EGR270 – MATERIALS LABORATORY

Lab 3 – Strain Gages

Assigned date: Jan 28th Due Date(s): Week of Feb 4th

Description

Students explore the calibration of load cells and fundamentals of weight measurement using NIST certified weights. Students also apply this knowledge to the measurement of lift of a small quadcopter.

Learning Objectives

- Calibrate a cantilever beam load cell.
- Calibrate weights to be used as local standards.
- Use local standards to estimate the uncertainty (error) in a scale.
- Explain how to measure the thrust output of a quadcopter.

Overall (non-detailed) Procedures

There are two primary "segments" to this week's lab. In Segment 1, you are acting as a cal/cert technician (someone who performs calibration to certify measurement items). In Segment 2, you are acting as a mechanical engineering testing the lift characteristics of a small quadcopter. The general procedure:

Segment 1 (calibration and certification):

1) Calibrate two cantilever beam load cells using calibrated and certified weights traceable to NIST.
2) Use the calibrated cantilever beam load cells to calibrate four different weights (these become "local standards" useable for calibrating other load cells, but with greater error and uncertainty than the certified weights used in step 1).

Segment 2 (test engineer, determine flight characteristic of a quadcopter):

3) Use the newly certified local standards to estimate uncertainty (error) in two different quadcopter test pads (a digital scale and a polymer cantilever beam).
4) Measure lift produced by a quadcopter using both quadcopter test stands.

Deliverables

See the attached letter.

Grading

This assignment counts as a worksheet. Students are awarded points as follows:

Identification

5 pts	Submission is clearly identified with submitter's name, section, and date.
0 pts	Missing or incomplete.

Submission Completeness

5 pts	All elements are included in a neat and orderly fashion.
2.5 pts	All elements are included. Neatness and order are lacking.
0-2.5 pts	One or more element(s) are missing. Neatness and order may be lacking.

Organization

15 pts	Each paragraph contains an identifiable and coherent idea, appropriately organized to support the thesis of the document. Sentences within each paragraph are logically arranged to support the purpose of the paragraph.
10 pts	Paragraphs are linked to the larger structure of the document. Coherent ideas are present, but are not presented in a way that facilitates comprehension.
0-5 pts	Coherent ideas are not easily identified within each paragraph. Organization of thought is lacking, either within paragraphs or the document.

Composition

10 pts	Each sentence is well composed. Choice of words facilitates clarity. Sentence structure promotes clarity but sufficiently varied. Exhibits proper economy of words (no cluttering phrases, redundancy, repetition, and circumlocution). Word order promotes proper emphasis of the main idea.
7.5 pts	Sentence composition is not consistently good. Choice of words results in ambiguity in some places. Sentence structure does not always promote clarity and/or is insufficiently varied. Proper economy of words is not practiced. Main ideas are not easily identifiable.
0-5 pts	Sentence composition is consistently poor.

Free-Body Diagram

5 pts	Well-defined, neat, and clear.
2.5 pts	Included, but lacking in quality.
0 pts	Missing.

Lab Documentation

5 pts	Included.
0 pts	Missing

Calibration Curve

5 pts	Well-defined, neat, and clear. Conforms to good graphing practice.
2.5 pts	Included, but lacking in quality. Deviates from standard practice.
0 pts	Missing.

Total Points: ____________ out of 50.

January 29, 2018

Students
Materials Science Laboratory
5000 N. Willamette Blvd.
Portland, OR 97203

Dear Students,

We request your assistance in two measurement tasks. First, we need you to calibrate a cantilever beam load cell and weights. We would like to know the calibration factor (the relationship between strain and applied weight). We also need assistance in evaluating the performance of a small quadcopter. We would like to know what the maximum load that this quadcopter can lift. We have provided you with the quadcopter, a set of NIST certified weights, a set of uncertified weights (that you will calibrate), as well as two quadcopter test stands.

It may interest you that a fellow engineer thinks that a simple scale will not be sufficient to measure the thrust of the quadcopter. He has already done some work in this area, and we have attached his notes. Please investigate this claim while you carry out this performance evaluation and let me know if you agree with his conclusion. Make sure you back up your claims with solid evidence, such as percent-differences between any measurement methods you may use.

