AC 2010-1370: LEARNING FROM RENEWABLE ENERGY RELATED CAPSTONE PROJECTS

Yuyi Lin, University of Missouri

© American Society for Engineering Education, 2010

Learning from Energy Conversion Related Capstone Projects

Abstract

Students' capstone-design projects are more and more focused on renewable energy generation and conversion due to ever-increasing energy consumption and a concern for environmental protection. The initial challenge arises from the first step in any design process -- how to justify working on energy-related topics given severe constraints on time and other resources in a typical capstone project. Since many topics and problems related to renewable energy have been investigated by well-equipped research teams all over the world, can student design teams make a significant and meaningful contribution to the use of renewable energy? Can students acquire useful knowledge in the application of physical and chemical principles for engineering design without duplicating or copying from existing products and processes?

During the past several years, our senior student capstone teams have designed biomass compactors, collecting and storing energy from human activities, biomass gasification equipment to generate fuel gas, solar water heaters, and similar projects. Some important lessons were learned from working on these design projects: 1) though the energy generated from human or animal physical activity may be limited, the design can still be innovative; 2) the process can also be an excellent intellectual exercise in the application of physics and chemistry principles; 3) the scope of each project must be well defined and managed in order to satisfy students, industrial reviewers, and project sponsors; and 4) some projects require multi-disciplinary teams for the production of meaningful results. Consequently, we have brought together faculty to begin the process of creating interdepartmental capstone teams for the future. These types of cooperative projects should be encouraged and promoted given our positive experience from previous endeavors.

With renewed and continuous student enthusiasm, as well as expressed community and faculty interest, more capstone design projects related to energy conversion have been planned for the future. These topics include biologically-based methane generation and storage, small steel tower design optimization for wind power generators, conversion and storage of energy from solar water heater, adaptor design for using biomass generated energy on internal combustion engines, and many others.

Introduction

Engineering faculty and students desire to raise people's standard of living and improve their quality of life. However, this undertaking demands a high consumption of energy. Traditionally, most energy comes from fossil fuels which is not only non-renewable, but also produces greenhouse gases which cause environmental degradation. To tackle this problem, senior mechanical engineering students at the department of Mechanical and Aerospace Engineering have enthusiastically chosen renewable energy generation and conversion-related topics for their capstone design course over the past several years. Both students and faculty members have learned valuable lessons working on these projects. Some characteristics are similar to those in other senior capstone design projects--for example, choosing topics that have the “right size.” A one-semester capstone design course may not have sufficient time to produce meaningful results if the project is too broad or complex.

Some characteristics are unique to renewable energy generation and conversion projects. Given the considerable research in this area, is there any topic that is the right fit for a meaningful capstone design project? This paper will present four cases, not all of which, in hindsight, were satisfactory projects. It will discuss what lessons were learned, and what improvements can be made in designing these types of capstone projects.

Case 1--Collecting Energy from using an Exercise Bike

Background and motivation—there are a number of reported devices or designs that collect or harvest energy from human activities. Since the generation of sustainable power from humans is insignificant, the energy generated is always a by-product of another activity, such as exercising or walking. For example, collect energy from the use of an exercise bike and then save it to power small appliances such as cell phones, laptops, etc. Because the leg is the most powerful muscle group in the human body, it is makes sense to use an exercise bike to generate electricity and store it in a battery. One argument against using this specific human activity for the capstone project was the existence of similar designs [1], meaning that the team would “reinvent the wheel.” An argument in favor of the design focuses on its flexibility which can be adapted to any bike with a light, low cost “docking station.” This flexibility alone may justify the need for the design.

Ideas and approach—the key feature was to produce a very light, portable, low-cost, but strong enough support structure that can be adapted to any commonly used bike.

Results—the team created the design and made a functional prototype which met the lightness and low-cost criteria. However, since the major components, the generator and regulator, were purchased, the cost savings were insignificant. Although the student team benefited from the application of FEA and other advance engineering analysis tools, the reviewers were not impressed (referring to Table 1).

