5-2018

A Human Powered Micro-generator for Charging Electronic Devices

John Adam
Linfield College

Recommended Citation

Adam, John, "A Human Powered Micro-generator for Charging Electronic Devices" (2018). *Senior Theses*. 32.
https://digitalcommons.linfield.edu/physstud_theses/32

A Human Powered Micro-generator for Charging Electronic Devices

John Adam

A THESIS

Submitted to

The Department of Physics

LINFIELD COLLEGE

McMinnville, Oregon

In partial fulfillment

of the requirements for the degree of

BACHELOR OF SCIENCE

May, 2018

THESIS COPYRIGHT PERMISSIONS

Please read this document carefully before signing. If you have questions about any of these permissions, please contact the DigitalCommons Coordinator.

Title of the Thesis:
A Human Powered Micro-generator for charging electronic Devices

Author's Name: (Last name, first name)
Adam John

Advisor's Name
Jennifer Health

DigitalCommons@Linfield (DC@L) is our web-based, open access-compliant institutional repository for digital content produced by Linfield faculty, students, staff, and their collaborators. It is a permanent archive. By placing your thesis in DC@L, it will be discoverable via Google Scholar and other search engines. Materials that are located in DC@L are freely accessible to the world; however, your copyright protects against unauthorized use of the content. Although you have certain rights and privileges with your copyright, there are also responsibilities. Please review the following statements and identify that you have read them by signing below. Some departments may choose to protect the work of their students because of continuing research. In these cases, the project is still posted in the repository but content will only be accessible by individuals who are part of the Linfield community.

CHOOSE THE STATEMENT BELOW THAT DEFINES HOW YOU WANT TO SHARE YOUR THESIS. THE FIRST STATEMENT PROVIDES THE MOST ACCESS TO YOUR WORK; THE LAST STATEMENT PROVIDES THE LEAST ACCESS. CHOOSE ONLY ONE STATEMENT.

_X_ I **agree** to make my thesis available to the Linfield College community and to the larger scholarly community upon its deposit in our permanent digital archive, DigitalCommons@Linfield, or its successor technology. My thesis will also be available in print at Nicholson Library and can be shared via interlibrary loan.

OR

____ I **agree** to make my thesis available **only** to the Linfield College community upon its deposit in our permanent digital archive, DigitalCommons@Linfield, or its successor technology. My thesis will also be available in print at Nicholson Library and can be shared via interlibrary loan.

OR

____ I **agree** to make my thesis available in print at Nicholson Library, including access for interlibrary loan.

OR

____ I **agree** to make my thesis available in print at Nicholson Library only.

Updated April 25, 2018

NOTICE OF ORIGINAL WORK AND USE OF COPYRIGHT-PROTECTED MATERIALS:

If your work includes images that are not original works by you, you must include permissions from the original content provider or the images will not be included in the repository. If your work includes videos, music, data sets, or other accompanying material that is not original work by you, the same copyright stipulations apply. If your work includes interviews, you must include a statement that you have the permission from the interviewees to make their interviews public. For information about obtaining permissions and sample forms, see https://copyright.columbia.edu/basics/permissions-and-licensing.html.

NOTICE OF APPROVAL TO USE HUMAN OR ANIMAL SUBJECTS:

If your research includes human subjects, you must include a letter of approval from the Linfield Institutional Review Board (IRB); see https://www.linfield.edu/faculty/irb.html for more information. If your research includes animal subjects, you must include a letter of approval from the Linfield Animal Care & Use Committee.

NOTICE OF SUBMITTED WORK AS POTENTIALLY CONSTITUTING AN EDUCATIONAL RECORD UNDER FERPA:

Under FERPA (20 U.S.C. § 1232g), this work may constitute an educational record. By signing below, you acknowledge this fact and expressly consent to the use of this work according to the terms of this agreement.

BY SIGNING THIS FORM, I ACKNOWLEDGE THAT ALL WORK CONTAINED IN THIS PAPER IS ORIGINAL WORK BY ME OR INCLUDES APPROPRIATE CITATIONS AND/OR PERMISSIONS WHEN CITING OR INCLUDING EXCERPTS OF WORK(S) BY OTHERS.

IF APPLICABLE, I HAVE INCLUDED AN APPROVAL LETTER FROM THE IRB TO USE HUMAN SUBJECTS OR FROM ANIMAL CARE & USE TO USE ANIMAL SUBJECTS.

Signature Signature redacted Date 5/16/18

Printed Name John Adam

Approved by Faculty Advisor Signature redacted Date 5/16/18

Updated April 25, 2018

Thesis Acceptance

Linfield College

Thesis Title: A Human Powered Micro-generator for Charging Electronic Devices

Submitted by: John Adam

Date Submitted: May, 2018

Thesis Advisor: ____

Dr. Tianbao Xie

Physics Department:____

Dr. Jennifer Heath

Physics Department:____

Dr. Bill Mackie

Abstract

A hand pulled generator has been designed and tested. A preliminary result has been obtained and discussed. This device was created to provide outlet free charging. Electronic devices are useful when going out into the wilderness. A portable power supply is necessary to keep an electronic device alive. This project created a device that converts human energy into electricity to charge electronic devices. This thesis overviews the device's design, build and tests. Two different tests were run to determine that the device is capable of charging the storage battery. The device presented can provide 14 minutes of charging time with one hour of string pulling. It is concluded that this device can be beneficial to people with electronic devices that need off grid charging.

Table of Contents

List of Figures

1. Introduction

Small electronic devices are essential for everyday life, and could play an even bigger role in the future. Some of these electronic devices include cell phones, pacemakers, headphones, watches, and health trackers. One thing these wearable devices all have in common is they all contain batteries to power the device. Most batteries are rechargeable. The most common method to charge these devices is through an adapter, which plugs into the power grid. Each battery requires a certain voltage to be able to charge. Once off the power grid, these devices can only be used for a short time unless there is another way of charging. There are several solutions to generate off grid electricity. This thesis designs and tests one of the options.

1.1. Five Different Ways to Generate Electricity

Currently there are five different ways to produce electricity to charge batteries when off the power grid. The five ways to generate electricity include devices based on piezoelectric, static electricity, photovoltaic effect, thermoelectric effect and Faraday's Law. When a piezo crystalline structure undergoes tension or compression, it will generate electricity. The Piezoelectric affect is mainly utilized in lighters and small mechanical movements such as those on telescopes. Electricity is added to the piezoelectric crystal to slightly move a telescope. Future use for this material can be in roads. A Stanford study shows piezoelectric could generate a significant amount of electricity [3].

Static electricity occurs when there is an accumulation of electric charge which creates a potential difference. This potential difference can be used as a power source.

