Incorporating Musical Instrument Design

Into A Freshmen Engineering Course

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Abstract

Technical interests and achievements of freshmen engineering students need to be encouraged. Developing strategies to increase the participation and enjoyment of these students in understanding and experiencing the design process is the basis for this project. It involves designing, building, and testing a simple stringed instrument. All work is done in teams.

A combination demo/hands-on exercise is being developed for inclusion as the design component of a freshmen engineering design and graphics course. The purpose of the exercise is to expose students to designing and building a simple stringed instrument. This instrument includes a strain gage to (indirectly) measure string tension which is then compared to mathematical models and resulting musical pitch. This musical pitch is analyzed using commercially available software that receives input from a contact microphone mounted on the instrument's body. Student teams document all information through reports and in-class presentations.

Background

An introductory 3-credit, 6-hour per week engineering design and graphics course (ED&G 100) is required for most engineering majors at Penn State. There is no prerequisite for the course, and so, most students are freshmen. This course provides students with the opportunity to improve their graphical skills and expand their knowledge of engineering design. The course introduces students to sketching, drafting, computer aided design, word processing, spreadsheet analysis, business graphics, communications, and the engineering design process.[1]

The first two authors are engineers who are faculty members in the College of Engineering at Penn State. They teach anywhere from one to three sections of ED&G 100 each year. The second author who also teaches a computer science course was instrumental in developing a Musical Instrument Digital Interface (MIDI) component for her computer science course. The MIDI component was developed in conjunction with the third faculty member who is in the Department of Music & Integrative Arts. A poster paper on the MIDI project was presented at the 2001 ASEE Annual Conference and Exposition.[2]

Through the collaborative efforts of the three faculty, a design project is under implementation to expand the experiential base of engineering students. Terms and concepts taken from non-technical areas of their lives are expected to reinforce the importance of engineering principles similar in manner to the approach taken by Jones, Lehrman, and Rogers.[3] Perhaps, this project, too, may become the basis for an interdisciplinary, prototype module for "engineers and their liberal arts counterparts."[3]

Design Criteria

Typically, first year engineering students have limited experience with designing, building, and modifying a prototype to achieve a viable product. Many are also unfamiliar with the proper use of power tools, e.g., band saws, drill presses, etc. However, a large portion the 3-credit ED&G 100 course is dedicated to design. In order to introduce basic design concepts in a manner that is both experiential and somewhat non-traditional to the present day engineering curriculum, a musical instrument design and construction project is presented. Teams of three to four students are given criteria that allow them to design and construct a simple, single-stringed musical instrument, Figure 1.

