ME-423B Engineering Design VII
Senior Design Project Phase 1 Report

Group B16

Wearable Biomechanical Energy Harvesting Device to Charge an iPhone

Due: October 4th, 2022

“We pledge our honor we have abided by the Stevens honor system”

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Project Statement

Motivation:

In recent years, technology has ingrained itself into the daily lives of nearly every person the world over. In particular, smartphones seem to have essentially become an extension of oneself holding the key to most forms of communication, financial operations, and a plethora of leisure activities. To better define the extent smartphones have proliferated themselves throughout the world, according to data collected by the Statista Research Department, there are over 6.5 billion smartphones being used across the globe. Regardless of one's personal opinions on the prevalence of phone usage, the device's potential to be used as a tool for a wide range of tasks is clear. Since so much of a person's life is connected to their smartphone, the phones themselves are used day in and day out for hours at a time. This use will inevitably drain the battery and unless a person is close to an outlet for charging there are very few options available to keep a phone operational. Normally this wouldn't be much of an issue, but under certain circumstances, a dead phone or tablet can spell disaster for someone depending on their phone for directions, financial transactions, communication, the list goes on. This is where our device would come in to remedy any potential issues. By harnessing the energy the body produces simply executing tasks such as walking around and the thermal energy released by a person simply existing we aim to charge external batteries that can be used to keep a phone online for as long as necessary.

Goals/Objectives:

The simplest way to define the key goal for this design project is to produce a prototype that can harness biomechanical energy to charge an iPhone in a manner that is as comfortable as possible for the user while still generating adequate power levels. Through preliminary research the team has found that very few devices designed around biomechanical energy harvesting are focused on user experience and aims to correct this issue by placing comfort second only to producing the most efficient device possible. The original prompt that the group was presented with assumes an iPhone battery has a capacity of 4.0mAh at 4.2V. The team has decided to pursue a design that can charge this type of battery through a mediary rechargeable battery connected directly to the energy harvesting device. Ideally this device would be tailored to anyone who uses their phone a lot but for the sake of the design project, the main demographic will be avid hikers and campers who would be separated from external power sources for prolonged periods of time. The team aims to produce a design that would appeal to these individuals first and foremost. With these key factors in mind, they will first develop an alpha prototype as a 'proof of concept' to show that the available energy released by the body is adequate for charging something comparable to a smartphone. After this is done successfully, the team will cater the design concerns towards the comfort of the user and plan to develop a low profile energy harvesting device capable of keeping a phone powered as long as one may want.

Major Issues:

Design and Analysis:

When considering the possible design and analysis issues the group will likely face, the team has to address the geometric constraints placed on any possible design path. Regardless of the final approach, be it a heel strike device, knee sleeve, backpack system, etc. it has to be able to be designed around the human form. As it is now, the team is planning on developing a boot attachment that will allow the user to harness the thermal and mechanical energy released by simply walking around. They will need to design something that can either fit inside the shoe or around it without infringing on the user's normal movement patterns. Since the device should be somewhat universal, the system will have to be standardized such that it can work in/on more than just one specific size boot.

Beyond the size constraints placed on the design, The efficiency levels in electricity production from both the piezoelectric and thermoelectric elements of the design must also be considered. The details of deriving these efficiency measures will be discussed in greater detail in the technical analysis of the finalized design, but in order to charge a phone, as is the main goal, the team needs to be able to ballpark the amount of piezoelectric and thermoelectric materials to be integrated into the system. If electricity can only be harvested at a certain efficiency level, the team will need to take that into account from the start and build the design around hitting that required energy output. This efficiency will also feed into the circuitry design, and the group will need to consider the best possible way to convert the AC current developed into DC current that can be harnessed by batteries. This is a key area the whole team will need to familiarize themselves with as none of the members have a solid background in designing rectifier circuits.

Once again looking at the design as a whole, the goal is to produce a product that will stand the test of time. In order for the energy harvester to be capable of long term use, mechanical failure is a possibility and must be considered throughout the design process, as any and all components are undergoing repeated loading and deloading. The piezoelectric material must be given room to deform or bend to produce electricity, but the team will have to design around this such that it can bounce back after constant use.

Even still, the availability of the piezoelectric material poses a challenge. Though the materials definitely exist, with a limited budget, the team has to prioritize other similar polymers. To summarize, the major issues the team has to tackle for the design include the small size of the boot, the efficiency of the electricity generating materials, the conversion of current, the risk of mechanical failure of the design and the feasibility of obtaining the materials.

Prototyping & Experimentation:

Building on the aforementioned design and analysis considerations, it is important to factor in major issues the team can currently perceive that will influence the prototyping and experimentation phase of the design process. Once a design is chosen, the team will begin constructing and will need raw materials that may be challenging to source and purchase. As is, the team has not settled on the particular piezoelectric and thermoelectric materials or the particular type of rechargeable battery, circuitry components, etc. What is certain, is the variety of components will result in some difficulties finding exactly what is needed to get the system up and running. Due to this, budgetary restrictions must be carefully considered when choosing the types of materials needed. There may be a more efficient material for energy harvesting, but that particular material could be too expensive and restrict the design in other more serious ways.

In regard to experimentation required, there will have to be phases. First the energy harvesting materials themselves must be tested to ensure they can produce adequate energy on scale with the results in the technical analysis. This will take time and will require special testing apparatuses. Learning about these tests and apparatuses will also take time, but is necessary to ensure the team's design is effective. Once the basic prototype is done, both electricity generation tests must be run to define the device's power production capabilities. In addition to this, stress testing must be conducted as well to make sure it can withstand the day to day operations of walking along a trail or road. Taking these issues into account, the team can make key decisions now that will make the project run smoother down the line.