For lab class next week, please submit a document with the following:

1. Clear indication of the submitter's name, class, lab section and the current date.
2. A four (4) paragraph write-up making an engineering recommendation about the measurement system. Each paragraph should not exceed five (5) sentences. The four (4) paragraphs should discuss the following:
    a. The percent difference in weight as measured by the digital scale vs. the cantilever strain gage (a.k.a. the instrumented helipad).
    b. The percent difference between the lift as measured by the digital scale vs. the cantilever strain gage.
    c. A reasonable and data-driven explanation for discrepancies between the two measurement systems.
    d. A reasonable and data-driven evaluation of which measurement system is correct.
3. A hand-drawn Free-Body Diagram of both quadcopter measurement systems (standard scale and cantilever strain gage)
4. A copy of the original lab documentation (description, letter, and data sheet).
5. A calibration curve for both the steel and aluminum cantilever beams, including R^2 values.

Thank you for help in this matter. If you have any questions, do not hesitate to contact one of your lab professors (see syllabus). Please note, we've provided a blank data sheet on the reverse side of this letter.

Sincerely,
(electronic)
Your Professors

Enclosed: one (1) set of NIST certified weights, four (4) uncertified weights, two (2) uncalibrated strain-gaged cantilevers, one (1) quadcopter, one (1) uncalibrated digital scale, one (1) instrumented helipad, clean gloves for each student, one (1) background document discussing calibration and quadcopter measurement.

Calibration Notes

Definitions:

Load cell: A load cell is a specific type of transducer that is used to create an electrical signal that is directly proportional to the force being measured.

Transducer: A transducer is a measuring device that converts variations in a physical quantity into a measurable quantity. A mercury-in-glass thermometer is a simple example of a transducer, and so is a strain gage.

Measurement Uncertainty: All engineering data is based on measurements; yet no measurement is perfect. Even the most accurate and precise measurement is an *estimation* of the true value. Measurement uncertainty is a statistically derived estimate for "error". "Error" is never known exactly, it is an estimate.

True value: if you could measure something perfectly, you would be measuring its true value. All measurements are approximations to the true value (the error is the difference between the measured value and true value).

Calibration: Calibration is the process of comparing values indicated by a measuring device with those of a calibration standard of known accuracy. Calibration allows for a certain degree of confidence in the measuring device's ability. This lab is meat to demonstrate the principles of calibration in a simplified way. Calibrations performed by calibration labs usually requires very precise procedures in a controlled environment.

Certification of measuring devices: Certification is the documentation showing the results of calibration by qualified personnel.

Cal Cert: The abbreviated version of "calibration and certification".

Hierarchy of Standards: **primary** standards are the definitions of the measurement. For example, there is only one primary standard for the definition of a kilogram (~~buried in a vault in France~~), and the speed of light (distance light travels in 1/299,792,458 seconds in a vacuum) is the primary standard for the meter. **Secondary standards** are produced by comparing them with the primary standard, and therefore, are very close approximations. Standards that are created by comparison to secondary standards are known as tertiary, **local**, or working standards.

Notes on Strain Gages:

There are several different types of strain gages used for measuring strain. For this experiment, you will be using etched foil strain gages. In an etched foil strain gage, a very thin piece of metal is etched and placed on a plastic film carrier. This is known as a bonded-foil strain gage. This assembly is then carefully glued onto the test specimen whose strain is to be measured. As the metal foil in the strain gage is stretched or compressed along with the test specimen, its electrical resistance changes. Depending on the metal used, very large strains of up to 50,000 $\mu\varepsilon$ ($50{,}000 \times 10^{-6}$ in/in) may be measured.

The so-called "gage factor" (GF) is a calibration factor that relates strain to a change in resistance. The gage factor must be known (it is provided by the gage manufacturer) and the value must be entered into the strain indicator. The course instructor will demonstrate this. The strain indicator is the little "black" box (or blue) that contains circuitry for converting resistance change into a strain reading.

Even large strains will result in only a very small change in the strain gage's resistance; therefore, a Wheatstone bridge is used to measure the resistance change. Wheatstone bridges are electrical circuits that produce a measurable voltage change based on very small changes in resistance. See Figure 1.

