LAB Week 13: Strain Gage Measurement

Wright State University: Mechanical Engineering

ME 3600L Section 01

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Experiment performed on April 6, 2015

Due: April 28, 2015
Instructor: Dr. Zifeng Yang

1. ABSTRACT

In the strain gage measurement lab, the introduction of a strain gages will be made. As well as how to use them in LabVIEW, to calibrate a cantilever beam and to find the ringing frequency of the beam. Two strain gages are attached to the beam being tested. One will be on the top in tension and the other one will be on the bottom in compression when a weight is applied to the beam. However, during the ringing frequency test it varies with the motion. The Wheatstone Half Bridge, Type II allows for the gages to only sense bending strain that is additive, doubling the sensitivity of the sensor. It also helps to eliminate error from temperature effects in the strain gages themselves and within the beam. Thus allowing a more accurate determination of the ringing frequency. The Wheatstone Half Bridge also allows for the relationship between the weight and strain on the beam to be shown. The ringing frequency was found to be approximately 18.4 Hz. The relationship between weight and strain was almost linear; found by analyzing the strain of the beam with several different weights.

2. NOMENCLATURE

f_s – *Sample Frequency (samples/second)*
f – *Frequency (Hz)*
f_N – *Nyquist Frequency*
f_{max} – *Maximum Frequency (Hz)*
f_{nd} – *Ringing Frequency*
GF – *The gage factor.*
$R_g = R_4 =$ *the beginning strain gage resistance, (ohm)*
$R_1 = R_2 = R_3 =$ *the resisters in the circuit which should be as close as possible to* R_g
$R_L = R_{wire\ 1} = R_{wire\ 2} = R_{wire\ 3}$ – *The lead wire resistance.*
T – *Period (second)*
u_d – *The Design-State Uncertainty*
u_o – *The Resolution Uncertainty*
u_c – *The Instrument Uncertainty*
V_{Ex} – *The excitation voltage (Volts)*
V_{CH} – *The measured voltage (Volts)*

3. INTRODUCTION

The objective of this lab is to use strain gages and create a Wheatstone bridge, which creates a sensor capable of calibrating a cantilever beam that can determine the weight. The ringing frequency (natural damped frequency) of the measurement device can be determined with LabVIEW and aid from the Wheatstone bridge. Strain gages can measure the stretch in a material by sensing the resistance change; which is the stretch per unit length of a member caused by mechanical strain. The resistance changed is sensed as a low voltage change across the Wheatstone bridge. LabVIEW is used to present the data collected by with the two strain gages. The Wheatstone Half Bridge, Type II, must be used because there are two gages being used with the need to add the strain, eliminating the possibility of them canceling. In this lab, it is import to calibrate the measurement devices in experiments. It is also needed to calculate the uncertainty of the measurements by using the accuracy values of the equipment.

4. THEORY

Strain gages (Figure 1) can measure strain that occurs when a material is stretched with mechanical strain, by sensing the stretch in a material; which creates a resistance change. Thermal expansion, caused by temperature changes, can cause errors in determining the mechanical strain. The use of the Wheatstone Half Bridge, with two resistors, restricts the effects from thermal expansion should be nearly eliminated. Figure 1 shows strain gages with no load, with a tension load and finally a compression load. The resistance change being sensed as a low voltage across the Wheatstone bridge is the basic use of strain gages. This experiment uses two active strain gages focusing on bending strain created, which is why the Wheatstone Half Bridge, Type II (Figure 2), was chosen. The Half Bridge, Type II, eliminates axial strain, but does leave the possibility of some temperature effects. One strain gage relates output voltage to a resistance as show below assuming all resistors are equal:

$$\frac{\Delta e_o}{e_i} = \frac{\frac{\Delta R}{R}}{4 + 2\frac{\Delta R}{R}}. \tag{1}$$

$$\Delta e_o = \frac{e_i(GF)\varepsilon}{4+2(GF)\varepsilon}\ . \tag{2}$$

Equation 2, relates the output voltage to the strain using a gage factor to make data easier to understand. Equation 1 is only for a system with one strain gage. A modified equation must be made since the experiment involves two strain gages. The new equation is shown in Equation 3.