Van de Graff invented a device that is able to generate very high voltages through charge accumulation. Static electricity can potentially generate electricity from the ocean using two blocks [7]. One block is heavy and unmovable. The other block is lighter allowing it to move up and down with the ocean’s current. These two blocks will rub against each other generating static electricity.

In photovoltaic devices photons (light) knocks free electrons loose in the solar cell, allowing them to flow through a circuit. Solar cells are most commonly made of crystalline silicon. They are doped with phosphorus and aluminum. Commercial solar panels are currently at about 15-20% efficiency. The main two types of solar panels are made of monocrystalline and polycrystalline silicon.

In a thermoelectric device there are two different ends, the hot and cold end. Two different types of metal wires are welded together at each end to create a junction. The two ends have different free electron densities which causes diffusion and the electrons will move to the cold end, leaving the hot end with a positive charge. A temperature change in the ends will create a voltage. This voltage can be used as a power source or a way to measure temperature. Thermoelectric device are selected to be a power generator because of their durable nature, low cost, and high temperature limits.

The final way to produce electricity is utilizing the principle of Faraday’s law. This is how most generators produce electricity. The voltage induced on a coil is determined by the rate of the change of the magnetic flux. The higher the rate of change of magnetic flux, the greater the generated voltage will be. There will be more detailed discussion about Faraday’s Law in the theory section of this thesis. The principle of Faraday’s law is used in most electrical generators as well as in this current device.

1.2. Electrical Input Necessary to Charge

Almost all small electronic devices require the same standard of electrical input to be able to charge, which is five volts and one amp or higher. The battery needs to be charged to 4.2 volts as it will then discharge to 3.7 volts [2]. 5 volts is necessary so there is enough overhead voltage to deliver 4.2 volts if there is a voltage drop. The current is proportional with the time of the charge. The higher the current the faster the battery will be charged. A computer block charger outputs a higher current than a normal small block, therefore it will charge a device faster. The big blocks are able to output a little over two amps versus the standard one amp. If the current surpasses a threshold it will ruin the battery. The specific current is dependent on the device. In this project there is a circuit created to provide electrical charging.

1.3. Harnessing Wasted Human Energy

In addition to outlet charging, it is possible to utilize wasted human mechanical energy to create another source of electricity. There are several ways of accomplishing this. In a study, the authors were able to create flexible piezoelectric nano composite films for kinetic energy harvesting from textiles [1]. This device is able to create electricity by absorbing mechanical energy from the users clothing. Another approach is to use human body heat energy with a wearable thermoelectric generator [4], which is not mechanical energy but will still provide no-outlet charging. This would also be inserted into the users clothing. There is also a way to use Faraday’s Law to harness energy from human motion using a magnet-mechanical vibration energy harvester [6]. This design uses a guided levitated magnet oscillating inside a multi-turn coil that is directed using four mechanical springs. There was an early attempt in this thesis to create a similar device but it did not generate enough voltage and current to charge a battery for an electronic device. Those are a few ways to utilize wasted human mechanical energy and create another source of off grid charging.

In this thesis a generator was built and powered by a pulley spring system. A preliminary result was obtained and concluded that the device can charge a storage battery, and then the storage battery will be able to charge an electronic device to a satisfactory level.

2. Experiment

2.1. Design & Build

Several different designs have been built and tested to convert mechanical energy into electricity during the course of this research. These devices include a wearable small tube, a yoyo and a gear device that connects to the knee. The final product is a device with a pulley spring system. A gear simultaneously moves with the string which turns a generator and produces electricity. This section will go over the mechanical components and the electrical system of the device.

2.1.1. Mechanical Components

First a housing unit for the device was designed and created. A 5 ft spring and a plastic rotor were ordered online. The rotor was shaped so that it would catch on the spring. Thus when the rotor was turned, the spring would snap it back into its original position. A 28 inch string was fastened to the rotor by a knot and the remaining string was wound around the rotor. The housing design was built around the measurements of the spring and rotor. At the bottom of the housing the spring fit snugly into place as shown in Fig. 2.1b. The housing was built in two parts, a lower half and an upper half as shown in Fig. 2.1a. The housing split allows the user to trap the tension from the spring when turning the rotor a few times and adding the top half. The housing unit was made from aluminum. It is little over three inches in diameter and one inch thick. The housing was put together and locked in with a screw, and then a hole was drilled into the very middle of the housing so the string could fit through. At the end of the string a ring was added to prevent the string from going back into the device. Once the rotor was turned a few times and the top half was locked in by screws, the ring attached to the string is pulled and it snapped back into its original position, touching the drilled hole. Fig. 2.1c shows the completed housing unit.

Figure 2.1 Mechanical assembly of string pulley system. (a) Individual components: A. housing unit, B. rotor, C. spring. (b) Spring put into the housing unit. (c) Pulley string components put together

The next step was to determine what type of generator to use and how to turn the generator. Initially, the generator was connected to the device by multiple gears. A connection piece was designed to lock into the rotor and had a slot on the top to connect to one of the gears. When the string was pulled the mechanism was very stiff and required too much effort to be feasible. The connection piece that linked to the gear was not perfectly straight which caused the string to stick in certain areas when it was pulled. This arrangement took a few tugs on the string to unstick it. Therefore the device was changed from a gear-based system to a belt-band system. A tool was used to cut a slit for the band to sit on the three inch gear. The gear was designed to be three inches to provide the generator with the desired angular velocity. The band was wrapped around the gear and the generator. The middle of the gear was tapped and a screw was added. The connection piece was also tapped, and then the gear was screwed into the connection piece, Fig. 2.2a. Now when the string is pulled the band simultaneously rotates. This belt generator design allows for the entire string pull to be smooth. Fig. 2.2b shows the mechanical parts assembled in the device. It is important to note that the gear’s radius is roughly ten times bigger than the generator; hence the speed of the generator is ten times faster than the gear, allowing it to generate adequate voltages. Now the device can easily generate electricity when the string is pulled. A typical voltage can be seen on the voltmeter in Fig. 2.2c.

