AC 2012-5130: ENGINEERING SQUEEZEOMETER AND HUGGOMETER

Dr. James Aflaki, Christian Brothers University

James Aflaki received his Ph.D. in mechanical engineering from the University of Maryland, College Park. His specialty is in the area of thermal fluids and his sub specialty is in the area of computer applications and MIS. He has more than 20 years of teaching, research, and industry experience in mechanical engineering, MIS. He has received the best paper award from the Computer and Information in Engineering Division of ASME International.

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Abstract: This paper discusses the design of two experiments developed to serve two primary purposes. The first one is to expose students to the application of strain gages and data acquisition system to measure stresses in a beam due to particular loading conditions and compare them with the results obtained from theoretical analysis. The second one is to use these experiments in engineering recruiting events and engage prospect engineering students in hands-on experiments so that they can envision great times while studying engineering.

The first experiment is a strain gage based scale called SqueezoMeter designed to measure the applied squeezing or pushing force. It is made of an S-shaped sensing element equipped with 4-strain gages, and two rectangular aluminum plates to apply the force.

The second experiment, HuggoMeter, consists of two parallel ¼ inch aluminum beams mounted on two 8.5 x 16 x 1 in hard boards that are 1.25 inches apart. Mounted on the constant bending portion of these beams are 4 strain gages forming a 4-active arm Wheatstone bridge. Students can hug the HuggoMeter and apply forces to it. The induced strains are measured through a din rail mounted signal conditioner and A/D module, converted to the applied force and displayed on the PC screen.

These experiments, while entertaining and educational, integrate and apply the knowledge obtained in courses such as statics, solid mechanics and instrumentation. It demonstrates the potential use of strain gages as sensors. Strain gages, and signal conditioners are used to measure, calculate and analyze force by direct application of a concentrated or distributed loads. These experiments provide students with hands on experience with using strain gages, signal amplifiers, and conditioners and setting up and balancing Wheatstone bridge.

Introduction

In engineering education today, instrumentation and computer integration are increasingly becoming part of teaching in classrooms. Faculty use new technologies to increase their teaching effectiveness in their classrooms. In addition, laboratory experiments are developed to demonstrate the theoretical concepts, gain and keep students' interest, and attract more students to a particular engineering discipline.

Two experiments are developed to introduce students to the application of strain gages and data acquisition system by measuring stresses in a beam due to certain loading conditions and allowing students to investigate the effects of different loads while having fun with these experiments.

Experimental Setup and Procedures (SqueezoMeter)

SqueezoMeter is a strain gage based scale which can also be used to measure the applied squeezing or pushing force. It is made of an S-shaped sensing element, a 6 x 1 x 0.5 in aluminum beam, equipped with 4 120-Ω strain gages, mounted 0.5 inches away from each end on both sides of the flexing beam, and forming a 4-active arm Wheatstone bridge. This is shown in Figure 1.

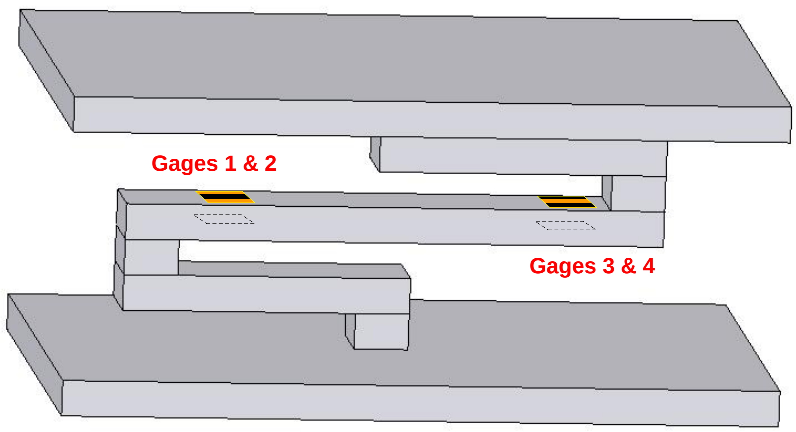


Figure 1: Schematic Diagram of the SqueezoMeter

Structural Analysis

The structural analysis of the SqueezoMeter is straightforward. A numerical example is used to demonstrate the application and analysis of the SqueezoMeter.

