ME3600/5600

EXPERIMENTAL MEASUREMENTS AND INSTRUMENTATION LABORATORY

Week 13: Strain Gage Measurement

WRIGHT STATE UNIVERSITY

Objective: There are three objectives to this lab: 1) to use a strain gage including the Wheatstone bridge, 2) to calibrate a cantilever beam to measure weight using the strain gage as the sensor, and 3) determine the ringing frequency (natural damped frequency) of your newly made measurement device.

References: LabVIEW help and Chapters 3 and 11 of textbook. Two other references are the National Instruments web site: http://zone.ni.com/devzone/cda/tut/p/id/4179 and the How Sensors Work website http://www.sensorland.com/HowPage002.html . See also the links presented on this web site.

Theory: The theory for strain gages is given in Chapter 11 of your book. The ringing frequency (natural damped frequency) is discussed in Chapter 3 of your book. For purposes of this lab, I would like to remind you of a few concepts and give you a few items that are special to this lab.

Strain gages measure the stretch in a material by sensing a resistance change. For the most part we are interested in stretch caused by mechanical strain. When the stretch is caused by mechanical strain this stretch per unit length of the member is called strain. You should be aware that stretch can be caused by thermal expansion as well. In general, this resistance change caused by the stretch in the strain gage is sensed as a voltage change across a Wheatstone bridge. The bridge used in this experiment is a Half Bridge, Type II, Wheatstone bridge. This type of Wheatstone bridge is shown in Figure 1. The half bridge refers to the fact that two active strain gages are in the bridge circuit and not one, three, or four active strain gages. The Type II implies the gages only sense bending strain in a manner that is additive. One gage is on the top of the cantilever beam and one gage is on the bottom of the cantilever beam. Thus one strain gage is in tension and one is in compression. This causes one to increase its resistance and one to decrease its resistance. Because the strain gages are placed in adjacent legs of the Wheatstone bridge the increase in resistance and the decrease in resistance are additive, instead of cancelling one another out. This doubles the sensitivity of the measurement. This arrangement also helps to eliminate temperature effects in the strain gages themselves and within the beam. Note that temperature effects in the two resister legs of the Wheatstone bridge may still show up in your measurements if they are not equal.

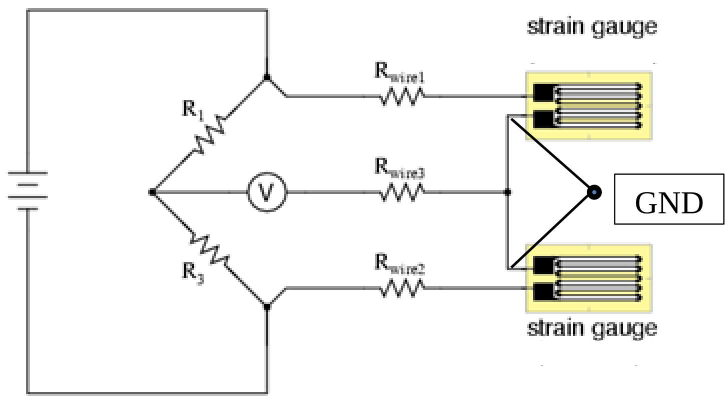

Figure 1. Electrical schematic of Wheatstone bridge circuit with strain gages attached to arms 3 and 4 of the bridge circuit. (From How sensors work: strain gage web site: http://www.sensorland.com/HowPage002.html).

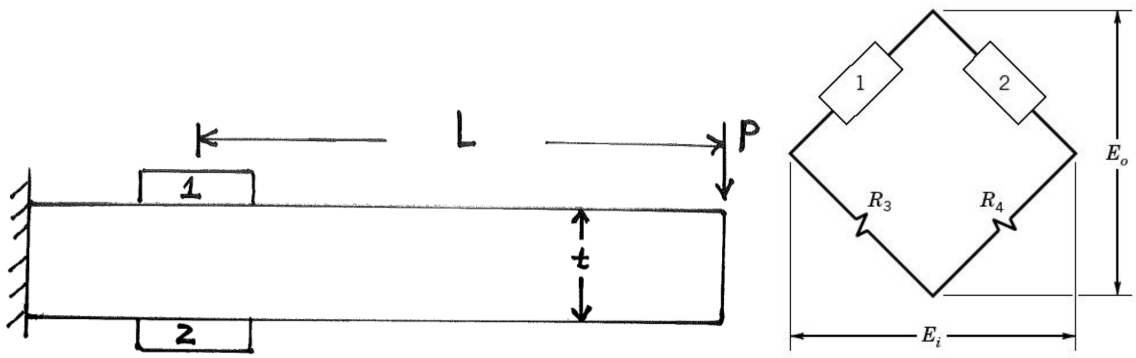

Figure 2. Strain gages mounted on a cantilever beam with end closer to strain gages clamped and strain gages connected to the arms 1 and 2 of the Wheatstone bridge circuit shown on the right.

