LAB 2

Alex Nagy **Claire Grover** **Santino Lupica-Tondo**

ABSTRACT

*An engineer's job is to evaluate the goals of a project and design an approach that prioritizes safety and cost-efficiency. To complete this task, it is vital to understand the mechanical properties of a wide range of materials to predict and prevent possible failures in the resulting structure. When analyzing the desired structure, the engineer must consider both the weight of the structure itself as well as the possible forces that can be caused by its surroundings. These forces are then distributed across each individual member of the structure. From here the stresses and strains of each material can be analyzed and compared to the known limits to check the safety of the desired structure. In the following report, experimental strain data for a brass element will be collected using both a single strain gauge and strain gauge rosette. The National Instruments (NI) Data Acquisition (DaQ) system will use a Wheatstone bridge to convert the strain gauge's signal to an experimental strain value. In part 1 of the experiment a single strain gauge will be used and for part 2 a rosette strain gauge is used. For part 2 of the experiment a strain is calculated for each strain gauge at the maximum displacement of the beam. The average strain is calculated, and the principal strains are derived from Mohr's circle. The experimental strain value for each part will be compared to a calculated strain value based on the geometry of the brass element used. When using a single strain gauge, the differences between these two values were low, with an error of **11.92%** (from* Eqn. (2)*). There were much greater differences introduced when using the rosette strain gauge, with the error amounting to **46.59%** for gauge A, **23.36%** for gauge B, and **103.5%** for gauge C (from* Eqn. (2)*). Two other major results of this lab were Poisson's Ratio which equaled **0.3660** and the principal angle for Mohr's Circle which was **18.43°**. This comparison will allow the engineers to evaluate the differences between experimental and calculated strain values and display how the deformation of structural members does not always align with theory. Knowing this, engineers can account for differences in deformation in the factor of safety of the structure, resulting in a safer final product.*

INTRODUCTION AND OBJECTIVES

In this experiment the primary objective was to compare experimental deformation data collected with electrical resistance wire gauges with theoretical values based on the dimensions of a specimen of brass. Part I and Part II both utilize MATLAB code (refer to *Annex B*) to derive these theoretical values, however, Part II requires Mohr's Circle to find all the necessary values. The purpose of this lab is to exercise the principles of Mohr's Circle and its corresponding equations, collect experimental data from electrical resistance strain gauges and compare the results to evaluate error.

PROCEDURE

Samples

A sample brass beam of width **25.4 mm**, thickness **3.42 mm**, and total length **225 mm**. The first beam is fitted with a strain gauge of gauge factor **2.100**. The second beam is fitted with a rosette strain gauge with gauge factors of **2.060**, **2.070**, **2.060** for gauges A, B, and C respectively.

Equipment:

Digital Caliper

A digital caliper is a precision instrument used to take measurements. This instrument was used to record the thickness and width of each sample before performing the strain test.

Ruler

A ruler is another instrument that was used to take accurate measurements in this project. A ruler was used to measure the length of the beam, distance from the clapped edge to the middle of the micrometer, and distance from the center of the strain gages to the middle of the micrometer.

Flexor Device

A flexor device is used in this project to elastically bend the beam. It is connected to a National Instruments (NI) data acquisition (DaQ) system which includes a Wheatstone bridge. The wires connecting the NIDaQ to MATLAB through the Wheatstone bridge are manually connected to pin connections on the flexor device based on the setup documents given in the laboratory. This is used for converting the gage signal into a strain value.

Micrometer

A micrometer is a device that incorporates a calibrated screw and is used for accurate measurement. A micrometer is attached to the flexor device and is used to bend the beam to a specific position by the millimeter. The micrometer used in this experiment has a tip in the shape of a spherical surface.

Strain Gauges (Single and Rosette)
A strain gauge is a sensor tool that changes electrical resistance as a force is applied. This tool converts the force into a change in electrical resistance which is then measured as strain. For this experiment, electrical resistance strain gages are used to measure the strains as the beam is elastically deformed. As the beam deforms, the gage deforms which causes the electrical resistance of the thin wires in the gage to change. A single strain gauge is pre-mounted to the beam for the first part of the experiment. This has one value for the gauge factor. For the second part of this experiment, the beam will have a rosette strain gauge attached to it which has three-gauge factors to record.

MATLAB/ National Instruments (NI) data acquisition (DaQ) system/Wheatstone Bridge
MATLAB is the program that is used in this experiment to record, calculate, and graph the data that is found from the strain gauges.

