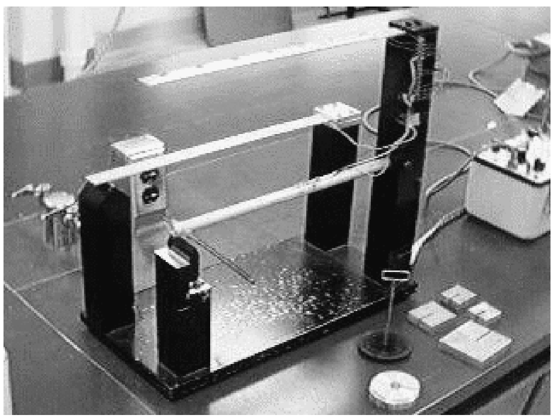
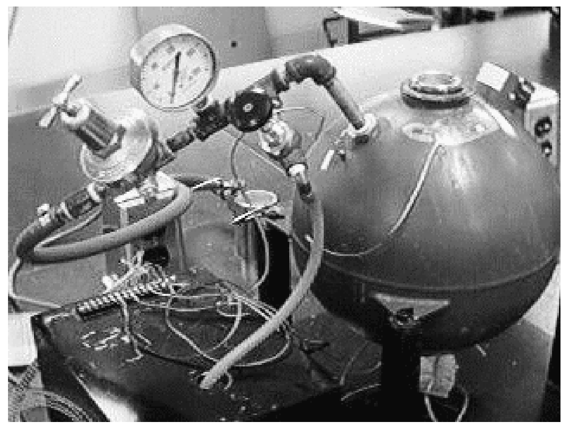
Experiment #6

Strain Measurement





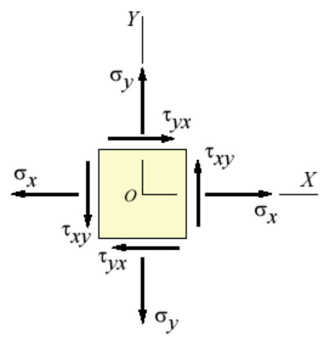
Motivation

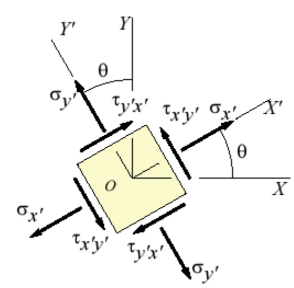
The main idea of this experiment is to revise the concept of stress, strain, their relation to the applied load in different types of structures, idea of stress and strain transformation, methods to calculate the strain in any required direction generated by the loads in direction different from the required one.

Before performing this lab you MUST be familiar with

1. Basic notion of stress and strain.
2. Plain stress and plain strain. Principal normal and shear stresses. Relation between Principal stresses and stresses at any other orientation.
3. Strain gage and its working principle.
4. Strain rosette and its utility.
5. Plain stress and strain transformation.
6. Mohr's Circle for stress and strain.
7. Transformation from stress to strain in 1-D, 2-D and 3-D.
8. Working principal of wheat-stone bridge.

INDIVIDUALLY submit the solution of following problem in the pre-lab report and before you start the experiment.





Original stress state is as under

$\sigma_x - \sigma_y - \tau_{xy} - \theta$ = mm – dd – yy – 30+dd (your date of birth mm-dd-yy (last two digits for year))

1. Transform it at the angle defined above using stress transformation equations
2. Draw Mohr's circle for stress and use this to find the transformed stresses.
3. Calculate the original longitudinal strains.
4. Calculate longitudinal strains in new transformed orientation

Introduction

A short lived engineer would be one that never considered stress or strain. Stress is present in all structures either static or dynamic, at least on earth anyway. Stress is typically a key element that dictates every design. Strain is the resulting deformation that a structure experiences under a given stress. For most materials considered in mainstream engineering, stress is directly proportional to strain. Within the design process a preliminary survey produces likely candidates for use as materials and the expected stress-strain quantities are calculated. At this point two key problems exist. These problems are
(1) How is the stress calculated for complex shapes such as curved areas? and
(2) How are the strains measured once the structure has been built?

