Session 2253

ENGINEERING PRINCIPLES OF AN ELECTRIC TOOTHBRUSH

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Abstract - The hallmark of the newly configured Rowan College of Engineering undergraduate program is the interdisciplinary, project oriented clinic sequence that spans 8 semesters. This sequence is taken by all engineering students. In this paper, we specifically describe the innovative efforts in the second semester of Freshman Clinic that is devoted to competitive assessment through reverse engineering. Specifically, experiments on a low cost consumer appliance (electric toothbrush) are described. This will enable the freshman students to determine how scientific principles, material properties, manufacturing techniques, cost, safety requirements, environmental considerations and intellectual property rights impact the design of a product. Also, the students perform experiments illustrating the engineering principles of the electric toothbrush.

Introduction

The College of Engineering at Rowan University is composed of four departments, namely, Chemical, Civil, Electrical and Mechanical Engineering. In each year, there are between 25 to 30 students in each department. This results in 100 to 120 students in the entire college. The size of the college has been chosen to provide specialization in small departments and permit the creation of a multidisciplinary curriculum in which laboratory/design courses are offered to all engineering students. The hallmark of the Rowan program is the interdisciplinary, project oriented clinic sequence. This 8 semester long sequence is taken by all engineering students.

The Engineering clinic is based on the medical school model and involves side by side interaction among students and faculty for performing laboratory experiments, design projects and research. Multidisciplinary design projects and laboratory experiments at the freshman and sophomore levels stress teamwork, implementation of engineering principles into practice, oral communication, and written communication [1][2]. In the freshman year, the theme of the fall semester is measurements [3], while the theme of the spring semester is competitive assessment (the topic of this paper). Comprehensive one semester and two semester projects at the junior and senior levels (more discipline specific) give the students exposure to the nature of scientific research and provide the initial maturity to appreciate how research is carried out. Although many schools have recognized the need to integrate design into the freshman year [4][5], most traditional programs offer only a senior capstone design course and ignore the freshman, sophomore and junior years in terms of design and research activities. Therefore, at most institutions, undergraduate students will not be provided with the necessary skills to conduct independent research until well into the senior year.

The focus of this paper is on the second semester Freshman Clinic course known as Freshman Clinic II. In this course, the theme is competitive assessment through reverse engineering. The term competitive assessment has been coined by manufacturers to describe the process of ethically acquiring, inspecting, analyzing, instrumenting and testing the product lines of other manufacturers. Reverse engineering is the process of developing sufficient information about a product to allow replication with or without enhancement in original or current technologies, materials and manufacturing processes. The objective of competitive assessment through reverse engineering is to understand and outdo the competition. In the Competitive Assessment Laboratory at Rowan University, multidisciplinary teams of freshman engineering students from each of the four engineering disciplines perform competitive assessment on a consumer appliance (in this case, an electric toothbrush).

The objectives of the Competitive Assessment Laboratory are as follows:

1. Provide the launching pad for an innovative, four year design curriculum by introducing freshmen to the science and art of design by evaluating the work of practicing engineers.
2. Introduce multidisciplinary groups of engineering students to unifying engineering principles.

3. Enable students to determine how scientific principles, material properties, manufacturing techniques, cost, safety requirements, environmental considerations and intellectual property rights impact the design of a product.
4. Allow freshman students to actively participate in a meaningful design effort by evaluating the performance of a consumer appliance.

In the course, both nonintrusive and intrusive testing was done.

Nonintrusive Testing

For the nonintrusive testing, students were asked to:

1. Record all external features, observe safety features and identify potential hazards.
2. Comment on the ergonomics and aesthetics of the design.
3. Record external dimensions, make a list of parts and understand the function of the various parts.
4. Do AUTOCAD drawings of the entire toothbrush and the various parts with proper labelling and dimensioning.
5. Note all intellectual property rights (like trademark, patent numbers and registration).
6. Do a patent search of related patents on the World Wide Web.
7. Estimate the cost of the product.
8. Check environmental feasibility in terms of recyclability and packaging.
9. Understand the operating instructions and operate the product.
10. Devise and perform an experiment to see how the electric toothbrush compares with a manual toothbrush in removing stains. Is the cost of the electric toothbrush justified in terms of its cleaning capability?
11. Recommend any improvements in terms of cost, manufacturing, aesthetics, safety and environmental issues.
12. Do a literature survey of electric toothbrushes available in the market.

Some of the observations and results of the above exercises are now given. Note that these results have been obtained by students working in teams under the direction of the faculty instructor.