Fig.1 Generating electricity from any regular bike while exercising

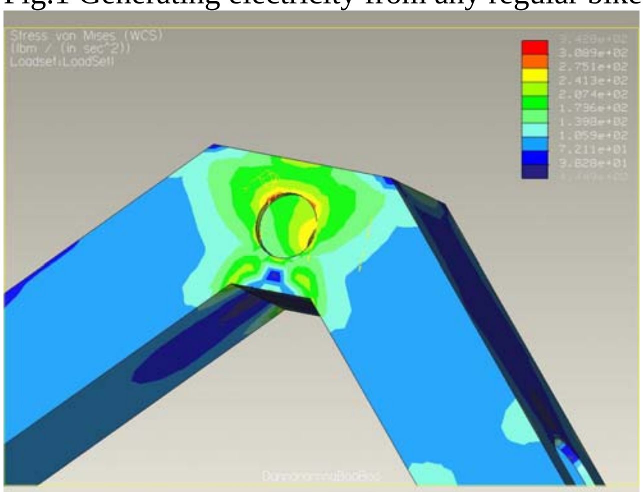


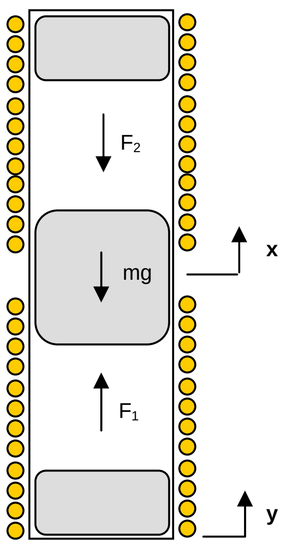
Fig.2 FEA stress analysis to derive minimum structure weight

Case 2—Harvesting Energy from Walking

Background and motivation—the original motivation for this project came from a "Request For Proposals" (RFP) from a government agency. Many small electronic devices, such as a GPS, a radio and a laptop computer, need electricity to operate. A battery's life is limited and may stop working at any time without a reliable recharging source. If the energy from walking could be harvested and stored in a battery, then these devices would have a reliable source of power [2].

Ideas and approach—students on this design team were academically strong, motivated, and extremely knowledgeable as a consequence of elective, technical courses. They also had excellent team skills and worked well with the faculty in the creation of a new device. One faculty advisor suggested using resonance phenomenon in a mechanical system to collect energy: carry a generator which has moving mass and a spring with a coil moving in a permanent magnetic field to generate electricity. The key was to design the natural frequency of this mechanical system so that is was easily excited by the frequency component while walking. An assumption was also made that the light weight generator was stored in a backpack or attached to the user's body. The leg as a possible location for attaching the device was eliminated because of the extra burden felt by the user in generating electricity. The location of the device should not strain or wear out the user.

Results—the Industrial Advisory Board was very impressed by this project. Although not all students had taken classes in vibration, dynamics or electronics, they learned from one another. The students made a functional prototype and demonstrated their innovative ideas and engineering knowledge. A patent disclosure was filed at the end of the semester.



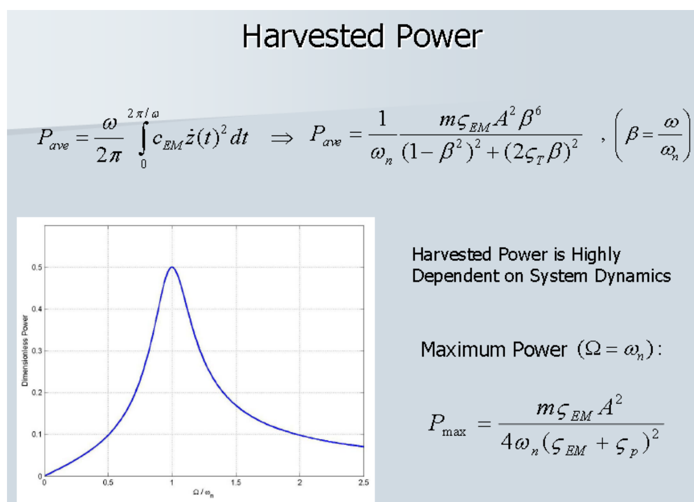


Fig.3 Electricity generated during walking caused resonance
Fig.4 Using walking excited resonance to generate electricity

Case 3—Making Biomass Fuel Logs

Background and motivation—biomass, especially fiber-based materials such as wood, is not widely used because of the cost of manufacturing. Currently, the cost of wood pellets is about 250$/ton, compared to coal which has about 1.5 times the heating value, but less than 20% of the cost. Another approach for a commercial wood fuel compactor is to use elevated heat (about 220C) in order to extract lignin from a finely ground woody material. Lignin exists in most fibrous biomass materials and is a good binder for producing a dense fuel rod. The drawback with this approach is the thermal energy needed to heat raw material to over 220C which significantly increases the manufacturing cost. The Capsule Pipeline Research Center (CPRC) at the University of Missouri has developed a compaction technology [3] that uses no binder or heat but relatively higher pressure to produce biomass fuel logs at a low cost. The fuel logs made from compaction may reduce the manufacturing cost so that it is comparable to that of coal.

Ideas and approach—the heating temperature should be easily controllable. For some material, the pressure alone may be sufficient to make a dense and solid fuel log where heating is completely unnecessary. Since the prototype could be used as a future testing platform, it should be able to provide sufficient pressure, in addition to the controlled heating capacity.

Results—because the controller was not implemented, the lignin product was not stable. The waste paper log could be made without heat. However, due to the small hydraulic pump, the production rate was too slow even for demonstration purposes. An exit pressure controller was designed but not implemented in the prototype. This project received the lowest score from the industrial reviewers (Table 1).

