A Senior Design Project in Prototyping Roadway Energy Harvesting with Piezoelectric Crystal

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Abstract

The paper presents a senior design project that engages in educational activities to enhance learning in green energy manufacturing, including construction of piezoelectric energy collector system and laboratory experiments in the efficient energy harvesting of the system. The goal of the senior design project was to engage students in real-world learning experiences for the design of energy harvesting as an initial stepping stone for the future construction of manufacturing plants in industry. The project design consists of stacks of piezoelectric sensors embedded within a wooden composite board to utilize roadway traffic. The design assures the piezoelectric material is subjected to strains and produces a charge used to supply voltage through the means of a harvesting circuit which charges capacitors and stores it in an onboard capacitor bank. A series of steps were taken to determine voltage, current, material properties and circuit configuration of the system. In order to maximize the potential of the piezoelectric energy harvesting system, a large amount of mechanical energy was present in order to harvest as much energy as possible. The higher the traffic volume, the more energy that can generated. The student learning outcome of this project was the successful design of the energy harvesting for collecting vibration energy. It provides an introduction to the different areas within engineering by including the mechanical design of a system to vibrate a piezoelectric device and the electrical conditioning and analysis of the piezoelectric energy input. For the sake of achieving the student learning outcomes, experiments were conducted, including sensor monitoring and process control. A concluding section discusses the student learning experiences during this project.

Keywords: Design, green energy manufacturing, piezoelectric crystal, energy harvesting

Introduction

This paper discusses an educational effort that incorporates green energy manufacturing concept for a harvesting energy using piezoelectric system applied to roadways in a senior design project at Drexel University[1]. A critical component of a national "green industries/ green/ energy jobs" effort is to motivate student communities and workforce to become proficient in STEM and associated manufacturing fields and trades, thus ensuring a 21st-century workforce. This senior design project engages students in the implementation of an innovative method for improving design and measuring energy efficiency. Through this project, students learn how to provide a design method for evaluating the characteristics of green energy manufacturing. The students incorporated real-world experience with innovative green energy design for the use of piezoelectric energy, as well as improving energy efficiency.

The main objective of senior design courses in the engineering technology curricula is to bridge the gap between academic theory and real-world practice. Accordingly, the proposed senior projects should include elements of both credible analysis and experimental proofing as mentioned in ABET criteria. The primary intent of this effort is to foster learning of class concepts and to impact the breadth of student learning (in terms of ABET outcomes "(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" and (h) "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context"). The senior design project can serve as an excellent culminating experience in the program of study when it focuses on research and design projects that have practical value to consumers or to industry. For the Engineering Technology (ET) Department at Drexel University, the senior design course is a year-long educational journey (three quarters) that takes an idea generated by a student or an industrial sponsor and culminates in a product or project. This course is an excellent capstone experience, which requires both teamwork and individual skills in solving a modern industrial problem. Senior design projects in fall, winter, and spring quarters bring the students, faculty, and industrial partners together to see the student's results and to give them the additional experience of public presentation of their work.

The purpose of this paper is to describe a capstone senior design project involved in the environmentally conscious manufacturing. The experience to improve industrial working environment and process costs in the project is discussed. The senior design project course is a 3-term core course usually taken by the students during their terminal year in the ET Department at Drexel University. The design involves an educational effort that incorporates environmental consciousness in the senior design project. Several design approaches are pursued as part of the project for green energy manufacturing. The paper discusses the steps taken and apparatus used for performing design, assembly, and temperature control measurements of greenhouse. For the sake of comparisons for greenhouse design, experiments were conducted, including temperature measurement, solar irradiance analysis, and piezoelectric energy efficiency. A concluding section discusses the experiences from this project.

Renewable energy is not used to its fullest potential in the Philadelphia metropolitan area. Systems such as solar, geothermal, wind and various other types are still not fully developed in our area. This project is to demonstrate the potential of piezoelectric sensors to become the new renewable source of energy that is utilized in our high traffic area. This untapped resource can be exploited for various remote or off-grid energy applications. Our society is full of harmful pollutants; about 20% of our total electrical consumption is for lighting. Power plants generate up to 2.4 billion tons of carbon dioxide per year according to Environmental Building News[2]. The increase in carbon dioxide emissions continues to throw off the balance of our ecosystem. This unbalance leads to climate change which affects crops, nature, and many other essential resources. These piezoelectric sensors have the potential to produce more energy than an average panel while avoiding the issue of inconsistent weather conditions.