1. External features:
   - (a) Automatic shut off after 2 minutes of operation.
   - (b) No metallic connection from toothbrush to charging surface.
   - (c) Removable brush head.
   - (d) Wall mounting capability.
   - (e) Toothbrush will not switch on while charging.
2. Safety features:
   - (a) O-ring seals and lubricant to prevent electrical hazard.
   - (b) Hard and durable plastic casing to prevent shock during charging and when in contact with water.
   - (c) Lack of orifices into the actual workings of the device to again prevent hazards.
3. Ergonomic and aesthetic properties:
   - (a) Casing is shaped to fit the hand and hence, allows for easy grip.
   - (b) Rubber on/off switch easy and comfortable to operate.
   - (c) Convenient rectangular wall mount.
4. Environmental aspects:
   - (a) Recyclable: Nickel cadmium battery, external packaging and operating instructions on paper.
   - (b) Not recyclable: Brush heads, charger and body of toothbrush
5. Recommendations for improvement:
   - (a) Operational tip is a puncturing hazard especially for small children. Protective covering is needed during routine changing of the brush head.
   - (b) Base of handle can easily tip over if a small amount of pressure is applied. There is a need for greater stability.
   - (c) Other components should be made recyclable.

The experiment to compare the electric toothbrush versus the manual toothbrush is very significant in determining whether the increased cost of the electric toothbrush is justified in terms of cleaning performance. Five teams determined the cleaning time for removing a tomato sauce stain on an enamel bowl. Statistics of the cleaning time were taken and it was found that the mean cleaning time for the manual toothbrush was 43.2 seconds and for the electric toothbrush was 47.8 seconds. The results indicate that the higher cost of the electric toothbrush is not justified. However, this is only a preliminary experiment that can lead to errors, particularly since the force applied to the manual toothbrush varies from person to person. Further investigation into this important issue is needed and more sophisticated experiments is a subject of further work. A literature search into how the company Braun compared the manual and electric toothbrushes will be done. It is intended that the experiments done by Braun will be replicated by the students.

Intrusive Testing

For the intrusive testing, two main experiments were conducted as follows:

1. Charging the toothbrush is done by electromagnetic induction. The coil in the toothbrush is evaluated in terms of the number of turns and the voltage across it. The number of turns are then varied to study its relationship to voltage induced. From these data points, least-squares curve fitting is taught and a curve is estimated to derive a mathematical relationship. The magnetic flux density is also measured using a Gauss meter for varying numbers of coil turns. Again, a least-squares fit is determined.
2. The energy stored in the nickel cadmium battery is measured. The voltage across the battery as a function of time is measured by building a simple resistive circuit through which the battery discharges. From the voltage and resistance, the power of the battery as a function of time is determined. Since the integral of the power is the energy, numerical integration is used to find the energy from the power curve. Students learn how to apply the trapezoidal rule of numerical integration to a practical problem.

In both experiments, the concepts taught in the core courses of Electric Circuits, Electromganetics, Calculus and Numerical Analysis are brought together to solve a real life engineering problem. Freshman students directly see the application of the mathematical concepts they concurrently learn.

In the first experiment, the students observe by making experimental measurements that as the number of turns of wire on the coil increase, the voltage induced also increases. A plot of the results is given in Figure 1 and the least-squares straight line fit is found to be $y = 0.03x + 0.4$ where y is the induced voltage and x is the number of turns of wire on the coil. Students determine the straight line fit by applying their calculus knowledge to compute the parameters of the straight line that minimize the mean-square error. The calculation is carried out by writing a MATLAB [6] program. Similarly, the variation of the magnetic flux density for varying numbers of coil turns is modelled by a straight line least-squares fit.