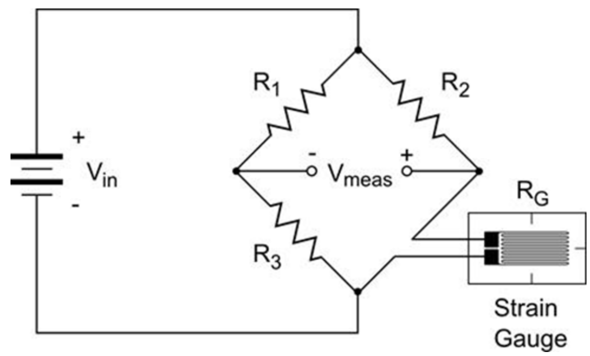

Figure 1 - Wheatstone bridge circuit for measuring strain ("quarter bridge")

<u>Notes for Calibrating Cantilever Beam Load Cell</u>

Materials and Supplies

- Instrumented cantilever beam test apparatus as shown in Figure 2
- P3 strain indicator (not calibrated or certified)
- Set of calibrated or certified masses: 20g, 50g, 100g, 200 g, and 500g
- Clean gloves to be **Worn always when handling certified blocks!**

NOTE TO SELF: I consider "load" and "weight" to be grams (which is actually a unit of mass).

Procedure for (unofficial) calibration of cantilever beam load cell:

1. Connect the strain gages on the cantilever beam load test apparatus to a strain indicator (if not already done). Enter appropriate gage factors for each gage. Balance the Wheatstone bridges.
2. Before collecting data, press down on the end of both cantilever beams to gain a qualitative sense for how much force is required to bend the aluminum and steel beams far enough to just contact the stop. This "real world" experience should help you to evaluate any differences you observe in the data from each beam. When a specific load such as 200g is placed on the aluminum beam, do you expect the strain to be more, less, or equivalent to the strain in the steel beam with the same load?

Calibration involves determining an unknown quantity by comparing with a known quantity. For this calibration, what is unknown is how much strain is produced by loads applied to the ends of the beams.

3. **Before handling the certified weights, put on clean gloves!**
4. Place loads shown in Table 1 at the small hole on the end of the steel beam. Measure and record the corresponding strains in Table 1. Keep an eye on the beam's stop – do not apply greater loads once contact has been made with the stop.
5. Repeat step 4 with the aluminum beam.
6. Using the data in Table 1 create a "calibration curve" for each of the two beams. Plot the load (g) as a function of strain (με). This is sort of an odd way to plot the data, because strain is the dependent variable and load is independent; but there is valid reason for plotting it this way. The slope of the line on the calibration curve is the calibration factor for the load cell and has units of *g/με*. Determine the calibration factor (slope) for both beams (using linear regression curve fit if possible). The calibration factor allows you to determine the applied load for a given strain reading.

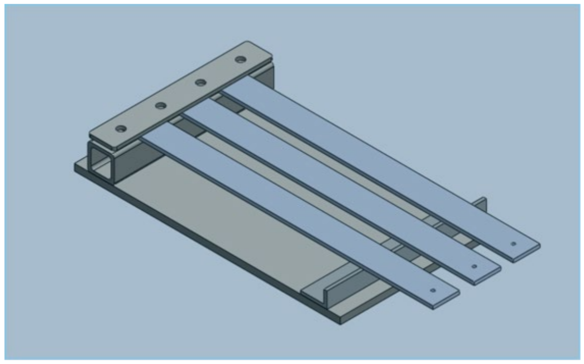

Figure 2 - Bending Load Test Apparatus

Procedure for (unofficially) certifying the three weights as "local standards":

These beams will now be used as load cells; a device used to measure force.

1. Using either the steel cantilever beam load cell, determine the "weight" (grams) of the four non-calibrated weights (nominally, 50g, 100g, 200g, 500g) by multiplying the strain reading for each weight by the calibration factor. Record in Table 2.
2. Repeat with the aluminum load cell. Record in Table 2.

Different results between the steel and aluminum load cell can be considered part of measurement uncertainty (error).

These weights are now your "local standards". You do not need to wear gloves when handling them, and can "transport" them to the helipads so that you can estimate how precise the helipad measurements are.

QUADCOPTER NOTES

Definitions

Quadcopter: Something that can be fun to play with in this lab.

Instrumented helipad: The transducer (load cell) in this lab is an instrumented beam. The beam deflects an amount proportional to an applied force. The deflection causes a change in resistance in a strain gage, and finally, the strain indicator uses a Wheatstone bridge to convert the change in resistance and gage factor into a strain reading. (It is common for there to be many different parts to a single measurement device).