Experimental Procedures:
It is indicated below when the procedure for Part 2 deviates from Part 1

1. Record the material/find the dimensions of the beam sample
The first thing done was choosing the material of the beam to undergo testing. Group 1 chose a brass beam. Then the width and thickness of the beam sample is measured using a digital caliper.

2. Insert the beam into the Flexure device/connect NIDaQ
The beam for each test, which already has a pre-mounted strain gauge attached to it, now gets mounted into the flexor device. It is important to make sure that the beam is all the way against the fixture, centered with the micrometer, and tightened down. The strain gauge wires will be connected to pin connections on the flexor device according to the setup documents given (Fig. 4). The wire connections differ between the single and rosette strain gauge. Once the Wheatstone Bridges circuit is set up testing is almost ready to begin.

3. Adjust/Measure the set up
Before getting any measurements, the micrometer must be adjusted so that it is just touching the beam. This is the zero position which means there should be no strain here. Repeat this step before each test. Now that the beam is set in place, it is time to get some more important measurements needed for the calculations. A ruler is now used to measure the distance from the clapped edge to the middle of the micrometer and to measure the distance from the center of the gage length to the middle of the micrometer.

4. Create table of calculated tip displacements
It is now important to create a table so that it is known how much to displace the micrometer from one position to another and what to input into the MATLAB program later. The table will have 3 rows. The first row is the number of data points, the second is micrometer reading, and the third is the displacement. An example of what one of these tables should look like is shown in *Table 3*.

5. Deflect beam
The beam will be deflected in eight equal increments which will add up to a total displacement of **8mm**. The starting point is the number that is read from the micrometer when it is just touching the beam. The first beam has a single gage and for this set up it is necessary to measure the displacement and strains down **8mm** and back up to the zero point. There should be a total of **15** points. The second part of this experiment only measures the **8mm** deflection down. So, for the rosette strain gauge, there are only **8** data points. As the beam deflects, the strain gauge elongates, changing the electrical resistance of the wire which is transmitted to the MATLAB program to calculate the strains.

6. Open/Use MATLAB
The last step is to open MATLAB. Once loaded, navigate to the 'me226_lab2_single_gauge_ver3.m' program and hit run. The first input will be the gauge factor which can be found on a label on the beam sample. The next input is the number of points which will be **15** for the single strain gauge and **8** for the rosette strain gauge as explained above. The next input is the displacements which were established when creating the table. Start off with the first displacement which should always be zero and continue to displace the beam until you have gone both directions. For the second test only displace the beam downwards. When doing this it is important to move the micrometer to the right number before imputing the displacement value into MATLAB. Once completing the first test, the graph should show up as a straight line. The points for the different positions coming down should be close to the ones going up. For the second test, there should be three separate lines showing the strain at three different locations on the beam. A line of best fit will be used to test the accuracy of these results in proceeding sections.

RESULTS

Table 4 contains the raw data collected from both the single and rosette strain gauge setups. The recorded elements include the following: beam thickness (*t*), width (*w*), length (*L*), length between the gauge and the micrometer (*l*), and predicted strain ($\epsilon_{Predicted}$). The brass specimen with the single strain gauge attached had a beam thickness (*t*) of **0.1350 in.**, width (*w*) of **0.965 in.**, length (*L*) of **9.941 in.**, length between the gauge and micrometer (*l*) of **8.858 in.**, and a predicted strain ($\epsilon_{Predicted}$) of **5.751e-04**. With respect to the rosette strain gauge, all these values were constant besides the length between the gauge and micrometer (*l*) and the predicted strain ($\epsilon_{Predicted}$) which were **8.661 in.** and **9.941 in.** respectively.

Table 1 contains the tabulated strain and displacement values for the single strain gauge at the 15 points of measurement – ascending by **1.14 mm.** displacements before cycling back to zero after the 8th data point. This strain gauge had a gauge factor of **2.100**. As seen in *Figure 1*, the resulting strains for the single strain gauge showed a relatively consistent linearity as the displacement increased towards the maximum displacement versus when the displacement decreased back towards the original starting location. Using both the raw data listed in *Table 4* and Eqn. (4) (used in MATLAB) shown below, the predicted strain was calculated and compared to the strain measured via MATLAB (refer to *Annex B*).

$$\epsilon_{Predictied} = \frac{3 * \left(\frac{t}{2}\right) * d * (L - x)}{L^3} \tag{4}$$

Refer to Annex A for equation derivation and explanation

As previously mentioned, when referring to *Table 4*, the predicted strain for the single strain gauge was equal to **5.751e-04** when calculated with the equation above. The measured strain and predicted strain were compared utilizing Eqn. (2) (used in u) shown below to derive a percent difference between the two values. The resulting percent difference was approximately **11.92%**.