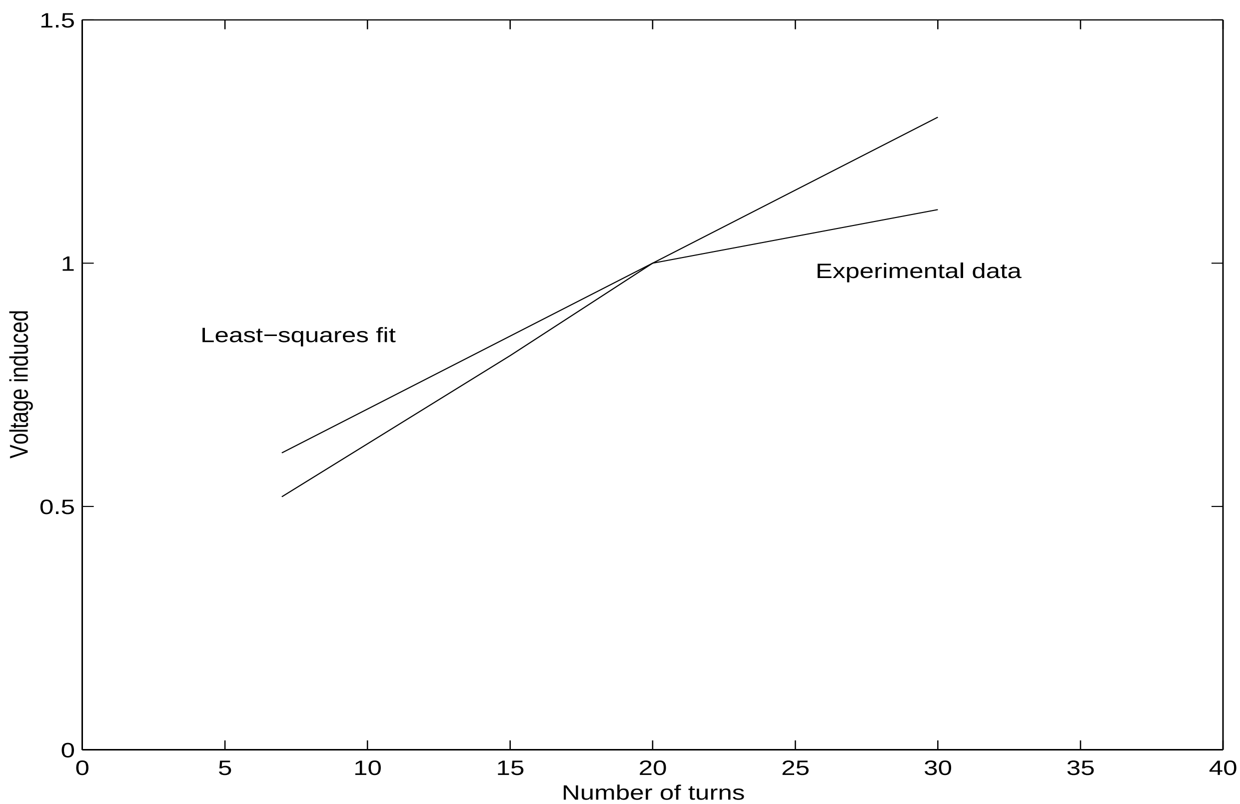

Figure 1 Voltage induced versus number of turns around coil

In the second experiment, the students will find the energy stored in the rechargeable nickel cadmium battery. The fully charged battery is connected across a 1 ohm resistor for discharging purposes. The voltage across the resistor is measured at 1 minute intervals until the voltage decreases to about 70 percent of its initial value. From this voltage versus time curve, the power versus time curve is determined merely as the square of the voltage. Numerical integration of the power curve results in the energy stored. The trapezoidal rule of integration [7] is programmed in MATLAB to calculate the energy. Figure 2 shows a plot of the voltage obtained versus time.