Digital scale: something used to weigh objects. The one in this lab has Velcro to prevent the quadcopter from flying up (used to measure lift produced by the quadcopter).

Notes for Quadcopter Performance Evaluation

Materials:

- An instrumented cantilever beam helipad with P3-strain indicator
- Digital scale (with Velcro) helipad
- The set of four weights you calibrated ("local standards")
- One fully functioning quadcopter
- Safety glasses.

Procedures for Performance Characterization

1. Put on safety glasses.
2. Zero the digital scale. One at a time, use the digital scale helipad to weigh each of the local standards (50g, 100g, 200g, 500g). Enter the data into Table 3 and determine the error between the actual calibrated/certified weight and the measured weight using the digital scale.
3. Attach the quadcopter to the Velcro on the digital scale. Record its weight in Table 4. These data provide an estimate of error for the digital scale.
4. While the quadcopter is securely attached using the Velcro, gradually increase power until full power is reached. Keep watching the digital read-out change as power is increased. A "zero" reading on the scale indicates that the lifting force balances the quadcopter weight; a negative reading would indicate upward force (lift). If the load indicated on the scale is positive, it indicates that it is not producing enough lift to take off. Record the value for full power "lift" in Table 4 (making sure to include a negative or positive sign as appropriate).
5. Zero the strain gage connected to the cantilever beam helipad.
6. Place the quadcopter onto the cantilever beam helipad and record the change to the strain reading in Table 5. Using the load cell's calibration factor (as indicated by a sticker on the beam), calculate the lift (multiply strain by the calibration factor). Enter this into Table 5.
7. Gently, throttle-up the quadcopter keeping an eye on the strain reading observing how it changes. Once full power is reached, measure and record the strain in Table 5. Using the calibration factor, calculate the lift and enter data into Table 5. If the quadcopter is producing enough lift to "take off" the strain indicated should be negative (upward force). If the strain indicated is positive, it means it indicates that it is not producing enough lift to take off.

Comment from conversation with boss: "Engineers should remember that expert opinion, analysis or even testing do not provide the answer to a design question. They merely provide data to help you make a decision. Decisions require judgment and are based on the available data. What's the importance of engineering judgment when interpreting the results of testing? If you used only the digital scale to measure lift, what might you have concluded about the quadcopters ability to fly? Does there appear to be some value in always questioning data and to view the same problem from different perspectives before judging the validity of your answer?"

Lab Title: ______________________________ Date Conducted:____________ Location: ___________

Table 1: Strain Value

Nominal Wt.* (g)	Corr. Wt (weight as stated in the certification documents) (g)	6061-T6 Strain (με)	AISI 1015 Strain (με)
0			
20			
50			
100			
200			
500			

*grams are a unit of mass, but are used as "weight" in this laboratory.

Determine calibration factor from the slope of the load vs. strain graph using Table 1 data:

Calibration factors: 6061-T6 load cell = ____________*(g/με). AISI 1015 load cell:*__________*(g/με)*

Table 2: Calibration of "Local Standards" (black hook weights)

	AISI 1015		**6061-T6**		
Nominal Weight *(g)*	**Measured Strain** *(με)*	**Calculated Weight*** *(g)*	**Measured Strain** *(με)*	**Calculated Weight*** *(g)*	**Difference between steel and aluminum load cell (~error)** *(g)*
50					
100					
200					
500					

*multiply the measured strain by the appropriate calibration factor to calculate the weight

Table 3: Digital Scale Error Estimate

Nominal weight *(g)*	Calibrated weight *(g)*	Measured weight *(g)*	Difference (~error) *(g)*
50			
100			
200			
500			

Table 4: Digital scale quadcopter results

Description	Measured Load *(g)*
Powered Off	
Full Power	
Total Thrust	

Table 5: Cantilever beam helipad quadcopter results. Calibration factor noted on the beam:_________$g/\mu\varepsilon$

Description	Measured Strain *($\mu\varepsilon$)*	Measured load *(g)*
Powered Off		
Full Power		

Photos (as deemed appropriate): ☐

I actively participated in the collection of this data. The information contained here has not been falsified and to the best of my knowledge correctly records the data obtained in the lab.

Print Name: ______________________________________ Signature: _________________________________