Weight Estimation Using Strain Gauge

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***Abstract*—This lab aims to estimate the weight of a Gatorade bottle using two different methods via a quarter Wheatstone-bridge strain gage. It also measured the weight of the average gulp and the uncertainties of both types of methods. The first method is the calibration method which plots weight vs. ΔV_{amp} and finding the slope. The second method is the mechanics of materials method which uses the geometry of the cantilever beam and the strain calculated by the strain gage to estimate the weight. The first method produced a weight of 2.7 ± 0.00125 N, and the second method produced a weight of ± 0.00745 N. The size of the average gulp using the first method was .168 N, and 0.215 N for the second method. These results demonstrate that the mechanics of materials method was much more accurate and precise than the calibration method.**

***Index Terms*— Strain, Stress, Uncertainty, Weight, Wheatstone-Bridge**

I. INTRODUCTION

This lab observes how to estimate the weight of an object on a 6061 T6 Aluminum Bar using a strain gage. This lab measures the change in voltage across a Wheatstone bridge to determine the amount of strain that is induced in the gage. Once these values are determined it will discuss its respective uncertainties and what one can infer from the results. There are two main methods of estimating stress: (1) from the calibration curve and the ΔV_{amp} (calibration method) and (2) from the geometry of the cantilever beam (Mechanics of Materials Method). These two methods will be compared after the experiment to determine which was more accurate and precise [1 pp. 81-82].

This lab utilizes a strain gage and a Wheatstone bridge to determine the weight of various items. A weight is placed at the end of the aluminum bar and its weight will be estimated by using the gage factor of the strain gage to find the stress and strain. Then the weight is estimated by using a calibration curve for known weights. The lab also measures the weight of an average gulp my taking measurements of a liquid and then taking gulps of roughly the same volume and measuring the weight difference between each gulp.

This lab in particular is using a quarter Wheatstone bridge that is adhered to one side of a 6061 T6 Aluminum bar. The strain can be calculated by using the following equation:

$$\varepsilon_x = \frac{4(\Delta V)}{V_s G_f} \tag{1}$$

Where V_s is the supply voltage, G_f is the Gage factor, and ΔV is the change in voltage from when there is no load to when its loaded. The stress is assumed to be 1D so we can use Hooke's law to determine the stress as:

$$\sigma_x = E\varepsilon_x \tag{2}$$

Where E is the young's modulus of the 6061 T6 Aluminum bar and ε_x is the strain in the x-direction. Once the stress and strain are calculated the estimation of the weight of the object can be determined by using the equation:

$$W = \left(\frac{Ebh^2}{6L}\right) \cdot \frac{4(\Delta V)}{V_s G_f} \tag{3}$$

Where W is the weight of the object in N, b is the base of the aluminum bar in m, h is the height of the aluminum bar in m, and L is the distance from the strain gage to the applied force in m. Before computing the strain, the calibration constant needs to be determined to determine the amplified ΔV. This is determined by plotting known weights vs. ΔV_{amp} and its slope is the calibration constant [1 pp. 70-73].

Once this lab measures and estimates the weight of the applied forces it can be compared to the actual force that was applied and we can produce a percent error of our strain-gage and determine its effectiveness. This lab combines electronics (strain-gage) with mechanics of materials methods to determine the weight of various objects by utilizing a change in voltage since strain and stress can't be measured directly, they have to be calculated from a change in something natural, i.e. voltage.

II. PROCEDURE

Materials

The materials that were needed to complete this lab are as follows: Laptop with an updated LabVIEW VI that functions with a DAQ, calipers, Gatorade, various weights, a scale, 6061 T6 Aluminum bar used as a cantilever beam, a strain gage amplifier with a Wheatstone-bridge, and a power supply for the DAQ.

Experimental Procedure

The first step that was completed was to produce a new and updated LabVIEW VI that functioned with the DAQ. The VI would use the change in voltage when the cantilever beam was loaded and then it would estimate the load based off of that value, the supply voltage, and the gage factor. The VI then displayed the change in voltage vs. time on a graph. After this the DAQ was powered and the strain gauge from the beam was wired to the breadboard. The complete setup of how the DAQ and strain gage was connected to the breadboard can be seen in the following image.