$$\varepsilon = \frac{-2V_r}{(GF)}\left(1+\frac{R_L}{R_g}\right) \tag{3}$$

$$V_r = \frac{V_{CH}(strained) - V_{CH}(unstrained)}{V_{Ex}}\ . \tag{4}$$

The signal is doubled by having one strain gage measuring the tension and another strain gage measuring compression. The measured strains are then added to double the signal and the sensitivity of the gage. The sampling theorem states that the frequency of the sampling rate must be more than double the maximum frequency being measured. This is expressed in Equation 5 below:

$$fs > 2*fmax\ . \tag{5}$$

The Nyquist frequency is simply half of the sampling frequency, this is used to decide a frequency to generate an accurate signal:

$$f_N = (1/2)*f_s\ . \tag{6}$$

The ringing frequency (natural damped frequency) of the beam can be obtained by causing the beam to vibrate at the end:

$$f_{nd} = f_n\sqrt{1-\xi^2}\ . \tag{7}$$

The damping or natural frequency of this system is unknown, so Equation 7 cannot be used in this experiment. Equation 8 can be used instead by striking the beam and analyzing the waveform created in the plot on LabVIEW.

$$f = 1/T\ . \tag{8}$$

Figure 8 is the unfiltered waveform to be analyzed with Equation 8. Using this equation with the period from figure 8 will be the calculation needed to determine the ringing frequency of the system. Figures 11 through 14 can be used to create an equation for the weight vs. strain scale of the cantilever beam. The slope equation is used to determine the scale since it is a linear relationship.

$$y = m * x + b \ . \tag{9}$$

The uncertainty of the system will be calculated using the RSS method at 95%. To calculate the uncertainty for multiple instruments will be done by using:

$$u_d = \pm\sqrt{u_o{}^2 + u_c{}^2} \ . \tag{10}$$

This is used to determine the total design uncertainty for multiple errors in the system, giving the range the results may vary from the correct value.