To attack the first problem, analytical solutions are available for almost every type of structure imaginable. These equations produce equations normal or shear stress as a function of loading and geometry. The equations are based entirely upon geometric quantities and don't depend on empirical data for a solution. In this experiment, we challenge those equations. Given various structures, loads are applied and measurements are made that will either coincide or diverge from values produced using theoretically derived equations.

Now all that's left to find is a means to measure strain. Most people, with the aid of a ruler, can measure 1/32 of an inch within +/- 1/64. That's fine for extremely high loadings or extremely weak materials, but many materials might fail at say 3500 μstrain, which would be well below 1/20 of the resolution of a ruler. To solve this problem several instruments can be used, one of which is the strain gage/Wheatstone bridge. This instrument combination allows measurements, in some cases, as low as +/- 1μstrain. With resolution this good the question arises "Is this minute quantity significantly useful in most applications?" Typically, this resolution is not needed and the closest desired resolution may be +/- 5μstrain.

In this experiment the student loads actual structures then examines the strains produced by the loading. Later, the student calculates the strains expected by geometrically derived equations and compares the difference in the two values. In the end, the student can provide evidence if the equations can accurately predict strains present in a structure and also if the strain gage/strain box combination is useful in the measurement of these strains.

Theory

Foil strain gages are essential elements in the measurement of small displacements of materials. Strain gages are constructed from a thin plastic film coated with a copper film layer. The copper film layer is etched away in a certain pattern to give the strain gage lines of conductive material. The direction of these conductive lines is the direction in which the strain is to be measured.

The strain gage is mounted to a material with some type of adhesive. This can be epoxy, cyanoacrilate, or numerous other bonding agents depending on the host material. Strain gauges are mounted with the plastic film backing next to the material that is being measured. Once again, the lines of conductive material run in the direction of the strain that is to be measured. When the host material is elongated (or compressed) the lines of copper are stretched as well. With Poisson effects in mind it is easy to image the cross sectional area of the lines getting smaller and the overall length of the gage increasing. These two effects give a change in resistance to the strain gage.

The change is resistance (strain) allows the transformation of a physical quantity into an electrical quantity. The change in strain typically may be only 1/10 Ohm at most. This presents a big challenge if one was to simply use an Ohm meter to gauge strain. A Wheatstone bridge, shown in figure 1, can be used in order to make this change in resistance meaningful. The gage is inserted in one “leg” of the bridge. The bridge is assumed to be balanced at a “no strain condition.” From there, when strain is applied, the complementary leg of the bridge is adjusted in order to re-balance the bridge. The amount of change in resistance used to re-balance the bridge is directly proportional to the strain that is being applied to the test material.

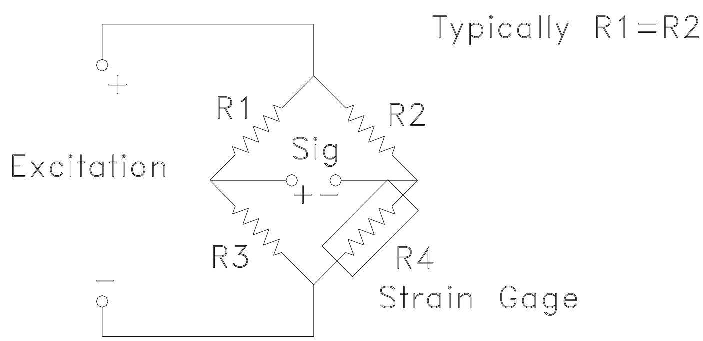


***Figure 1**, Wheatstone bridge with strain gage in place.*

$$R_4 = \frac{R_2}{R_1} R_3 \tag{1}$$

Equation (1) gives the relationship to R_4 as a function of the remaining resistor. In most bridge configurations, R_3 is made close to R_4 and R_1 is made close to R_2. It's easy to imagine that by correct selection of the resistors, R_1 and R_2 that a multiplier effect occurs in the R_2/R_1 ratio. For example, if R_4 is 100 ohms and changes 1/10 Ohm, then the R_2/R_1 ratio has to change by 1.001 for the bridge to stay in equilibrium. If, say $R_2 = R_1 = 100$ kOhms, then the change in R_2 has to be 100 Ohms. The quantity 100 Ohms is much easier to determine than 1/10 Ohm and also provides more accuracy in doing so.