Piezoelectric energy conversion is based on the piezoelectric effect of materials such as certain ceramics that can develop a voltage proportional to an applied mechanical stress, or conversely, geometric deformation or strain proportional to an applied voltage. Piezoelectric materials used for this project will be based on the concept of a system converting mechanical energy from an environment in the forms of vibration and deflection, at output levels of milliwatts. Basically, the design assures the piezoelectric material is subjected to strains and vibration so the piezoelectric material will produce a charge used to supply voltage through the means of a harvesting circuit which will charge capacitors and store it in an onboard capacitor bank. Once the 47μF output capacitor is fully charged, it will release the 5V 100mA continuous output to charge the battery[3]. With this generated energy, it will be powering a 2W 20W equivalent LED. An LED can reduce energy consumption over a traditional incandescent bulb up to 85 percent, and last up to 25 times longer[4-6]. By implementing the system it will increase safety by powering illumination lights and roadway signs to assist students on where they are and how to get to where they are going. Along with increasing the safety of the campus, piezoelectric sensors can be used as a teaching tool to show students how to construct their own circuit and used in manufacturing plants to absorb the vibrations off the motors. By incorporating piezoelectrics, consumers can save money, reduce global pollution and provide a valuable learning experience to students. Based on an NJ.gov traffic counter, RT-38 receives 50,833 cars per day and RT-295 sees a peak of 129,697 cars per day[7]. These large daily traffic volumes per day can be used to harvest energy with our system and power nearby lighting, particularly energy efficient LED.

Background and Problem Statement

To gain more knowledge and information of piezoelectric disks, the team took a trip out to Mackeyville, PA to speak with American Piezo Corporation (APC) International; the manufactures of the disks the team is utilizing for the project. The team spoke with the sales representative for APC who gave team a tour of their facilities and gave the team some background information on each type of piezoelectric material they have to offer. The sales representative mentioned some of the countries they worked with for using piezoelectric disk for energy generation, one being Israel stated below as the patents. The vice-president of APC gave the team some technical guidance based on his experience with these disks on incorporating them into the roadway strip under the given conditions. He also gave the team helpful tips on the conductivity and wire connections on our disks. In the team’s initial testing, the team was getting inconsistent readings from our disks; this was because the top of the disks were not completely flat. The disks needed to be sanded down lightly with 120 grit sandpaper in order to remove oxidation for better conductivity. Taking the tour of their facilities and talking with them one on one gave the team a better understanding of piezoelectric technology and how it is applied in the world today[8].

Upon researching piezoelectric sensors the team found a prototype design in Israel in 2008 in which they tested a 1km stretch of road covered with piezoelectric sensors. Their system was expected to produce 400 kilowatts and use sensors to power lighting and other energy consuming parts of roadways, such as signs and call stations. The team’s proposed system differs from the aforementioned Israel design in that it is constructed on a much smaller scale. The focus is to provide energy at scales suitable for lighting campuses and parking lots, but could eventually be scaled up to highways and highly traffic roads[9].

Another similar patent the team found was the Goshiki Zakura Ohashi Bridge in Japan. This bridge has piezoelectric crystals beneath the roadway attached to a pendulum. Once the pendulums swing, they generate energy to power the 10 generators beneath the bridge. The generators then aid in powering the 108 LEDs on the bridge. Sound power Corporation is the implementer of this project patent US# application 20120248937. They state that they are currently working on remodeled generators to power 100 percent of the LEDs on the bridge. This system differs from ours due to they are using pendulums and generators to power their lighting. With the team's system design the team will be using pressure sensors and an energy harvester to capture all the energy from passing vehicles[10]. The team also referenced the piezoelectric stun gun patent # application 20080289531. The electric stun gun utilizes a piezoelectric sensor with both an electrical and mechanical oscillating circuit in order to generate an electric pulse. The team referred to his patent for the specifications of our disk to generate the optimal power[11].

To gain knowledge regarding renewable energy usage, the team contacted the Township Manager of Mount Laurel to discuss the design of the team project, incorporating renewable energy in Mt. Laurel, and traffic data. The team was informed that the township only uses solar power as their source of renewable energy[12]. Even with the addition of solar, Mt Laurel still powers most of their street lights off of the power grid with none of the lights powered directly off of solar power. The team was also familiarized with the zoning boards that determine where the system could be implemented and depending on its location whether or not it would benefit the area. From the information the team gathered from the Township Manager, it is clear the sources of renewable energy for the Mt. Laurel area are under construction.