The induced strain caused by the application of the 100-lb load can be calculated by using the bending moment theory and Hook's law for elastic materials[2] (James M. Gere, 2009). The free body diagram of the flexing beam up the gage locations is shown in Figure 2.

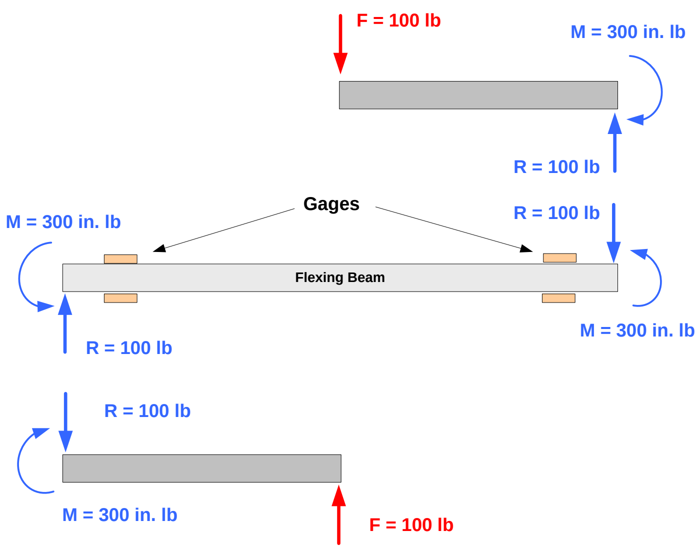


Figure 1: Free body diagram of the SqueezoMeter for the applied Load

The following equations are used in the example.

$$I = \frac{1}{12} bh^3 \qquad (1)$$

$$\sigma = \frac{Mc}{I} = \frac{F.Lc}{I} \qquad (2)$$

$$\varepsilon = \frac{\sigma}{\mathrm{E}} \qquad (3)$$

$$\mathrm{V_{out}} = \frac{\mathrm{GF}}{4}(\varepsilon_1 + \varepsilon_3 - \varepsilon_2 - \varepsilon_4)V_{in} = GF\varepsilon_1 V_{in} \qquad (4)$$

Where:

I: The area moment of inertia of the cross-section of the beam with respect to its neutral axis
b: Width of the beam cross section
h: Height of the beam cross section
σ: Normal stress acting on the cross section of the beam
M: Bending moment at the gage location
E: Modulus of elasticity of the material
ε: Axial strain

G: Gage factor of the strain gage (2.08)
V Voltage

$$M = 300 - (100)(0.5) = 250 \text{ in. lb}$$

$$I = \frac{1}{12} bh^3 = \frac{1}{12}(1)(0.5)^3 = 0.0104167 \text{ in}^4$$

$$\sigma = \frac{Mc}{I} = \frac{F.Lc}{I} = \frac{(250)(0.5/2)}{0.0104167} = 6{,}000.0 \text{ psi}$$

$$\varepsilon = \frac{\sigma}{E} = \frac{6{,}000.0}{10.7 \times 10^6} = 0.0005607 = 560.7 \ \mu \text{strains}$$

$$V_{out} = \frac{GF}{4}(\varepsilon_1 + \varepsilon_3 - \varepsilon_2 - \varepsilon_4)V_{in} = GF\varepsilon_1 V_{in}$$

$$V_{out} = (2.08)(0.0005607)(10) = 0.0117 \text{ VDC} = 11.77 \text{ mV}$$

The gages are connected to a 5M38-03 signal conditioner which provides excitation and amplification for the bridge and it is shown in Figure 3.