Manufacturers provide two important pieces of information for the strain gages they sell; the resistance and the gage factor of the gage. The gage factor is a value that relates change in size to change in resistance. No strain gage is usable for measuring strain without these values. These values are used in conjunction with the change in resistance value mentioned above to determine the strain in the tested material. Equation 2 below identifies the relation of strain, resistance and gage factor.

$$\Delta\varepsilon = \frac{1}{K}\frac{\Delta R}{R_0} \tag{2}$$

An interesting use of the strain gage is in a load cell. Typically load cells are used to measure loads in one direction. In actual set-ups, load cells are calibrated in two ways. The first way is in which the load cell bridge is calibrated by a shunt calibration technique. This is where a known precision resistor is placed across the terminals of the strain gage. A formula determines what the reading should be across the bridge. The value of the output is then interpreted from that reading to give a reading in lb, kg, etc.

The second method of calibration is known as dead weight calibration. This type of calibration is significantly easier and also aids the user in believing the reading produced from the set-up. The load cell (bridge) is balanced from a no-load state. Now increments of weights are added and the potential across the bridge is recorded. The corresponding weight to potential values are recorded and used as a formula for determining unknown loads. This may seem like more physical work, but once again it provides a sense of security in seeing that the loads placed on the cell have a certain conformable value.

The first structure examined in this experiment is the cantilever beam. A beam under bending can be characterized by equation (3).

$$\frac{1}{\rho} = \frac{M}{EI} \tag{3}$$

The radius of curvature can also given by equation (4)

$$\frac{1}{\rho} = \frac{d^2y / dx^2}{\left(1 + \left(dy/dx\right)^2\right)^{3/2}} \tag{4}$$

where y is the deflection in the y direction at any given point x along the beam. For many problems, the deflection is very small compared to (2). This means that the denominator can be neglected in most cases, which causes equation (4) to become

$$\frac{M}{EI} = \frac{d^2y}{dx^2} \tag{5}$$

when combined with equation (2). This further reduces to a convenient form of the equation for stress in the cantilever beam.

$$\sigma = \frac{My}{I} \tag{6}$$

From there, an equation of the strain in the beam can be written considering any point in the beam. Equation (3) has been derived through fundamentals of mechanics. The parameters in these two equations involve discrete physical values with no inclusion of "mysterious" correction factors. What's significant about this point is that theory will predict (very closely) what we actually see in the loading of the structure. The case of the cantilever beam is a simple introduction to this argument. The same principles and analyses applied to the cantilever beam can be applied to more complicated structures. This results in a compounding of the confirmation of theoretically derived equations through experimentation. Solutions for the remaining structures can be found in most solid mechanics textbooks and therefore no additional work will be devoted to their identification.

Also, there should be some observation about the usability and reliability of the relatively crude instrumentation involved in the experiment. In most cases, strain values differ at most by 5 μstrain from the actual values. In most of the experiments here, that relates to much less than an ounce of resolution. In the laboratory most load cells typically fall within 0.5 % error.

Apparatus

1) Mounted Foil strain gages
2) Data Logger
3) Cantilever beam fixed at other end
4) Cantilever Beam
5) Cantilever tube.
6) Pressure vessel (Sphere) with air regulator
7) Assorted weights with hanger
8) Agilent Data Acquisition system
9) PC