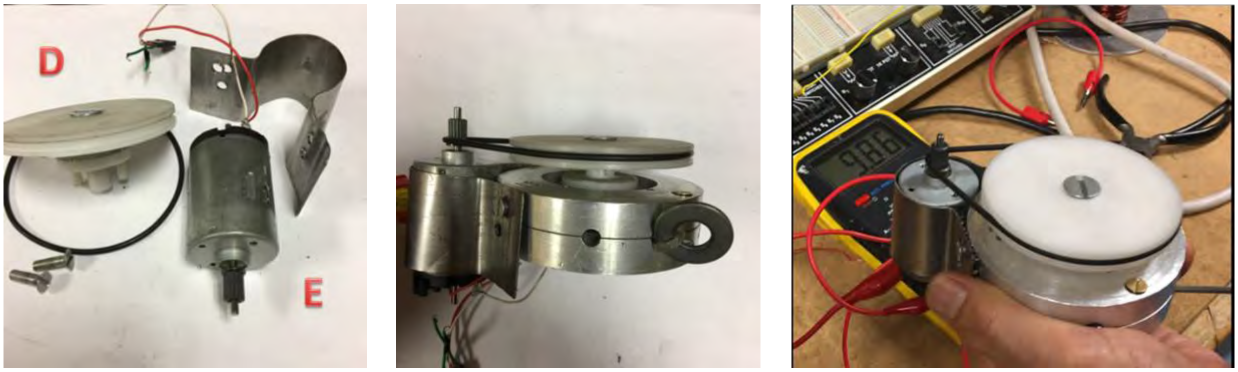


Figure 2.2 Parts and assembly of the belt band system. (a) Individual components: D. Gear & connection piece E. Generator. (b) Pulley spring and belt band system put together.
(c) Device generating electricity

2.1.2. Electrical System

The last thing needed for the device to charge a phone is the electrical system. Each electrical component is labeled (F-K) in Fig. 2.3.

First, the generator is connected to a bridge rectifier. The bridge rectifier converts the AC current into DC current which is necessary to charge the storage battery.

Following the rectifier, a voltage regulator chip converts the voltage to a stable 5 volts, as needed to charge an electronic device. The chip needs an input of 5-35V which the generator will supply. A second voltage regulator is next in the circuit to produce an even steadier voltage.

After the electricity is converted it runs through a diode. This ensures the electricity only flows away from the generator. The diode is difficult to see on Fig.2.3a because it is directly connected to the second voltage regulator.

The switch follows the diode. The switch can be set in to mode one or mode two. Mode one enables the generator to connect to the storage battery. Mode two connects the storage battery to the USB port and electronic device. To charge the storage battery the switch must be set to mode one. To charge an electronic device the switch must be set to mode two. It is recommended that mode one is turned on unless a person is charging an electronic device as, this will result in a longer lasting battery.

Last in the circuit is a USB port. This gives access to the electricity to charge a device. A normal phone charger will be able to hook into the circuit. Fig.2.3b presents the complete electrical system of the device. The device is put into a fanny pack and a small hole is cut for the draw string to fit through. The mechanical parts and the electrical system make it possible to have no-outlet charging for electronic devices.

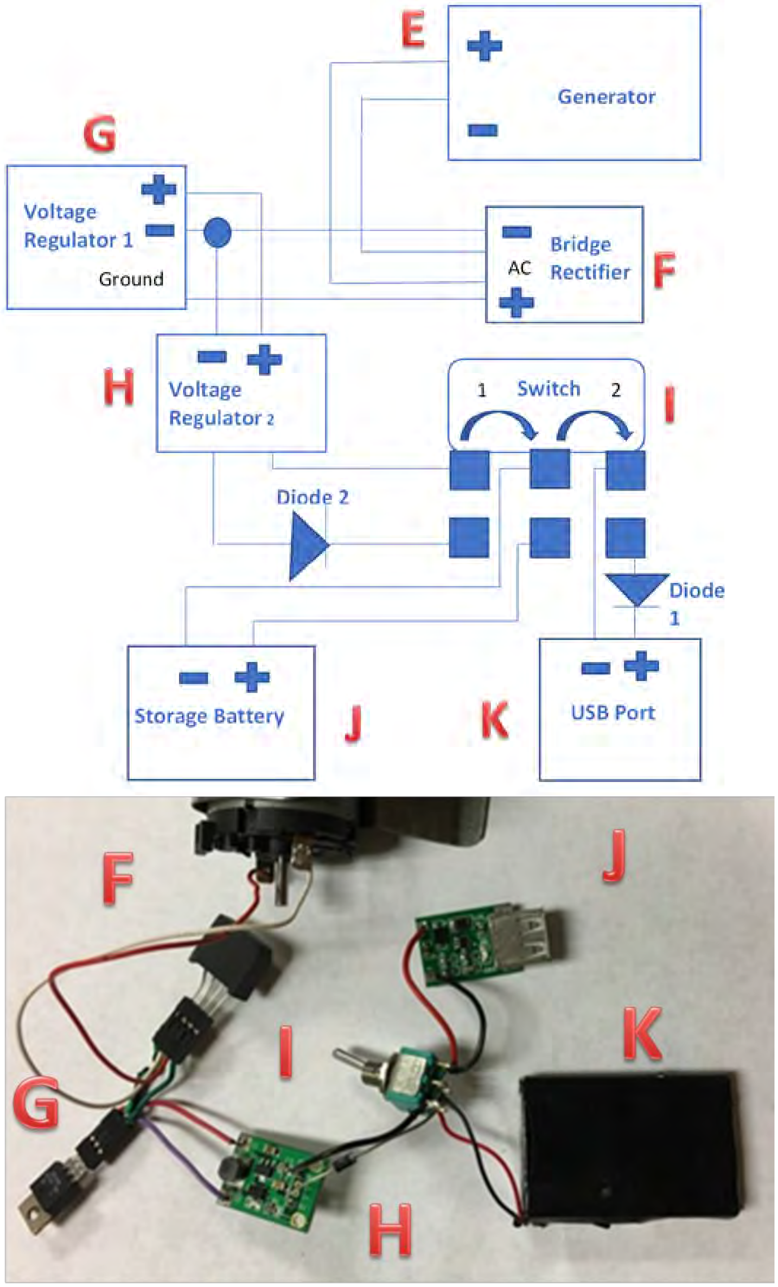


Figure 2.3 Electrical system of the device, all parts are label F-K. (a) Design of the electrical system. (b) Photo of the electrical system

2.2. Testing

The device’s capability was tested using a digital oscilloscope. The first test included eight different measurements during which the entire string was pulled and retracted back to its starting position at different rates. For this test the oscilloscope was hooked up directly to the generator’s output. The different times tested ranged from 1.0 to 5.0 seconds per pull period. The peak voltage for each time trial was recorded. This particular test was performed four different times. The first trial was not used because the data from that oscilloscope could not be exported. The other three trials performed offered reliable and similar data. Between the three trials there was only an uncertainty in the peak voltage by ± 1 volt. A graph was produced from each time trial with the corresponding peak voltages. A line of best fit was then placed. This test was performed to see the raw output of the generator and the minimum pull period that would be able to charge the storage battery.

