Use of Knowledge and Skill Builders (KSBs) in a Measurements Laboratory Course

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KSBs ("Knowledge and Skill Builders") have been successfully used in design activities for middle and high school students. This paper discusses their use in a college level engineering laboratory course. Suggestions are also given for their potential use in other courses.

Background

Design activities greatly enhance the technological knowledge of students of all grade levels. A typical design process includes the steps of: Problem definition, including constraints; Research and investigation of possible solutions; Generation of alternative designs; Choice of the optimal design; Construction of a prototype or mathematical model of the chosen design; Testing and evaluating the chosen design; Modifying the design, as appropriate, based on the test results; and finally, Documenting the solution.

"Informed" design is a design process developed through the NSF-funded NYSCATE (New York State Curriculum for Advanced Technological Education) Project.[1] In this pedagogical approach to design, students increase their knowledge and skill base before addressing the specific design problem. This is done through the performance of short, focused activities known as "Knowledge and Skill Builders", or "KSBs".

As an example of KSBs: One popular design activity for middle school students involves the students designing their bedroom in a house they are moving to. [2] The problem definition includes several constraints: minimum room size, minimum ceiling height, minimum window area, specified construction cost per square foot of floor area. The student must design the bedroom, including furnishings, and keep within a specified budget. The student must consider alternative designs, and must construct a scale model of the successful, chosen design. Before starting on the bedroom design, the students engage in KSB activities to enhance their knowledge and skills in areas pertinent to the design project. There are KSBs on geometric shapes, ratios and proportions, scaling of drawings, aesthetics, and cost calculations. The KSBs prepare the students for the actual design activity.

The Current Work

For the past three years, the author has been a participant in the NSF-funded MSTP Project, "Mathematics Across the Middle School MST Curriculum" [3,4]. In this project, he has worked with middle school technology teachers on Long Island on several design activities based on the informed design/KSB approach. In addition to middle and high schools, it appears that this approach could indeed be used beneficially in a variety of college level engineering courses.

As a trial, KSBs were used last semester (Fall 2006) in an activity in Hofstra's ENGG 160A, a sophomore Measurements and Instrumentation Laboratory course. The purpose of the activity was to introduce students to strain gages and their uses. The experimental apparatus consisted of a strain gage mounted on a cantilever beam, a variety of weights to be hung at the end of the beam, and a Wheatstone bridge circuit to measure the resistance changes of the strain gage due to different loadings. A worksheet incorporating KSBs was used to introduce the students to cantilever beam theory, strain gage characteristics, and Wheatstone bridge circuit calculations. This worksheet is attached as an Appendix to this paper.

In previous offerings of the course, strain gages had been introduced to the students by a straight lecture. By using the worksheet and the KSBs, the students were engaged in active learning. They worked together on the KSB calculations, and then loaded the beam with a weight and verified that the measurements agreed with the calculated predictions. The lab session was lively and the students really enjoyed it. They gained knowledge in a manner superior to a straight lecture.

A follow-on activity was to design a scale using the cantilever beam apparatus. An outline of the activity is given at the end of the Appendix. The scale was to be designed for a given weight range (e. g., 0 to 10 lb.). The students specify the material and dimensions of the beam, determine the placement location of the strain gage, and determine the appropriate resistances and voltage of the Wheatstone bridge circuit. If time permits (it didn't in 2006, but hopefully it will in 2007), the students would actually construct the scale and compare its performance with the predictions.

<u>Planned Future Work</u>

The author plans to expand the use of KSBs to a senior mechanical engineering lab (ENGG 170) and the thermal/fluids senior design course (ENGG 143F).

At Hofstra, engineering labs are generally given one semester after the corresponding lecture class. KSBs should be very useful in reacquainting students with the lecture material and with introducing topics not covered (or covered insufficiently) in the lecture class. For example, ENGG 170 has a pump experiment which deals with two pumps operating individually or in series and parallel arrangements. KSBs could be developed on pressure losses in piping, pump head/flow curves, pump operating characteristics, theoretical performance of pumps operating in series and in parallel. These KSBs would hopefully prepare the students for a more meaningful laboratory experience.

