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BYOE: Strain Measurement in a Simply Supported Beam

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Educational Goals

Strain measurement experiments have been a staple of mechanical engineering laboratory courses for years. Previous experiments in the course entitled Measurement and Analysis with Thermal Science Application at Northeastern University suffered from being too canned or too much of a 'black box'. Students were instructed to configure wires and circuits, and measure strain, but were often able to get through the lab without developing a deep understanding of the interaction between strain gauge placement and electric circuit arrangement. In an attempt to fix the problem, National Instruments LabView strain modules were used in order to force students to think harder about what they were doing. However, despite the fact that these are state of the art data acquisition systems, they were not robust, were expensive, and broke if too many students handled them. Consequently, the experiment described here was designed to eliminate outdated or overly canned experiments, while choosing robust equipment that the students could interact with in a much more open-ended way.

Measurement and Analysis is a required course for junior level mechanical engineers. The overall purpose of the course is to teach students how to design experiments, how to measure common engineering variables, and how to use and select sensors. The experiment in question is designed to teach students how to measure strain. Students are asked to investigate the effect of different numbers of strain gauges on the output of a Wheatstone bridge circuit, and observe the relationship between physical location on the object and location in the circuit. The specific goals are:

1. To use strain gauges to measure strain in a simply supported beam with a load equally distributed across two points
2. To determine the effect of different Wheatstone bridge circuit arrangements on the measured strain
3. To use the strain data to develop a relationship between strain and weight, in order to use the aluminum beam as a homemade scale.

In addition to the specific goals, the experiment provides students the ability to make mistakes and learn from them, troubleshoot experimental equipment, and attempt to relate analytically predicted values to measured values. It also allows for integration with the rest of the curriculum by requiring students to use previously learned skills from their statics course to calculate the expected strain in the beam.

Equipment Used

The equipment required for this experiment is as follows:

- VISHAY Precision Groups Model P3 Strain Gauge Indicator box (Figure 1)
- Omega Model SG-6/120-LY13 strain gauges
- Calibration weights (1kg to 15kg)

- Electronic scale (50 kg capacity)
- Aluminum beam setup (Figure 2)
- Connecting wires and various hardware
- Calipers and tape measures