Energy Harvesting for Green Energy Manufacturing

Piezoelectrics can also be used to collect energy from motor vibrations by connecting a piezoelectric sensor to the outside casing of an electric motor and mounting it in a direct or indirect configuration as shown in figure 1. Vibrations resulting from the motor being used will result in forces resonating into the sensor, which will cause an electrical charge that can be harvested and stored for powering equipment in structures that utilize motors as a form manufacturing production. The indirect method of mounting a piezoelectric sensor in the cantilever configuration allows the sensor to have more deflection to produce the maximum amount of power.

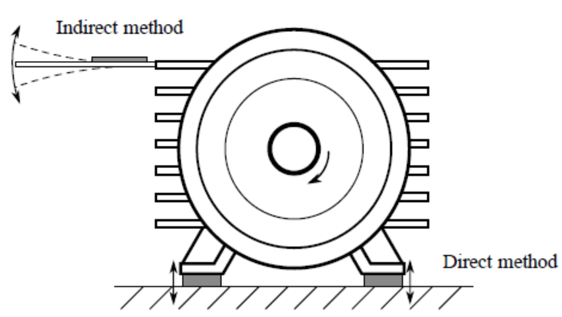


Figure 1: Electric Motor

When the team first did research on piezoelectricity and utilizing it as a source for renewable energy, the team had the idea of integrating a solar panel into the design in order to achieve a more efficient system with a higher energy output. The concept of incorporating solar power involved a 70 watt photovoltaic panel being mounted on a nearby light post and having the piezoelectric system across a lane of traffic on the road below. From the panel the team expected to produce anywhere between 70 watt-hrs and 5.8 amp-hrs on the cloudiest day and 280 watt-hrs and 23.3 amp-hrs on the sunniest day[13]. The team decided against merging solar power and piezoelectricity due to the solar panels ability to produce more energy by itself then combined with the initial piezoelectric system. By creating a solely piezoelectric system, the team would be able to develop and expand upon a renewable energy source that would be beneficial to the area it is implemented. Our local area is one of the most densely populated in terms of traffic volumes and the team plans to take advantage of the wasted energy generated everyday by simply driving to work or school.

Alternative Designs and Concepts

During the course of constructing the team's project, the team approached many different designs before reaching the optimal solution for the piezoelectric system design. While designing the project the team tested three different types of piezoelectric disks: a 35mm diameter non-PZT flat disk, a 19mm diameter by 12mm thickness PZT disk and a stack of 2mm diameter by 30mm thickness disks in configuration in the strip the team designed. The team initially chose the 35mm flat disks based off a low profile design and the desire to make the strip as flush with the ground as possible. After testing the 35mm disks and having it result with less than desirable amounts of voltage and current, the team researched a PZT material sensor with a much greater thickness in hopes to obtain better readings. When the team stepped up to the 19mm by 12mm PZT disk and began testing, the team received higher voltage readings but the current generated was still less than sufficient. After the team visited the piezoelectric disk supplier, APC International, the team was advised to stack 2mm thick disks together and wire them in parallel in order to increase the current generated. From these disks and this configuration, the team received the largest of amount of current and voltage when testing them under the roadway conditions.

When it came to wiring the sensors together, the team initially wired the leads directly onto the sensors but during testing the vibrations caused the bond to fail. There was also the risk of the high temperatures associated with soldering damaging the piezoelectric properties of the element. The wiring method currently implemented into the design involves brass shims attached to the top and bottom of each piezoelectric disk. For constructing the housing of our piezoelectric system the team evaluated two design approaches: a low profile flexible rubber enclosure and a solid thicker wooden board. The team decided to use the thicker wooden board because the team required good stability, strength, and extra depth for the stacks of sensors. The rubber enclosure would have been about half of an inch thinner, but that prevented the stacks of sensors from being embedded. After going through different concepts and designs, the team came to the conclusion of using 2mm by 30mm disks in a stacking configuration wired in parallel and embedded within a wooden board.

Piezo Selection and Configuration:

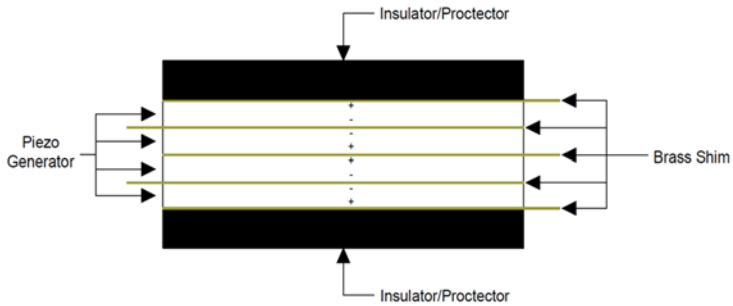


Figure 2: Stack Configuration

The piezoelectric the team chose is APC 880 disk shape piezo generator, which is a hard ceramic piezoelectric with low mechanical loss and high dielectric stability. Hard ceramics are more stable than soft ceramics but the displacement produced by hard ceramics is not as large as soft ceramics. For our application it is not a problem because the team only need the ceramic to displace .015µm to generate a maximum of 20V. When deciding what piezo material to use in the team's application, the thickness, diameter, and g_{33} values had to be determined. The g_{33} value is the piezoelectric voltage constant. This constant is the induced electric field in the direction parallel to the polarization of the disk per unit stress applied. The g_{33} value of the disk the team chose is 25×10^{-3} Vm/N. With this g_{33} value, a thickness of 2mm, and a diameter of 30mm, the calculated static voltage of the disk is 70V with a 1000N force using the Static Voltage equation in the calculation section of the report.

Four disks are stacked to maximize current generation. The team chose a 30mm diameter by 2mm thick disk from what the supplier, American Piezo, had to offer. The sensor specifications were decided based off of the theory. When the composition of the ceramic, the volume of the ceramic element, and the applied force are constant, the element that has the smallest surface area will generate the most electrical energy[8]. A stack height of 8mm, excluding the brass and rubber, was determined based on the dimensions of the strip. Using the stack configuration, as shown in figure 2, each disk will receive the same amount of force. They are connected in parallel electrically with brass shims in between each disk to connect the positive nodes on one side and negative nodes on the other side. The team is using multiple stacks of generators to distribute the overall force applied and minimize the stress on each stack. To insulate the charged disks and protect them under load, two custom made pieces of neoprene rubber with 1/8in thickness and 1.18in diameter were placed on the top and bottom of the disk. This ensured the highest efficiency out of the disks and kept energy losses as low as possible. The piezo disks and brass shims are bonded together using silver epoxy #83315 for conductivity and the insulators are bonded to the brass shims using Hysol Epoxy #29330 for strong non-conductive bond.

Board Design

The prototype strip the piezoelectric disks were embedded within was constructed out of a composite wood 18in in length by 5.5in in width and 1in thick. As shown in figure 3, the board was shaved on each side to make 14 degree angles of incline, with a 1.5in flat plane down the middle where the piezoelectric sensors reside. This was all completed using a band saw for precise cutting and to get the desired shape. Three holes 1.5in in diameter for the 1.18in diameter stacks were drilled to a depth of 0.5in to have the disks completely flush with the top of the board. These holes were placed 1.5in from each other to cover the specific contact patch of the 8in tire. To provide evenly distributed force over the 3 stack of sensors a 0.25in thick low carbon steel bar is placed on top of the stacks. This steel was anchored to the composite board with two wood screws on each end countersunk within the metal. A recycled 5/16in rubber was then placed over the whole strip to ensure the safety of the vehicles driving over the system and the safety of the disks inside.

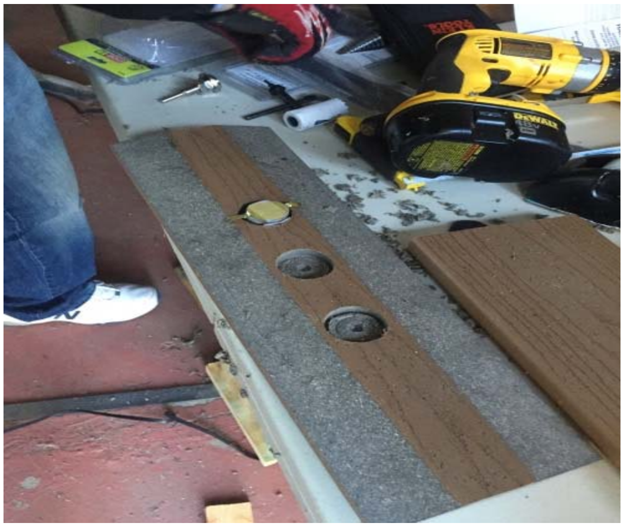


Figure 3: Board Construction

For the final design, which can be viewed in figure 4, the team constructed two identical 4 foot long boards which kept all of the prototypes characteristics and features. The length of the boards was based on the width of one lane of traffic leading up to the stop sign in the testing area. The team applied recyclable rubber and mastic tape for roadway surfaces on the bottom of the boards to prevent them from sliding while cars passed over them. To assist in the safety of the design, white lines were painted on the strip to improve the visibility from the driver’s standpoint.