Literature Review

State of the Art Technology

In an effort to discover the optimal forms of biomechanical energy to harvest for use in our power-providing device, the team divided to separately investigate different existing technologies in the main categories researched. For thermoelectric energy, the team discovered thermoelectric generators, artificial latent absorbing tunnels, and a thermal powered watch. There were three types of TEGs, vertical, planar, and mixed, all of which generated voltage based on temperature difference between the ambient and body heat. A study was done on nasal passages of the human nose, reversing the insulating effect to absorb energy from latent heat in tunnels. The thermal powered watch, dubbed the Seiko Thermic, was a practical application of thermoelectric energy that utilized the wrist's body heat to operate perpetually. These technologies such practical promise in the potential of harvesting thermoelectric technology in the form of multiple flexible and convenient ways.

The piezoelectric energy research led the team to piezoelectric harvesters, piezo ignition, sensors, and nanomotion motors. Piezoelectric harvesters come in three types, macros and mesoscale, MEMS scale, and nanoscale, each of which achieve power based on oscillatory mechanical energy pulses stored in a capacitor. Piezo ignition found in sources like electric lighters and gas stoves create sparks from the energy of deforming a material. Nanomotion motors are a form of motors revolving around a series of piezoelectric crystals that capitalize on the small size for accurate directional force triggered by electrical impulses. These technologies hold practical promise for developing applications in the form of static triggered signals and material flexing based implementations.

The triboelectric research led the team to existing technologies such as an energy harvesting wristband, and more cutting edge nanogenerators that functioned using triboelectric materials. The energy harvesting wristband operated using a rolling polytetrafluoroethylene (PTFE) ball and copper foil electrode casing for conducting triboelectric energy. The PTFE ball was designed to develop a charge opposite that of the copper foil while revolving around the wristband naturally from the swaying motion of a person's arm while walking. This energy was then amplified by the electrostatic energy produced by walking around that also stems from frictional contact with the ground. The study in question found that by coupling the triboelectric wristband with naturally produced electrostatic energy, the overall efficiency of the triboelectric energy production could be enhanced by 12.98 times the levels observed from the wristband operating alone. To quantify this in a more meaningful way, the wristband was able to develop a usable current of $0.43\mu A$ with a voltage of 42V while the combined system output $5.5\mu A$ at a voltage of 545V resulting in a power output of 2.99 milliwatts (Zhai,Gao,Wang). This research indicates that if triboelectricity were to be used it would need to be in tandem with another system in order for it to reach any output level close to reaching the groups need. Further research was done into possible material options and orientations that could be used in the upcoming design. The nanogenerators developed in the study utilized 4 different pairings between materials: contact-separation mode, sliding mode, single electrode mode, and freestanding mode. The research in question found that contact-separation orientations were best for power production when using organic materials such as dry leaf powders alongside polyvinylidene fluoride. The result was a power output of 14 milliwatts that was also disheartening for the potential of use in a phone charging design (Slabov, Svitlana,Santos,Kholkin). Although the use of triboelectric materials is promising with research indicating useful applications in wearable sensor technologies, the state of the art review helped to remove it from the list of options, opting for the more readily available and thoroughly researched piezoelectric and thermoelectric energy harvesters.

Commercial Applications:

Being able to harvest energy from natural movements has many commercial benefits and applications. There are often hikers or joggers far from home and without power that could benefit from the ability to charge on the go without having to carry around heavy battery packs and chargers. Take a hiker for example; a hiker will go on a hike lasting multiple hours and often use a cellphone for either music, directions, emergency calls, or all of the above. However, packing hiking gear is typically a strategic process since they will need to bring all necessary equipment to complete the hike, but may not have room or the ability to carry extra weight for excess batteries. They will also be constantly moving while hiking which outputs a lot of body heat and exerts a lot of force on both the ground and body movement in general could pose a potential way to harvest the energy exerted. A wearable suit to harvest this energy would be ideal for these kinds of athletic or outdoors communities that rely on lots of body movement to complete their exercise. The energy harvesting suit would be ideal for this demographic to be able to convert the energy from their exercises to electrical potential energy stored in a capacitor and then be able to be used to power a phone at a later point in time when necessary. This technology could also eventually be applied to military personnel once adjustments and more developments are made to suit this application. The military is known for being deployed to remote areas where resources and luxuries such as electricity are uncommon which makes energy harvesting a suitable method of power generation for them. The military often moves by foot as well which means a boot style energy harvesting device would be compatible with their uniform choices and needs.

Needs and Specifications

Societal:

In a society of non-stop technological innovation, it is common for people to continue to consume more and more power which not only becomes expensive, but also the devices they tend to use most frequently are wearable or carried on their person at most times such as a cell phone, Apple or electronic watch, or any other future forms of technology that will need charging throughout the day. With current political and environmental climates shifting, it is clear that former methods of generating electricity such as burning fossil fuels or setting up massive infrastructure like water dams are becoming outdated and inefficient. With the changes in technology, it would be extremely beneficial and marketable to offer a new form of power generation that not only would be greener for the environment, but would keep up with modern trends of becoming more advanced in the technology sector and save the government massive amounts of money to generate power. A point can also be made that while these forms of technology are becoming increasingly more advanced, there are more sources where energy transfers can be converted into something beneficial to everyday life. That being said, the human body itself is an untapped mine of potential due to the fact that a human will move a lot throughout the day and is constantly radiating heat. Previously, humans were able to use their own bodies to harvest energy, but this required focus on that task specifically and presents the question: what if humans could harvest energy naturally that would otherwise be transferred into their surroundings and the environment and use that more productively in their daily lives? For example, there are plenty of homemade generators that have been made as an experiment such as a person riding a bicycle which powers a generator and in turn powers a light bulb. However, this is a deliberate task which is much greener for the environment, but also is only useful in that certain application. It would be much more beneficial to mankind if there was a natural way to generate power in a cheap and environmentally friendly way that one simply did not have to focus on. For these reasons, societal needs will consist of a cheap and environmentally friendly way to generate power effortlessly to be able to carry on with day to day life.