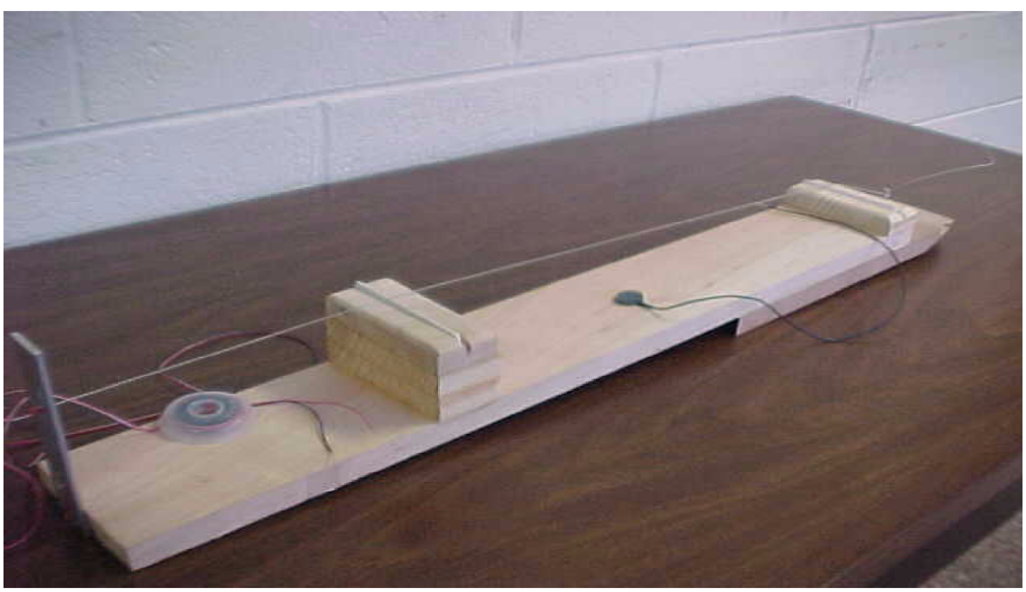

Figure 1. Simple-Stringed Instrument.

Figure 2. Contact Microphone in Center of Body.

Although not required to learn fundamentals of musical composition (nor to perform a composition as per Rogers, Cyr, McDonald, and Nocera[4]), the students are reminded to develop an instrument that produces a tone (musical note). They are instructed as to why their instrument must have a string capable of being tightened, how the string tension must be measured, and how the supplied contact microphone must be mounted on the instrument body. See Figure 2, above. It is suggested their design be a "bridge-to-bridge" system as shown, in Figure 3, below.

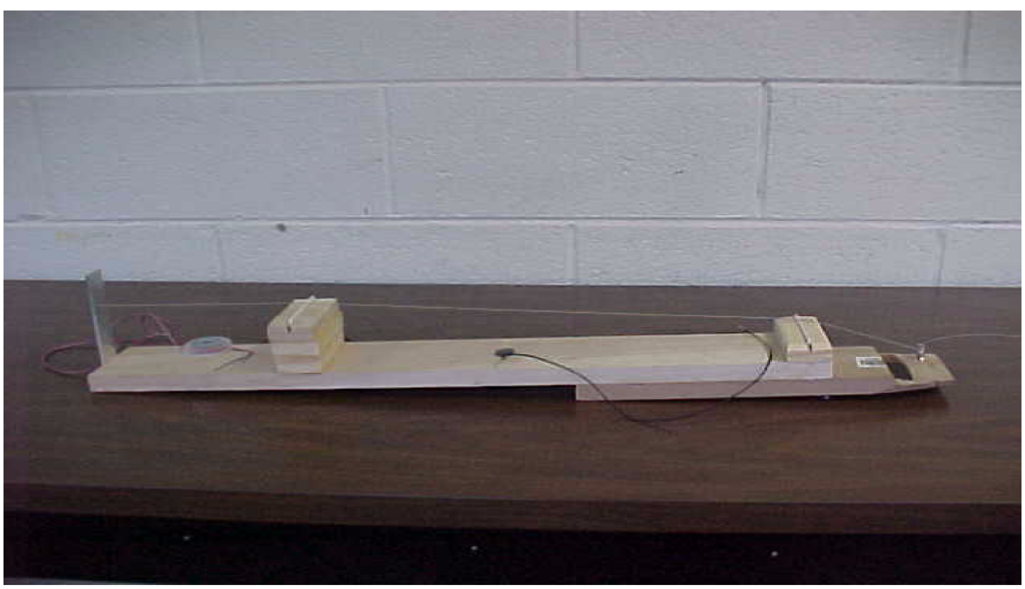

Figure 3. Bridge to Bridge System.

Teams are provided materials including wood for the musical instrument body, plastic frets, guitar tuners, guitar strings, fasteners, aluminum bar stock, strain gages, tuning forks, contact microphones, and Sound Forge[5] software. Total recurring costs: approximately $30 per team.