Figure 4: Final Board Design

Engineering Design and Analysis

Some of the power electronic circuits chosen to utilize the electrical energy produced from the piezoelectric multiple axial sensor design for this project, consisted of the low-loss AC-DC diode-bridge rectifier shown in figure 5. The AC-DC rectifier serves two purposes for the first stage of this nanopower energy harvesting design. First it converts the AC input voltage produced by the multiple axial sensor stacks and convert it to a DC voltage that can be stored in an integrated input capacitor that will output energy to an external storage device. Second, the AC-DC rectifier will help reduce the loss of the energy harvesting circuit by blocking the rectified voltage from re-entering the piezoelectric generating device[14].

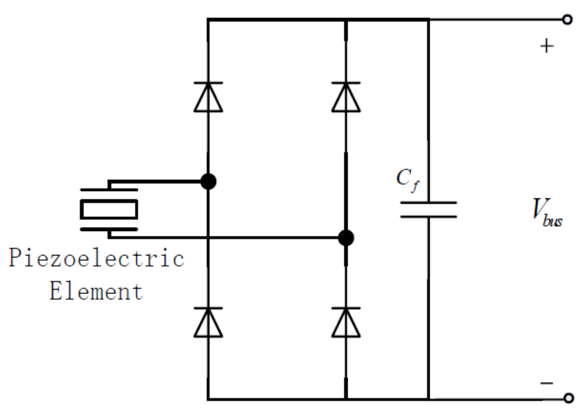


Figure 5: AC-DC rectifier based energy harvesting circuit

Another pupose of the AC-DC rectifier is to take advantage of the output having an inherently lesser ripple than if just a half wave rectifier was used[15]. The power loss of the rectifier used in our teams harvesting circuit is rated for a max of 1500nA, and 450mV found by applying the formula $(|V_{PZ1} - V_{PZ2}|) - V_{IN}$[16]. The maximum V_{IN} for the harvesting circuit is intenally clamped by a zener diode at 20V as shown in figure 5, which prevents the internal circuitry of the harvester from being damaged during the energy collection process.

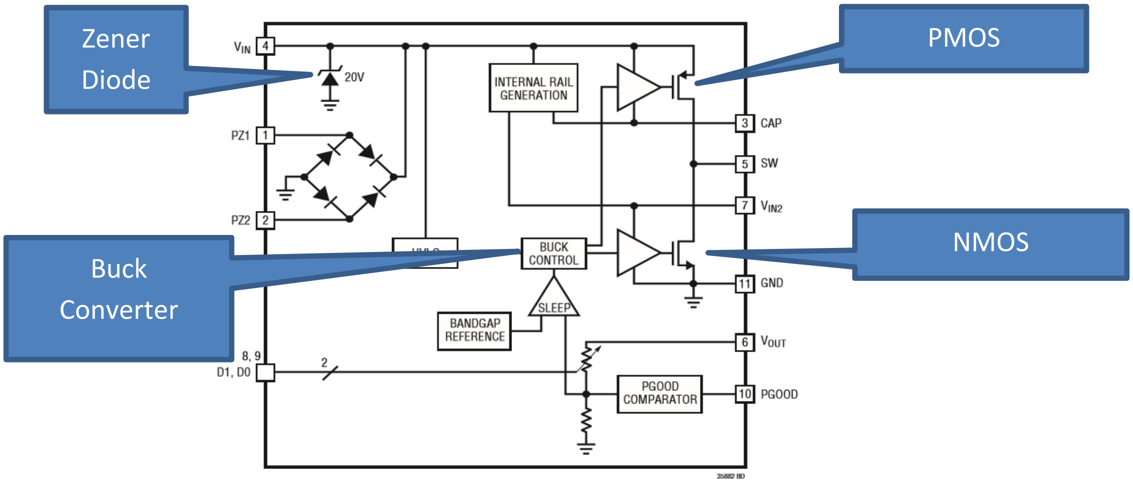


Figure 6: Nanopower Energy Harvesting Circuit

The next power electronics stage in this circuit utilizes a buck converter which allows the output voltage of the harvester to be lower than the input voltage[15-25]. The buck in this harvesting design is controlled by an undervoltage lock out which turns the buck on and off when the input voltage rises above its rating of 16-17V or below 13V. This allows the input voltage stored on the internal capacitors to power the buck converter which in turns delivers power to a high side PMOS, and a low side NMOS shown in figure 6. The high side PMOS switches on and increases the current through the means of an internal inductor to a preset value of 22µH, while charging an external capacitor which will be used to power the buck control while the Vin to the UVLO is being recharged. Once this value is reached the PMOS switches off and the lower NMOS turns on to bring down the current, which allows the energy input from Vin to be transferred to a output storage device such as a capacitor or battery. The final output voltages from the energy harvester that can be selected for use are of the following values: 3.45, 4.1, 4.5, and 5.0VDC. With an extenal load attached to the energy harvesting circuit the output amperage rating is capable of 100mA of continuos output current which can be incorporated into the design for the charging of an external Li-Ion battery or a supercapacitor.