Customers:

As a customer, input and advice can be canvassed from focus groups, interviews, and surveys to gain more of an understanding as to what aspects of the product would make it more marketable to them. From prior knowledge and intuition, it is understandable that a customer would need the product to be cheap, comfortable to wear, lightweight, durable, and effective. Specifically, if the target demographic were to be hikers, a lightweight and comfortable boot would be a need generated from this group, but since it is a larger boot, the shoe could be bulkier to accommodate more sources of power such as adding piezoelectric materials or thermoelectric materials in the padding of the shoe to target more areas that tend to generate more heat to be converted to electric potential energy. However, if the target market were joggers, a small and lightweight shoe that is comfortable and flexible would be necessary to cater to the movements and comfort needs that a jogger would need. On the other end of the spectrum, if this product were to be applied to the military, the same style as the hiking boot could be used and may be able to be even heavier since military boots tend to be on the heavier and less comfortable side to offset the cost of outfitting the entire military with uniforms. A common theme among them nonetheless, is that the product needs to be durable and affordable for it to be competitive against current products on the market even though they cannot perform the same functions as the product being developed here.

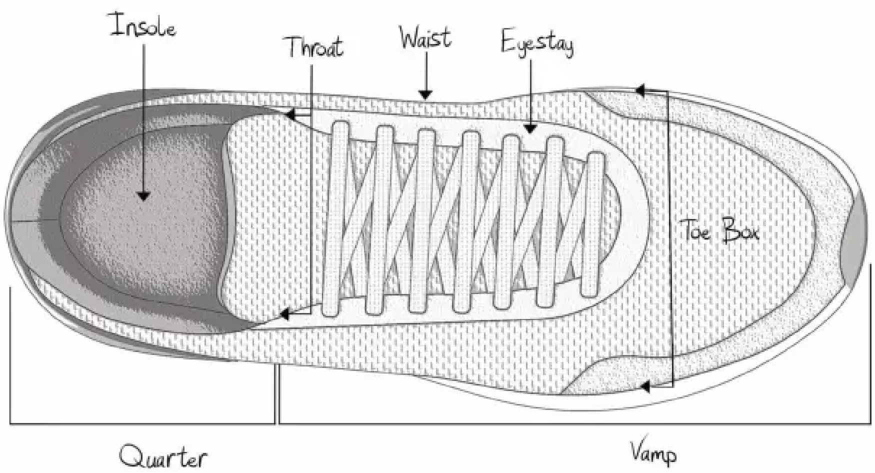
Concept Generation/Selection

Click here: Triboelectric Material Implemented Into Gear Train

Triboelectric material was one of the first technologies the team seriously considered. The video above shows a central gear train that would cause the two pieces of triboelectric material, indicated by the blue and green pieces, to oscillate between one another therefore producing power. This whole system would be made small enough to be implemented into the heel of a shoe, therefore the volume of the system would need to be a matter of square inches. The first, larger gear would be spun by a type of plunger located in the shoe that would strike downward on the gear and cause it to rotate upon the heel making contact with the ground. The plunger would reset when the heel is lifted off the ground and strike the gear again on the next step. The group realizes that if it were to use this idea, more gears may need to be added to get the materials to oscillate at a high enough frequency to generate the power required. The smaller the surface area of triboelectric material, the faster it needs to oscillate. The larger the surface area, the slower it can oscillate. In this specific case, the contact area would be small because it is being put in the heel of a shoe. However, the issue with this design is generating enough torque with the heel strike to be able to turn a gear train with a very low gear ratio of say 1:50. Not only would this be difficult for a grown adult, it would be nearly impossible if individuals of lesser mass wanted to use the shoes as well. However, one thing the team discovered for certain after diving into this design, is that they will be harnessing the power of the heel striking the ground as this is one of the most repetitive and powerful motions humans create while walking.

Click Here: Piezoelectric Material

Moving onto what the team feels right now is the most promising technology: piezoelectric material. This type of material generates energy whenever it is put under stress, such as bending. As shown in the video above, the chartreuse colored surfaces would be lined with piezoelectric material and the entire piece depicted would be implemented again into the heel of a shoe. When the heel comes in contact with the ground, the flexible arches would bend when under load and then flex back to their original shape when the foot is lifted off the ground. Power would be generated during both flexing motions and the spring-like mechanism may even make walking feel easier due to the elasticity of the mechanism helping a user lift their heel off the ground. Piezoelectric technology could also be implemented into the toe of a shoe.



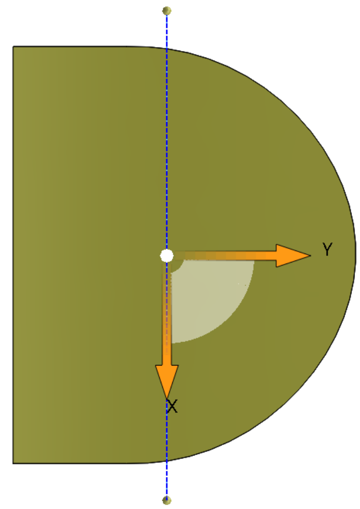


Figure 1: Shoe Parts + Piezoelectric Material for Toe Box

The toe box of a shoe endures a lot of bending. If another piece of piezoelectric material were sewn into the toe box, we could harness more energy due to the bending of the material along the X-axis as depicted.

The last form of technology the group discussed was generating energy from the heat produced from the foot of a person.