Another similar test was conducted measuring over the output of the bridge rectifier over a load resistor. Fig. 2.4b shows how the oscilloscope is connected. The resistor makes it possible to measure the current flowing through the circuit. This measurement shows a lower limit on the possible output current, the actual loads will have lower resistances, and so actual output currents will be higher. The current determines the time it takes to charge the storage battery. Nine trials were conducted. Fig .2.4a shows the oscilloscope output for a typical trial. The computer provided 10,000 points of data in four seconds. Once converted into Excel, each cell was averaged with the next five points to clean up the data. This reduced the noise for both tests. The data is used to determine the device’s ability to charge the storage battery.

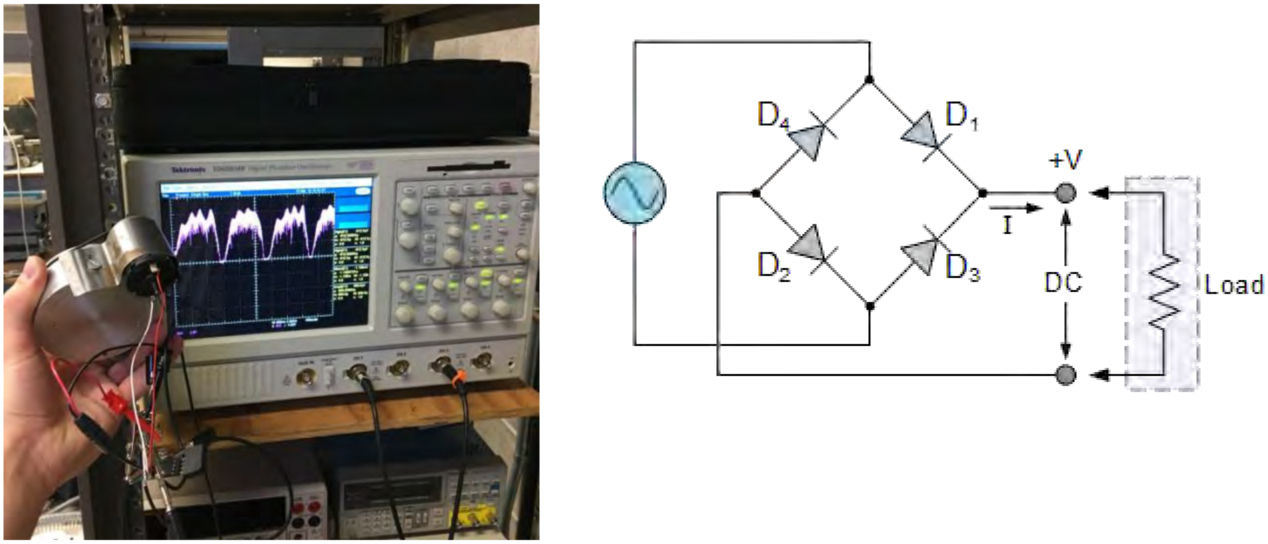


Figure 2.4 The setup of the oscilloscope with the device. (a) Digital oscilloscope with one result showing. (b) Bridge rectifier circuit the oscilloscope is reading, how AC current is produced into DC current, reproduced from https://www.electronicstutorials.ws/diode/diode_6.html [8]

3. Theory

In this section angular velocity, Faraday's law, Ohm's law, and the storage battery will be discussed. Angular velocity determined the three inch diameter of the belt band gear. The principle of Faraday's Law was used in the decision for the device's final generator. The theory behind Ohm's Law was harnessed in the hypothesis of the storage battery's recharge time. Information about the storage battery will lead to a better understanding of how the device will operate.

3.1. Angular Velocity

Angular velocity is the speed at which the gear and generator are rotating. Where $\vec{v}$ is the linear velocity, r radius, and $\vec{\omega}$ is the angular velocity.

$$\vec{v} = r\vec{\omega} = \frac{2\pi r}{T} \tag{1}$$

The linear velocity of the gear and generator has to be the same since they are linked by the belt. Thus the product of the gear's radius and angular velocity is equal to the product of the generator's radius and velocity.

$$\vec{V}_{gear} = \vec{V}_{gen} \rightarrow \quad r_{gear} * \vec{\omega}_{gear} = r_{gen} * \vec{\omega}_{gen} \tag{2}$$

Angular velocity is important when analyzing the belt band system that connects the spring action gear to the generator's gear. The gear's radius was designed to be ten times bigger than the generator's radius. This ensured the angular velocity of the generator to be ten times faster.

$$\frac{\omega_{gen}}{\omega_{gear}} = \frac{r_{gear}}{r_{gen}} = 10 \therefore \omega_{gen} = 10\omega_{gear} \tag{3}$$

Using angular velocity principle the gear was designed at three inches which provides the desired angular velocity for the generator's gear. The generators gear turns ten times fast than the string is pulled, thus creating a significantly higher voltage.

3.2. Faraday's Law

Faraday's Law is a principle about a change in magnetic flux which will generate an electric field. Any change in the magnetic field within a coiled wire will cause a voltage to be induced in the coil, known as electromagnetic force (EMF). EMF can be defined as the rate of change of the magnetic flux which is a change of the total magnetic field through a given area. ε is EMF, N is the number of loops, $\Delta\varphi_m$ is change in magnetic flux, Δt is the change in time. This law is linear, as the change in magnetic flux and or coils goes up so does the EMF generated. Therefore it is predicted the device will have a linear output corresponding with the pull time and the voltage.

$$\varepsilon = -N\frac{\Delta\varphi_m}{\Delta t} \tag{4}$$

Voltage between two points is a constant E field multiplied by the distance between the two points. V is voltage, E is electric field, and dl is the change in length. Inversely the electric field is a measure on how fast the voltage is changing along a path. These equations are helpful when solving for voltage or the electric field and being able to derive or integrate the equation as needed.

$$V_b - V_a = \Delta V = \int_a^b E \cdot d\ell \tag{5}$$

$$E_{\ell} = \frac{dV}{dl} \tag{6}$$

Measuring the magnetic flux is not possible in generators with housing units. So using the measured voltage, the magnetic flux of the generator was calculated. Towards the end of the project it was decided to change the generator because the initial one did not provide a large enough magnetic flux and had a high internal resistance. The new generator uses a neodymium rare earth permanent magnet. This rare earth metal creates a larger magnetic field which in turn provides a larger magnetic flux. The second generator is discussed in the appendix.