Weights

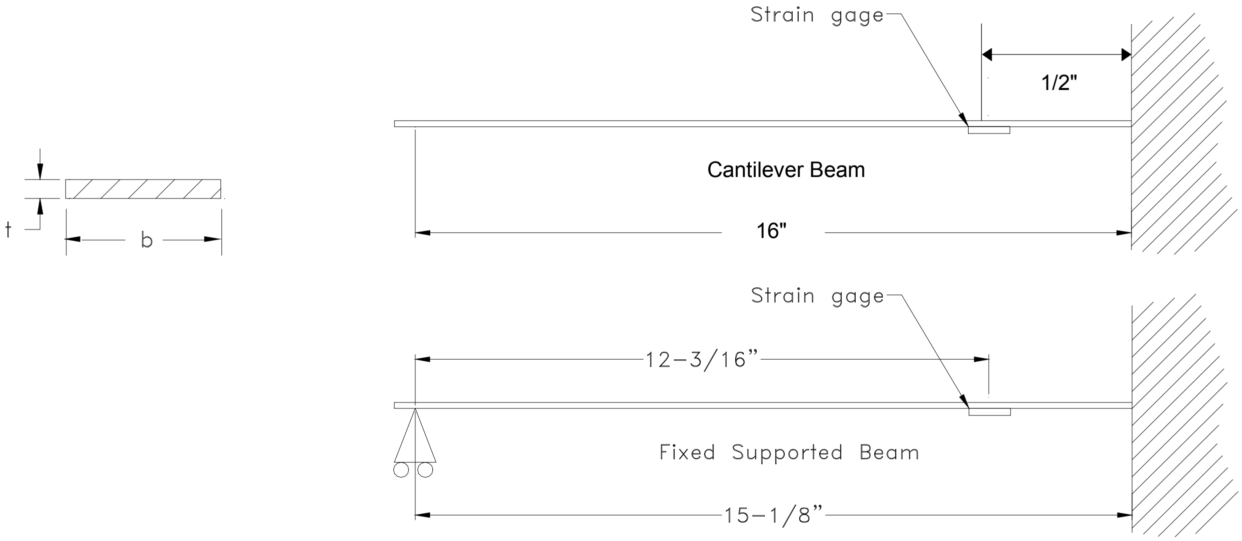
Holder	.531 lb.
#1	.445 lb.
#2	.103 lb.
#3	.119 lb.
#5	.197 lb.

Sphere

Material	Stainless Steel
Thickness	1/8" +/- 1/64"
Outside diameter	10" +/- 1/8"
E	28 Mpsi
G	10.6 Mpsi

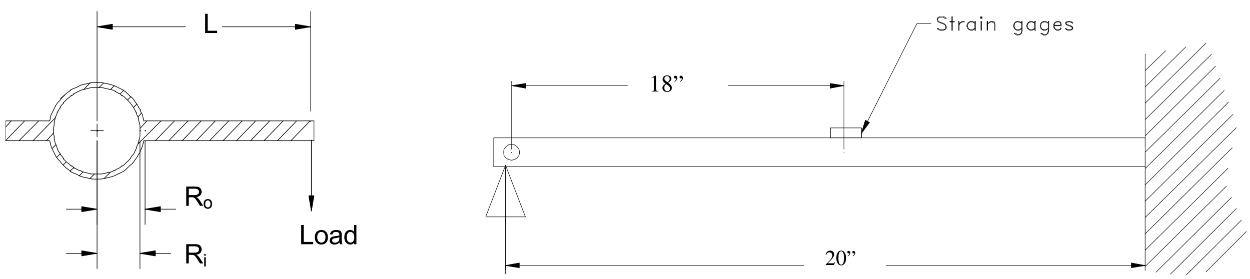
All Rectangular Beams

Material	Aluminum
Thickness, t	.122" +/- .001"
Width, b	1.0" +/- .01"
E	10 Mpsi
G	3.8 Mpsi



Tubular Beam

Material	6061-T6 Aluminum
R_o	1/2” +/-1/32”
R_I	3/8” +/-1/32”
Arm, L	18” +/- 1/32”



Objective

1) The confirmation of theoretically derived equations through the use of actual testing.
2) To evaluate the use of the strain gage/strain indicator as a tool in the measurement of strain.

Requirements

1) Make all the calculations indicated by the data table. The calculated strains should correspond and be compared to the measured data.
2) Calculate the maximum percent difference between the theoretical and the experimental data.
3) For the cantilever beam and fixed supported beam, plot the measured and calculated strain as a function of the load’s distance from the gage.
4) Compare the Digital and Analog system.

