Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
Cambridge, MA 02139

16.01/16.02 Unified Engineering I, II
Fall 2003

Systems Problem 10

Name: ______________________

Due Date: 11/19/03

	Time Spent (min)
SP10	
Study Time	

Announcements:

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Aeronautics and Astronautics
16.010 / 16.020 Unified Engineering

Systems Problems #10

Issued: November 6, 2003 Due: 5 pm November 19th, 2003

MEASURING STRAIN AND MATERIAL PROPERTIES

Note: This Systems Problem has a pre-lab that must be completed before arriving at the laboratory.

Objectives

After this lab, you will be able to:

- Apply a strain gauge to a specimen, solder wires to the pads, and make electrical connections to a strain gauge amplifier

- Use strain gauges to determine material properties such as Young's modulus and Poisson's ratio

- Discuss the elastic behavior of various materials and the experimental observation thereof

Introduction

In this systems problem you will apply an axial load to three different materials and measure the axial and lateral strains using strain gauges that you apply to the materials. You will then be able to estimate two material properties (Young's modulus and Poisson's ratio) for each material and compare them to published values.

Poisson's Ratio

You are already somewhat familiar with stress and strain in an axial direction, for instance in the bar of a truss. For example, consider the material below:

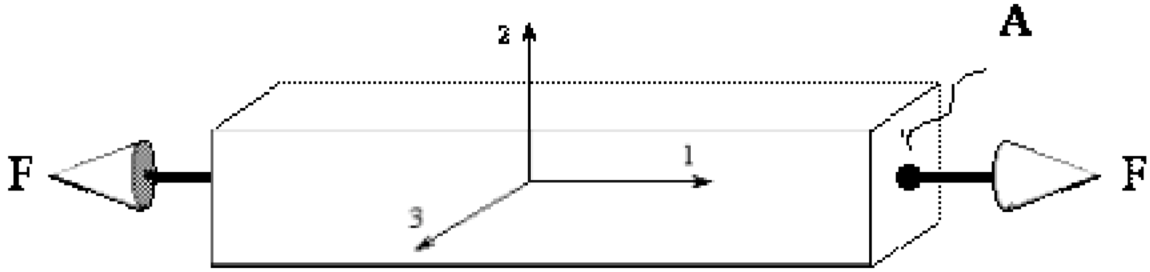


Figure 1. Material Under an Axial Load

An axial force F is being applied in the x_1 direction. This results in a stress in the material in the x_1 direction: $\sigma_{11} = \dfrac{F}{A}$ and a strain in the x_1 direction: $\varepsilon_{11} = \dfrac{\sigma_{11}}{E}$ where E is the Young's modulus. Because the material's volume remains essentially constant, an elongation in the x_1 direction means that the material also contracts slightly in the x_2 and x_3

directions. So, we would expect ε_{22}, for example, to have some negative value if ε_{11} is positive. The ratio of the (negative) lateral strain to the axial strain is defined as the Poisson's ratio, ν:

$$\nu_{12} = -\frac{\varepsilon_{22}}{\varepsilon_{11}}$$

The subscripts on ν_{12} indicate that the Poisson's ratio is representing the ratio of lateral (or transverse) strain in the x_2 direction over the axial strain in the x_1 direction.

Strain Gauges

In SP9, the truss lab, we introduced strain gauges. Now we will take a slightly more detailed look at their operation. As we discussed in SP9, the resistance R of a wire (measured in Ohms) is given by:

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

where ρ is the wire material resistivity, L is the wire length, and A is the cross-sectional area of the wire. Now, if the wire is lengthened by ΔL, its resistance will change by some amount ΔR:

$$R + \Delta R = \frac{\rho(L + \Delta L)}{A}$$

(assuming the change in A is negligibly small). Dividing both sides by R:

$$\frac{R}{R} + \frac{\Delta R}{R} = \frac{\rho L}{AR} + \frac{\rho \Delta L}{AR}$$

Noting that $\frac{\rho L}{AR} = 1$, this reduces to:

$$\frac{\Delta R}{R} = \frac{\rho \Delta L}{AR} = \frac{\Delta L}{L} = \varepsilon$$

So, the proportional change in R is equal to the strain of the wire. Due to non-ideal behavior of the strain gauge, there is actually a proportional constant called the Gauge Factor (GF) that results in a larger change in resistance for a given strain than the above equation predicts:

$$\varepsilon = \frac{1}{GF}\frac{\Delta R}{R}$$

where GF is typically about 2.0. The baseline values for R is 120 Ω. Your task then is to measure the change in resistance, and from it determine the strain in the material.