$$\% \, Error = \left| \frac{Approx.\ Data - Exp.\ Data}{Exp.Data} \right| * 100 \tag{2}$$

Table 2 contains the tabulated strain and displacement values for the 45° rosette strain gauge at the 8 points of measurement – ascending by **1.14 mm** displacements until the 8th and final data point. The rosette strain gauge is composed of three different gauges – each with independent gauge factors. These gauges had the following gauge factors: Gauge A = **2.060**, Gauge B = **2.070**, Gauge C = **2.060**. As a result of these independent gauges, each displacement has three separate strains that correlate to gauges A, B, and C. Utilizing the rosette MATLAB code, Eqn. (4) for the predicted strain, and the raw data listed in *Table 4*, the predicted strains were calculated. Similarly, to the calculations for the single strain gauge, the strain at the maximum displacement for all three gauges was calculated with MATLAB. The measured strains for each gauge were all compared to the predicted strain from Eqn. (4) listed above by measuring the percent difference from Eqn. (2). The resulting percent differences are approximated as follows: **46.59%** for Gauge A, **23.36%** for Gauge B, and **103.58%** for Gauge C.

The principal strains for each gauge of the rosette strain gauge were calculated using several equations. The first equation necessary is Eqn. (6) to find the average strain and center of Mohr's Circle. The succeeding equation to use would be Eqn. (7) to find the radius of Mohr's Circle and the distance to each principal strain. Thus, the final equation to use is Eqn. (8) which represents the center of Mohr's circle plus or minus the radius to find the first and second principal strains. The previous equations mentioned are all shown below.

$$\epsilon_{Average} = \frac{\epsilon_A + \epsilon_C}{2} \tag{6}$$

$$R_{Mohr's\ Circ.} = \sqrt{\left(\frac{\epsilon_A - \epsilon_C}{2}\right)^2 + \left(\frac{G_{xy}}{2}\right)^2} \tag{7}$$

$$\epsilon_{1,2} = \epsilon_{Average} \pm R \tag{8}$$

The average principal strains were **-9.392e-05** for the lower bound (ϵ_2) and **2.378e-04** for the upper bound (ϵ_1) and they were plotted in *Figure 3* on a principal strain versus displacement graph with best fit lines. Utilizing the measured strains and shear strain from MATLAB, the principal angle was calculated via Eqn. (9) listed below. The principal angle that was measured from the lab was approximately **15.5°** and the average principal angle was calculated to be **18.43**°, counterclockwise with respect to the horizontal axis along the beam. This value is shown in *Figure 3*. Based on these angles, the error is approximately **18.89%** calculated from Eqn. (2).

$$\theta_P = \frac{\tan^{-1}\left(\frac{G_{xy}}{\epsilon_A - \epsilon_C}\right)}{2} \tag{9}$$

Another value that was calculated/predicted was Poisson's ratio. Using both principal strains in Eqn. (3) (listed below) and the MATLAB code, Poisson's ratio for the brass specimen used was calculated to be **0.3660**. The Poisson's ratio listed in the course textbook (refer to references) for brass is **0.34** – indicating minimal error in the calculation of Poisson's ratio and both principal strains. Based on these values, the error equates to approximately **7.658%** calculated from Eqn. (2).

$$v = \frac{-\epsilon_1}{\epsilon_2} \tag{3}$$

When referring to the error produced from these values, there are several different reasons for why the predicted values may differ from their actual values. For instance, the mechanical instrument utilizes a ball-shaped tip on the micrometer which may not read the proper displacements. Additionally, the system may have some hysteresis or backlash within the tool, meaning that the dial may not be turning as accurately as the user thinks. Based on the data collected, there appeared to be less error with the calculations for the single strain gauge than compared to the rosette strain gauge calculations.

DISCUSSION QUESTIONS

1. A sketch of a strain gauge with its gauge length and direction shown in *Figure 5*. Long gauge length sensors are usually used for strain measurements on inhomogeneous materials. One advantages of having a long gauge length sensor is that they are easier to deal with when it comes to the installation process.

Another advantage of a longer gauge is that they provide more efficient heat dissipation since they have a smaller wattage per unit grid area which is beneficial when it comes to testing because heat dissipation could affect gauge performance. A disadvantage of having a long gauge length sensor is that they tend to cost more while still having about the same life span, elongation, and stability as a shorter gauge which will cost less.