3.3. Ohm’s Law

Ohm’s law is the relationship of the voltage difference between two points, the electric current flowing between them, and the resistance of the path of the current. Ohm’s law plays a pivotal role in understanding electrical systems and being able to solve for unknown variables. Ohm’s original equation J is current density, σ is conductivity, E is the electric field.

$$\vec{J} = \sigma * \vec{E} \tag{7}$$

This was used to prove the measurements of voltage and current obtained from various lengths of wire. The equation slightly evolved into what is widely used today as Ohm’s law. V is voltage, I is current, R is resistance

$$V = I * R \tag{8}$$

It is possible to solve for voltage, current or resistance as long as two of the variables are known. Current values are necessary to be able to determine the charge time of the storage battery. Voltage was measured over a specified resistance so that it is possible to solve for current. Using Ohm's law it is hypothesized that the generator will generate a peak voltage of 20 volts and a peak current of 2 amps at the fastest pull rate possible and with minimal resistance (around 10 Ω).

$$20V = 2A * 10\Omega \tag{9}$$

3.4. Storage Battery

Based on the generator's unstable output it was decided to have the device charge a storage battery rather than directly charging an electronic device. The storage battery is 1.8 Ah and 5 volts. It constantly outputs five volts, exactly what is needed to charge an electronic device. The time it takes to charge a battery can be found by dividing the current charging the battery, Fig. 3.1b. The graph results from taking the capacity of the battery (in mAh) and dividing it by various possible currents to get the time required to fully charge the battery. The closer the battery gets to 100% the more difficult it is to charge. The storage battery can charge the phone at any battery level. When the battery reaches 60% of full charge the charging current drops and the cell voltage is slightly raised. The first 60% takes about 20% of the time it takes to fully charge the battery, Fig. 3.1a. From the graph in Fig. 3.1b it is predicted that the generator would be able to recharge the storage battery within 20 hours. Generally to charge a rechargeable battery it is not necessary to "fully" charge a battery, 80% charge is considered as fully charged. Battery recharge rate is nonlinear as shown by the dotted line in Fig. 3.1a. The closer the battery level becomes to fully charged the longer the recharge rate will take.

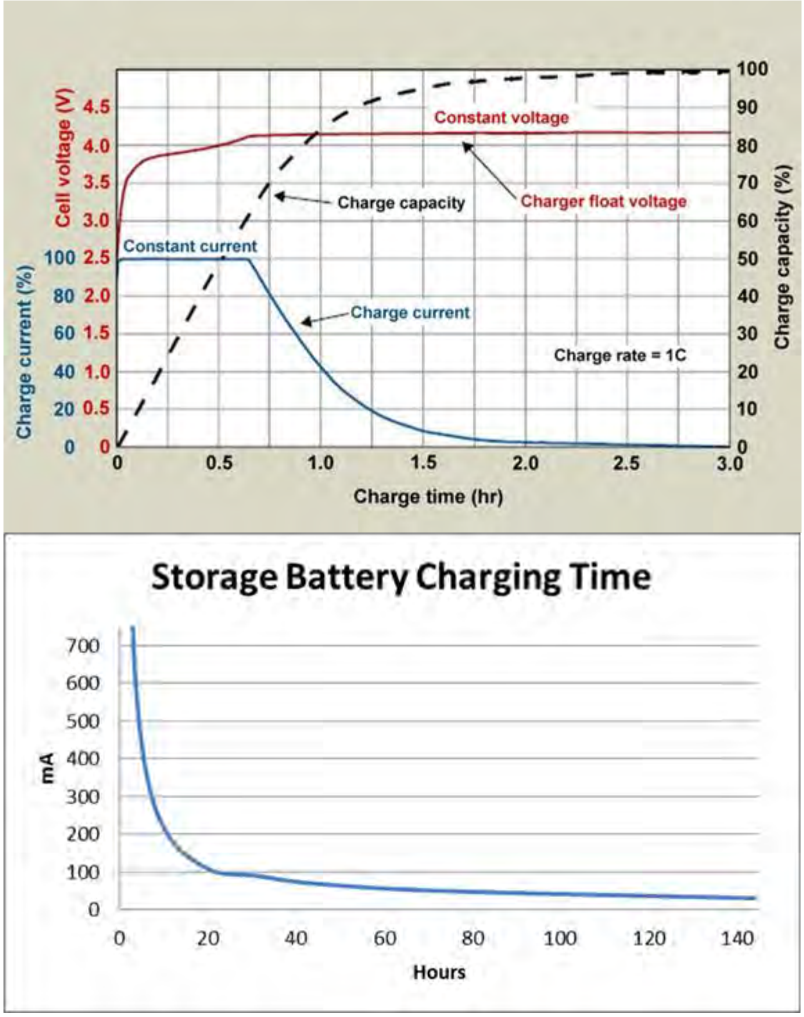


Figure 3-1 Information on batteries. (a) Recharge info of a battery, battery recharge rate in non-linear, reproduced from http://batteryuniversity.com/learn/article/charging_lithium_ion.[9]
(b) Project's storage battery charging time with a particular current input, t=mAh/mA

3.5. E

4. A

4. Analysis

These analyses overview the data point average, the circuit design, the generators capability to charge the storage battery, and the storage battery usage.

4.1. Five data point average

The experiment produces fairly noisy data so a five point data average technique was used to help analyze. The first step taken after the experiment was averaging every five data points to replace one single point. In each trial there were 10,000 points. The positive impact of averaging data is it provides more precise data, there is a smaller amount of uncertainty, and it helps to understand the trend over time. The potential negative impact of averaging data is it will eliminate single outlier data points that could be significant. Fig.4.1ab shows the data before and after the five data point average. In this data the generator is directly hooked up to the oscilloscope. As you can see the data is much more precise allowing for a cleaner interpretation. The graphs shown will have the five data point average.

