Measurement of Young's Modulus using Strain Gauges

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***Abstract*— Young's Modulus is a critical piece of information when designing mechanical systems. The goal of this lab is to find the Young's Modulus of a beam. To accomplish this goal strain gauges were used. The data gained from these were converted to stress and strain and then graphed. The slope of the curve fitted line was the Young's Modulus. The Young's Modulus calculated was $\mathbf{1.3(10^{11})}$Pa which was lower than expected but this error can be due to malfunctioning equipment and/or human error.**

I. Introduction

When designing structures and mechanical systems knowing the properties of the materials you are using is critical. One of these critical characteristics is called Young's Modulus. Young's Modulus is the slope of the stress vs. strain curve and can be very useful when studying deformation. Given a beam of steel the objective was to calculate the Young's modulus. Strain gauges were used to calculate the stress and strain which were then plotted. The plot had stress vs. strain and the slope of this plot was the Young's Modulus we were looking for.

II. Methods

In the next sections I will explain how the stain gauges were used and how to convert the voltage differences to usable stress and strain data.

A. *Analysis*

The setup used in this experiment comprised of three major sections, which I will break down further. The parts are the beam apparatus, the instrumentation amplifier and lastly the half arm Wheatstone bridge.

The beam apparatus consists of a metal beam fixed in a cantilever configuration. On the top and bottom of the beam two strain gauges are located. A strain gauge is a resistor that changes it's resistance by small amounts when it is stretched or compressed by the deflecting beam. When a voltage source powers the gauges the voltage difference before and during loading can be measured using a table top DMM.

The instrumentation operational amplifier (AD622) was used to amplify the output voltage from the half arm Wheatstone bridge so that it can be easily read from the table top DMM. The voltages that are being read are the voltages during loading and before loading.

The half arm Wheatstone bridge is a circuit comprising of four resistors. Two of those resistors are the strain Gauges and the other two are precision resistors of the same value.

The experimental setup for this experiment is as follows.

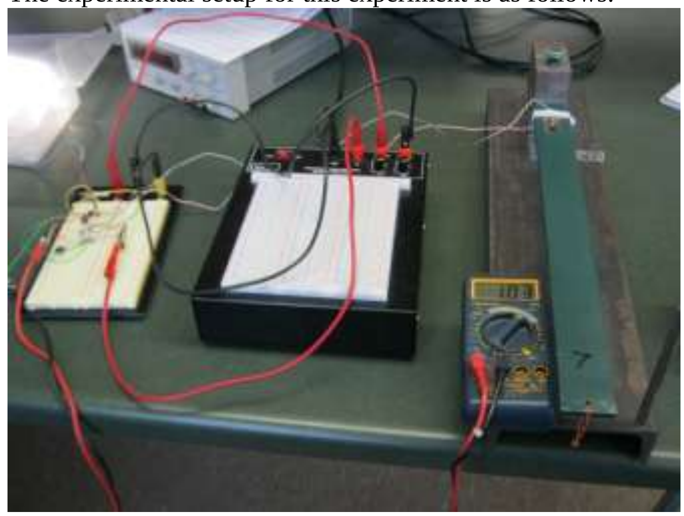


Figure 2- Setup in its entirety.

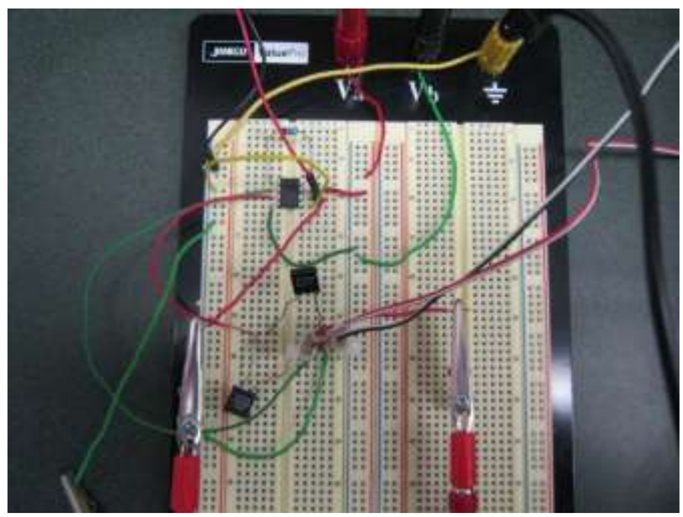


Figure 1- Circuit setup showing the Op Amp and Wheatstone Bridge.