Procedure

Turn on the Data Logger. Obtain from the instructor, the amount of load to be used for the beam and the tube. Also, obtain the pressure to be used in pressure vessel. Before performing work with the pressure vessel, see if the tank needs to have water drained. This can be done by the removal of the 2” dome on the tank. Data such as gage factors, structural properties, operating instructions, and structure dimensions should be on the information sheet.

Analog System

Cantilever Beam

1) Study the experimental setup and read the available operating instructions.
2) On the Portable Strain Indicator box, power on the device by moving the power switch to AC.
3) Select the channel 7 and adjust the strain indicator to the correct gage factor (2.04).
4) Zero the indicator prior to loading. Place NO load on the cantilever beam. Place the strain reading to 0000 by using the large black knob and turn the balance knob (on either or both boxes) until the galvanometer is centered.
5) Apply the load at the required positions. Re-center the galvanometer needle by using the big black knob (not the balance knob). The display should change as this knob is being turned.
6) Repeat for remaining points identified on beam.

Digital System

1) From the desktop, click on “Benchlink”.
2) Click on the green button titled “Scan and Log Data”.
3) Click on the “Start/Stop” button, when the 34970A unit begins clicking, the data collection process has begun. Take the readings from the channels as indicated on the data sheet.
4) Record the initial resistance value after about 45 seconds.

Cantilever Beam

1) Apply the load at the required positions
2) After any vibrations have died off, record the resistance value after 45 seconds.
3) Repeat for remaining points.

Cantilever Tube

1) Apply a load to the lever arm as instructed by the assistant. Make sure the wedge is securely placed at the end of the tube.
2) Wait for vibrations to die off and record the readings.

Pressure Vessel

1) Close the air release valve (black knob) and open the inlet regulator valve (T-handle) until the correct amount of pressure is obtained.
2) Record the readings
3) Close (CCW) the air regulator valve and open the outlet valve to empty the tank.

Nomenclature

b	=	thickness
E	=	modulus of elasticity
F	=	force
G	=	shear modulus
I	=	moment of inertia
K	=	gage factor
L	=	length of arm

M	=	moment
P	=	pressure
R	=	resistance or radius
t	=	thickness
x	=	distance parallel to beam
y	=	distance from neutral axis
ε	=	strain
ρ	=	radius of curvature (of neutral axis)
σ	=	stress

Subscripts

1-4	=	resistor number
0	=	unstrained
i	=	inside
o	=	outside

References

1) Figliola, R. S. and Beasly, D. E., Theory and Design for Mechanical Measurements, John Wiley and Sons, New York, 1991.
2) Popov, Introduction to Solid Mechanics, Prentice Hall, 1968.
3) Shigley, J. E. and Mischke, C. R., Mechanical Engineering Design, 5^{th} ed., McGraw-Hill Book Co., 1989.
4) Gere, J. M. and Timoshenko, S. P., Mechanics of Materials, 2^{nd} ed., Wadsworth, Inc., 1984.

Data Sheets

I Cantilever Beam Analog

Gage #7
Load, F=_______lb.
Gage Factor = 2.04

Distance from Gage to Load (in.)	Measured μstrain	Calculated μstrain	% Difference
14			
12			
10			
8			
6			
4			
2			

Maximum percent difference = ______________%, (between calculated and measured strain)

II Cantilever Beam Digital

Channel 101
Load, F=_______lb.
Gage Factor = 2.04

Distance from Gage to Load (in.)	Measured μstrain	Calculated μstrain	% Difference
14			
12			
10			
8			
6			
4			
2			

Maximum percent difference = ______________%, (between calculated and measured strain)

III Cantilever Tube

Load, F=_______lb.
Gage Factor = 2.04

Channel	Measured μstrain	Calculated μstrain	% Difference
112			
113			
114			

Maximum percent difference = ______________%, (between calculated and measured strain)

Instructor's Initials_________________________

IV Spherical Pressure Vessel

Pressure, P=___60___psi

Gage #	Gage Factor	Measured μstrain	Calculated μstrain	% Difference
107	2.065			
108	2.065			
111	2.065			

Maximum percent difference = _______________%, (between calculated and measured strain)

Instructor's Initials__________________________