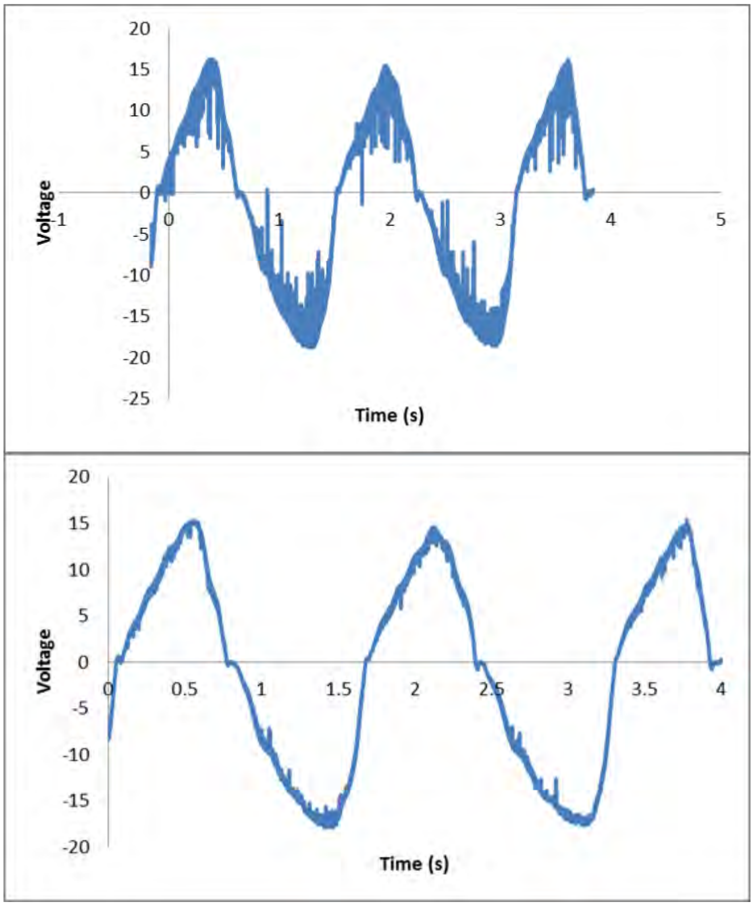


Figure 4.1 Five point data average. (a) before the data average produced noisy results. (b) after the data average produced clean crisp results.

4.2. Circuit Design

The circuit was designed to provide the user with charging capability. After the generator, a bridge rectifier was added in the circuit. This bridge rectifier does not have a capacitor within its circuit, but capacitance is displayed in the system from the PN junction of the diodes. A single rectifier was not chosen because it only utilizes half of the wave form. The bridge rectifier utilizes both positive and negative parts of the current. Fig. 4.2ab (pg. 20) shows the difference in the generator's output with and without a bridge rectifier. The bridge rectifier data is not smooth, dipping up and down within each peak due to a small capacitance produced at the PN junction of the diodes. The capacitance associated with the charge variation in the depletion layer is called the junction capacitance, while the capacitance associated with the excess carriers in the quasi-neutral region is called the diffusion capacitance. Junction capacitance dominates reverse-biased diodes, while the diffusion capacitance dominates in forward-biased diodes [5]. When the bridge rectifier is attached, the device outputs positive voltage twice as long as the AC current. In this case each pull from 4.2b is 0.50 (±.15) seconds longer than each pull from 4.2a. This uncertainty exists because of the human error in the ability to pull the string in an exact time frame and the device's natural mechanical behaviors are not uniform.

Next in the circuit is the three terminal positive voltage regulator, followed by one more voltage regulator. A single regulator did not meet the requirement voltage so an additional voltage regulator was added. The final measured output voltage of the device before it goes to the storage battery is 5.35 (±0.1)V. This uncertainty stems from the slight imperfection of the voltage regulators.

.

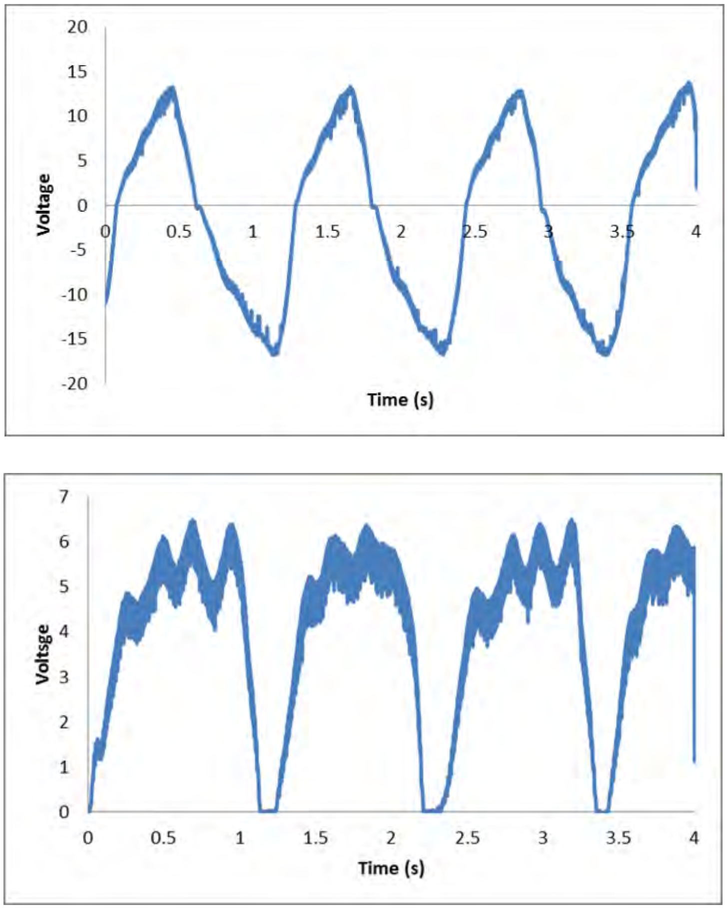
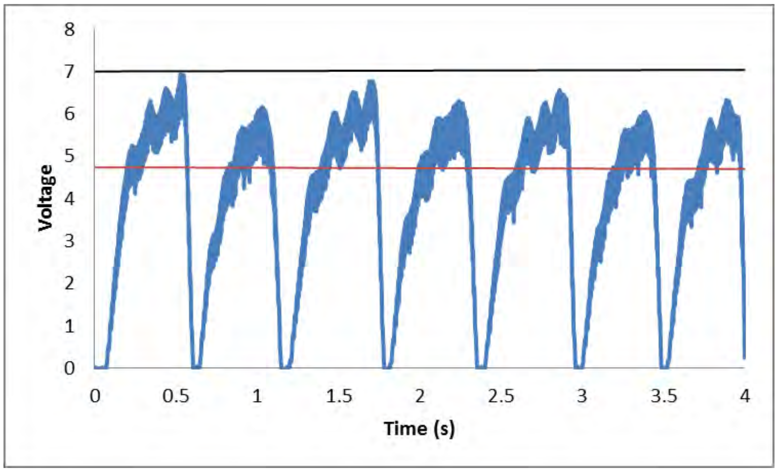


Figure 4.2 Circuit manipulation. (a) oscilloscope hooked up directly to the generator (b) oscilloscope hooked up to generator with bridge rectifier and 100 Ω impedance, the capacitance from the diode causes the wave forms within each peak.