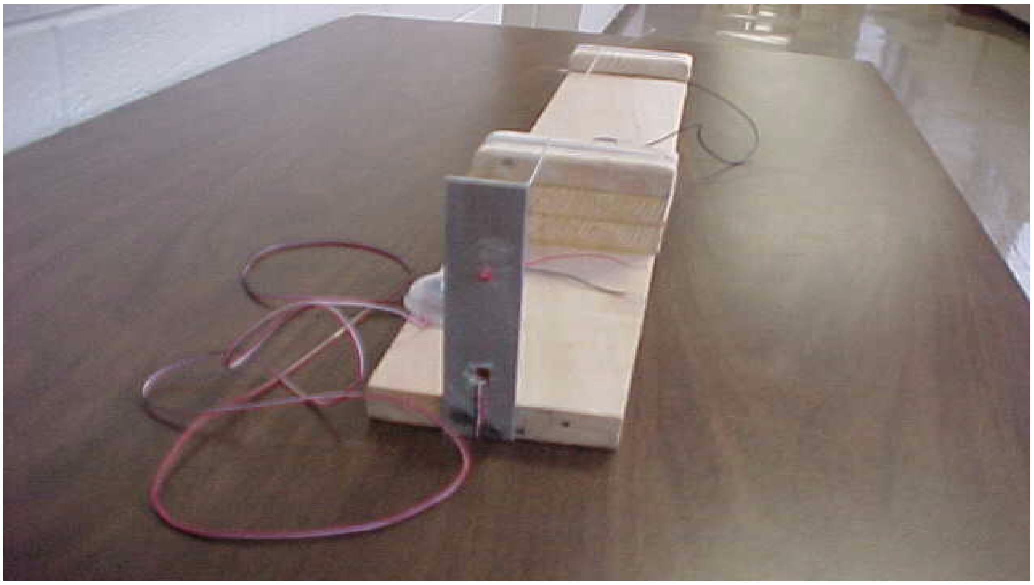

Figure 4. Strain Gage Affixed to Base of Aluminum Plate.

At one end of the instrument body, students are told to secure the string to the strain-gaged aluminum plate, Figure 4, while at the other end affixing the string to the guitar tuner, Figure 5, below. This design allows for uniform tension in the string. Teams are told that the guitar tuner, an example of a worm gear system, allows for adjustment of the string tension.

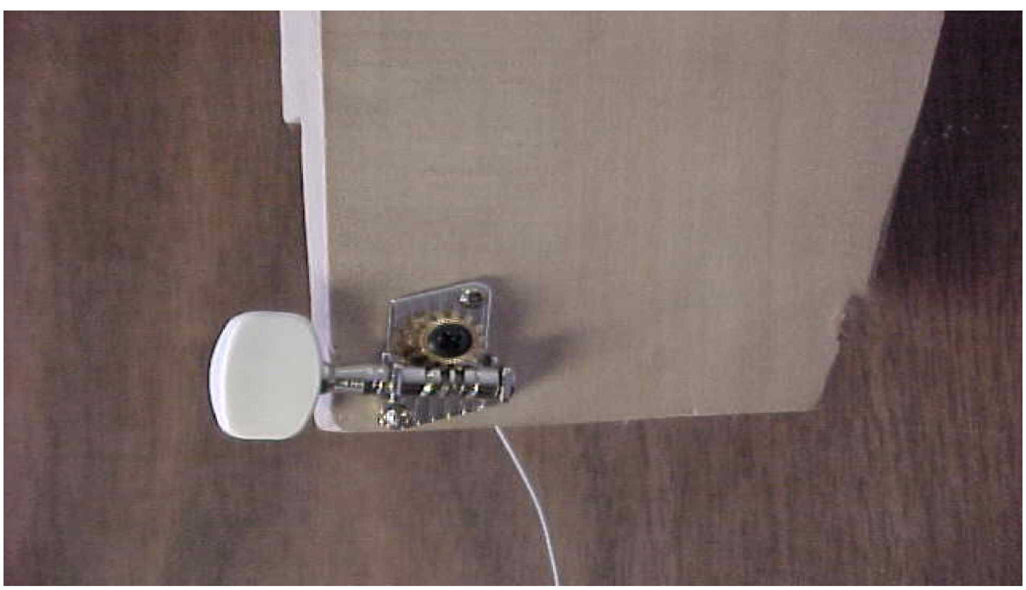

Figure 5. Guitar Tuner: Example of a Worm Gear.