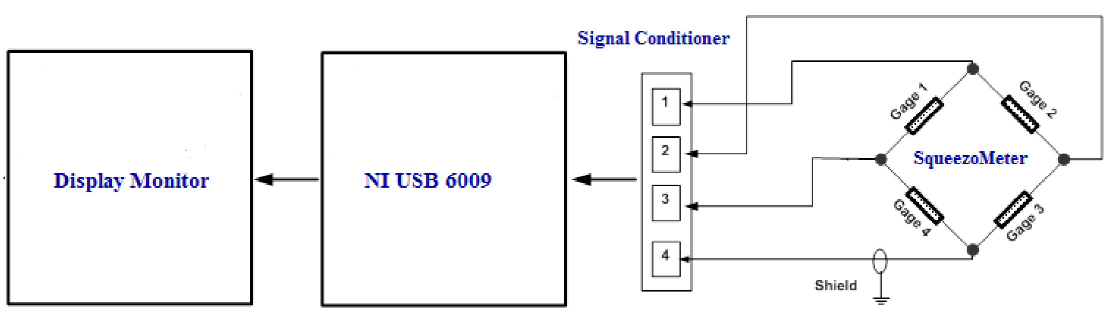


Figure 2: Schematic Diagram of the Data Acquisition System

Several known forces are applied to the SqueezoMeter and the output voltage is measured. Then, the calibration chart is constructed and is shown in Figure 3. As expected, the response is linear. A linear line is passed through the data point and the equation of the line is obtained which is used in a Visual Basic program to output the result directly on the screen.

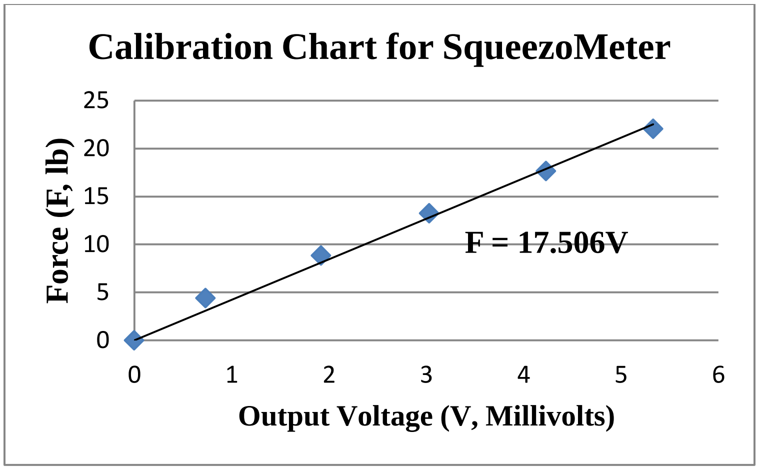
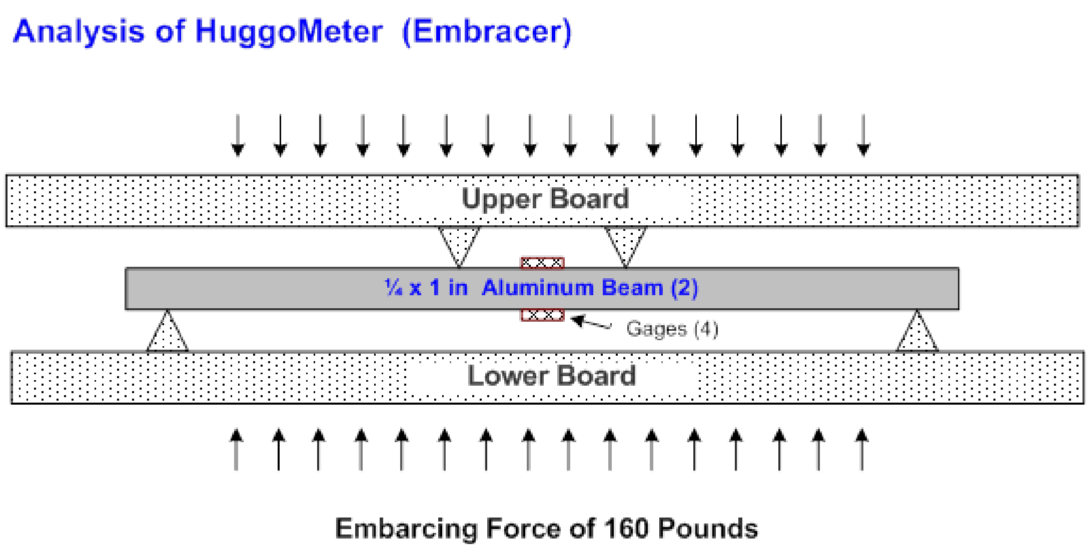


Figure 3: Calibration Chart for the SqueezoMeter

HuggoMeter

HuggoMeter consists of two parallel ¼ inch aluminum beams mounted on two 8.5 x 16 x 1 in boards that are 1.25 inches apart. Mounted on the constant bending portion of these beams are 4 350-Ω strain gages forming a 4-active arm of a Wheatstone bridge. A 5M38-03 signal conditioner provides excitation and amplifications for the bridge.