4.3. Generator's Capability

The generators peak voltage was 15.3 (±1.0)V with a pull period of one second, and the lowest output voltage was 8.1V (±1.0) with a pull period of five seconds. The pull period is the time it takes to completely pull the string out and let it retract back to its starting position. The dependence of output voltage on the pull period is shown in Fig.4.3b. The oscilloscope was hooked directly up to the generator; therefore the only output impedance was the small amount within the generator. The generator by itself will be able to charge the storage battery with a pull period of five seconds with minimal resistance. The uncertainty of ±1.0 volt from this data comes from the human ability of not being able to pull exactly within a precise time frame and due the nature of the pulley spring system. The line of best fit for this graph is linear like predicted from Faraday's law. As the string is pulled faster the voltage will linearly increase. This stems from the linear relationship from the EMF the generator produces. The pull rate and EMF generated are directly proportional, the higher the pull rate the more EMF produced. Higher EMF generation will have an increase in voltage and current which will charge the storage battery faster.

Taking a measurement after the bridge rectifier with a 100 Ω resistor, the peak voltage was 7 volts (indicated by the black line) with a pull period of 0.6 (±0.1) seconds, Fig.4.3a. Using Ohm's law it is possible to solve for the current. The current is equal to 7 volts divided by 100Ω which equals 0.07 amps. The impedance of the circuit is very likely to be less than 100Ω therefore the current will be larger than 0.07 amps. The red line shows the minimum voltage produced that can charge the storage battery. Adding both voltage regulators also ensures that the storage battery receives a voltage input of 5.35V (±0.1). The generator will be able to charge the storage battery.



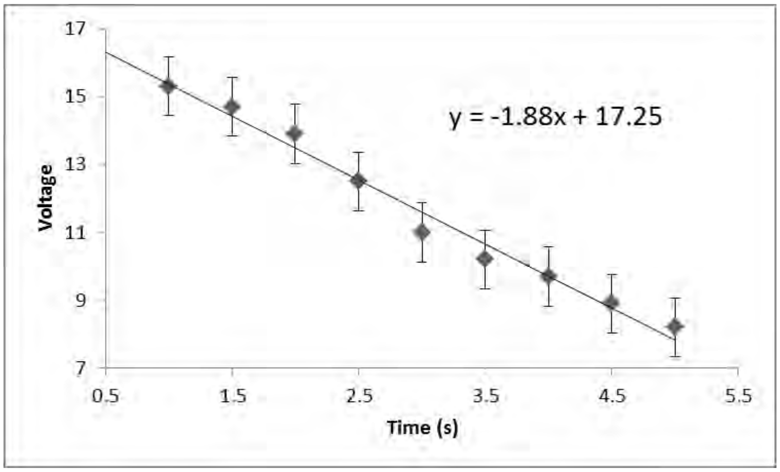


Figure 4.3 Generators capabilities.(a) generator's output with a bridge rectifier measuring over 100 Ω resistor, the black line is the peak voltage, the red line is the minimum generation needed. (b) generator's peak voltage output corresponding with the time it took to pull a full period, The line is linear because of the linear relationship of Faraday's law, pull period and EMF generated are directly correlated.

4.4. Storage Battery Usage

From the data sheet, when the storage battery receives an input of five volts and two amps it can go from dead to fully charged within 8 hours. Therefore, to fully recharge the storage battery it would require 16 hours if the generator provided a current of 1 amp. Also from the data sheet, the storage battery is able to fully charge an iPhone 6 in 1.5 hours and with a full battery it can charge the phone 2.5 times before a recharge is needed. The total time that the battery can be used for charging is 1.5 hours multiplied by 2.5 times, which equals 3.75 total hours of charging. It takes 16 hours (1 amp input) to charge this battery to provide 3.75 hours of charging time. One hour of pulling (at 1 amp input) delivers a charging time of 0.234 hours, which is equal to 14.1 minutes of charging use if the storage battery recharge time rate is linear. Eq. 9 shows how that was calculated. Charging rate of a battery is nonlinear, overviewed in the theory section. The charging rate will be faster when the battery is more depleted, and when the battery is getting full the charging rate is much slower.

$$\frac{3.75\ hour\ charging\ use}{16\ hour\ recharge} = \frac{x\ hour\ charging\ use}{1\ hour\ recharge}, x = 0.234\ hours \qquad (10)$$

5. Conclusion

5.1. Hypothesis

The hypothesis of this experiment is the draw string mechanism is capable of charging an electronic device, It can output a peak voltage of 20 volts and a peak current of 2 amps with fastest possible pull rate with minimal resistance. The end results are not too far off from the hypothesis. The raw output of the generator produced five less volts and 1.9 less amps (with an impedance of 100 Ω), than predicted. The resistance of the system was less than 100 Ω therefore the current was larger than 0.1 amps.

The second hypothesis was the ability of the generator recharging the storage battery within 20 hours. With one hour of pulling it was predicted that the storage battery will be able to provide 0.188 hours or 11.3 minutes of charging time. This hypothesis was also similar to the results. The charging time prediction was short by 2.8 minutes. Note that the charge rate of a battery is nonlinear, therefore these recharge times will vary for different battery levels.

5.2. Results

The results showed that the generator was capable of providing the storage battery with enough current and voltage to recharge. The peak voltage of the generator was 15.3 volts and when measured over a 100 Ω resistor was 7 volts. This provides enough overhead voltage for the voltage converters to allow an output of 5 volts which is necessary for the storage battery to charge. It is also concluded that the entire battery can be charged within 16 hours with a 1 amp input. In other words, one hour of pulling can provide fourteen minutes of charging use. This device can be used for a no-outlet or off grid charging. It is mainly designed to take on off grid ventures when having a charged device can be useful to staying safe.

5.3. Future Work

There is still future work to be done. The mechanism's circuit can be simplified. It would have been much easier to use a power bank rather than a storage battery. There would be no need for a switch because the bank has an input for recharging the battery and an output for charging an electronic device. It is possible to charge the power bank while charging an electronic device. The current device with a switch only has one option, charging the storage battery or charging an electronic device. A power bank can also have a higher amp hour than the battery used so the device will provide longer charge times.

A generator with more power and less internal impedance could be implemented. A generator that outputs a larger current would decrease the charging time for the battery. In one hour of pulling the device would provide more than 15 minutes of charging time. A device with less internal impedance would increase the efficiency of the recharge rate. Higher impedances cause smaller currents which will increase the recharge time of the storage battery.

6. Appendix

Towards the end of this project a change in the generator, electrical system and storage battery were made. This change can be seen in Fig. 6.1a. This update allows for a faster time in the recharge rate of the storage battery and the charge rate of an electronic device.

The belt band system now connects to an entirely new generator. This generator was chosen because it has a larger magnetic flux and a lower internal resistance compared to the previous generator. A greater magnetic flux and smaller resistance produces a larger current output. This generator's magnet is composed of neodymium rare earth metal which creates a larger magnetic field resulting in a larger magnetic flux. This generator is also a three phase generator compared to old single phase generator. Three phase generators are more efficient to generate electricity because there is less space in between each pole. This will create a smoother voltage output.