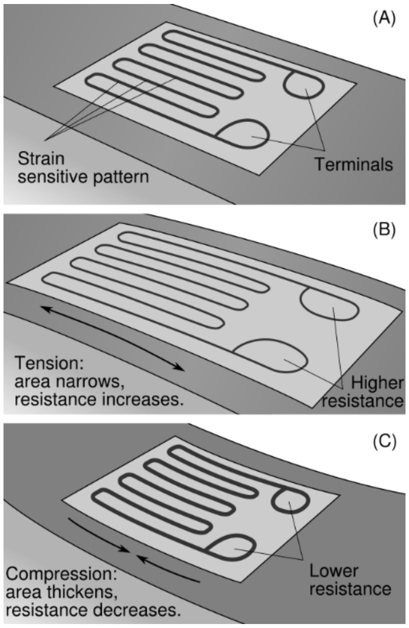


Figure 1: Strain gauge

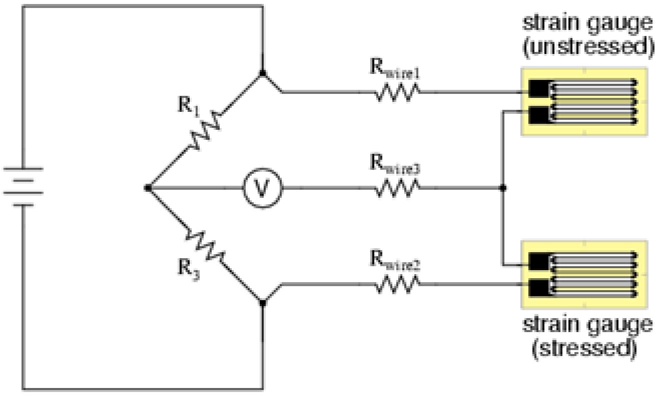


Figure 2: Wheatstone half Bridge Circuit

5. EXPERIMENTAL APPARATUS AND PROCEDURE

The equipment used in this lab was a computer with LabVIEW, data acquisition card, connector box, breadboard, strain gages, OHAUS CS2000 Compact scale with an accuracy of ±1 gram, 350 ohm resistors, aluminum bar, c-clamp, alligator clamp wires, small wires, caliper, three weights and a voltmeter. The computer that was used is seen in figure 6. The data acquisition card (Figure 4) also has a sampling rate maximum of 250 KS/s with no minimum value, with multiple input ranges: ±10, ±5, ±1, and ±0.2 volts. The data acquisition card is a National Instrument 6221 model, which has 8 differential channels and 16 single ended channels. Data is sent to LabVIEW once the card has acquired the signal. The connector box is a National Instruments model SCC-68 which has a power supply of ±15 volts, a max load current of 50 mA, and a tolerance of ±5%. The strain gages used are two SKF-28899 KYOWA linear strain gage with a nominal resistance of 350 ohms, a GF = 2.1, and tolerance of ±1%.

The setup for this lab, which can be seen if Figure 3. The weight part of the lab introduces a lot of human error that will need to be taken note of. The resistors, strain gages and power supply, are first connected to the breadboard making the Wheatstone Half Bridge. The breadboard is then connected to the connecter box that connected to the computer via a cable to the installed data acquisition card. The data acquisition card takes the analog signal and transforms it into a digital signal to be presented on the waveforms in LabVIEW front panel.

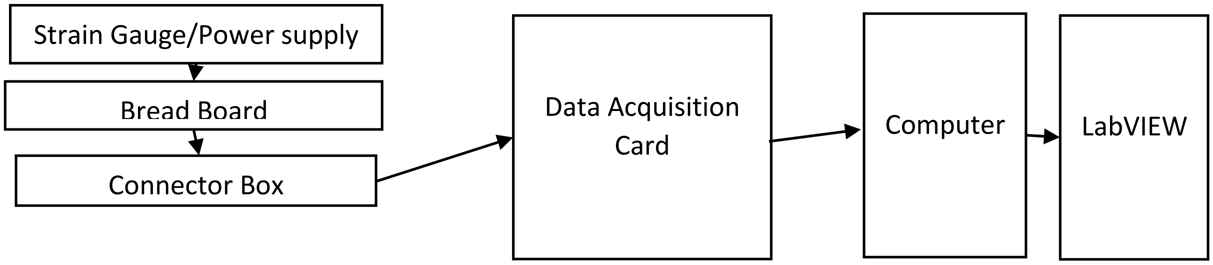
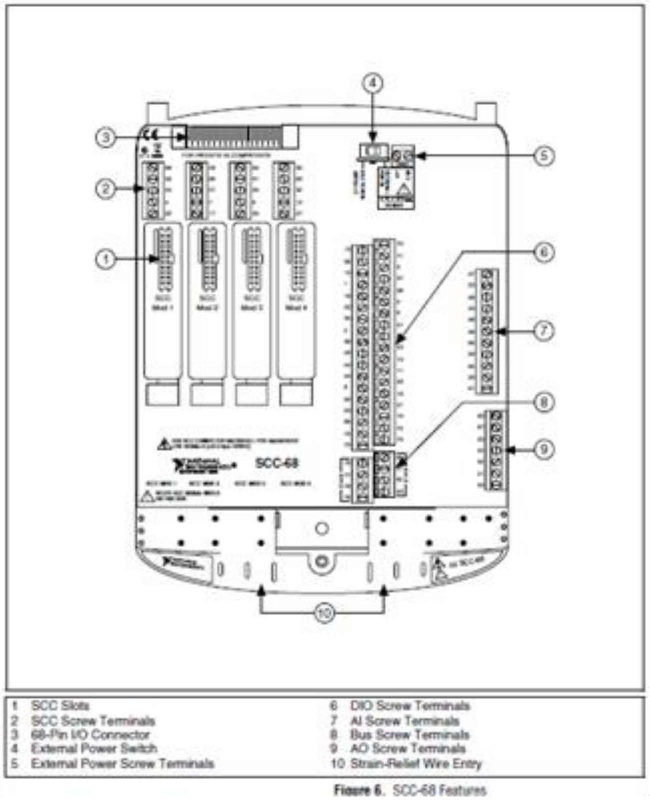


Figure 3: Setup Diagram.