Fig.5a-5b Biomass fuel logs and compactor prototype

Case 4—Biomass Fuel Gas Generation

Background and motivation—there are quite a few testing and commercial biomass fuel gas generating devices available on different size scales [4-5]. Fig.6a-6b showed two of these products. The advantage of using compacted biomass logs, instead of original biomass material in loose form is that manufactured biomass logs require lower transportation and storage cost for raw materials.

Ideas and approach—the key idea was to have a CO gas monitor for the produced gas and use the feedback to regulate the fresh air intake. Too little oxygen would not assist in the production of high-yield fuel gas. However, too much oxygen will produce CO_2, which is not a fuel gas and has no heating value to the user.

Results—as shown in Fig.7, the biomass fuel gas generator was of an appropriate size for the project. Due to resource and time constraints, the CO monitoring device and intake air regulating device were not implemented. As a consequence, the prototype did not achieve its intended design objectives. The fuel gas generating efficiency did not even achieve the level of the simple design shown in Fig.6b. This simple design wisely used the density difference and a small motor to draw fresh air down and force fuel gas up. The capstone design project could not work properly without an air pump or a blower with the output fuel gas monitoring device.

Fig.6a-6b Existing biomass fuel gas generating devices

Fig.7 Prototype of a fuel gas generator using biomass logs

Conclusions

Each semester, the departmental Industrial Advisory Board is invited to review and judge Senior Capstone Design Projects. The IAC board consists of alumni who are leaders in the industry. This semester, a few faculty members also participated in the grading. The table below showed the scores of these four design teams.

Table 1. Team Scores in Project Presentation

	Team Name	Scores
1	Collecting energy from exercise bike	78/100
2	Harvesting energy from walking	92/100
3	Fuel log made from biomass	61.5/100
4	Fuel gas generation from biomass	82.5/100

The scores reflect and support our judgment, which is summarized as follows:

1. The re-creation of simple, commercialized designs is not a good idea for capstone design projects. Even with a simple commercial product, limited time (one semester, senior capstone design course), resources (machine shop facility, funding for materials and equipment), and other constraints present insurmountable difficulties for students. For this reason, a re-working of Case #1 is not recommended for a future project, while Case #4 is.

2. Our IAC reviewers (in a sense, the general public) expect more than a demonstration of the application of basic engineering knowledge in a capstone design project. Even if the students felt they had gained valuable knowledge and demonstrated that knowledge to some extent, the project topic should not be chosen based solely on the demonstration of what was learned. Case #1 is a typical example.

3. Higher motivation and unity correlated closely with greater achievement among the student teams. Some teams that had more than one “good design engineer” present. If such a team could not reach consensus and support for a single idea, the team would not function well or produce the best possible result.

4. Either mechanical engineers need to learn more about electronic design, or they need to work with the support of electronic staff. Almost all modern designs, even those small and simple, rely on the integrated knowledge of multiple engineering disciplines. As seen from these four projects, each has a substantial electronic component or subsystem design involved. Some teams did get more support from the college electronic shop. A consideration for future capstone design projects is to combine design teams from different engineering departments.

5. The student design team should work closely with faculty member who is an expert in the subject area. In the success of Case #2, the student team worked with a faculty member whose research is in dynamics and vibration. In Case #3, the student team could have produced a better compactor with lower cost and higher fuel log quality if they had utilized more assistance from an electronic technician and the faculty expert.

6. The machining skills and analytical capabilities of the student teams are quite varied. The faculty advisor for capstone projects must have a thorough understanding of the team and be selective in the design topic for the team so that the best result can be achieved.

Although more capstone design projects focused on energy generation and conversion have been planned for the future, these past projects provide invaluable lessons for the faculty member--be more selective when approaching these kinds of projects and encourage constant, quality interaction among student team members, technical support staff, and faculty experts. Mechanical design is no longer just a technical exercise – social skills are highly valued and necessary for success.

Acknowledgement

The authors appreciate the enthusiasm and effort that so many students have put into these renewable, energy-related projects in the capstone design course at University of Missouri.

References

[1] http://www.econvergence.net/electro.htm bike electricity generator kit available.
[2] Stephen, N.G. "On Energy Harvesting from Ambient Vibration," *Journal of Sound and Vibration*, 293, (2006), 409-425.
[3]Li, Y. and Lin, Y., 2002, Compacting Solid waste Materials Generated in Missouri to Form New Products, MDNR Project No.00038-1
[4] http://www.woodgas.com/bookstove.htm a commercial wood fuel gas stove
[5] http://www.croreyrenewable.com, a larger biomass gasifier
(Design project reports are available upon request for teaching and learning purpose. Student names are purposely removed.)