A simpler electrical system was implemented. The generator runs to a homemade three phase full wave rectifier. A three phase full wave rectifier consists of six diodes; this can be seen in Fig. 6.2b. It has the same affect as a bridge rectifier; the only difference is it is used for a three phase AC source input. Following the three phase full wave rectifier is a 1000uF capacitor. This capacitor smooths out the wave form allowing a constant stream of voltage. After the capacitor is a voltage regulator USB chip. This chip will convert the input voltage to exactly what the power bank needs to charge. It also allows easy access because the standard power bank charging cable can fit into the slot.

The old storage battery was replaced with a power bank. This power bank provides 6600mAh compared to the old battery with 1800mAh. This device will last 3.6

times longer if both batteries were put under the same conditions. The power bank is able to recharge while charging an electronic device. The old storage battery could only recharge or charge a personal device at one time. The power bank also allows for two USB outputs, one outputting 1 amp and the other 2 amps. Two devices can be charged at one time, the 2 amp output will charge an electronic device faster than the 1 amp output.

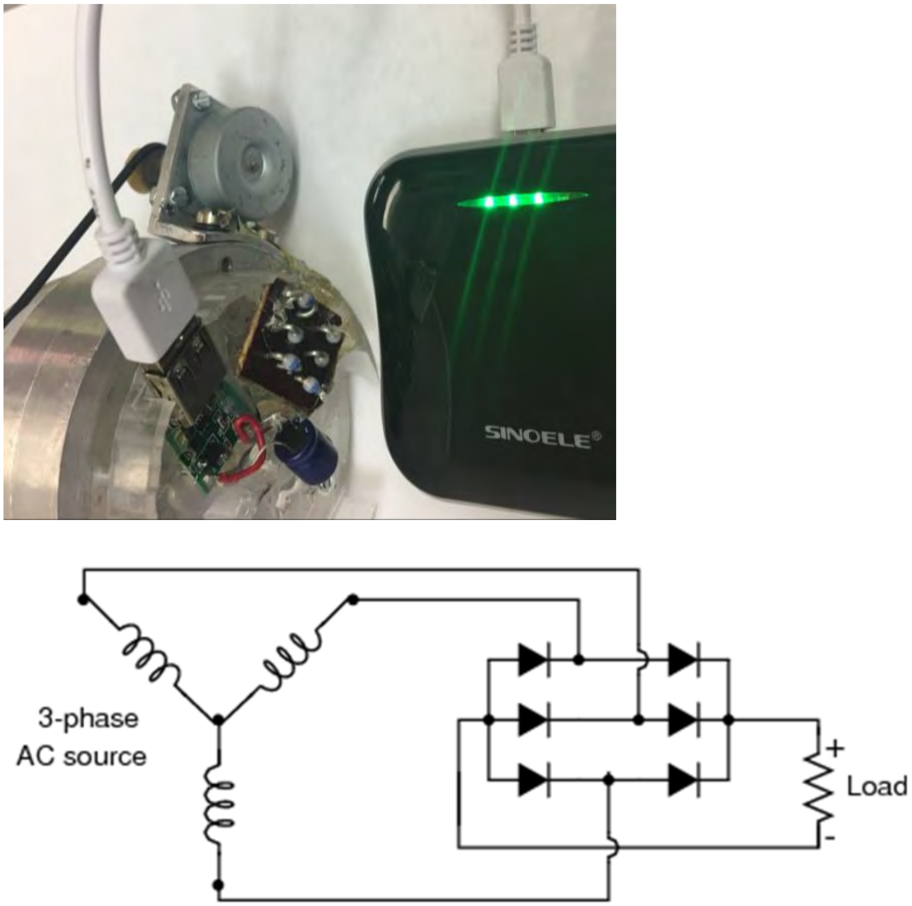


Figure 6.1 Recent changes to the project. (a) L. new generator, M. three phase full wave rectifier, N. capacitor, O. USB voltage regulator chip, P. power bank. (b) Three phase full wave rectifer circuit https://www.quora.com/What-is-a-three-phase-rectification-with-its-diagrams [10]

7. Acknowledgements

In concluding this document I would like to thank Tianbao Xie for his help and expertise in the machine shop. He has spent countless hours with me working on the design, build, electrical system, and writing portion of this project. Without him this research would not have been the same. I am grateful for Dr. Heath for all the hard work and dedication she has put into ideas regarding the experiments and the edits she has made to this paper. Thanks to my thesis committee for aiding me in creating this document and helping me gain a better understanding of scientific writing. A special thank you to my fellow researcher and friend Nick Villalobos, he played a tremendous role in the initial design and build of the device. Lastly, I would like to acknowledge my dear friends and wonderful family for all the support in my pursuit of physics knowledge.

References

[1] Almusallam, A., Luo, Z., Komolafe, A., Yang, K., Robinson, A., Torah, R., & Beeby, S. (2017). Flexible piezoelectric nano-composite films for kinetic energy harvesting from textiles. Nano Energy, **33**, 146-156. doi:10.1016/j.nanoen.2017.01.037

[2] Atkinson, Robert. “BU-303: Confusion with Voltages.” Charging Lithium-Ion Batteries – Battery University, batteryuniversity.com/learn/article/confusion _with_ voltages. downloaded Apr 25, 2018

[3] Garland, Rex. “Piezoelectric Roads in California.” Piezoelectric Roads in California, 26 Apr. 2013, large.stanford.edu/courses/2012/ph240/garland1/.

[4] Kim, M., Kim, M., Lee, S., Kim, C., & Kim, Y. (2014). Wearable thermoelectric generator for harvesting human body heat energy. Smart Materials and Structures, **23**, 105002. doi:10.1088/0964

[5] Lackey, John E., Jerry L. Massey, and Merlin D. Hehn (1986). Solid State Electronics, **10**, 281-287

[6] Nammari, A., Caskey, L., Negrete, J., & Bardaweel, H. (2018). Fabrication and characterization of non-resonant magneto-mechanical low-frequency vibration energy harvester. Mechanical Systems and Signal Processing, **102**, 298-311. doi:10.1016/j.ymssp.2017.09.036.

[7] Viñolo, C., Toma, D., Mànuel, A., & Rio, J. D. (2013). An ocean kinetic energy converter for low-power applications. The European Physical Journal Special Topics, **222**, 1685-1698. doi:10.1140/3741

[8] https://www.electronicstutorials.ws/diode/diode_6.html, downloaded Apr 17, 2018

[9] http://batteryuniversity.com/learn/article/charging_lithium_ion, downloaded Apr 22, 2018

[10] https://www.quora.com/What-is-a-three-phase-rectification-with-its-diagrams, downloaded May 3, 2018