The strain gage, which is affixed to the outside face of the aluminum plate (see Figure 4), is located in close proximity to where the plate is rigidly attached to the wood. This strain-gaged plate allows for quantification of the string tension using equations based on cantilever beam/plate theory. Student teams calibrate this strain-gaged beam/plate by attaching known weights to the free end and then recording the strain output. Using spreadsheet software, they furthermore generate a calibration curve which allows them to compare experimentally derived results (Strain versus Force) to theoretical predictions. The entire process reinforces the relationship between prototype-generated data and supporting theory.

Sound Forge[5] software, used to measure the frequency of the note/sounds produced by this "musical instrument," receives input from the contact microphone which is positioned on the wood base (approximately) midway between the two bridges. Design teams must measure the frequency of this stretched string and document specific parameters such as string diameter and location of excitation, i.e., where the string is being plucked. Teams must investigate plucking (exciting) the string at a variety of distances: one-quarter, one-third, and one-half the length and then, at a selected location as a constant factor.

Teams are required to document their designs and are reminded that, at the end of the semester, they must submit a written report and present their results to the entire class using presentation software. They are presented with a set of seven design criteria for their simple, single-stringed instrument. The criteria are as follows:

1. The single string is to be mounted on the instrument.
2. The string tension must be capable of being adjusted.
3. A strain-gaged aluminum beam/plate will be attached at one end.
4. The string will be attached to the beam/plate at one end and to the tuner at the other.
5. A contact microphone will be installed on the body of the instrument.
6. The string must be capable of being vibrated (free vibrations) from a variety of positions along the string.
7. The output from the contact microphone must be measured (frequency and amplitude) by the Sound Forge[5] software.

Design and construction are to be accomplished using a team approach. All finished design drawings are to be done using computer drawing software (AutoCAD[6] and IronCAD[7]) and included in the documentation and team presentations at the end of the semester.

Expectations

Through this exercise, engineering students become familiar with simple mathematical modeling, use of electrical instrumentation, calibration techniques, 3-D computer drafting software, and application of commercial software used for frequency analysis. The mathematical basis for this design is illustrated when string tension and vibration fundamentals are considered. The frequency of produced sounds (vibrations) and stress-strain concepts are further used for mathematical modeling. Exposure to electrical instrumentation occurs through the use of strain gages and associated instrumentation, e.g., use of Wheatstone bridge circuitry. Use of the supplied contact microphones and frequency analysis software, i.e. Sound Forge,[5] allows students to become familiar with the use of A to D equipment. Further, students calibrate the string tension measuring equipment using a strain-gaged cantilever plate and develop a calibration curve. Finally, to "check" the supplied frequency analysis software, tuning forks of a given frequency are used.

What Next?

The simple stringed instrument was introduced for the first time in one section of ED&G 100 during the spring of 2002 and for the second time in the fall of 2002. Each time changes in the project requirements were introduced. Changes will be introduced again in spring of 2003.

In the future, students will be expected to use cantilever beam/plate equations for their strained-gaged component and then compare the calibration results to the theory. They will not be asked to develop the equations, but to search for, select, and use appropriate equations using library supplied references and appropriate websites (reviewed by faculty). This is similar to activities performed by engineers in industry. These students will be asked to conceptualize a design, build their design, test their design, and compare their test results to the standard theoretical model supplied by the faculty. New instrument designs will include (a) varying the string length with the tension constant and (b) varying the string tension with the length constant. Both processes will use Sound Forge[5] to record results.

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Biographical Information

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