From our book the equation relating output voltage to the resistance changes in four strain gages placed in a Wheatstone Bridge arrangement is

$$\frac{\delta E_o}{E_i} = \frac{GF}{4}\left[\varepsilon_1 - \varepsilon_2 + \varepsilon_4 - \varepsilon_3\right], \tag{1}$$

where all strain gages are the same. For a half bridge arrangement this can be written as

$$\frac{\delta E_o}{E_i} = \frac{GF}{4}\left[-\varepsilon_2 + \varepsilon_4\right]. \tag{2}$$

Since one of our strain gages is in compression and one is in tension (they are equal and opposite) this can be written as

$$\frac{\delta E_o}{E_i} = \frac{GF\varepsilon}{2}. \tag{3}$$

Solving for strain gives

$$\varepsilon = \frac{2\delta E_o}{(GF)E_i} \quad (4)$$

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To be more precise, more effects can be included in this equation, such as the effect of the lead resistances and the fact that the Wheatstone bridge may need to be zeroed before the strain measurement is taken. In this case Equation (4) becomes

$$\varepsilon = \frac{-2V_r}{(GF)}\left(1 + \frac{R_L}{R_g}\right) \quad (5)$$

where

$$V_r = \frac{V_{CH}(strained) - V_{CH}(unstrained)}{V_{Ex}} \ , \quad (6)$$

R_g = the strain gage resistance,

$R_1 = R_3$ = 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

GF = the gage factor

V_{Ex} = the excitation voltage

V_{CH} = the measured voltage

In this lab the strain gages have been mounted to register a bending moment strain. Because two are used, one measuring tension and one measuring compression, the signal is doubled. For purposes of this lab we do not have to relate this strain to a stress. We simply have to record the strain for different conditions. However, it would be very interesting to compare your stress determined from your strain gage measurements to an analytical result.

With this strain gage you are required to do two things: calibrate it so that it can measure the weight of a light object and then measure the ringing frequency of this measurement device. The calibration of a measurement device can be performed by putting known weights on the cantilever beam and recording the measured output. Since the device is linear, only two points should be required. However, it is always a good idea to obtain a few other points. I am requiring four points and one of these is the no load point. Make sure you mark and measure the position of where you put the weights. This position needs to be put in your lab report. You should also measure the size of your beam and state it in your report. The critical length is the distance from the table to the end of your beam, not the total length of the beam.

The ringing frequency can be obtained by perturbing the system and watching its time response. The formula for the ringing frequency is

$$f_d = f_n\sqrt{1-\varsigma^2} \ . \quad (5)$$

You cannot calculate the ringing frequency from this formula because you do not know the damping ratio or the natural frequency. You need to get the ringing frequency by measuring the response of the beam to a step perturbation.

Equipment:
1. Computer
2. LabView Software
3. Data Acquisition Card
4. Connector Box
5. Breadboard
6. Two 350 ohm resisters. Note that this inaccuracy will be handled by adjusting the zero point of our data acquisition system.
7. Two SKF-28899 KYOWA linear strain gage with a nominal resistance of 350 ohms, a GF = 2.1, and tolerance of ±1%
8. One aluminum bar with strain gage attached
9. One C-clamp
10. Four alligator clamp wires
11. Small connector wires
12. Voltmeter
13. A vernier caliper
14. Three weights
15. One OHAUS CS2000 Compact Scale balance scale for entire class with ±1.0 gram accuracy

Caution!
1. Be very careful with the strain gages and the bars. The gages are somewhat delicate. Do not hold these aluminum bars by the strain gage wires.
2. Do not put your C-clamp on the strain gage or its wires.
3. Make sure you have a good connection between the alligator clamps and the wires they are connected to.
4. Be careful that the voltmeter is not set to resistance when measuring a powered component. There cannot be any voltage present when measuring resistance.
5. Be careful when placing your hands at the back of the Strain Gage Panel Meter. The 110 volt connection is made back here. These cord connection sometimes comes loose.
6. Do not bend the aluminum bars too far. This can bend the bar permanently and break the glue bond between the strain gage and the bar.
7. Save your programs and results to your thumb drive!