2. A Wheatstone Bridge is a sensing circuit that connects to a strain gauge and computation device such as MATLAB to transform minute changes in electrical resistance into a strain measurement. The Wheatstone bridge is a suitable approach for strain gauge applications because it can detect very small resistance changes which is essential when working with very small deformations of a prismatic beam. It is also widely used due to its ability to have zero voltage when at zero position and it provides compensation for resistance changes in the circuit due to fluctuations in temperature. The three-wire Wheatstone Bridge is used as opposed to the two-wire circuit due to its ability to automatically compensate for the electrical resistance changes caused by temperature changes in the lead wire. The three-wire circuit has a lead wire in series with the strain gauge and a second lead wire in series with a dummy resistor.

3. A strain gauge utilizes a wire that deforms when the beam it is placed on deforms. This deformation changes the electrical resistance of the wire which is transformed into a strain measurement for the beam. The electrical resistance of the strain gauge is calculated using the following equation:

$$R = \frac{pLF\varepsilon}{A} \tag{1}$$

From this equation it shows that the resistance of the wire has a proportional relationship to the resistivity, length, gage factor, and strain. There is also an inversely proportional relationship to the area of the wire. The sensitivity of the wire will increase if the resistivity, length, gage factor, or strain increases or if the area decreases.

4. Poisson's ratio is derived from the principal strains in a prismatic tensile bar under a uniaxial stress state and it is defined by a change in the transversal length divided by a change in the axial length (Eqn. (3)). When a beam undergoes bending, there are also changes to the transversal and axial length, which is why Poisson’s ratio applies. In this scenario, the principal strains are calculated. This is only considering the beam in a uniaxial stress state. Furthermore, by using the principal strains the bending moment is ignored. The bar also has a uniform cross section and the face on which the strain gauge is placed is in tension. Since both criteria for deriving Poisson’s ratio are met, it can be calculated in this case even though the beam is under bending.

5. While the data collected in Part 1 and Part 2 should be similar across all groups using the same material, it will not be the same due to the sources of error in the experiment. The largest source of error is from the beginning of the lab when setting the micrometer to its initial position. Here, the micrometer is supposed to just touch the beam without bending it to find the zero position. However, if the micrometer is set slightly too low or high the displacements will be off and won’t produce the same strains. There are also errors in the micrometer itself that could differ between each test or lab set up that could give different strain measurements. This includes the inherent hysteresis of the micrometer and the fact that the sphere at the tip might not be positioned straight. The latter will cause a shorter displacement than necessary as the sphere rotates around an axis that is not aligned with its diameter, and the former will cause a lagging effect where the displacements as the beam is rising back to zero differs from its displacement on the way down.

6. Shear stress in the beam should not affect the calculations for strain because strain gauges are only able to calculate strain in one direction. Since the strain gauge is positioned longitudinally, it will only sense strain along this axis. Shear stress is parallel to the cross-sectional area so it will have no effect on the strain gauge. The strains calculated through MATLAB are the normal strains and these are the only values that affect the rest of the calculations. Therefore, shear stress should not affect any of the strains that are calculated.

7. Strain gauge technology is greatly dependent on temperature changes. As electric current flows through the wire, it is more susceptible to temperature changes that affects the resistance of the wire and therefore the strain calculation. This is especially prominent in a two-wire circuit because there is no temperature compensation in this setup. Therefore, a Wheatstone Bridge circuit is widely used for strain calculations. This circuit has two lead wires as opposed to one and if they are the same material and length, they will have the same resistance. The symmetrical setup of this bridge allows it to remain balanced even when exposed to temperature fluctuations as the lead wires balance out.

ACKNOWLEDGMENTS

Group 1 would like to acknowledge Chriss Pratt for being an amazing help during the lab. Chris Pratt was very informative and helpful when it came to setting up and performing the lab. In addition, Chris Pratt did a great job at testing the group’s knowledge through several questions relating to the material centered around the lab. Group 1 would also like to thank Jose for taking time to check the lab write up and answering all questions and concerns. As a final point, the group was also very appreciative of one another for effectively participating, communicating, and dedicating time to the required work for this lab.

REFERENCES

Goodno, Barry J., and James M. Gere. Mechanics of Materials. Cengage Learning

Student Manual for Strain Gage Technology. Vishay Measurements Group, Inc.