Basic Energy Harvester Circuit

The team constructed the harvester, as shown in Figure 7, because the pre-built harvester did not have the specifications to support the piezoelectric the team is using. The harvester the team built is in the most basic form. The full-bridge rectifier will keep the waveform in a constant polarity and the smoothing capacitor will collect the varying voltages generated from the piezoelectric element. When the capacitor is fully charged, it will release the charge into the battery. Since the battery is much larger than the capacitor and requires a steadier wave to charge, the smoothing capacitor is necessary.

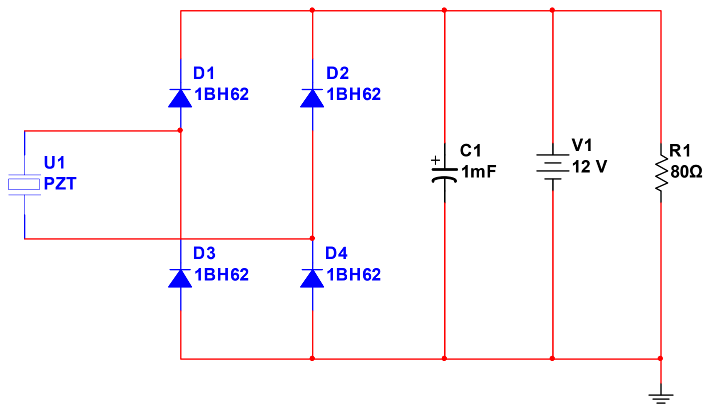


Figure 7: Energy Harvester

Progress towards solution:

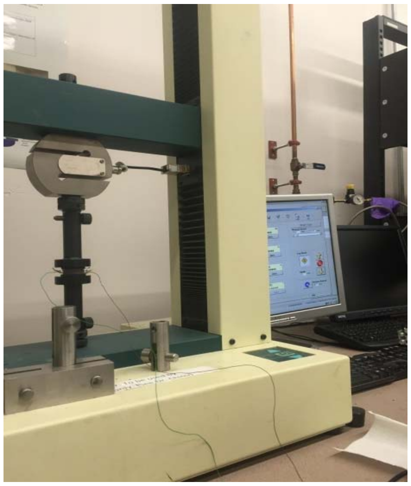


Figure 8: Tensile Machine

Our initial design included utilizing 35mm piezoelectric flat disks. After analyzing the results, the team sourced out other sensors with different g_{33} values and thicknesses that might better suit our application. The team first tested a larger APC 850 19mm diameter by 12mm thick disk with a g_{33} value of 24.8 x 10^{-3}Vm/N. Based on the Static Voltage equation, this would prove to yield higher voltages and current based on the larger area of deformation. The team tested these sensors using a H25kt Tinius Olsen tensile machine seen in figure 6 to compress and decompress the sensor with a measurable force. The team measured all of our data using a Tekpower TP5000 multimeter. The team reached a maximum voltage of 124V under decompression with a force of 1200lbf or 5337N with a release speed of 50in/min. Utilizing the same specifications of force and speed the team retrieved a current of 9.36mA.

From the tensile machine the team determined the ultimate tensile strength of the material to be 1500lbf or 6672N. After various compression tests, the team discovered the material fatigued due to the characteristics of 850 soft ceramics. Once this material fatigued, it would produce little to no current or voltage. From these measurements the team came to the conclusion that utilizing a soft material sensor would fail under roadway conditions with continuous traffic and heat applied to them. As stated in the piezo selection and configuration section, the ceramic material used in this project is APC 880 hard material. To verity the configuration of stacking four 880 hard material piezo disks together, the team tested it in the tensile machine to gather base measurements of voltage and current to compare with the 19mm diameter by 12mm thick disk. From this testing, the team was able determined that by stacking thinner generators together the team could generate more current. Under a 600lbf or 2668N load the stack generated about 13V with a current of 10mA.