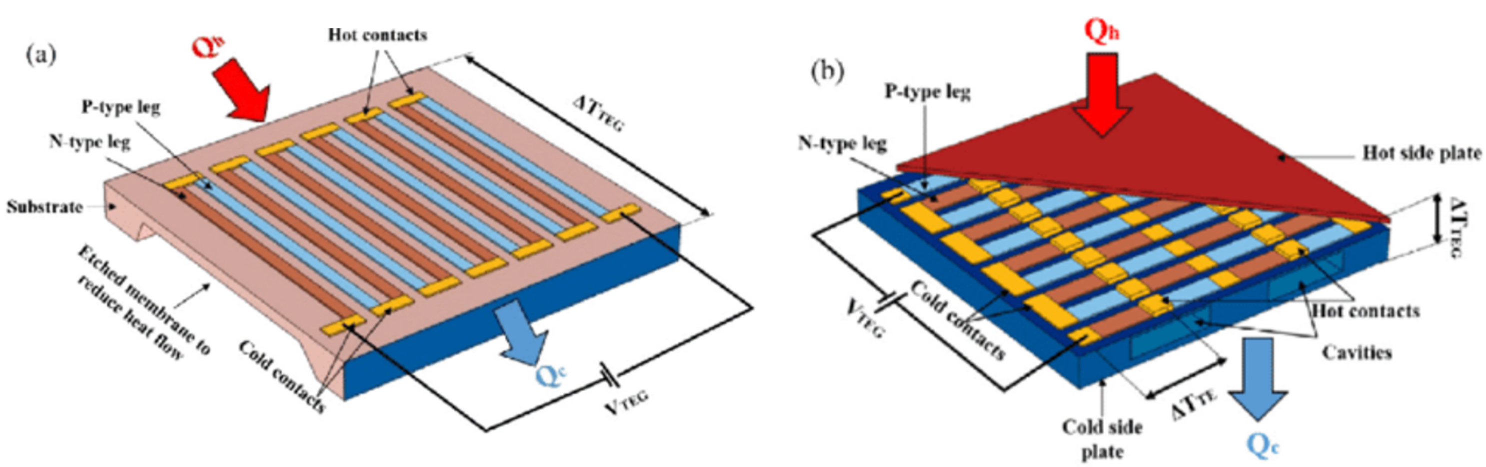


Figure 2: Vertical TEG *Figure 3: Horizontal TEG*

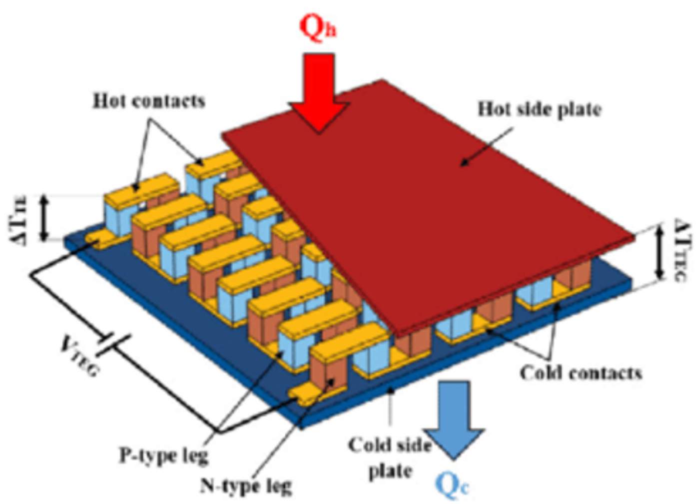


Figure 4: Mixed TEG

ThermoElectric Generators(TEGs) turn what would be wasted energy into power by harnessing the electricity found in the difference in temperature between the hot and cold contacts(similar to how triboelectric and piezoelectric materials created energy from the separation of charge). TEGs can be broken up into three categories: planar, horizontal, and mixed. Planar and horizontal TEG's best harvest energy when heat runs across them in a specific direction. Since the group's implementation of TEGs will be in the sole of a shoe, and heat will not be flowing in one specific direction, mixed TEGs which specialize in harness heat regardless of the direction it flows(shown in Figure 4). The group has decided the system should not be dependent on one method to generate power. Therefore, given our current research we feel as though piezoelectric material combined with thermal energy is the most likely combination to generate the power required to charge a cell which could then charge an iPhone.

Technical Analysis

Plans for Phase 2:

Once the scope of the project has been used to establish preliminary ideas and target needs and specifications, it is important to identify the relevant technical principles, equations, and concepts that will be the backbone of the product itself. A biomechanical energy harvesting system will have many technical components to consider such as the energy source, the circuitry, and the potential use of a mechanical system i.e. a gear train or a rotary cam. Going into Phase 2, the intended sources of energy to extract through movement of the human body will be piezoelectric and thermal energy.

Given that the mechanical efficiency of the human body is about 15-30% there is a considerable amount of thermal energy released from the body that can be converted into electrical energy. For the next phase of this project, the group plans on looking specifically at the amount of energy one can harvest from the body using thermal and piezoelectric energy because it is integral to the functionality of the device that enough energy is extracted in order to charge a cellular phone. Given that it is difficult to harvest enough energy using one method, the combination of two or more sources will hopefully harvest enough energy to efficiently charge a battery. Starting with thermal energy, the equation below, *Figure 5*, shows the optimal efficiency of a heat harvesting system at 0℃ or 273 K.

$$\text{Efficiency} = \frac{T_{Body} - T_{Ambient}}{T_{Body}}$$
$$= \frac{310 - 273}{310} = 12\%,$$

Figure 5: Optimal efficiency of a heat-harvesting system

The equation above comes from Carnot's equation, which is based on the ability of a heat engine to convert heat energy into mechanical energy. Given the range of temperature differences the human body experiences with the surrounding environment however, it is more likely that one would use a thermoelectric device than a heat engine, although efficiently inferior. In order to determine the efficiency of such thermoelectric devices the equation below, *Figure 6*, would be used.

$$\mu = \frac{\Delta T}{T_h} \cdot \frac{\sqrt{1 + ZT} - 1}{\sqrt{1 + ZT} + T_c/T_h}$$

Figure 6: Efficiency equation for a thermoelectric device

Moving on to the piezoelectric materials the team aims to use in the design, careful consideration has to be taken when determining which materials to use. Although the true efficiency can't be determined until the material is implemented into a prototype, the team can use the current understanding of the piezoelectric effect to inform their material selection and further design decisions. First, it is important to acknowledge that piezoelectric materials are anisotropic, meaning that they will exhibit different energy production levels when analyzed and interacted with from different orientations. These different orientations are known as stock and bender configurations, 33 mode and 31 mode respectively. The first 3 refers to the direction of polarization in the material where electrical voltage will flow and the 1 or 3 accounts for the direction of mechanical displacement. Stock configurations produce electricity through strain in the material along the same axis as the voltage that will be produced while the bender configuration produces electricity through bending the piezoelectric material in a perpendicular fashion relative to the voltage produced. In practice, stock configurations result in a high piezoelectric constant, d. This constant is a numerical representation of the electric field generated per unit of mechanical stress applied to the system (Subhash, Horrocks). By effect, the team wants to maximize this to get the most out of a limited space. Another property of concern is the efficiency of energy conversion for the material that is derived below in *Figure 7* which results in a value for the electrical energy produced divided by the elastic energy absorbed by the material under mechanical stress.