Figure 2 shows the wiring diagram for each strain gauge. In the lab, you will connect one lead from the strain gauge to the terminal on the strain gauge reader labeled *S+* and the other lead to the terminal labeled *D120*. The strain gauge reader then measures the voltage between *S+* and *S-* and from this determines the change in strain gauge resistance, ΔR.

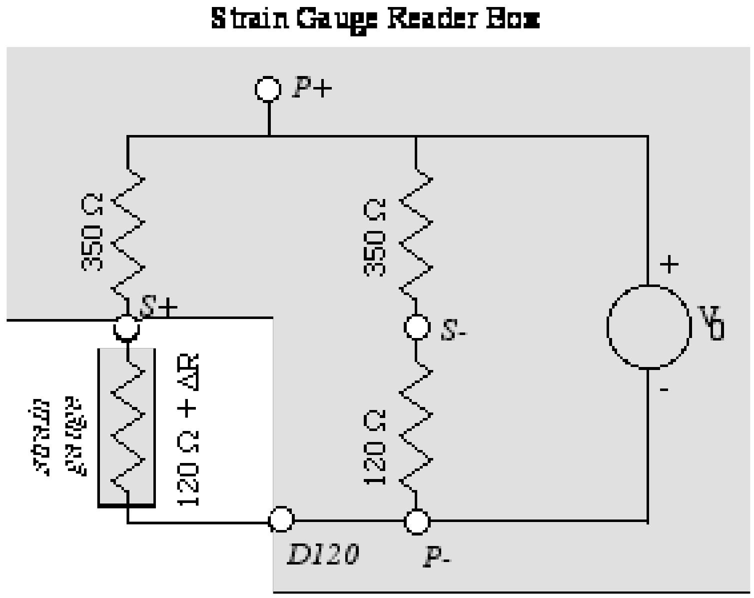


Figure 2. Strain Gauge Wiring Diagram (Wheatstone Bridge Circuit)
(labeled terminals shown as white circles)

Lab Exercise

The straing gauging portion of the lab will be conducted in the electronic shop in the basement of building 33, and the mechanical testing component in the hangar, where you conducted the truss lab. Each lab session will take approximately 2 hours. You will work in a team of six students. In each lab session, the lab team will test four different specimens, each made of a different, industrially important aerospace material. The materials you will test are:

- Aluminum – Al 7075
- Titanium – 6Al 4V
- A steel alloy
- A carbon fiber reinforced epoxy laminate. This will already have strain gauges attached to it.

These materials have been cut into specimens as depicted in Figure 3 below. The team will apply two strain gauges to each specimen (one in the axial direction, one in the lateral direction). With teams of six applying two gauges to each of three metal specimens, each of you will have the opportunity to apply a strain gauge to a specimen.

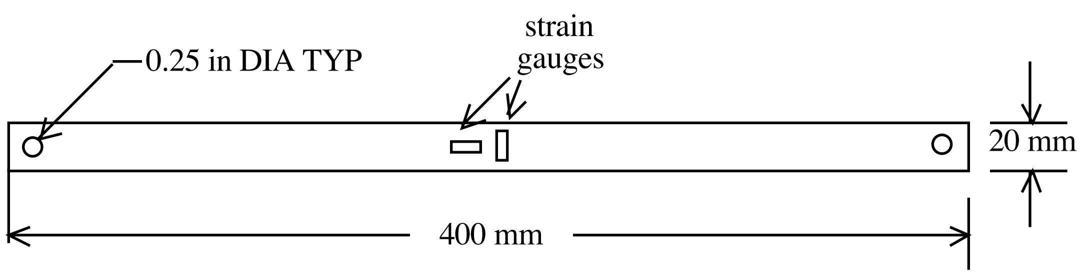
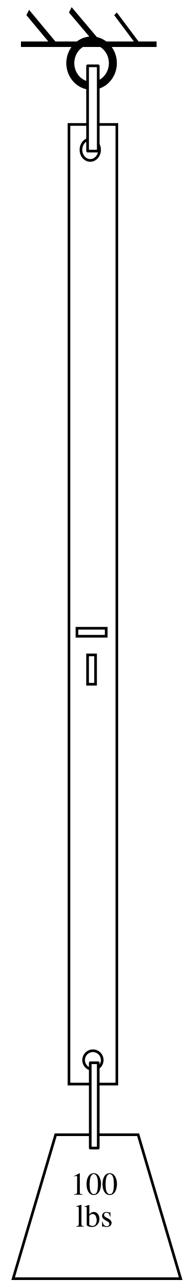