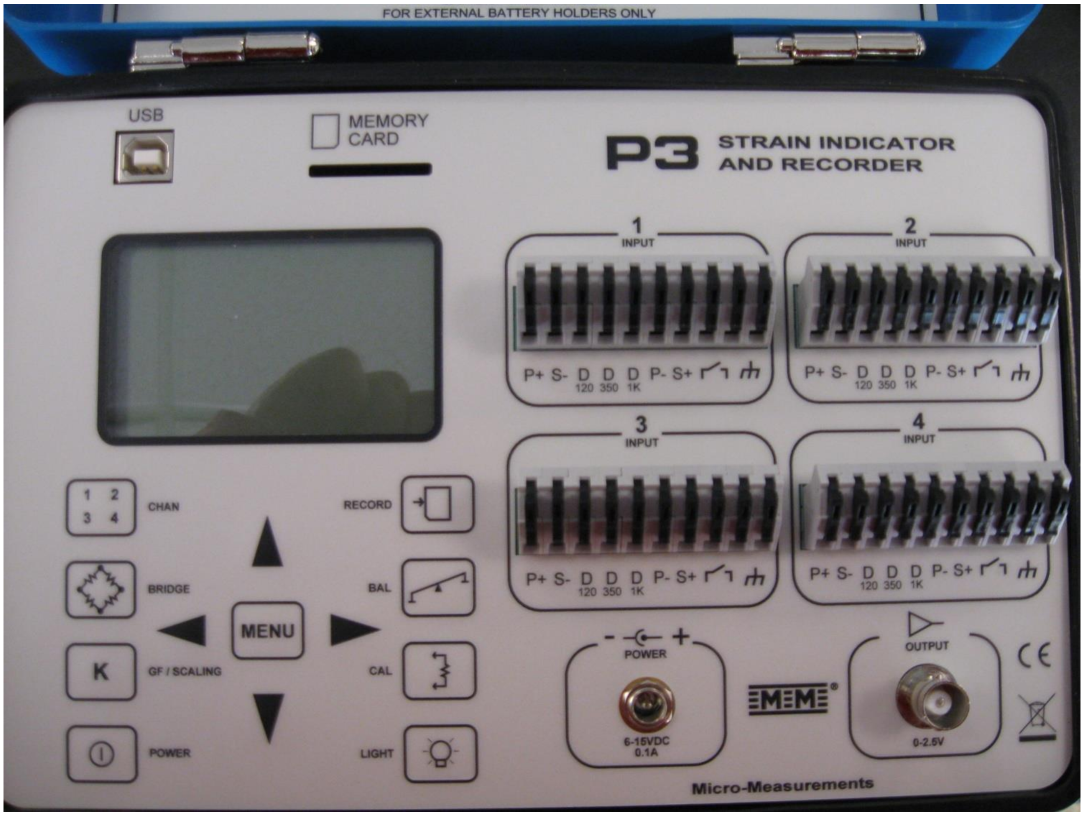

Figure 1: VISHAY strain gauge indicator, showing controls and inputs for up to four full Wheatstone bridges. Students can select various quarter, half, and full Wheatstone bridge arrangements to match the wiring setup chosen for the physical setup.

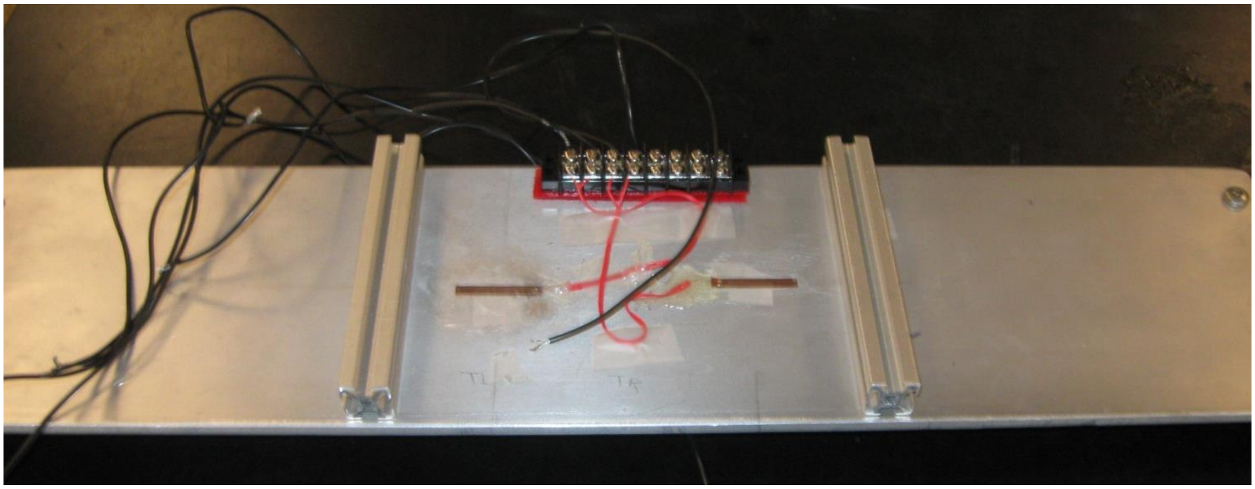

Figure 2: Aluminum beam setup. A board is placed across the visible aluminum supports for the experiment. Two strain gauges are visible on the surface; two more are located underneath the beam. The spring loaded connectors allow for quick reconfiguring of the Wheatstone bridge setup.

The dimensions of the beam setup are shown in Figures 3 and 4 below. Students are assumed to have taken statics prior to this course. The connections between the beam and the supporting feet are deliberately kept as loose as possible, in order to allow the beam to act as a simply supported beam. The beam is constructed of 6061 aluminum, with 80/20 extrusion used for the feet and supports.

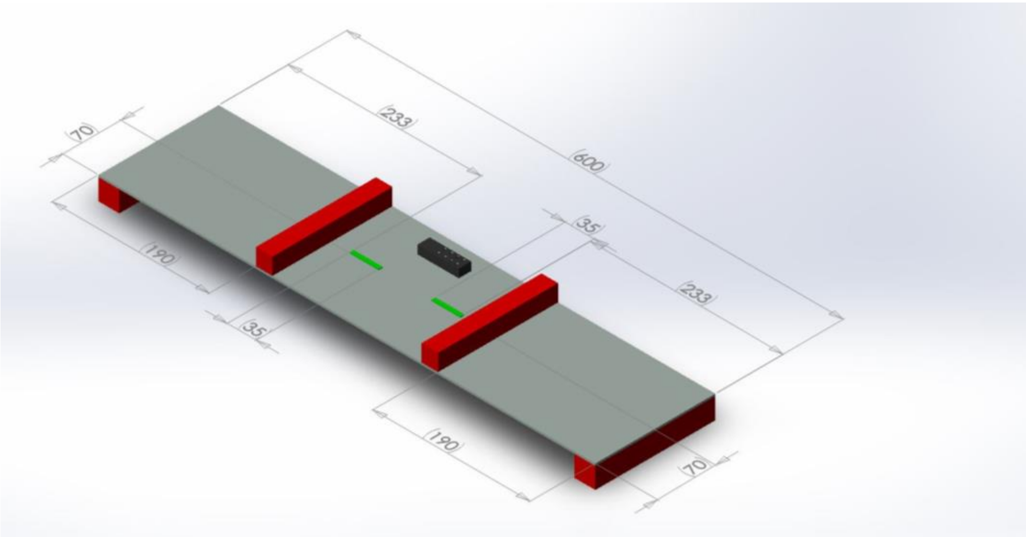

Figure 3: Model of experimental setup. All dimensions given in mm.