KSBs should also be useful in senior design courses where students are often applying knowledge gained in lecture courses taken one, two or even three semesters previously. For example, the author often uses projects in ENGG 143F that are associated with air conditioning of a building. The students size the air conditioning units and determine the air conditioning duct sizes and layouts. The sizing of the air conditioning units is based on the cooling load for the building, which, in turn is based on heat transfer through walls, roofs, floors, windows, etc. The duct design is based on pressure losses in the ducts. System design is also heavily concerned with thermodynamic processes. The heat transfer lecture course is generally taken one semester before the senior design course; the fluid mechanics and thermodynamics lecture courses are taken two or more semesters previous to the design course. KSBs would be very helpful in reacquainting the students with the relevant lecture material and enabling the students to better perform "informed" design. Possible KSBs could deal with heat transfer through various building envelope elements and pressure losses for different flow rates through ducts and fittings. KSBs could also deal with thermodynamic processes for moist air and the use of the psychrometric chart. The KSBs would be developed as preliminary activities prior to the students tackling the full-blown design project.

The author plans to develop the KSBs for these courses next year as part of his involvement in the above-mentioned MSTP Project.

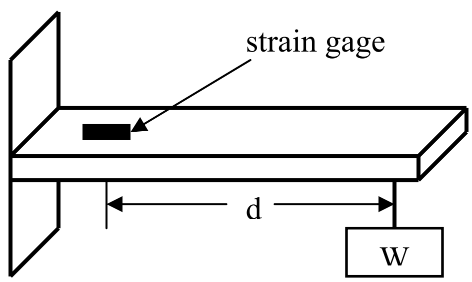
Conclusion

KSBs have been successfully used at the middle school and high school levels. They should also prove to be very beneficial at the college level.

Appendix

ENGG 160A **Design of a Strain Gage Experiment**

Objective: Design an experiment to illustrate the use and concepts of strain gages and associated circuitry. In particular, a weighing scale will be designed using a strain gage as the sensor.



The scale consists of a cantilever beam of rectangular cross section. The strain gage is mounted (i. e., glued) to the top of the beam. The objects to be weighed are hung on the beam a distance “d” from the strain gage.

When a weight is hung on the beam, the beam deflects and causes a small change in the electrical resistance of the strain gage. Since the strain gage is mounted on the top of the beam, the gage will be stretched slightly and the resistance will increase. (If the gage had been mounted on the bottom of the beam, the gage would have contracted slightly when the weight was applied, and the resistance of the gage would have decreased.)

Knowledge and Skill Builders (KSB)

KSB #1 Cantilever Beam Theory No. 1

A weight “W” is hung from the beam at a distance “d” from the strain gage. The weight causes a bending stress in the beam at the location of the strain gage. This stress is

$$\sigma = \frac{M\,c}{I}$$

where: σ = bending stress (psi)
M = bending moment (in-lb_f) = W (lb) x d (in)
c = ½ the thickness of the beam (in)
I = moment of inertia of the beam (in^4)

For a beam of rectangular cross section, $I = (1 / 12)\ b\ h^3$
where "b" is the width of the beam and "h" is the thickness of the beam.

Sample Calculation

A beam is 20 inches long and has a cross section that is 1-1/4 inch wide and 1/8 inch high. A mass of 1 kg is hung 12" from the strain gage. What is the bending stress at the location of the strain gage?

$$\sigma = \frac{M\ c}{I}$$

$$M = W \times d = M \times g \times d = \underline{\quad\quad} \text{kg} \times 9.807\ \text{m/s}^2 \times \frac{0.2248\ lb_f}{1\ \text{N}} \times \underline{\quad\quad}\ \text{in}$$

$$M = \underline{\quad\quad\quad\quad\quad}\ \text{in - } lb_f$$

$$c = ½\ h = ½\ (\quad\quad\quad) = \underline{\quad\quad\quad\quad}\ \text{in}$$

$$I = 1 / 12\ b\ h^3 = 1 / 12\ (\quad\quad\quad)\ (\quad\quad\quad)^3 = \underline{\quad\quad\quad\quad\quad}\ \text{in}^4$$

$$\sigma = \frac{M\ c}{I} = \frac{(\quad\quad\quad)\ (\quad\quad\quad)}{(\quad\quad\quad)} = \underline{\quad\quad\quad\quad\quad\quad}\ \text{psi}$$

It is often desirable to determine stresses in structural members. Since the stress is difficult to measure directly, a common approach is to measure the strain using strain gages and then calculate the stress using Hooke's Law for an elastic material. Hooke's Law is

$$\sigma = E\ \varepsilon$$

where: σ = stress (psi)
ε = strain (dimensionless)
E = modulus of elasticity = Young's modulus (psi)

At a temperature of 20 C, $E = 1 \times 10^7$ psi for aluminum
$E = 29.6 \times 10^6$ psi for carbon steel