Similar to the efficiency of the thermoelectric devices, it is possible to test the efficiency of piezoelectric devices as well. To determine the information needed for the equation below, *Figure 7*, data can be obtained from the piezoelectric devices using a laser vibrometer, force transducer, and the voltage outputs.

$$\begin{aligned}\eta &= \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\% \\ &= \frac{1}{m}\sum_{n=2}^{m} \frac{(V_n + V_{n-1})^2/R}{[(F_n + F_{n-1}) \cdot (d_n - d_{n-1})]/(t_n - t_{n-1})} \times 100\%\end{aligned}$$

Figure 7: Average efficiency of a piezoelectric device, (V = voltage drop across load resistance R, F = force applied to the base of the plate, d = displacement of plate, t = time increment between data points, m = total number of data points)

The above equation of Pin/Pout is derived from the below equation which models the overall system, as one part mechanical (denominator) and one part electrical (numerator).

$$\eta = \frac{E_{out}}{W} = \frac{V_{RMS}^2/R}{\frac{1}{2} m \times (\ddot{X})_{amp} \times (\dot{Z})_{amp} \sin(\phi_x)}.$$

*Figure 8: Efficiency equation relating Mechanical Energy Input vs Electrical Output in a nonlinear system. (V_{rms}= root mean square voltage ,R= Resistance , m= mass , X** = second derivative of displacement (absolute acceleration), Z*= velocity of excitation source , sin(ox)= different excitation frequency points (0-180)*

Efficiency can now be defined as the ratio of net output electrical energy to net input mechanical energy (Figure 8) Efficiency is directly proportional to the phase difference between excitation and response[Yang et al., 2017]. Therefore, its important to take advantage of the 90 degree phase shift at resonance (evaluating different PEHs at this state) to select the best material based on the following:

1. On resonance efficiency is easy to be calculated experimentally and theoretically.
2. On resonance efficiency reflects the real working performance.
3. Efficiency monotonically decreases with excitation frequency; meaning efficiency values at other points can be extrapolated with the on resonance efficiency.

Note that resonance state is synonymous with <u>maximum power</u> output. Not to be confused with <u>optimal power</u> output conditions (frequency, resistance, damping, etc.) do not coincide with those of the <u>optimal efficiency</u>. Systems (ref. Figure 9) with weak damping effects and low-frequency excitations always show high efficiency, regardless of the energy harvesting capability[Yang et al., 2017]. Therefore, it is more reasonable to discuss efficiency values at the maximum power output conditions, not at the optimal efficiency points.

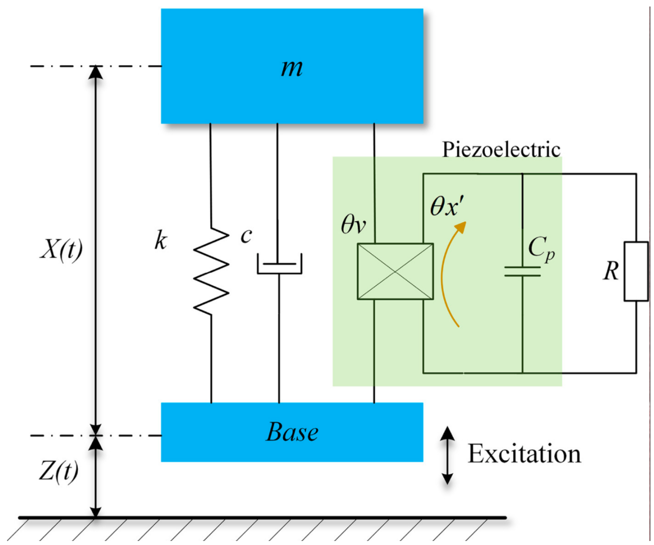


Figure 9: System Diagram

Focusing on maximum efficiency may likely result in a significant drop on power output, and misguide the development of the PEH. Therefore, it is important to focus on a set of figures of merit, including efficiency, power density, excitation-normalized power density, frequency bandwidth, etc; instead of one performance metric [Yang et el., 2017]. In addition, it is important to include the working conditions such as volume, mass and excitation strength.

Three piezoelectric energy harvesting devices were tested and compared according to their calculated efficiency and feasibility in practical applications by determining the maximum capacity battery they can charge as well as the charge time. The three devices were the macro-fiber composite (MFC), the bimorph Quick Pack (QP), and the monolithic piezoceramic material lead-zirconate-titanate (PZT). PZT is a large consideration for this project as it is a very popular piezoelectric material and extensive research has been done on this material. The results from the efficiency testing proved that the PZT was far more efficient as each of the different signals; resonant, chirp, and random, that they tested it at. When it came to recharging batteries, the QP and PZT were both capable of recharging the batteries ranging from size 40 mAh to 1000 mAh. The MFC however proved itself to be not well suited for power harvesting due to its low current generation. Information about the potential materials is integral and will save additional time and energy in the next phase of the project when material testing and selection occurs.

In the past few decades especially, increased research has gone into power harvesting devices as the demand for self-powered electronics has heightened. As a result of this push for new technology, piezoelectric energy harvesting specifically has attracted greater attention. In

2009 a Heel Strike Generator, seen in *Figure 10,* was developed that converted mechanical energy, developed during walking, into electrical energy.