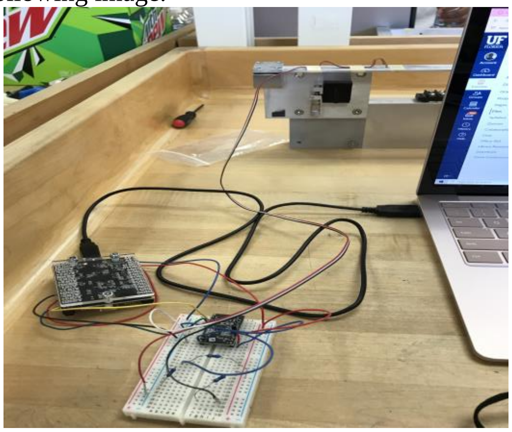

Fig. 1. This is how to setup the DAQ and strain gage

After all of the electronics were set up, the next step was to input the measurements of the cross-sectional area of the beam and the distance from the strain gage to the applied load. Then the V_{amp} had to be tared to get the base value so accurate measurements and inferences could be made. After the value was tared various weights of increasing magnitude were placed on the cantilever beam and then a plot of Weight vs. ΔV_{amp} was created to determine the calibration constant of the strain gage (the calibration constant is the slope of the trendline) [1 pp. 70-72].

The final step that was completed was to use Gatorade and measure it 10 times to determine the repeatability and accuracy of the newly calibrated strain gage. After the uncertainty of the of strain gage was determined the lab measured the weight of an average gulp. This was achieved by measuring the full cup of Gatorade and then taking a second-long gulp and then measuring it until the Gatorade was empty. The change in weight can then be calculated using the change in voltage.

After all of the steps of the lab were completed a Monte Carlo Simulation was utilized to estimate the uncertainty of the linear fit of the weight's vs ΔV_{amp} graph [4].

III. Results

The measured values of the cross-sectional area (base and height) and length from strain gage to the applied force were 0.025m, 0.003m, and 0.17m respectively. These measurements were taken from a caliper to ensure accuracy. The calibration constant was $103.69\frac{N}{V}$ and was found from the slope of the following trendline of weight vs. ΔV_{amp}.

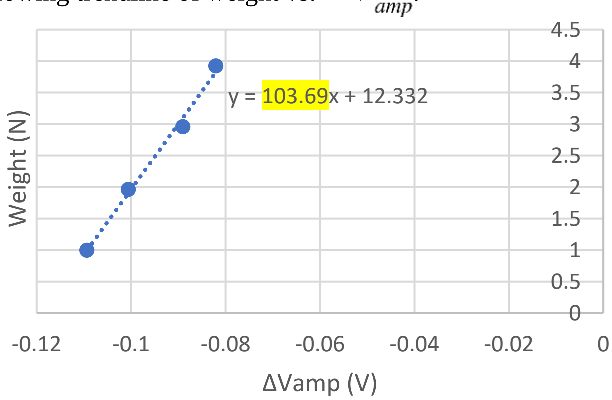

Fig. 2. This curve illustrates the Weight vs. ΔV_{amp} and is how to calculate the calibration constant

The change in voltage for the average gulp was 0.0019 V with a standard deviation of 0.00142 and was found by finding the difference between the voltage after every sip and then averaging all of them. The calibrated weight of the full bottle of Gatorade was 3.869N and the calibrated weight of the empty Gatorade bottle was 0.198N. The tare value for V_{amp} was 0.0533714 V. The change in voltage vs time for the gulp size can be observed below.

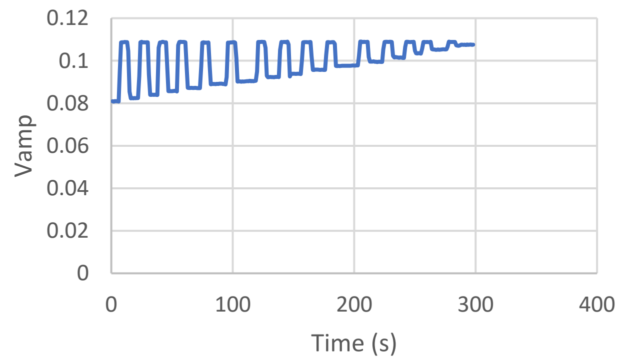

Fig. 3. This shows the change in V_{amp} vs. time when the Gatorade bottle was losing volume

