in a Thin-Wall Cylinder

Background

In your Familiarization Experiment 5a you followed established procedures that were prepared for you. If all went well, you installed some strain gauges on your pop-can and confirmed their correct functioning. The approach taken was “cook-book” style, where you followed a given recipe, without much independent thought being needed.

In this Exploration Experiment you are asked to be more independent and proactive in the design your own experiment to plan the procedure and choose your analysis method. This will be more representative of what you will do in your future professional life -- there are no instruction manuals for new measurements ! The basic measurement to be done here is to evaluate the pressure within your pop-can. This can be done straightforwardly given the preparation you made during your Familiarization Experiment. You are further asked to extend and enrich the basic experiment to probe further and deeper into some aspect of can behaviour.

Objectives

- To gain experience in designing experimental research.
- To learn how to plan and execute your own experiments.
- To get practice in analyzing your results and presenting them in the most effective way to demonstrate your conclusions.
- To discover that doing good experiments is challenging. The more revealing they are, the more valuable they are.

Experimental Work

To create an effective experimental plan, you will need to:

1. identify exactly what you wish to investigate
2. determine how to measure the target quantities without influence of other factors
3. organize a safe and efficient experimental plan
4. formulate an effective way to analyze your measurements and present your results.

The initial objective of the experiment here is to determine the pressure within your pop can. The pressure will depend on many factors, notably the type and temperature of the can contents. These details should be recorded carefully. You can determine the internal pressure by observing the strain change caused by opening the can followed by repressurization to restore the original strain readings. **(Keep the can mostly full of liquid when repressurizing.)**

After completing the initial experiment, go on to complete one of the follow-up experiments suggested below, or a related experiment of your own suggestion.

- Investigate the effect of temperature on the can pressure. This could conveniently be done by taking strain readings on your can at several different temperatures. Do these measurements **<u>before</u>** opening the can and **do not go above 50ºC.** At the end, open the can to get the zero pressure reading. You will need to take precautions to avoid strain gauge temperature effects.
- Evaluate the thermal expansion coefficient of the can material. This could conveniently be done by taking strain readings on an opened can at several different temperatures. You will need to take precautions to compensate for the thermal response of your strain gauges. Available for your use are some silicon wafers of known low thermal expansion coefficient. Be sure to keep your strain gauges dry because moisture will distort the readings.
- Investigate the influence of the end surfaces on can deformation. The deformations in a metal pop can are small and difficult to measure. Therefore, you can alternatively explore the deformations of a 2 litre plastic pop bottle. **Bring a plastic bottle in advance.** Be sure to select a bottle that has parallel sides, not the contoured type used by some manufacturers. Carefully measure the diameter profile along the length of the bottle before and after opening. No strain gauges are needed for this measurement. After opening, empty the bottle and refill it 90% full with water, install a Schrader valve in the cap and repressurize the bottle to various pressures **(maximum 50psi).** Measure the diameter profile at each pressure. Explore the end effects and infer the original pressure.

Prelab Preparation

To prepare for the lab, complete the following tasks.

7. Think carefully about what you did in your Familiarization Experiment. Identify an Exploration Experiment of interest to you from the list above, or propose an experiment of your own choosing.
8. Plan the practical steps required to investigate the experimental objective you have identified. Seek to find a procedure that will give you unambiguous results, uninfluenced by other non-target factors.
9. Write a detailed summary of your planned experiment procedure in bullet form.
10. Send your planned experiment objective and procedure to your lab TA four days ahead of time. Discuss your plans and, if needed, make modifications to enhance their safety and effectiveness.
11. Prepare any additional needed apparatus so that it is ready for your use on lab day.

Lab Report

In your memo style report, clearly describe your research objectives and the prior observations/thought process that motivated your choice. Describe your experiment plan and explain how it focuses on your target question and how it avoids undesired side effects with other factors. Present your results compactly and give conclusions that respond to your stated research objectives.