ANNEX A

FIGURE 1
Single Strain Gauge – Strain Vs. Disp. Curve

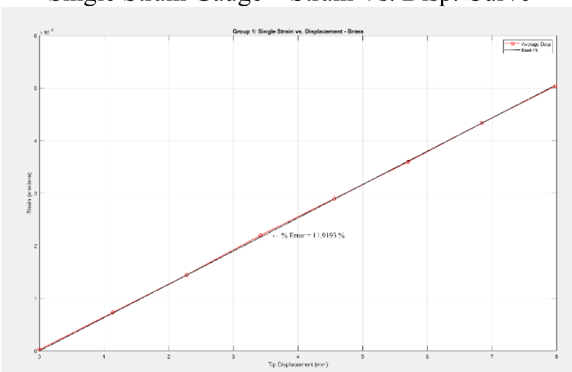

FIGURE 2
Rosette Strain Gauge - Strain Vs. Disp. Curve

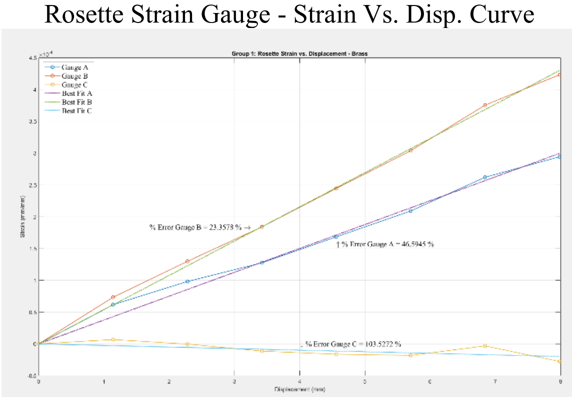

FIGURE 3
Rosette Strain Gauge – Principal Strain Vs. Disp.

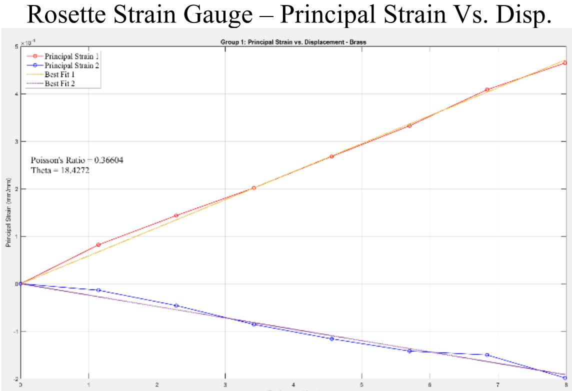

FIGURE 4
Brass Strain Gauge – Wire Setups

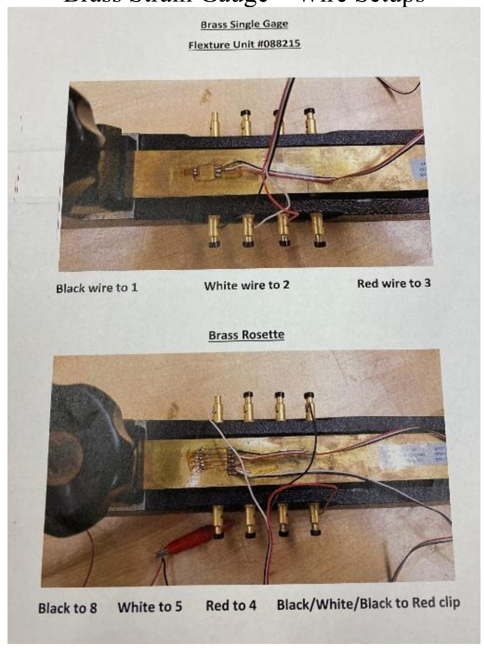

FIGURE 5
Problem 1 Image – Strain Gauge Direction & Length

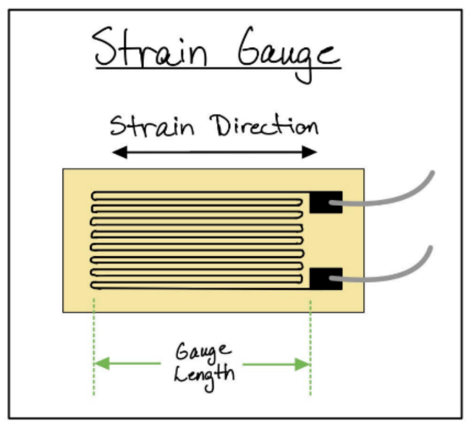

FIGURE 6
Diagram of Cantilever Beam Used in Strain Gauge Testing

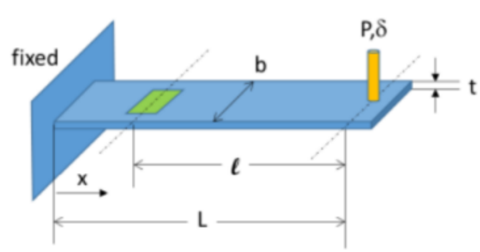

TABLE 1
Displacement & Strain Measurements – Brass Single Strain Gauge Beam

Data Point	Tip Displacement (mm)	Strain (mm/mm)
1	0.00	0.000e-00
2	1.14	7.197e-05
3	2.28	1.435e-04
4	3.42	2.212e-04
5	4.56	2.896e-04
6	5.70	3.590e-04
7	6.84	4.335e-04
8	7.98	5.039e-04
9	6.84	4.332e-04
10	5.70	3.600e-04
11	4.56	2.897e-04
12	3.42	2.185e-04
13	2.28	1.459e-04
14	1.14	7.456e-05
15	0.00	4.723e-06