Figure 2 show the correct circuit wire diagram of the Wheatstone Half Bridge that is used in this lab, which will be created on the breadboard. The error of the resistors will be taken at 5%, but this error can be minimized by adjusting the zero point of the system.

To begin this lab, a new program must be created by using LabVIEW on the computer. This is to analyze and save the data. Two small wires must be connected to the connector box from A-7 and A-15 input terminal. The setup shown in Figure 2 is to be built on the breadboard. The power supply and the wires coming out of the connector box will be connected to the correct sections seen in figure 2. The measuring device can be adjusted by measuring the voltage across the circuit and entering the offset value into LabVIEW. The program can then be used to graph the strain with multiple amounts of weight on it; which can be used to create a scale for weight measurement.

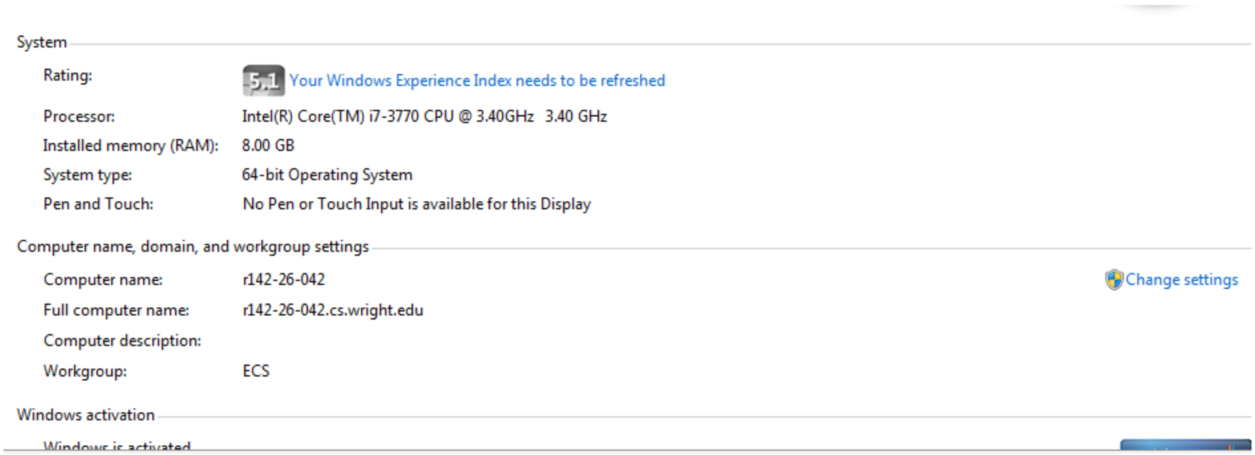
Figure 4: Picture of the Data Acquisition Card (DAQ).



1	SCC Slots	6	DIO Screw Terminals
2	SCC Screw Terminals	7	AI Screw Terminals
3	68-Pin I/O Connector	8	Bus Screw Terminals
4	External Power Switch	9	AO Screw Terminals
5	External Power Screw Terminals	10	Strain-Relief Wire Entry

Figure 6. SCC-68 Features

Figure 5: Connector Box.



System

Rating:	5.1 Your Windows Experience Index needs to be refreshed
Processor:	Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz 3.40 GHz
Installed memory (RAM):	8.00 GB
System type:	64-bit Operating System
Pen and Touch:	No Pen or Touch Input is available for this Display

Computer name, domain, and workgroup settings

Computer name:	r142-26-042
Full computer name:	r142-26-042.cs.wright.edu
Computer description:	
Workgroup:	ECS

Windows activation

Windows is activated

Figure 6: Computer specs.