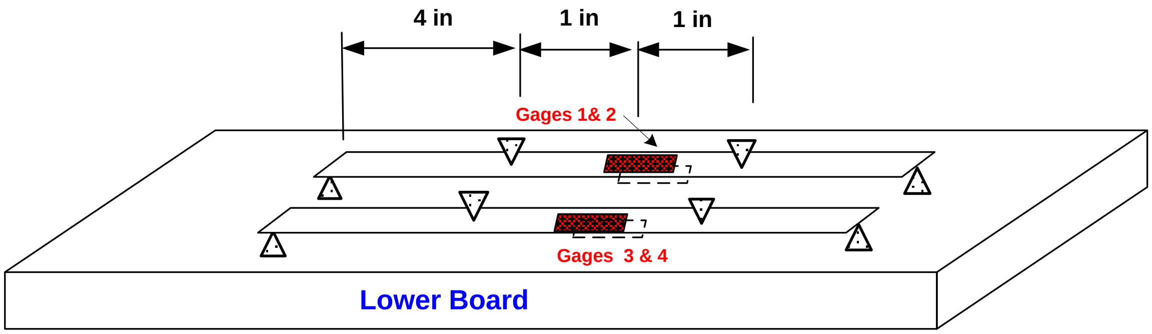
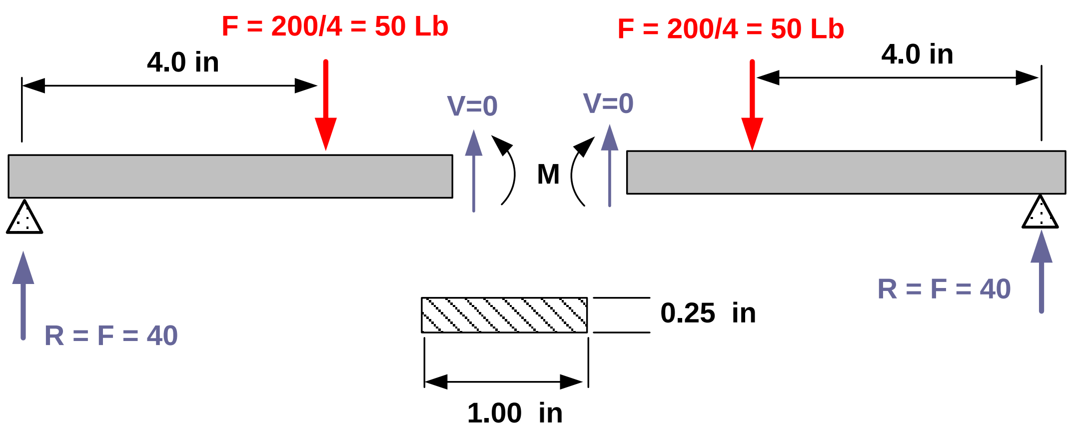


Figure 4: Schematic Diagram of the HuggoMeter

Embracing force is distributed equally over four contact points. The resulting strain at each gage location is found by using beam theory.



$$I = \frac{1}{12} bh^3 = \frac{\mathbf{1}}{\mathbf{12}}\mathbf{(1)(0.25)^3} = \mathbf{0.0013021\ in^4}$$

$$\sigma = \frac{\mathbf{Mc}}{\mathbf{I}} = \frac{\mathbf{F.Lc}}{\mathbf{I}} = \frac{\mathbf{(50)(4)(0.25/2)}}{\mathbf{0.0013021}} = \mathbf{19{,}199.7\,psi}$$

$$\varepsilon = \frac{\sigma}{\mathbf{E}} = \frac{\mathbf{19199.7}}{\mathbf{10.7 \times 10^6}} = \mathbf{0.0017944} = \mathbf{1794\ \mu\, strains}$$

The gages are connected to a 5M38-03 signal conditioner which provides excitation and amplification for the bridge and it is shown in Figure 5.