TABLE 2
Displacement & Strain Measurements – Brass Rosette Strain Gauge Beam

Data Point	Tip Displacement (mm)	Gage A - Strain (mm/mm)	Gage B - Strain (mm/mm)	Gage C - Strain (mm/mm)
1	0.00	0.000e-00	0.000e-00	0.000e-00
2	1.14	6.171e-05	7.334e-05	6.698e-06
3	2.28	9.812e-05	1.299e-04	-3.106e-07
4	3.42	1.275e-04	1.840e-04	-1.135e-05
5	4.56	1.683e-04	2.445e-04	-1.623e-05
6	5.70	2.081e-04	3.037e-04	-1.811e-05
7	6.84	2.621e-04	3.755e-04	-3.182e-06
8	7.98	2.942e-04	4.233e-04	-2.759e-05

TABLE 3
Tip Displacement Table – Strain Gauges

Data Point	Micrometer Position (mm)	Displacement (mm)
1	25.00	0.00
2	23.86	1.14
3	22.72	2.28
4	21.58	3.42
5	20.44	4.56
6	19.30	5.70
7	18.16	6.84
8	17.02	7.98

TABLE 4
Raw Data Measurements – Single and Rosette Strain Gauges

	Single Strain Gauge	**Rosette Strain Gauge**
***t* (in)**	0.1350	0.1350
***w* (in)**	0.9650	0.9650
***l* (in)**	8.858	8.661
***L* (in)**	9.941	9.941
$\epsilon_{Predicted}$	5.751e-04	5.623e-04

TABLE 5
MATLAB Data Calculated – Single Strain Gauge

	Single Strain Gauge
% Error of Computed Maximum Strain	11.91 %
$\epsilon_{Predicted}$	5.751e-04

TABLE 6
MATLAB Data Calculated – Rosette Strain Gauge

	Rosette Strain Gauge
$\epsilon_{Predicted}$	5.623e-04
Poisson's Ratio (ν)	0.3660
Principal Angle (θ_P)	18.43°
% Error of Poisson's Ratio	7.658 %
% Error of Principal Angle	18.89 %
Shear Strain (G_{xy})	3.311e-04
Principal Strain 1	2.717e-04
Principal Strain 2	-1.073e-04
% Error Gauge A	46.59 %
% Error Gauge B	23.36 %
% Error Gauge C	103.5 %
$R_{Mohr's\ Circ.}$	1.895e-04
Average Principal Strain	8.221e-05
Strain At Maximum Displacement – Gauge A	3.003e-04
Strain At Maximum Displacement – Gauge B	4.310e-04
Strain At Maximum Displacement – Gauge C	-1.983e-05

PRELAB DERIVATION

$$\sum M_x = 0 = -PL + M_o \tag{10}$$

Here the sum of the moments around the fixed end of the cantilever beam shown in *Figure 6*.

$$M_o = PL \tag{11}$$

The moment caused by the fixed end of the cantilever beam (M_o) is then calculated from this equation.

$$M(x) = Px - PL \tag{12}$$

The total bending moment along any section of the beam can be calculated from Eqn. (12). Here the moment caused by the force on the end of the beam is P*x as it varies as you move along the x-direction of the beam.

$$EI\frac{d^2y}{dx^2} = Px - PL \tag{13}$$

Now the second-order differential equation for the deflection curve for the beam is applied and the total bending moment calculated in Eqn. (12) is substituted in for M.

$$EI\frac{dy}{dx} = \frac{Px^2}{2} - PLx + C_1 \tag{14}$$

Eqn. (13) is integrated, and this equation is derived. As seen in *Figure 6*, since the beam is fixed on the left end, the deflection at this end is zero. The x position at this end is also zero. If this initial condition is applied to Eqn. (14), C1 can be found to equal zero.