6. RESULTS AND DISCUSSION

Figures 8 and 9 shows the strain on the beam after being let go with the initial displacement not zero before. The waveform in these figures are sinusoidal wave after the beam was let go with decreasing amplitude over time. This is a result of the natural dampening frequency, which was found to be 18.4 Hz. Figures 11 through 14 shows the response of the device with weights centered 115mm away from the strain gages; in order for the weight measurement deice to work properly it is important to place the weight at that point. Figure 11 shows the response with no weight, which in ideal situation would be exactly zero, but in this lab was found to be 2.7E-06. Figures 12, 13 and 14 were the response with 9.746g, 19.479g, and 29.164g placed on the beam respectively. The average output of each weight was plotted using Excel and a line of linear fit was placed on the plot, with the calibration data in table 1. The R value clearly shows how closely the system is to a linear scale being R=.9995, allowing for the weight of an object to be able to be found by finding the strain on the beam. However, the range of the weight that can be measured with the strain gage system is small. It will only being able to accurately weigh objects between about 1-225 grams. The range can be changed by changing the distance away from the strain gages, or the material the bar is made of allowing for heavier weights to be places on the same distance.

The sampling frequency needed to determine the ringing frequency had to be 1000 samples/second. The uncertainty of this lab was calculated using the RSS method shown in equation 10. Both of the 350 ohm resistors had a ±5% accuracy, while the strain gages had a tolerance of ±1%. The calculated uncertainty for this measuring device was found to be ±.2 μvolts at a 95% confidence interval. This measurement device is a first order system when in static and a second order system in dynamic.

Table 1.

#	Weight of Washers (grams)	Total Weight on Beam (grams)	Output Voltage (volts)
NONE	0	0	.0000027
1	9.746	9.746	-0.0000538
2	9.733	19.479	-0.0001129
3	9.685	29.164	-0.0001716

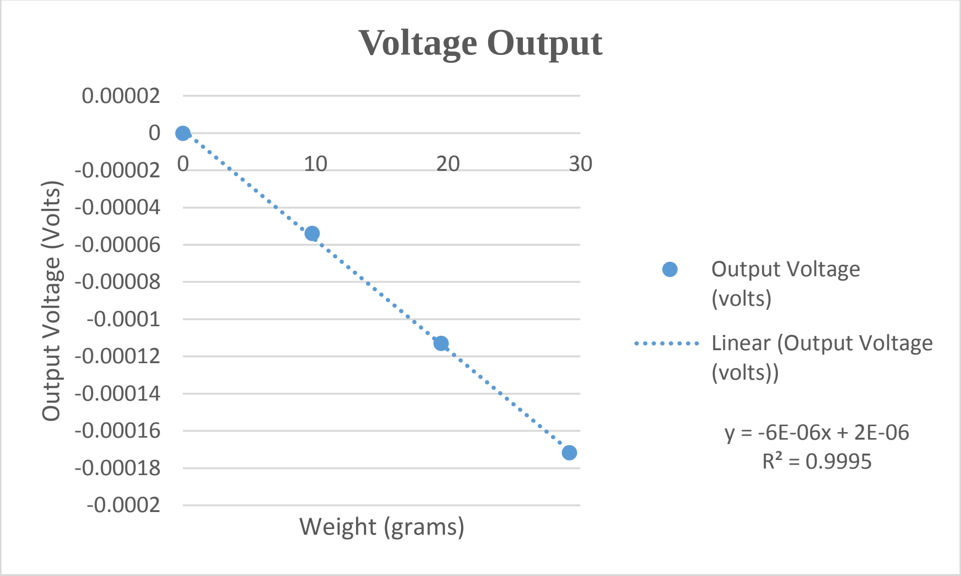


Figure 7: Weight vs. Output Voltage.