Sample Calculation (Cont'd)

The above beam is aluminum. The strain at the location of the strain gage is

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

KSB #2 Strain Gage Factor

Specifications provided by the strain gage manufacturer include the nominal resistance "R" of the strain gage and the gage factor "F" for the gage. The gage factor is used to determine the resistance change of the gage when it is subjected to a given strain. The relationship between the gage factor, the resistance change "ΔR", the strain, and the gage resistance is

$$F = \frac{(\Delta R / R)}{\varepsilon}$$

Sample Calculation (Cont'd)

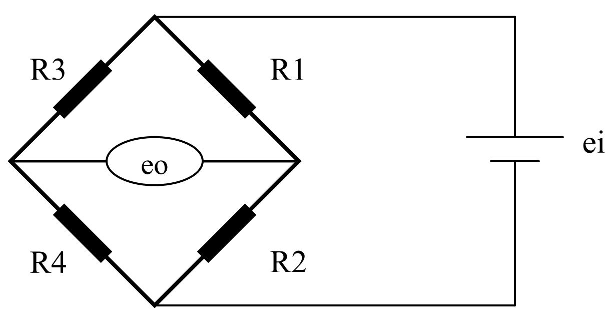
The strain gage has a gage factor of 3.05 and a nominal resistance of 500 Ω. Determine the resistance change of the gage for the above loading.

$$\Delta R = F \times \varepsilon \times R = (\qquad\qquad)\ (\qquad\qquad)\ (\qquad\qquad)$$

$$= \underline{\qquad\qquad}\ \Omega$$

KSB #3 Wheatstone Bridge

It is seen that the resistance change of the strain gage is very small compared to the nominal resistance of the gage. This is often the case. A Wheatstone Bridge circuit may be used to determine the resistance change of the gage. The circuit consists of four resistors (one of which is the strain gage), a power source, and a voltmeter. The schematic for the bridge is



From electrical circuit analysis the output voltage is

$$eo = ei \times \frac{((R1 \times R4) - (R2 \times R3))}{(R1 + R2)\ (R3 + R4)}$$

where: eo = output voltage (volts)
ei = input voltage (volts)
R1, R2, R3, R4 = resistances (Ω)

If the output voltage is zero, the bridge is said to be "balanced". This will occur if R1 x R4 = R2 x R3 . That is,

$$R1 \;/\; R2 = R3 \;/\; R4$$

Note: All resistors have some tolerance associated with their resistance values. Even if we put 4 resistors of the same nominal resistance in the bridge, it is unlikely that the bridge will be balanced due to the tolerances of the resistors. Hence, if it is necessary to start with a balanced bridge, a variable resistor is put into the circuit as one of the four resistors so that the bridge can be initially balanced. It is often unnecessary in strain gage measurements to start with a balance bridge. If the bridge initially has a non-zero output voltage "eo" when the gage in unstrained, then we merely subtract this initial "eo" reading from the reading obtained when the gage has an imposed strain.

Sample Calculation (Cont'd)

Let's make R1 the strain gage. When the gage is unstrained, its resistance is 500 Ω. When the gage is strained, its resistance changes to 500 + ΔR, where ΔR is the value calculated above. Let's make the other three resistors 500 Ω and the power input 9 volts. Using the above equation for the output voltage of the bridge, we get

$$eo = 9 \times \frac{(\,(500 + \Delta R) \times 500) - (500 \times 500)\,)}{(500 + \Delta R + 500)\;(500 + 500)}$$

eo = __________ volts

Design of a Scale using a Cantilever Beam with Strain Gage

Task:

Design a scale to weigh objects in one of the following ranges (to be selected by the student):

a) 0 to 0.1 lb.
b) 0 to 1 lb.
c) 0 to 5 lb.
d) 0 to 20 lb.
e) 0 to 50 lb.
f) 0 to 100 lb.

The scale shall use a cantilever beam with a strain gage mounted on its top surface. The beam shall be of aluminum or carbon steel and shall have a maximum width of 2 inches and a maximum length of 2 feet.

A strain gage having a nominal resistance of 500 ohms and a gage factor of 3.05 shall be used.

The voltage output of the Wheatstone bridge shall be measurable by a millivolt meter or a microvolt meter. The input to the bridge shall be a maximum of 50 volts.

Determine the material and dimensions of the beam, the location at which the beam shall be clamped to the table, the voltage meter to be used, and the location of the strain gage on the beam. Determine where the weight shall be hung and predict the strain and stress values for the given range of loadings and the output voltage for the bridge.

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