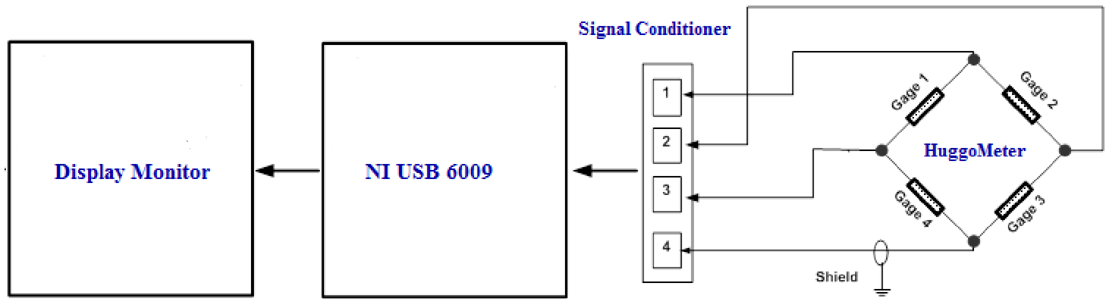


Figure 5: Schematic Diagram of the Data Acquisition System

For a full bridge configuration and 3.33 VDC excitation the output voltage will be:

$$V_{out} = \frac{\text{GF}}{4}(\varepsilon_1 + \varepsilon_3 - \varepsilon_2 - \varepsilon_4)V_{in}$$

Since $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \varepsilon_4$ then

$$V_{out} = \text{GF}\,\varepsilon_1 V_{in} = 2.15(0.0017944)(3.33) = 0.01285 \text{ VDC } = 12.85 \text{ mV}$$

Several known forces are applied to the HuggoMeter and the output voltage is measured. Then, the calibration chart is constructed and is shown in Figure 6. As expected, the response is linear. A linear line is passed through the data point and the equation of the line is obtained which is used in a Visual Basic program to output the result directly on the screen.