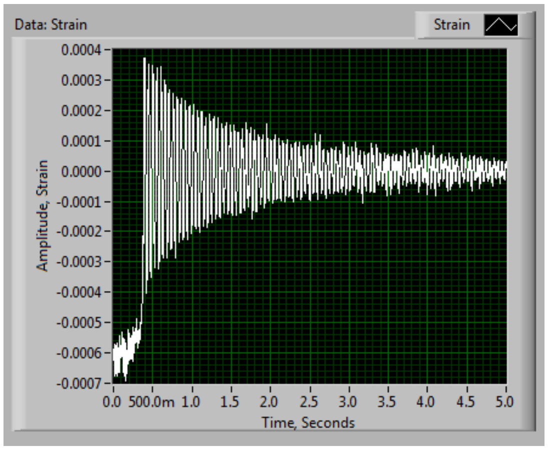


Figure 8: Unfiltered data of Ringing Frequency.

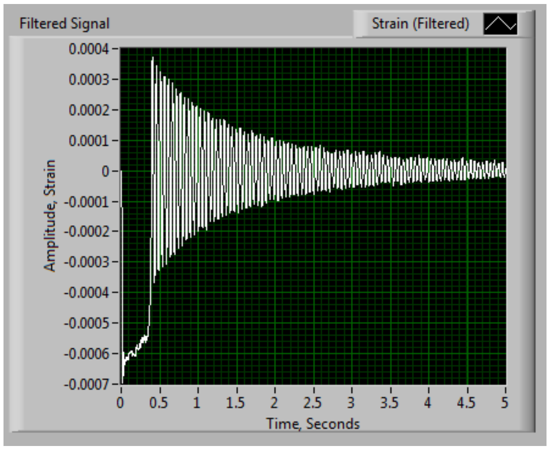


Figure 9: Filtered data of Ringing Frequency.

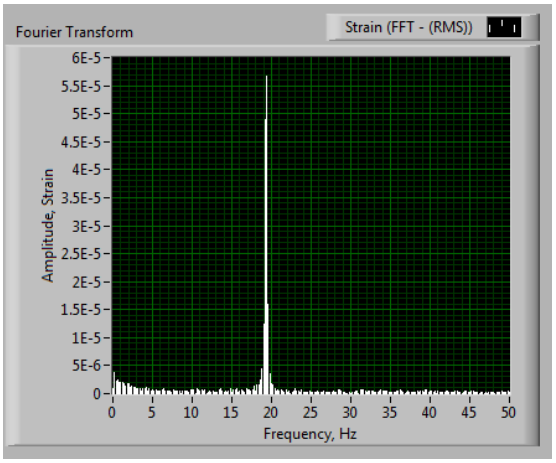


Figure 10: Fourier Transform of Ringing Frequency.

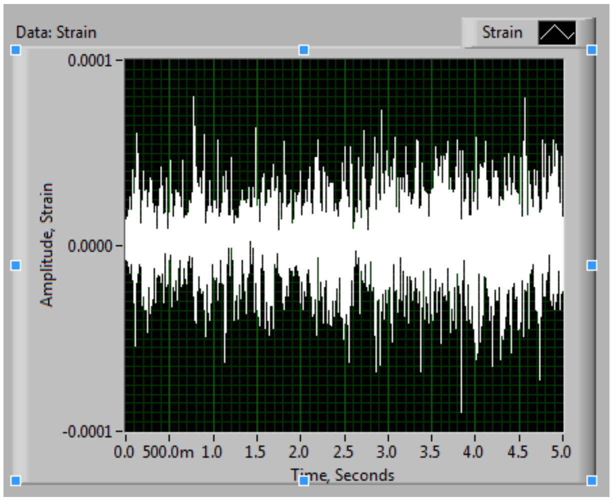


Figure 11: Unfiltered data with no weight.

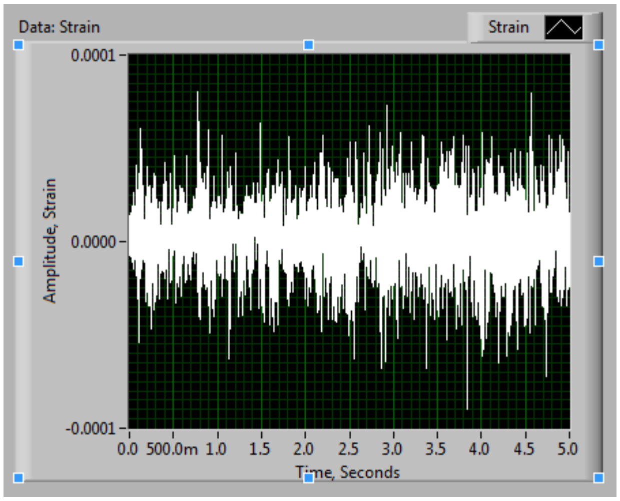


Figure 12: Unfiltered data with 9.373 grams.