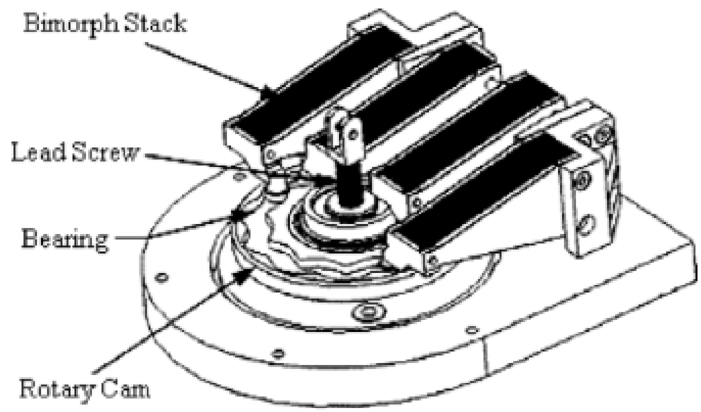


Figure 10: Heel Strike Generator schematic

When compression occurs on the Heel Strike Generator above, the lead screw and gear train turn the rotary cam causing the piezoelectric material to deflect sinusoidally. The oscillating material produces a voltage that is then regulated by a circuit that is capable of taking in the AC voltage and producing DC pulses to charge a storage capacitor. The power consumption of a lithium ion battery is about 0.042 W and the Heel Strike Generator was able to produce 0.0903 W of power, therefore this model is a good starting point for the scope of this project, harvesting energy to charge an iPhone.

Converting the produced electricity would be necessary, due to the AC output and varying magnitude. This is commonly performed with single/multi diode rectifiers that allow for alternating current inputs to be converted to direct current outputs. Because size is of concern, the rectifier circuit will need to be given further attention as far as its physical design is concerned. There are small bridge rectifier designs that account for the lack of space being used, which would be promising when incorporated into our design. The following schematic presented in Figure 11 illustrates the bridge rectifier design using diodes, where R_{Load} represents the electricity collection apparatus that will be discussed later.

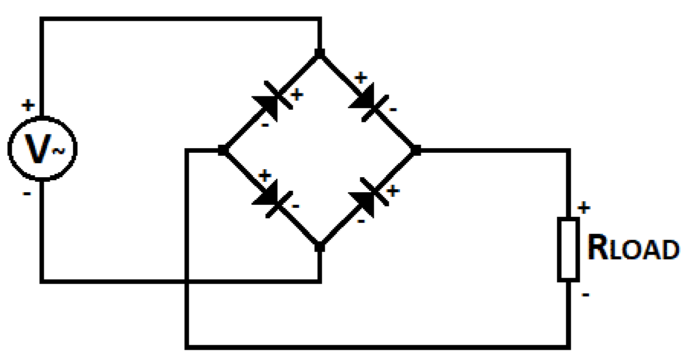


Figure 11: Bridge Rectifier Schematic

In terms of honing in on an ideal energy storage unit for the design, lithium batteries offer great potential. However, since this will be stored inside of a shoe, weight is of concern as well. Thus, a polymer battery can offer a reduction in weight compared to a normal lithium ion battery. A lithium polymer battery, or lithium-ion polymer battery (LiPo battery), is a rechargeable battery of lithium-ion technology that uses a polymer electrolyte instead of a liquid electrolyte. In place of the aforementioned liquid electrolyte, high conductivity semi solid polymers form this electrolyte.

For the phone charger, a circuit would need to be designed with the following requirements:

- Boost – From the battery, the stored electricity must be boosted to meet the 5 V/1 A requirements for charging a phone. (DC-DC conversion would allow for this)
- Implement constant current/constant voltage short-circuit
- Protect – Implement an over-discharge and short-circuit protection circuit

A circuit that can perform these functions using a LiPo battery has been worked on before, where it can be charged and used to power various devices. The following schematic design (Figure 12) was provided by [GreatScottLab](), and it provides all of the previously discussed requirements to allow for a LiPo battery to be recharged and used safely in conjunction with a device, under the assumption that the rectifier talked about before provides a proper undamped source of current that would result in the desired 5 V and 1 A charging requirements.

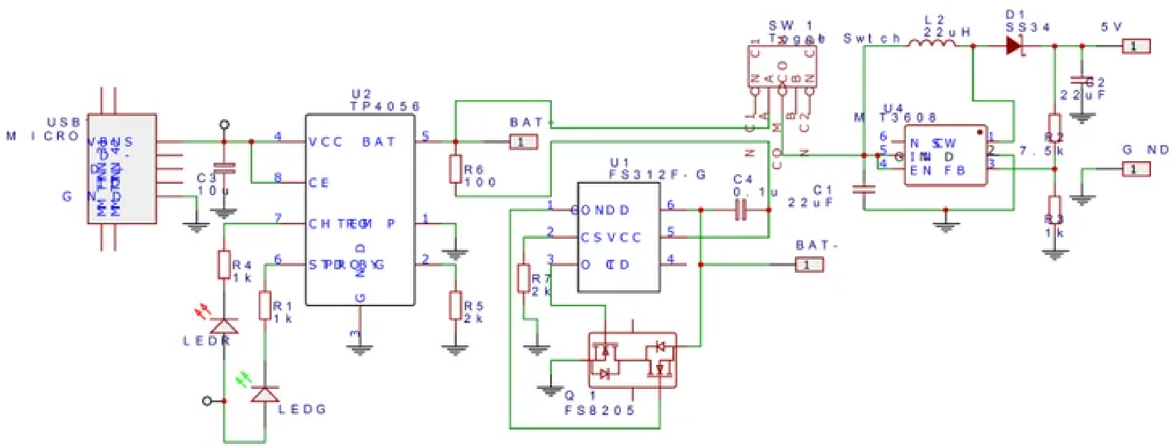


Figure 12: LiPo Battery Over Discharge Protection Circuit

Similar Systems:

In the past decade, the concept of portable chargers became very popular. Nearly every dedicated smartphone user has one or has used one. This trend only continued to grow as we became more attached to our devices. As a result, innovative ideas such as solar-powered portable chargers sought to establish a method of generating power without the need for an outlet. Unfortunately, the more mobile versions of these portable chargers take an extremely long time to charge (via sunlight) compared to the amount of watt hours they provide. Efforts to harness the immense amounts of energy produced by the human body have been explored before, but most of these ventures didn't exceed the prototype phase due to either cost or issues involving practicality. However, that does not mean there is no potential in this field. Researchers at the University of Wisconsin exemplified that a similar product of this caliber could be achieved. While with a different energy generation method and design strategy, it proves that there is much that can be done with the energy our bodies produce.