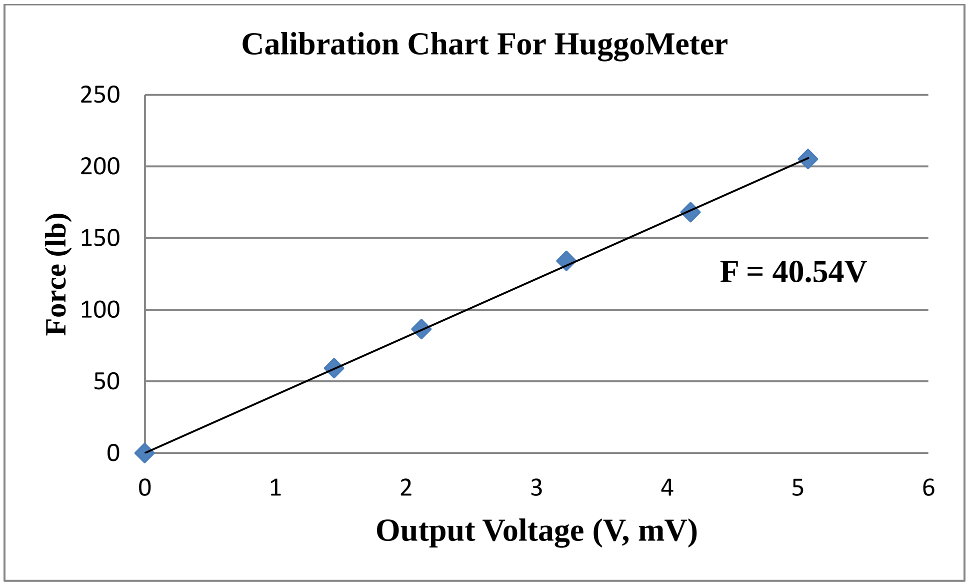


Figure 6: Calibration Chart for HuggoMeter

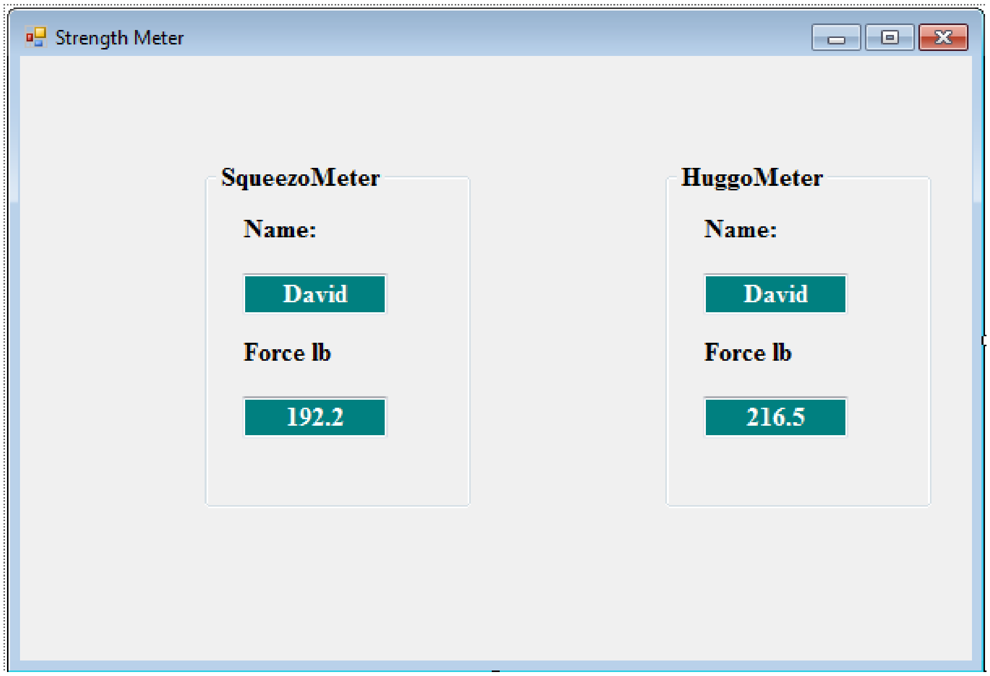


Figure 7: Screen Shot of the Output Results

Engineering Application:

Many engineering schools are continuously trying to make engineering fields more attractive to high school students. SqueezoMeter and HuggoMeter are designed to serve two primary purposes. The first one is to entertain and introduce prospect engineering students to the application of strain gages and data acquisition system. A competition is arranged to find the strongest student among the contestants. Students are asked to apply forces to SqueezoMeter and hug the HuggoMeter and apply as much force as they can to it. Data for each student is recorded and the strongest student is selected and recognized. These experiments show students that while engineering is a highly technical field it can also be fun to study.

The second application of these experiments is in a mechanical engineering laboratory course. Students are asked to build the experiments from scratch and connect them to data acquisition system and measure their data. These experiments, although simple, enable students to apply their knowledge from several courses to measure stresses in a beam due to particular loading conditions and compare them with the results obtained from theoretical analysis.

These experiments have been developed recently and only a small group of students have been exposed to them. While a statistical analysis is desirable to assess the effectiveness of these tools, at the present time, there is not sufficient data to perform such analysis. However, the overwhelming responses and comments from students have been positive and encouraging.

Conclusion

Two experiments are developed to expose students to the application of strain gages and data acquisition system by measuring the applied load to a beam. Students are able to use the concepts learned in multiple courses by using these two experiments. Students are exposed to practical hands-on engineering applications and data acquisition systems.

In addition, these experiments can be used in engineering recruiting events and engage prospect engineering students in hands-on experiments while observing the application of strain gages, signal amplifiers, and conditioners and setting up and balancing Wheatstone bridge.
Students who performed these experiments have expressed that these have been entertaining and exciting as well as educational experiments.

1. Holman, J. P. (2001). *Experimental Methods for Engineers.* McGrawHill.
2. James M. Gere, B. J. (2009). *Mechanics Of Materials.* Cengage Learning.
3. Julia case Bradley, A. C. (2011). *Programming in Visual Basic 2010.* McGrawHill.
4. King, R. H. (2009). *Introduction to Data Acquisition with LabVIEW.* McGrawHill.