Procedure:

1. Make the circuit shown in Figure 1.
2. Write a LabVIEW program to measure strain.
3. Set your sampling rate and number of samples to numbers that provide good representations of the waveform. You will need to use two different sampling rates that do not change your results to make sure you are obeying the sampling theorem. Note that you do not know what the ringing frequency is, and therefore you need to make sure your results do not change as you change your sampling rate.

4. Perturb the beam downward with your finger and let it go. Make measurements during this time to determine the ringing frequency. This will give you an idea of the time response characteristics of your device. While we will only do a static calibration of this system, it is nice to have an idea of its dynamic response. Do a Fourier transform on this signal.
5. Because you essentially have a linear system for measuring weight, over a limited range, you only need two points to do your calibration. I am requiring that you have three nonzero points and a zero point for a total of four points. The additional two points will help you to realize errors in your measurement, or if your system is not responding linearly. You need to give me an equation that will provide the weight of an object placed on your beam as a function of the reading from the strain gage. Use a regression analysis to do this. To calibrate your beam you should be using a numerical output from the computer as opposed to the plotted output.
6. You need to do an uncertainty analysis on your new weight measurement device so that you may specify a 95% confidence interval for your device. I do not want an uncertainty analysis of the strain gage; I want an uncertainty analysis of your measurement device, which is mainly from the calibration process. Give me the confidence interval for the largest weight measurement that you used to calibrate. On the other hand, you can use results for one of your single weight measurements to determine the precision uncertainty. Make sure you use a significant number of points to do this. With your LabVIEW program you should be taking several points at each calibration point and averaging. In this uncertainty analysis you do not need to account for the bias uncertainty of the excitation voltage or the resisters in the bridge. We will assume we can zero these out. There are some uncertainties here but we will ignore them. The part that we are not able to zero out will be present in your random uncertainty. Only include the uncertainties that affect your weight measurement device. You need to do some thinking about this.
7. Measure your beam thickness, width, and length with the veneer calipers or a ruler so that you can quantify it in the “Experimental Apparatus” part in your report. Also measure the distance from the location of the weight on your beam to the location of the strain gage.
8. Make sure answer or discuss all questions below in the “Results and Discussion” part in your lab report.

Evaluation: A PDF containing a formal lab report must be submitted. The LabVIEW program must also be submitted. When this report is written, it is not necessary to go back and provide a great deal of theory on topics which have been dealt with in the previous formal lab report. For example, do not discuss the sampling theorem, just inform the reader of the sampling rate used and if it obeys the sampling theorem, focusing on topics new to this lab. Do not submit any raw data generated. The program should be presented in your report and the required results should be presented as well. Save your raw, it may be request at a later date. Submit your documents to the Dropbox on Pilot. The naming of the files must include the student's first name, last name, corresponding lab week, and task name separated by underscores. For instance, a student named Thomas Anderson would submit files named the following for this lab:

thomas_anderson_week13_strainGage.pdf
thomas_anderson_week13_strainGage.vi

Failure to follow the above file naming protocol may result in a submission not being graded. Submissions for this lab are due during week 15 on the day of the week which the student attends lab by 11:59pm. Deductions for late submissions will be proportional to the extent of the corresponding lateness. Reports submitted after six days following the due date will not be graded and will receive a grade of zero.

Required Results (all plots must be the screenshots of lab view plots unless otherwise explicitly stated)**:**

1. Provide plots of the data used to determine the ringing frequency.
2. Provide plots of the raw data used to do your calibration. You should have four plots here.
3. Provide a table of your calibration data.
4. Provide an equation that converts the reading that you get from the strain gage to the appropriate weight. Make sure you give me the units you are using. You should plot this line as well as the data points used to determine the line.
5. Give me the uncertainty present in your new weight measurement device for the largest weight measured.

Questions to think about while writing your lab report:

1. Is your measurement device a zeroth, first, or second order system? Does it depend on whether you are looking at the system from a static perspective or a dynamic perspective?
2. Is a strain gage a zeroth, first, second order system? Again, does this answer depend on the frequency at which the strain gage is used?
3. What makes the ringing frequency slightly different from the natural frequency?
4. Did you use a high enough sampling frequency to determine the ringing frequency?
5. Why do we use a Wheatstone bridge with a strain gage?
6. Over what weight range would you recommend your new scale be used?
7. What is the uncertainty in your new weight measurement system?
8. Are there any peculiarities in your new weight measurement device that you should pass on to someone who uses it?