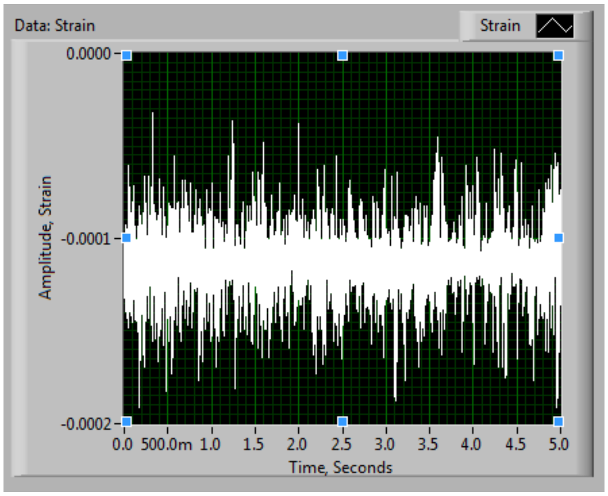


Figure 13: Unfiltered data with 19.2435 grams.

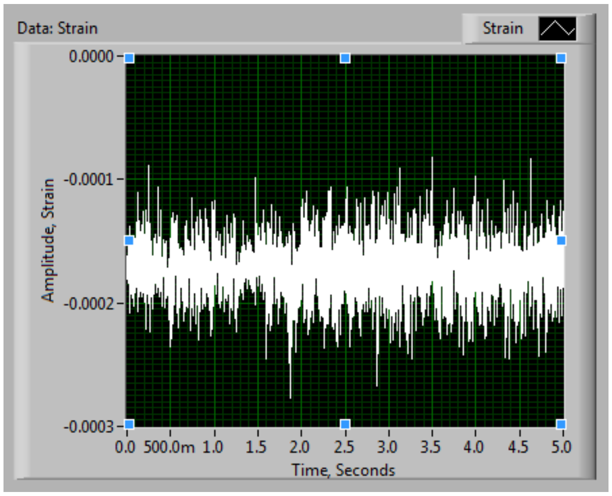


Figure 14: Unfiltered data with 28.7659 grams.

8. CONCLUSION

This strain gauge measurement lab introduces how strain gauges work. Using LabVIEW and a data acquisition card to collect data and analysis it. Understanding the principles of sampling theory and the Nyquist frequency was important to get accurate results and avoid alias frequencies. By understanding these principles, accurate measurements of the output from the strain gage was made possible. The Wheatstone bridge allowed measurements of the low voltages of the strain gages to be viewed. However, it was needed to find the offset with a voltmeter to calibrate the cantilever beam so it can be used as an accurate scale, do to imperfections in the resistors within the Wheatstone bridge. The ringing frequency seen in Figure 8 shows it to be approximately 18.4Hz. The strain gage is a second order system and the system doesn’t depend on the frequency. The uncertainty of the weigh scale was calculated to be ±.2 µvolts. This means that the scale is only able to measure small weights, between 1 to 225 grams.

REFERENCES

1. Laboratory Manual, Week 13 Lab: Strain Gauge Measurement, Dr. Yang, Wright State University 2015
2. Sections 1 and 2 of Chapter 7 of Figliola, R. S. and Beasley, D. E, *Theory and Design for Mechanical Measurements*, 5th Edition, Wiley, 2011
3. LabVIEW Help
4. Equipment Manuals, Dr. Yang, Pilot, Wright State University 2015
5. https://en.wikipedia.org/wiki/Strain_gauge
6. http://www.sensorland.com/HowPage002.html

APPENDIX

Measured data available upon request.

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