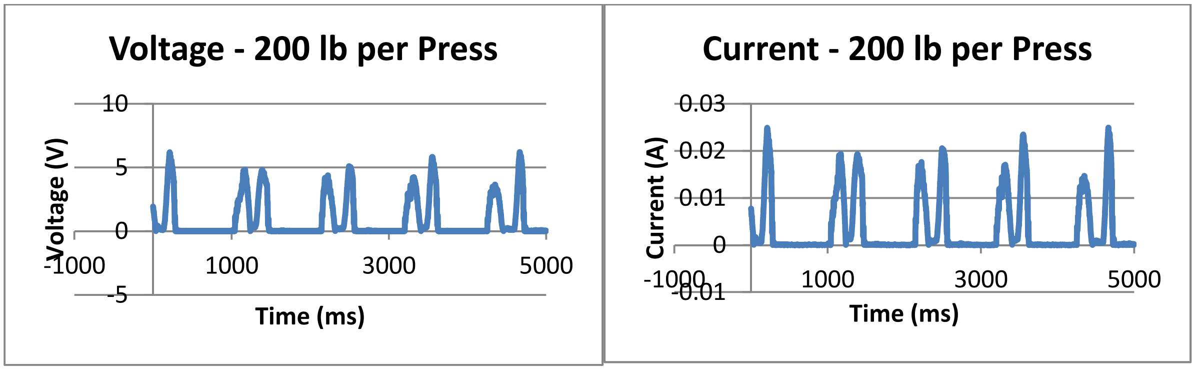
Testing Procedure

Figure 9: Drill Press

Utilizing the tensile machine gave the team a good estimate of the amount of force applied to the disk, but the compression rate is too slow. To replicate the vehicle driving over the sensor and achieve a faster dynamic force the team used a RYOBI 10in drill press Model # DP103L as shown in figure 9. Putting a scale on the bottom of the press allowed us to measure the amount of weight applied to the stack and in turn calculate the applied force. Once the force was determined, the team continuously compressed the stack at a rate of one compression per second using the drill press to simulate an oscillating force. With the positive and negative leads of the stack connected to the myDAQ device, the team used LabVIEW to measure the current and voltage generated from the compression. The collected data is then exported to Excel for further analysis and graph creation. The team gathered data using the same compressing method at approximately 200 and 300lbs. Once the preliminary testing was completed, the stack was placed in the strip and wired to length for road testing. The team used two types of vehicles to test the strip; a Honda civic and a Chevy Trailblazer weighing approximately 2500 and 4500lbs. respectively. The strip was tested under three conditions; driving over it at 5mph, 15mph, and gradually braking.

Results and Analysis

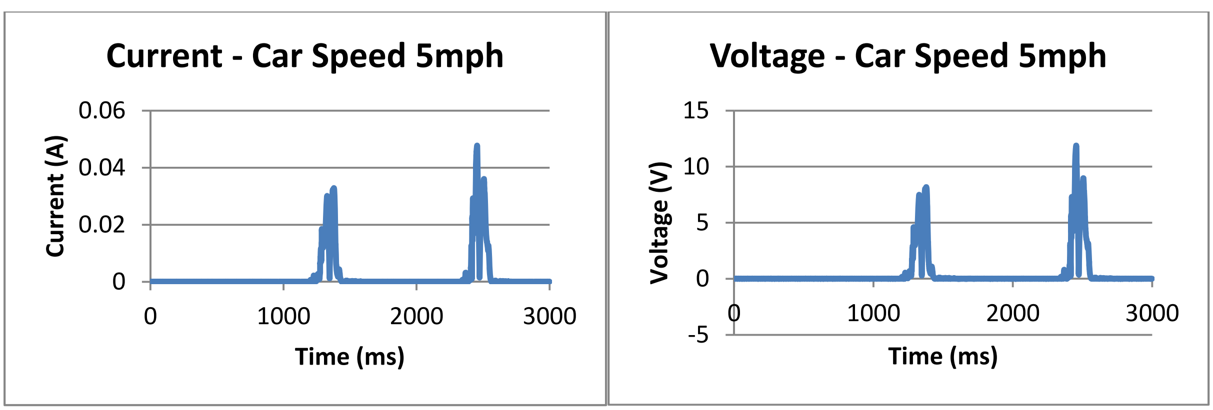
From the oscillating drill press method mentioned above, the stack are compressed with an estimated weight of 200lbs, which generated an average of about 5V and 25mA approximately every second, as shown in figure 10. At 300lbs, the stack generated an average of approximately 7V and 27mA.



(a) 200lb per Press (b) 200lb per Press

Figure 10: Experimental data from the oscillating drill press method

When the team moved on to the road test, the team started testing with the Honda Civic driving over the strip at 5mph and the stacks generated about 8V and 32mA from the front tire and about 12V and 48mA from the back tire. The results are shown in figure 11. The first pair of pulses in the graphs represents the front tire and the second pair represents the back tire going over the strip. The team then tested driving over the strip at 15mph, which resulted in generating 20V and 80mA from both the front and back tire. The final test with the Civic is approached the strip while braking. Going over the strip as the car is slowing down resulted in the stack generating about 5V and 19mA from the front tire and about 7V and 28mA from the back tire.