Project Plan

- **Deliverables:** At a glance, the team's deliverables for this project seem obvious, harvesting biomechanical energy to charge an iPhone, when in reality we have delved deeper into the question.
    - Our list of deliverables is as follows:
        - A convenient device that won't hassle users to use daily
        - Lightweight and comfortable
        - Low market price, affordable
        - Effective, can generate a considerable amount of power to keep a phone working in a pinch

- **Gantt Chart:**

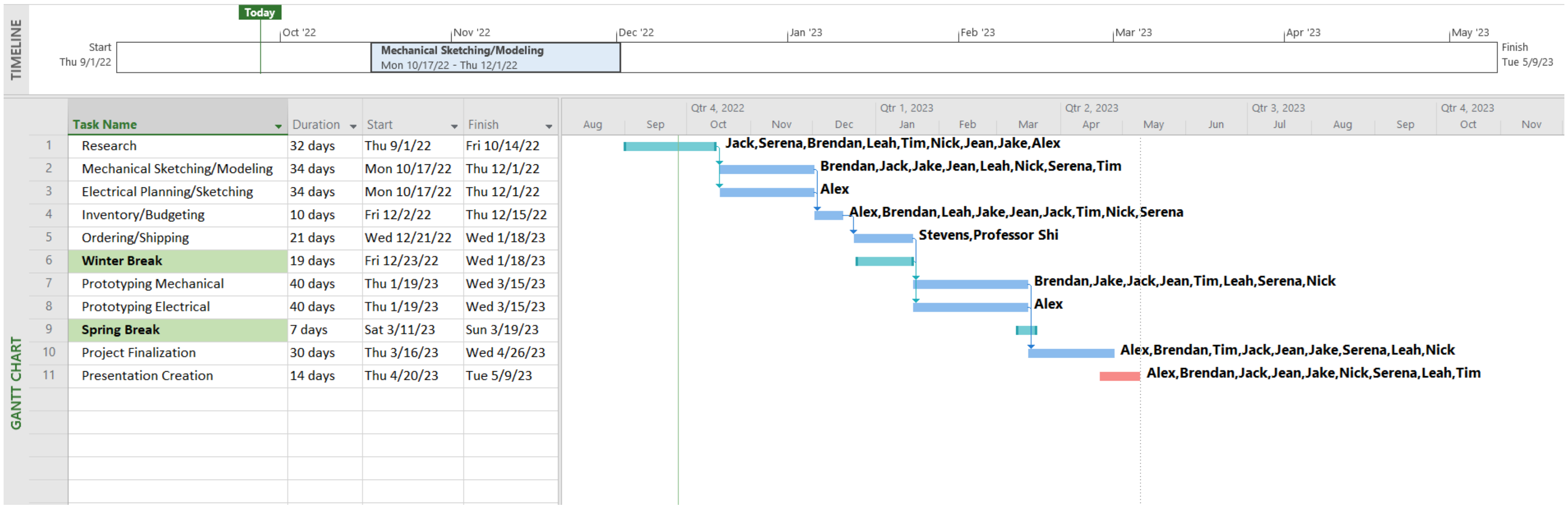


Figure 13: Team Gantt Chart

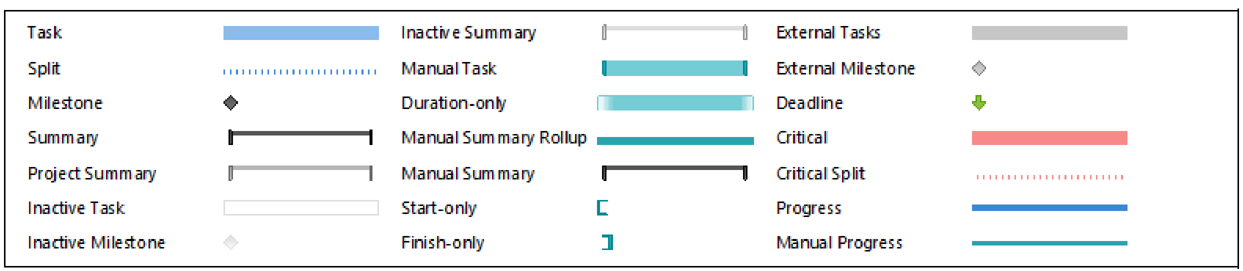


Figure 14: Key for Project Gantt Chart

Budget:

When talking to the Project's Advisor, it was established that the current budget for the project stands at $700. This is the standard budget for each senior design group but it doesn't mean the project won't receive more funding in the future. As it stands, however, the budget breakdown this early into the project is as follows:

- Materials
    - Electrical
        - Parts will likely all be ordered online through various retailers
    - Mechanical
        - Raw materials to make custom parts by 3D printing or other means
        - Intricate Parts to difficult to make by hand or power tool
- Fabrication Costs
    - In the event it is not feasible to produce something using what we have on campus, allocating funds to getting a custom ordered part may be necessary.
    - Renting or buying a tools/software campus doesn't provide so the team can produce a part.

As the project progresses and the team has a better understanding of what exact materials are needed the budget will be updated with actual values. It is too early to narrow in on specific materials or electrical components.