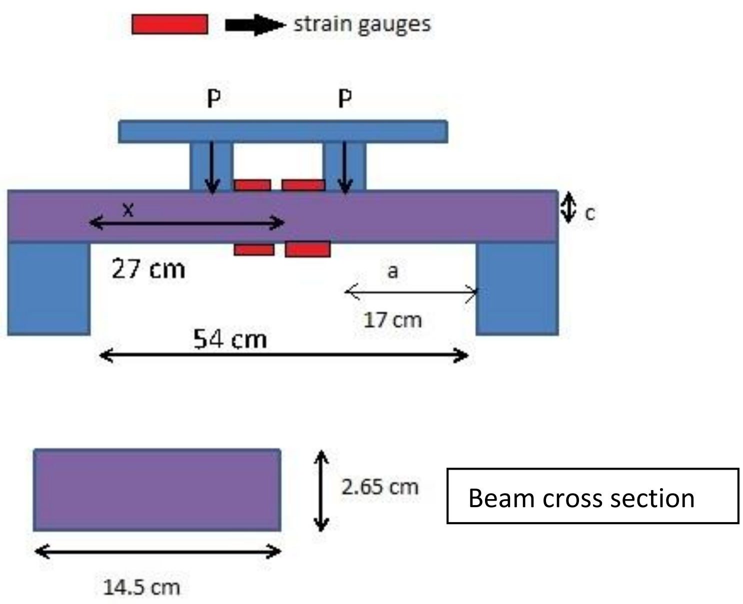

Figure 4: Sketch of side view of the aluminum beam. P is the load, assumed to be equally distributed across the two supports. The distance from the leg to the midpoint of one of the supports is a, and the distance from the leg to the midpoint of the beam between the load supports is x. The distance to the central line of the beam is c. The cross section refers to the width and thickness of the beam itself, shown in purple. The red boxes indicate the location of the strain gauges.

The largest expense for this experiment was the strain indicator boxes, which cost approximately $2500 each. These were acquired with the help of a grant from the Lufkin Foundation. Scales, calipers and other measuring devices were already present in the labs as part of the standard set of equipment for each lab station. The remainder of the materials for this lab cost approximately $300 per setup. From one term to the next, the only consumables are the connecting wires, which become frayed over time and must be replaced.

Experimental Procedure

Prior to the lab, students complete a pre-lab homework assignment. This assignment is written to require students to read the lab handout in order to complete it. They are asked to use the appropriate beam theory to calculate expected deflections and stresses. They are also asked to develop a data table and decide what data they would have to gather during the lab. Finally, they are asked to examine the specifications for the various sensing devices in order to estimate the uncertainty expected in the measurement.

The experiment is performed in groups of 3 to 4 students. Students are asked to begin the experiment by measuring the beam setup to confirm the as-built dimensions using calipers and tape measures. In the first portion of the lab, students are asked to connect one of the four strain gauges to the indicator box in a quarter bridge setup. They then add at least three different weights to the setup, recording the strain each time. This is repeated for each of the four strain gauges in turn.

For the second portion of the lab, students are asked to choose various combinations of two strain gauges to create half bridge circuits. Students are directed to select certain combinations that are known to produce erroneous readings; for example, choosing two gauges in compression and arranging them in the circuit such that the strains measured by each cancel out. The purpose of this is to cause students to recognize the relationship between the location of the strain gauge on the piece being measured, the location of the strain gauge in the circuit, and the strain read from the indicator box. For each half bridge circuit, the students again take measurements of three different weights. This process is repeated once more for a full bridge circuit using all four strain gauges.

The final part of the lab requires the students to choose one of the bridge setups (quarter, half, or full) to measure an unknown weight. At least four known calibration weights are used to create a calibration curve relating weight and strain as measured by their chosen Wheatstone bridge setup. They then choose some object that they want to weigh, which can be a textbook, a backpack, or even a fellow classmate. This object is weighed on their 'scale' – the instrumented aluminum beam – and then weighed on a calibrated laboratory scale to get the reference value. This allows them to be able to compare the weight determined by their scale to a reference value, and determine the estimated error in their measurement.