Figure 3. Approximate dimensions of the material specimens, each specimen is approximately 2 mm thick.

Pre-Lab Assignment

Read through the entire lab handout carefully so that you have a clear idea of what needs to be accomplished. Be sure to read the section on strain gauge application; it will make the lab period go much more smoothly. Also, complete the questions below and bring your solutions with you to lab. You may need to refer to Ashby and Jones chapter 3 and Crandall section 5.4.



1. If the specimen described in Figure 3 is hung from a hook and a 100 pound load is applied what will be the resulting stress (in each direction) in the vicinity of the strain gauges for each material (aluminum, Titanium, CF composite and steel)?

2. For each of the four materials (aluminum, titanium, carbon-fiber composite and steel), what will be the approximate strain (in each direction) in the vicinity of the strain gauges?

3. For the aluminum specimen, what will be the change in resistance of the two strain gauges if the gauge factor is 2.06 and the baseline resistance R of the strain gauge is 120 Ω ?

4. Referring to Figure 2, let V_0 be the voltage difference between *P+* and *P-* . If the change in resistance of the strain gauge is what you computed in #3, what would be the voltage between *S+* and *S-* in the Wheatstone bridge circuit, in terms of V_0?

Laboratory Assignment

The technical instructors will assist you in applying the strain gauges and soldering the leads to the pads. TA's will be available to help you with the loading of your specimens. Be sure to listen carefully to their instructions and follow sound safety procedures. Carry out the following steps:

I. **Apply a strain gauge to a specimen.** This is a fairly complex and delicate operation. You need to prepare the specimen, apply the gauge, and solder the leads onto the pads. Since this is your first time, it will take about an hour. There will be technical instructors (John Kane and Dave Robertson), who are skilled in the art of strain gauging available to help you Please take your time and do not hesitate to ask questions. Please read the section of this hand-out on strain gauge application

II. **Connect your leads to the strain gauge amplifier.** Connect the leads of your strain gauge to the terminal board for the strain gauge amplifier.

III. **Apply the load and record the change in strain.** You will be using the loading apparatus and load cells from the truss lab to apply the load to your specimens. For each of the four specimens in turn complete the following steps:

   (a) **Balance the bridge.** Hang your specimen from the hook provided. Attach the loading cable to the hole in the lower end of your specimen

   (b) **Apply the load and record the strain.** Using the hydraulic jack provided, apply load to the specimen. Do not exceed a stress of 50 MPa or a load of 500 lbs (whichever is smaller) for any of the specimens. Take enough load readings to obtain an accurate estimate of the Young's Modulus and Poisson's ratio, and to confirm that the material response is linear.

Post-Lab Assignment

5. For each material, make plots of applied stress versus strain (in axial and transverse directions). Discuss your results and be sure to make note of any significant hysteresis or non-linearity.

6. For each of the four materials (aluminum, composite laminate, titanium, and steel), what are your measured values of Young's modulus and Poisson's ratio? How do your measured values compare with published values?

7. Estimate the accuracy of this experimental technique for measuring elastic properties (Young's modulus and Poisson's ratio).

8. Discuss the fidelity of the engineering model in light of your experimental results (i.e., the degree to which linear elastic behavior was confirmed experimentally).

9. Discuss your experience in this lab. Did you experience any significant difficulties in applying the strain gauges?