(a) Car Speed 5mph (b) Car Speed 5mph

Figure 11: Experimental data from the road test

Using the collected data from all testing, the team created a power curve, as shown in figure 11. The generated power grows at an exponential rate as the force exerted on the strip increases. However, the maximum power reached a limit of about 1.6 W due to limitation as shown in figure 12. The energy harvester the team used has input limit that prevents the piezoelectric to perform at its full potential. With a better spec energy harvester, it is possible to harvest higher voltage without hindering the capability of the piezoelectric. Other limitations the team faced are the building space and testing location. The strip has to be constructed in the smallest possible size to prevent causing any disturbance to the vehicle efficiency or the driver comfort. Since placing object on a road is not something that can be done casually, the team needed approval from authority. Testing the concept on a highway could possibly yield better results.

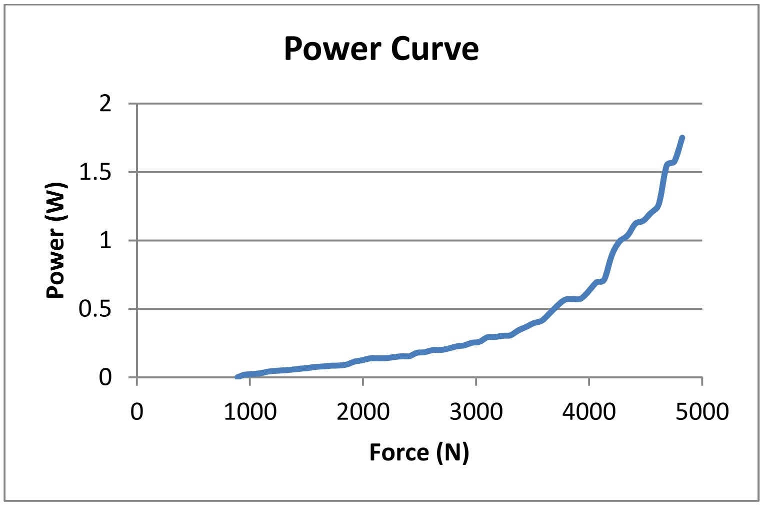


Figure 12: the maximum power is estimated increased as force is increased

Student Learning Experience for Green Energy Manufacturing

For the past years, the focus has shifted towards incorporating renewable energy manufacturing topics in the senior design project course. In the first senior design project term, the students are assigned to the project topics related to renewable energy, power systems, or green energy manufacturing. These projects provide multi-disciplinary collaboration and valuable hands-on experience to the students. In addition to useful lessons on teamwork and project management, the project provides working demonstration of green energy manufacturing. During the first fall quarter of the course, each team is given with guidelines for the senior design project. The team demonstrates the senior design proposal to the entire class and then a written proposal summarizing the proposed activities is handed-in as one of requirements of the senior project design course. To enhance the hands-on experience, the senior design course has been restructured as a project-based course. Students are required to analyze, design, simulate, and build a completely functional system by the end-of-term project. The goal of the project was achieved to enhance student understanding of the fundamental concept of design-for-environment (dfE) and hands-on learning of green energy manufacturing. Students understood the design for the environment by improving and optimizing the environmental performance of products, impact on human health, associated energy, and material and process costs. Students commented that they enjoyed working in such green energy manufacturing project with hands-on laboratory experiments.

Conclusions

We believe that problem-based learning, as exemplified by a capstone Senior Design project such as this one, provides students with important knowledge about green design. In addition, such projects provide students with the essential project management and engineering skills required to bring complex projects from idea to completion. The project begins by defining a performance problem associated with applications and ends with a prototype for a green design solution. The problem drives the learning required to complete the project. Managing the project requires the students to demonstrate effective teamwork, clear communication and the ability to balance the social, economic and environmental impacts of the project. In addition, as empathized, this alterative solution as compared to photovoltaic and resistive heating elements proves both more efficient and cost effective in the long term. This, in turn, will result in significantly decreased costs to farmers, greatly expanded ranges of profitable fruits and vegetable harvests, and a decrease in the environmental impact of greenhouse heating. Fundamentally, the design completed herein will also contribute vastly to the Drexel community at large as it can be used to demonstrate renewable energy systems to students for years to come.

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