Analysis

Students present their results in the form of an individually written memo style lab report. They are asked to present both measured and calculated theoretical data in well-organized tables. They are asked to graph the calibration curve for their home made scale, and to correct the data as needed in order to find the most accurate possible value for their unknown weight.

Data analysis questions require students to compare their theoretical and measured strain values for all the different bridge arrangements. Students also discuss the difference between different bridge arrangements and explain why some arrangements do not return accurate values. Bridge arrangements are also discussed with regards to the accuracy of the different types of bridge. Accuracy and precision are also determined for the measured values of the unknown weight. They are asked to explain how various bridge arrangements compensate for axial and temperature strains. Finally, they are asked to provide suggestions on what could be done to improve the accuracy of their scale if the experiment were performed again.

Benefits of Approach

Prior to the development of this experiment, strain measurement was accomplished using a cantilever beam arrangement that was connected permanently to a junction box that depicted a Wheatstone bridge arrangement. This in turn was attached to a LabView data acquisition module[1]. The original setup had the advantage of being somewhat robust, but made it difficult for students to make conceptual connections. The lab handout was written in a very sequential, cookbook style. Students got reliable and repeatable answers, provided all the equipment worked. However, there was no way for students to do any troubleshooting on their own when things went wrong. Students had no opportunity to learn from mistakes. Instead, they tended to call over the lab technician or TA to fix the apparatus so that the 'right' answer came up. In subsequent exams, students had difficulty discussing 'what-if' questions related to strain gauges, showing a disconnect between the theoretical concepts and what they had seen in the lab.

The current lab was deliberately designed to require hands on work from the students, and to require student troubleshooting. The strain gauge indicator boxes are extremely robust, but still allow students to connect and disconnect wires on their own, in order to wire the circuits in different ways. In contrast, due to the fragility of the LabView modules, students were only allowed to touch the junction box. This clearly artificial connection did not allow students to directly interact with a measurement device that could be used in other situations. Students are encouraged to solve problems with the apparatus on their own. This is highly beneficial to the students, but it is also beneficial to the instructor and teaching assistants. The instructors need to do much less hands on work during the lab sessions, and can instead guide, suggest, and answer conceptual questions. Since it is virtually impossible to break the apparatus, short of dropping it on the floor, it is possible to let even large numbers of students touch and explore the equipment.

An added unexpected benefit was the increase in the number of students who asked to borrow the strain gauge indicator boxes for capstone design projects and student competition teams. Prior to the new experiment, very few capstone design students incorporated strain gauges into their design. Despite having taken the Measurements course, students didn't seem to remember that strain gauges were a possible measurement device, or dismissed them as too difficult or fussy to use. This was likely due to the fact that the students were allowed to alter very little of the setups, and were repeatedly warned about the fragility of the LabView modules. After the new experiment was implemented, students became aware that strain gauges were tricky, but not impossible, to install, and were very comfortable with using the indicator boxes. In one notable case, the Mini Baja competition team borrowed one of the strain indicator boxes as an initial measurement device in order to gather strain data on the suspension of their competition vehicle. When this initial experiment was very successful, they sought out corporate sponsorship in order to acquire an NI Rio system to be able to do long term data acquisition which led to a new suspension design. The experience provided through the Vishay indicator boxes provided enough of a solid foundation to allow students to move easily to other data acquisition systems.

Conclusion

This experiment was successful in teaching the students how to use strain gauges. Students found the experiment engaging and challenging, as determined by surveys conducted at the end of the course. These results, previously reported by the author[2], showed that 46% of the students agreed or strongly agreed that the experiment was interesting and engaging, compared to 25% with the previous strain experiment. In addition, 67% of the students agreed or strongly agreed that the experiment helped them learn strain concepts, versus 57% with the previous experiment. The experiment encourages exploration and independence in the students, and allows them a certain degree of control over the outcome. Although the indicator boxes are a significant cost, the remainder of the experimental equipment is reasonably inexpensive and easily constructed. Finally, this experiment is rapid to set up and store and compact, which is an advantage if space is limited.

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[1] National Instruments, "SCC-SG Series Strain-Gauge Modules User Guide and Specifications", http://digital.ni.com/manuals.nsf/websearch/876393DF257DB5B086256E55005A51CE , Accessed 3/12/15

[2] Smyser, B. M. and McCue, K., "From Demonstration to Open Ended: Revitalizing a Measurements and Analysis Course", *Proceedings of the ASEE Annual Convention*, San Antonio, TX 2012