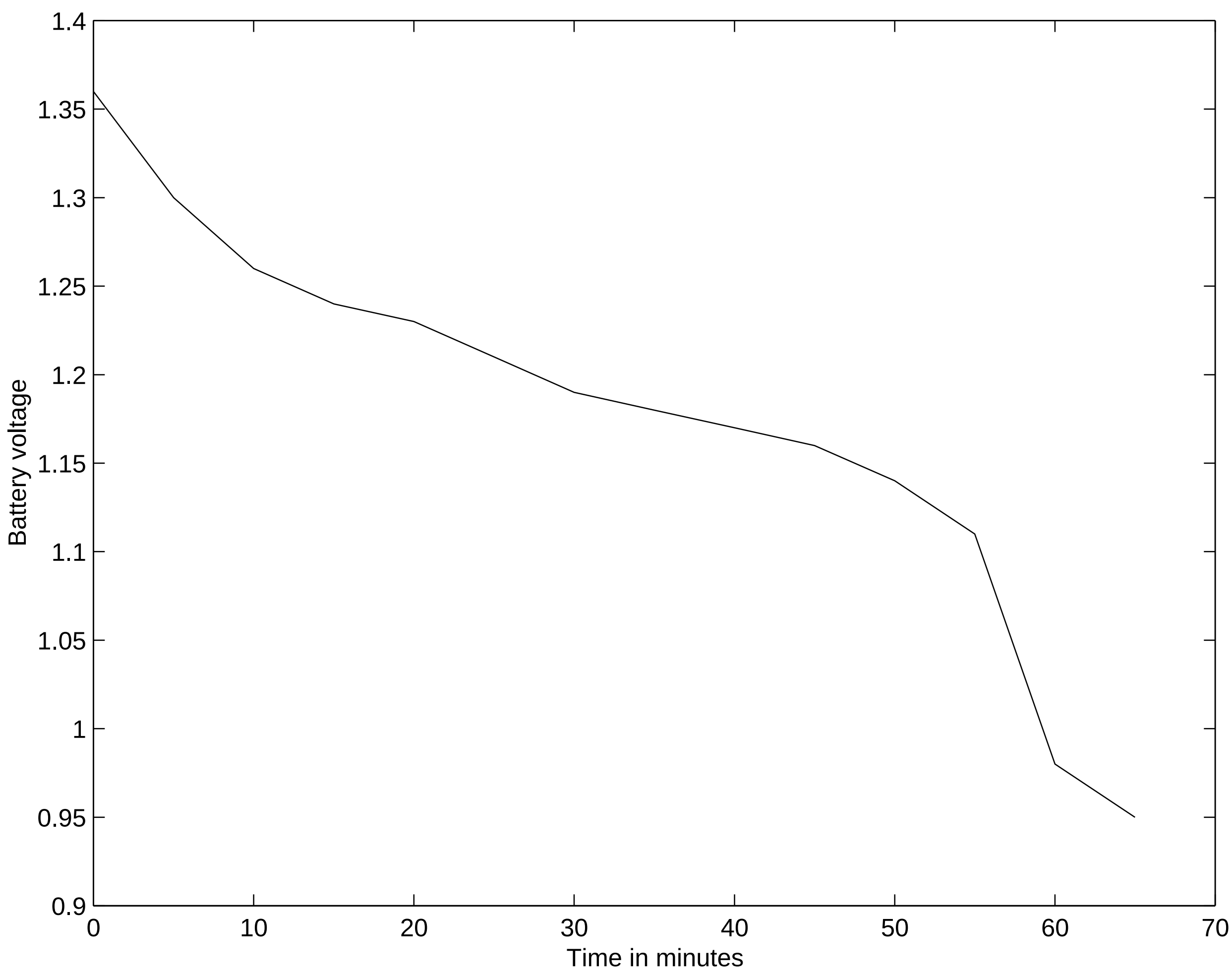

Figure 2 Battery voltage versus time

Summary

The clinic course gives the freshmen students:

1. Hands-on exposure to the electric toothbrush.
2. Computer skills in terms of using AUTOCAD, MATLAB and the Web.
3. An understanding of safety, aesthetics, cost, environmental issues and efficacy of a product.
4. Some exposure to entrepreneurship in terms of comprehending about intellectual property and patents.
5. An opportunity to devise their own experiments.
6. The ability to do a statistical analysis.
7. The ability to apply engineering and mathematical principles in experiments relating to electromagnetic induction and energy storage.
8. Training in effective oral and written communication. Students are asked to do Microsoft Powerpoint presentations of their work. Also, formal reports were written that included a cover sheet, table of contents, executive summary, narrative describing and analyzing all the work, list of references and appendices (includes a glossary and one page resume).

References

1. R. P. Hesketh, K. Jahan and A. J. Marchese, “Multidisciplinary experimental experiences in the freshman engineering clinic design at Rowan university”, *ASEE Annual Conference,* Milwaukee, Wisconsin, June 1997.
2. A. J. Marchese, R. P. Hesketh and K. Jahan, “Design in the Rowan university freshman engineering clinic”, *ASEE Annual Conference*, Milwaukee, Wisconsin, June 1997.
3. K. Jahan, R. A. Dusseau, R. P. Hesketh, A. J. Marchese, R. P. Ramachandran, S. A. Mandayam and J. L. Schmalzel, "Engineering measurements in the freshman engineering clinic at Rowan university", *ASEE Annual Conference*, Seattle, Washington, June 1998.
4. B. W. McNeill, "Beginning design education with freshmen", *Journal of Engineering Education*, vol. 79, pp. 548--553, 1990.
5. J. W. Dally and G. M. Zhang, "A freshman engineering design course", *Journal of Engineering Education*, vol. 82, pp. 83--91, 1993.
6. W. J. Palm III, *MATLAB for Engineering Applications*, McGraw-Hill, 1999.

7. E. Kreyszig, *Advanced Engineering Mathematics*, John Wiley and Sons, 1993.

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Biography

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