IV. Discussion

This lab aims to examine the accuracy, precision, and repeatability of the use of a strain gage with a Wheatstone-bridge. The values this lab investigates are as follows: the maximum weight capacity of the 6061 T6 Aluminum beam, estimated weight from the calibration curve, estimated weight from the Mechanics of Materials method, average weight and standard deviation of a gulp, and the uncertainties of each method. These calculations will be determined by utilizing the Weight vs ΔV_{amp} graph, using the change in voltage to determine the stress, and using the uncertainty equations for each value. The key results that were found was that the maximum weight of the 6061 T6 Aluminum beam was 52.9 N ± 0.00098, the weight of the average gulp was 0.215 N (MOM method) and 0.168 N (calibration method).

The maximum weight the aluminum beam can withstand is much larger than the largest weight that the beam was subjected to (full Gatorade bottle). The full Gatorade bottle was approximately 13 times below the maximum weight capacity so it can be ensured that the beam did not plastically deform since it was within its elastic limit.

The mean and standard deviation of the full Gatorade bottle for the mechanics of materials method were 3.63 ± 0.00745 N, and 0.0597N. The mean and standard deviation of the full Gatorade bottle by using the calibration method were 2.7± 0.00125 N and 0.0346N. The weight of the full Gatorade bottle given by the commercial scale was 3.89 ± 0.00098 N. Comparing these two methods, the MOM method produced a more accurate weight since it was closer in value to the actual weight, and the calibration method produced a more precise result since it had a low standard deviation and variance. The method chosen to represent the mean and standard deviation of the full Gatorade bottle is the MOM method since it was closer

to the actual value and its standard deviation wasn't significantly greater than the
calibration method making it an overall better result. The uncertainties of the two methods to estimate weight are similar but illustrate how one method is superior. The calibration method produced a much lower uncertainty illustrating that the results are more reliable and precise. The uncertainty propagated at a much slower rate and was found using the Monte Carlo simulation.

Weighing the Gatorade bottle 10 times and then using a 95% confidence interval determined that the statistical uncertainty of the weight of the unopened beverage was 0.00645 N. Weighing the can using the strain gage produced a larger uncertainty value than the commercial scale. Even though it is less accurate, it still suggests that it has high repeatability due to its precision. Something that affects the uncertainty of the strain gage is how far you place the item from the strain gage (L). If it is farther away it will produce a higher uncertainty because then the uncertainty in L will propagate at a faster rate.

The mean and standard deviation of the average gulp size is 0.168N and 0.0011N. The method chosen was the calibration method since it had a lower standard deviation value, and it had the most consistent change in weight compared to the MOM method.

Measuring the weight of the empty Gatorade bottle using the strain gage and the commercial scale produced some variance. Measuring it via the MOM method produced the most accurate and precise result, but it was still a factor of 10 more uncertain than using the commercial scale. While it can provide reliable results, the commercial scale proved to be more consistent and efficient for measuring the weight of something.

There are a variety of improvements that could be made to reduce the uncertainty of the strain gage that was used. One of the biggest changes would be to make the strain gage into a full Wheatstone-Bridge to increase its accuracy, range, and precision. Another change that would reduce uncertainty would be to have a more accurate DAQ that had a smaller gain window to produce more accurate results and changes in voltage [3].

The weight of the beam does not affect the calibration of the beam. The calibration of the beam is the slope of the weight vs. ΔV_{amp} graph. If ΔV_{amp} wasn't tared then it would still have the same slope, but it would have a different y-intercept.

There were a variety of limitations that were present within this lab. One was the use of a quarter Wheatstone-bridge instead of a full. Another limitation was the fact that the strain gage can only accurately measure up to 5% of the strain value. If the value was 5% over then it would produce incorrect results and invalidate data [2 pp. 60].