Discussions/Conclusions

The team has considered many preliminary ideas as well as potential challenges for a wearable biomechanical energy harvesting device. Though there are a handful of wearable products that currently exist, none are as efficient as this product aims to be. Further, this product is intended to be comfortable for the users and cost effective, unlike current products on the market. Through intricate research on piezoelectricity, circuits, and thermal energy, the team is starting off strong. As of now, the team aims to harvest the energy that comes from a natural heel strike through piezoelectric materials. In addition to this, the team also hopes to harness a fraction of the thermal energy that the human body produces. This combination, in theory, could create a product with a high enough efficiency not only to charge a cell phone, but to knock other competitors directly out of the market, while still satisfying customer needs.

Based on current research the team aims to produce a product that is made either entirely of, or with piezoelectric materials and or fibers. This way, every time someone walks, and their heel strikes the ground, the force deforms the material to provide electricity. This electricity would then be converted from AC current to DC current and stored in a small battery. This battery would later be used to charge devices.

Further, based on the team's plan for Phase II, to create a working prototype, the team would need to acquire parts for circuitry, a LiPo battery, as well as piezoelectric materials. Piezoelectric materials can be quite expensive, especially on the scale the team is looking to use them for. That being said, budgetary constraints do pose an issue to the team, but can be overcome by considering similar polymers with similar properties, though they may not be as efficient in the long run. In addition to this, the team may choose to delve deeper into thermal energy in order to compensate for any losses.

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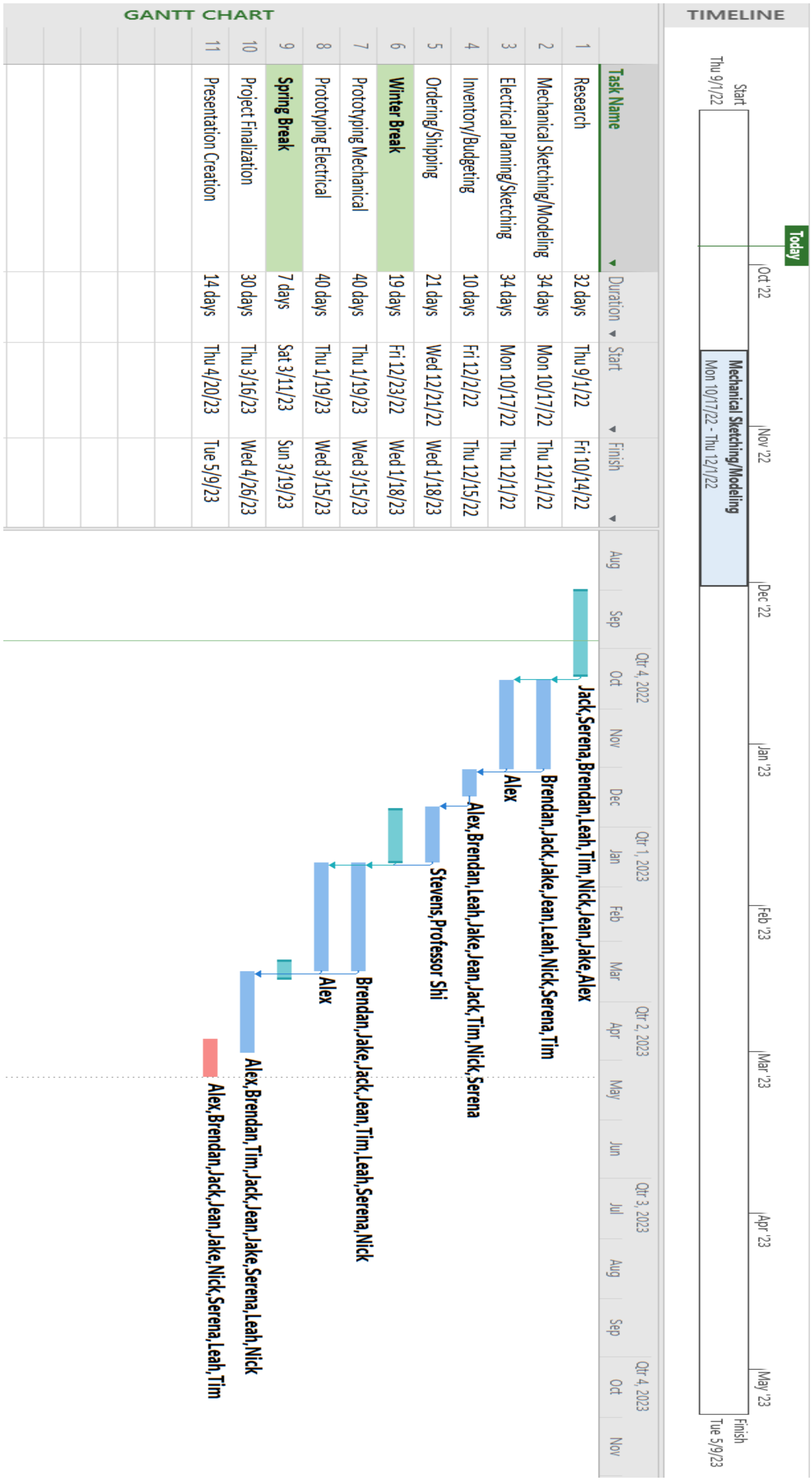
Appendix



	Task Name	Duration	Start	Finish
1	Research	32 days	Thu 9/1/22	Fri 10/14/22
2	Mechanical Sketching/Modeling	34 days	Mon 10/17/22	Thu 12/1/22
3	Electrical Planning/Sketching	34 days	Mon 10/17/22	Thu 12/1/22
4	Inventory/Budgeting	10 days	Fri 12/2/22	Thu 12/15/22
5	Ordering/Shipping	21 days	Wed 12/21/22	Wed 1/18/23
6	**Winter Break**	19 days	Fri 12/23/22	Wed 1/18/23
7	Prototyping Mechanical	40 days	Thu 1/19/23	Wed 3/15/23
8	Prototyping Electrical	40 days	Thu 1/19/23	Wed 3/15/23
9	**Spring Break**	7 days	Sat 3/11/23	Sun 3/19/23
10	Project Finalization	30 days	Thu 3/16/23	Wed 4/26/23
11	Presentation Creation	14 days	Thu 4/20/23	Tue 5/9/23