Before the strains could be measured the next thing to be calculated was the gain of the AD622 by using the equation form the AD622's information sheet which is as follows.

$$G = \frac{50.5\ K\Omega}{R} + 1$$

The desired gain for the AD622 needed to be at the least 400 so the resistance (R) was chosen to give above that. The value for gain will come in when calculating the stress and strain.

B. Experimental Program

To calculate the stress and strain known masses where attached to the cantilever beam and the output voltage before and during the loading was recorded for eight different masses. This process was then done again with the exact masses to help our accuracy. To change the voltage reading into stress and strain that can be plotted the following equations for stress and strain can be used.

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

$$\varepsilon = \frac{2(\delta E_o)}{V_{in}(GF)G}$$

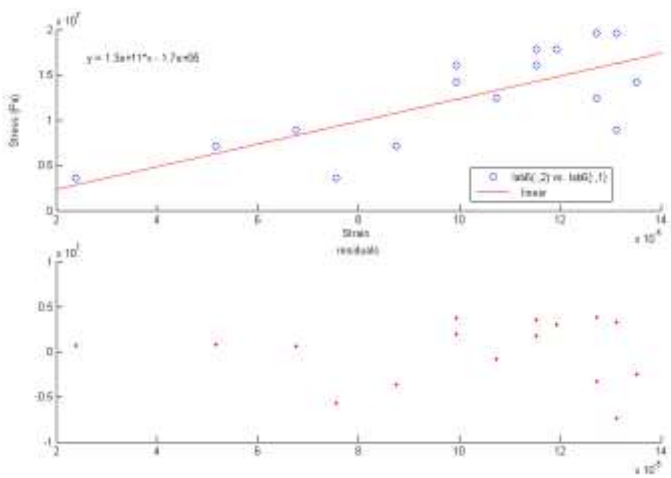
First in the stress equation (σ) the M is the applied moment, y is the distance from the centroid to the top or bottom fibers and I is the moment of inertia of the cross section of the beam.

In the strain equation (ε) the δE_o is the difference in loaded voltage and loaded voltage. The Vi_n is the voltage that is supplied to the Wheatstone bridge and the GF is the gauge factor that is supplied by the manufacturer. Lastly the G is the gain of the Op Amp calculated using the equation above.

To change the voltage differences into stress and strain in an efficient manner the program I decided to use was TK Solver. The list solving features in TK Solver are user friendly and the information outputs are well organized. The TK Solver Report can be viewed at the request of the reader. This stress and strain data was inputted into Matlab and plotted. Using Matlabs curve fitting tools the slope of the data was calculated to give the Young's Modulus (E) of the metal beam.

III. Results

The goal of this study was to find the Young's Modulus (E) of the metal beam. The E is the slope of the stress vs. strain curve. The curve obtained is as follows.
Figure 3-Stress vs. Strain graph showing the slope (E).



The slope of the stress vs. strain curve can be seen in the equation of the curve fitted line. The line follows the equation of $y = mx + b$ where m is the slope of the line. The slope is $1.3(10^{11})$Pa. Knowing that the beam is made of steel the value given in most text books is around $2.0(10^{11})$Pa. The number calculated is off from the standard by a significant amount. This error can be due to the uncertainties of the equipment as well as human error. During the lab I noticed that the equipment being used was not preforming to the standards that I thought were suitable but the TA assured me that because of multiple factors it could lead it to the loss of its accuracy. Some of these factors include the construction of the Wheatstone Bridge or a malfunctioning Op Amp. Using Matlab the standard error of fit for the Young's Modulus was calculated to be 32,343,306.42. This error of the fit is quite large and if this were being done in industry this experiment would be done again to try to lower this error. This error can also be interpreted as the uncertainty of the calculated Young's Modulus.

IV. Discussion and Conclusions

The results for this study were not exactly what was expected but this information means that there was something wrong with the setup in some area however, the fundamental question was answered, "What is the Young's Modulus for this beam"? I think that there is something wrong with the setup but not something major because the answer is off but relatively speaking it is pretty close. Using my basic trouble shooting skills I think that the problem lies in the Op Amp because the voltage readings that we took would not stop fluctuating by significant amounts. The one type of stain not accounted for was transversal strain but in comparison to the axial strain it is quite small. This experiment was in the elastic region of this beam but if it went into the plastic region then the information from the strain gauges would not be valid because E is only the slope of the elastic region. All in all, this lab was very interesting and practical and I can see myself using the knowledge and skills from this lab later as an engineer.