A. Summation of Strain Gage Weight Estimation

This lab determined that the best method of weight estimation via strain gage was to use the MOM method which utilized the geometry of the 6061 T6 Aluminum cantilever beam. It estimated a weight of 3.63 ± 0.00745 N and was less precise but more accurate and reliable than the calibration method. This lab also determined that the average gulp size was 0.215 N utilizing the same method. These results are critical because it illustrates the capability of a strain gage. These strain gages can be applied to almost any surface and if one can measure the geometry of the beam and the applied forces, they can semi-accurately measure its weight. One can also measure the max weight that the material can endure before plastic deformation incurs. This is a non-destructive technique that analyzes the properties of any material. More research needs to be done to see how the effectiveness of these strain gages differ between beam types and different types of strain gages. It would also be beneficial to develop a strain gage that could measure beyond 5% strain for some of the more ductile materials.

APPENDIX

Table 1: Values for Uncertainties

Measurement	Value	Uncertainty
Weight (Scale) (N)	3.89	± 0.00098
Weight (MOM) (N)	3.63	± 0.00745
Weight (Cal Method) (N)	2.70	± 0.00125
L (m)	0.17	±0.0005
H(m)	0.003	±0.00001
B(m)	0.025	±0.00001
V_{tare}(V)	0.0534	± 0.00001
ΔV_{amp}	0.0019	±0.0002
Vg (V)	0.000036	±0.00004
Vs (V)	3.307	±0.00028
Gf	2.1	± 0.220
Calibration Constant (N/V)	103.69	± 0.96
Strain-ϵ	0.000256	± 0.00000045
Elastic Modulus (GPa)-E	68.9	± 0.689
Af	220	± 0.220
Stress-σ (MPA)	17.63	± 0.00385
Resistor -Ω	120	± 0.12

Table 2: Uncertainty Equations

W(Cal)	$U_w=\sqrt{\left(\frac{\partial W}{\partial m}\right)^2 U_m{}^2+\left(\frac{\partial W}{\partial \Delta V_{amp}}\right)^2 U_{\Delta V_{amp}}{}^2}$	(4)
W (MOM)	$U_w=\sqrt{\left(\frac{\partial W}{\partial \sigma_x}\right)^2 U^2_{\sigma_x}+\left(\frac{\partial W}{\partial b}\right)^2 U^2_b+\left(\frac{\partial W}{\partial h}\right)^2 U^2_h+\left(\frac{\partial W}{\partial L}\right) U^2_L}$	(5)
ΔV_{amp}	$U_{\Delta V_{amp}}=\sqrt{\left(\frac{\partial \Delta V_{amp}}{\partial V_{amp}}\right)^2 U^2_{V_{amp}}+\left(\frac{\partial \Delta V_{amp}}{\partial V_{tare}}\right)^2 U^2_{V_{tare}}}$	(6)
Strain- ϵ	$U_{\varepsilon_x}=\sqrt{\left(\frac{\partial \varepsilon_x}{\partial V_g}\right)^2 U^2_{V_g}+\left(\frac{\partial \varepsilon_x}{\partial V_s}\right)^2 U^2_{V_s}+\left(\frac{\partial \varepsilon_x}{\partial G_f}\right)^2 U^2_{G_f}}$	(7)
Stress-σ	$U_{\sigma_x}=\sqrt{\left(\frac{\partial \sigma_x}{\partial E}\right)^2 U^2_E+\left(\frac{\partial \sigma_x}{\partial \varepsilon_x}\right)^2 U^2_{\varepsilon_x}}$	(8)

The uncertainty of the weight of the Gatorade bottle using the calibration method was achieved by running a Monte Carlo simulation to determine the uncertainty in the calibration constant (2*standard deviation), and by using the uncertainty value found in equation (3). The uncertainty of the Gatorade bottle using the Mechanics of Materials method was found by finding the uncertainties of the geometry of the cantilever beam and the uncertainty of the stress at distance L away from the strain gage. The values used were the height, base, and length and then calculations were performed to understand how uncertainties propagated.

The uncertainty in ΔV_{amp} was calculated by equation (6) using the uncertainties of V_{amp} and V_{tare} to determine the overall uncertainty.

The uncertainty of the strain was calculated by determining the uncertainty in V_g, V_s, and G_f and using equation (4) to see how the uncertainty propagated.

The uncertainty of the stress was calculated by using the uncertainty in the Young's Modulus (E) and the uncertainty in the strain (ε_x).

References

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