$$EIy = \frac{Px^3}{6} - \frac{PLx^2}{2} + C_2 \tag{15}$$

If Eqn. (14) integrated, this equation is derived. The initial condition for this equation is zero deflection where x equals zero. By applying this to Eqn. (15) it is found C2 is also equal to zero.

$$\delta = \frac{PL^3}{3EI} \tag{16}$$

This equation is found from Eqn. (15) when the initial conditions are applied. Y is the displacement of the beam so here it is subbed for delta

$$\sigma = E\epsilon \tag{17}$$

Hooke's Law is applied to translate the displacement measurement into a strain measurement.

$$\sigma = \frac{-My}{I} \tag{18}$$

The equation for bending stress is applied to turn displacement measurement into strain measurement.

$$\epsilon = \frac{-Mt}{2EI} \tag{19}$$

This equation is derived by combining Eqn. (17) and Eqn. (18). The derivation for strain is finished by replacing M in Eqn. (19) with Eqn. (12). The final strain equation is shown in Eqn. (4) and is used to calculate the predicted strain in a cantilever beam undergoing bending.

ANNEX B

MATLAB Code

Part I: Single Strain Gauge

```
clear all, close all

% Import data from .mat file
data = load('lab2_group1_single.mat');
disp = data.disp'; % load displacement into array
strain = data.strain'; % load strain into array

% Average data
% On the right side, there are 15 values in each array representing 8
measurements back and forth
% For each measurement/displacement, take the average value of the forward
and backward strains
disp1 = disp(1:8,:); % forward displacements
```

```
disp2 = flip(disp(8:15,:)); % backward displacements - flip the array to
align with forward disp
strain1 = strain(1:8,:); % forward strain
strain2 = flip(strain(8:15,:)); % backward strain - flip the array to align
with forward strain
disp_avg = (disp1 + disp2)/2; % average displacement - or just 0-8 [mm] in 8
increments
strain_avg = (strain1 + strain2)/2; % average strain measurements

% Plot Strain vs. Displacement
plot(disp_avg,strain_avg,'ro-','linewidth',1)
set(gcf,'Units','Normalized','OuterPosition',[0 0 1 1]); % expand window
xlabel('Tip Displacement (mm)')
ylabel('Strain (mm/mm)')
title('Group 1: Single Strain vs. Displacement - Brass')

% Plot best-fit line
slope = disp_avg\strain_avg; % Slope of best-fit line
hold on, grid on
plot(disp_avg,disp_avg*slope,'k:','linewidth',1.5);
legend('Average Data','Best-Fit');

% Calculate predicted strain (Pre-lab)
t = 0.135; % thickness of beam [in]; 3.42mm
w = 0.965; % width of beam [in]; 24.5mm
L = 9.941; % length of beam [in]; 25.25cm
l = 8.858; % length between gauge and micrometer [in]; 22.5cm
x = L - l; % x = L - l [in]
d = 8/25.4; % disp at tip [in]
epsilon = (3*(t/2)*(L-x)*d)/L^3; % compute predicted strain

% Calculate measured strain at max disp using best fit line
s = slope*8; % compute measured strain at max disp 8mm based on best-fit line

% Compare the predicted strain (Pre-lab) and measured strain at max disp
(best-fit line)
error = abs(100*(s-epsilon)/epsilon); % calculate percent of difference

% Plot the error percent onto Strain vs. Displacement plot using
text(x,y,...) command
txt = ['\leftarrow % Error = ', num2str(error), ' %'];
t = text(3.6,strain_avg(4),txt); t.FontSize = 14; t.FontName = 'Times New
Roman';
```

Part II: Rosette Strain Gauge

```
clear all, close all

% Import data from .mat file
data = load('lab2_group1_rosette.mat');
disp = data.disp'; % load displacement into array
strain = data.strain; % load strain into array
strainA = strain(:,1); strainB = strain(:,2); strainC = strain(:,3);

% Plot Strain vs. Displacement
plot(disp,[strainA,strainB,strainC],'-o','linewidth',1);
set(gcf,'Units','Normalized','OuterPosition',[0 0 1 1]); % expand window
```

```
xlabel('Displacement (mm)');
ylabel('Strain (mm/mm)');
title('Group 1: Rosette Strain vs. Displacement - Brass');
hold on, grid on

% Plot best-fit line
for i = 1:3 % loop through 3 strain data sets
    s(i) = disp\strain(:,i); % calculate slope of each line
    plot(disp,disp*(s(i)),':','linewidth',1.5); % plot best-fit lines
end
lgd1 = legend('Gauge A','Gauge B','Gauge C','Best Fit A','Best Fit B','Best
Fit C','location','NorthWest');
lgd1.FontSize = 14; lgd1.FontName = 'Times New Roman';

% Calculate predicted strain (Pre-lab)
t = 0.135; % thickness of beam [in]; 3.42mm
w = 0.965; % width of beam [in]; 24.5mm
L = 9.941; % length of beam [in]; 25.25cm
l = 8.661; % length between gauge and micrometer [in]; 22cm
x = L - l; % x = L - l [in]
d = 8/25.4; % disp at tip [in]
epsilon = (3*(t/2)*(L-x)*d)/L^3; % compute predicted strain - same for 3
gauges

% Calculate measured strain at max disp using best fit line
% Slope of lines are already defined in Step 3: s(j) with j = 1, 2, 3
corresponds to slope A, B, C
sA = s(1)*8; % compute measured strain A at max disp 8mm based on best-fit
line
sB = s(2)*8; % compute measured strain B at max disp 8mm based on best-fit
line
sC = s(3)*8; % compute measured strain C at max disp 8mm based on best-fit
line

% Compare the predicted strain (Pre-lab) and measured strain at max disp
(best-fit line)
errorA = abs(100*(sA-epsilon)/epsilon); % calculate percent of difference for
gauge A
errorB = abs(100*(sB-epsilon)/epsilon); % calculate percent of difference for
gauge A
errorC = abs(100*(sC-epsilon)/epsilon); % calculate percent of difference for
gauge A

txtA = ['\uparrow % Error Gauge A = ', num2str(errorA), ' %'];
txtB = ['% Error Gauge B = ', num2str(errorB), ' % \rightarrow '];
txtC = ['\downarrow % Error Gauge C = ', num2str(errorC), ' %'];

tA = text(4.56,0.000157,txtA); tA.FontSize = 14; tA.FontName = 'Times New
Roman';
tB = text(1.7,0.000184,txtB); tB.FontSize = 14; tB.FontName = 'Times New
Roman';
tC = text(4,0,txtC); tC.FontSize = 14; tC.FontName = 'Times New Roman';

% Calculate principal strains
ea = strain(:,1); % define strain of each gauge
eb = strain(:,2);
ec = strain(:,3);
```

```
% Calculate Mohr's circle parameters (Refer to Example 7-8 in textbook for
rosette strain)
Gxy = 2*eb-(ea+ec); % shear strain
C = (ea+ec)/2; % average strain
R = sqrt(((ea-ec)/2).^2+(Gxy/2).^2); % radius of Mohr's circle
e1 = C + R; % principal strains
e2 = C - R;

% Plot principal strains
figure % New figure created to separate from Strain vs. Displacement plot in
Step 3
plot(disp,e1,'r-o',disp,e2,'b-o','linewidth',1);
set(gcf,'Units','Normalized','OuterPosition',[0 0 1 1]); % expand window
xlabel('Displacement (mm)');
ylabel('Principal Strain (mm/mm)');
title('Group 1: Principal Strain vs. Displacement - Brass');
hold on, grid on

% Plot best-fit lines
slope1 = disp\e1; % Slope of best-fit lines
slope2 = disp\e2;
plot(disp,[disp*slope1,disp*slope2],':','linewidth',1.5);
lgd2 = legend('Principal Strain 1','Principal Strain 2','Best Fit 1','Best
Fit 2','location','northwest');
lgd2.FontSize = 14; lgd2.FontName = 'Times New Roman';

% Calculate angle of maximum principal strain
theta = atand(Gxy/(ea-ec))/2;

% Compare the measured angle of maximum principal strain with calculated one
measured_angle = 15.5; % your measured angle
error_angle = abs(100*(theta-measured_angle)/measured_angle);

% Calculate Poisson ratio
v = -e2(2:end)./e1(2:end);

txtbook_v = 0.34; % Poisson ratio of brass; pg 992
error_v = abs(100*(v-txtbook_v)/txtbook_v); % percent difference

% Compute averages for data
Gxy_avg = mean(Gxy(2:end));
ps1 = mean(e1(2:end));
ps2 = mean(e2(2:end));
v_avg = mean(v); v_error = abs(100*(v_avg - 0.34)/0.34);
theta_avg = mean(theta(:,8)); theta_error = abs(100*(theta_avg - 15.5)/15.5);
R_avg = mean(R(2:end)); C_avg = mean(C(2:end));

fig_txt = ['Poisson' '''s Ratio = ', num2str(v_avg), newline...
    'Theta = ', num2str(theta_avg)];
fig_t = text(0.15,0.00025,fig_txt); fig_t.FontSize = 16; fig_t.FontName =
'Times New Roman';
```