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Induction phone charger case

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ENTITLED

Induction Phone Charger Case

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

THESIS ADVISOR

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INDUCTION PHONE CHARGER CASE

by

Dante Eley, Nicholas Mason, and Laurence Pringle

SENIOR DESIGN PROJECT REPORT

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Abstract

This report discusses the project of creating a manual charging phone case for smartphones by means of electromagnetic induction. In today's world, smartphones are being used on the go more often, creating an increased demand for battery life. The capacity of current batteries cannot keep up with the constant usage of data in such activities as emailing, social media, apps, and more. We developed an efficient, ergonomic, and aesthetically pleasing phone case that can manually charge a smartphone without an electrical outlet, but by means of electromagnetic induction. This product would target two main demographics: business people who are constantly on the go, and the outdoors enthusiasts who are not always near an electrical outlet. The product will give users peace of mind knowing that their phone will not die without an outlet or a plug-in phone charger. The phone case would feature a magnet and coil system as an electrical power generator. The magnet and coil will convert energy from mechanical input created by the user spinning a wheel mounted to the rear face of the case. The rotational input of the user is transferred to the generator via a gear train with a final drive ratio of 1:48. With an average input of 4 newtons of force, 2 revolutions per second, and a radius of 2 centimeters of the disc, the mechanical energy provided will create the needed voltage and current for approximately 1 Watt of electrical power. A smartphone draws around 0.4 to 0.5 Watts of power in an idle state, meaning that this 1 Watt will provide the power to overcome idle power draw. We made a simple and intuitive case that features lightweight, ergonomic, and efficient attributes. Physical testing has been conducted on selected generators, yielding promising results. Housing prototypes were 3D printed for fitment testing, while drop tests were conducted theoretically through FEA modelling and testing.

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1. Introduction

1.1 Background and Motivation

In today's society of widespread mobile electronic device usage, people are encountering an increasingly common problem: more on-the-go use of one's device means more rapid consumption of the limited power available from the device's battery. In order to combat this, some manufacturers increased the capacity of their battery packs, but this typically results in increased price and bulkier designs. Other companies have produced expensive after-market battery pack expansions, some of which can double battery life of user's devices, which add significant physical bulk. For the average user, the options are relatively limited. Many people will buy spare charging accessories to carry with them for the sole use of charging their device at any opportunity they can. This can be a hassle though, as finding an outlet when commuting or traveling is not always the easiest thing to do, and even if an outlet can be found, it is only useful if one has the time to recharge his/her device for a significant period. Other options, such as solar chargers, hand crank phone chargers, and even thermoelectric generators, exist for travelers, commuters, and people with outdoors lifestyles. Most of these products are expensive and bulky, and all of them are yet another accessory to carry along with the device. The average person needs something smaller, lighter, and more affordable to extend the battery life of his/her device on a daily basis.

We aim to solve this problem by creating a light, ergonomic, and aesthetically pleasing phone case with an integrated mechanical charging system. The mechanical charging system is based on the principles of magnetic induction, and uses an input force from the user to drive a spinning disk connected to a gear train that drives the induction. We will design the system to produce enough power by the continuously changing magnetic field acting on the copper wire to overcome the power draw of a mobile phone in an idle state. By integrating a coil of magnetic wire into the back of the case and using a simple gear train, the spinning magnet can achieve a desirable RPM, thus creating a usable amount of power. The device is incorporated into a phone case, allowing it to maintain a reasonably low profile. Research into similar products has shown us that, while some alternatives have the potential for creating larger amounts of power, they are too large and bulky to integrate into a case that also protects the device. Other products that use similar designs to ours are, for the most part, very bulky because they include other hardware that is unnecessary in a phone case. We aim to fill a niche in the market with a product that provides a solution to a common problem that many mobile phone users share.

1.2 Review of Literature

In the use of mobile electronics, battery life is one of the biggest obstacles to overcome. Our phone case design uses Faraday's principle of electromagnetic induction to allow a user to manually keep a phone's battery alive. The use of electromagnetic induction has been proven to provide energy in many products before, such as alternators for cars, handheld flashlights, and radios.

Through extensive testing and research, Michael Faraday found that a changing magnetic field in the presence of wire induces an EMF and can produce an electric current in the wire. The magnet or the wire could be moving to induce this EMF, as it is their relative motions that count. Furthermore, Faraday found that the induced EMF could be increased by increasing the rate of changing magnetic flux. Thus, EMF induced is proportional to the rate of change of the magnetic flux passing through the area, A, of a loop of wire. The magnetic flux is given by:

$$\Phi = \mathrm{B} \cdot \mathrm{A} \cdot \cos(\theta)$$

Where, ϕ is the magnetic flux, B is the magnetic field (typically measured in Teslas), A is the area of the wire loop, and Θ is the angle between B and the area A. Knowing the magnetic flux we can now compute the EMF induced in a circuit. The EMF induced in a circuit is equal to the rate of change of magnetic flux through the circuit or loop. The result is Faraday's Law of Induction:

$$\varepsilon = -\mathrm{N}\frac{\mathrm{d}\Phi}{\mathrm{dt}}$$

Where, ε is the induced EMF (typically found in volts), N is the number of loops if the circuit contains closely wrapped wires that the same flux passes through, $d\phi$ is the change in magnetic flux, and dt is the change in time.

The power needed to charge the phone through induction will need to be more than the power needed to keep the phone on while in idle. According to *An Analysis of Power Consumption in a Smartphone*, the average consumption of a smartphone in idle with the backlight off is 268.8 mW. Also advertised by Apple, the current needed to trickle charge the phone is less than 0.25 Amps. This power is easily attainable by the flashlight design already being produced. The flashlight mentioned utilize electromagnetic induction with a crank and gear system to generate energy to power the flashlight.

1.3 Project Goals

As a team, we had many goals we aimed to accomplish. We divided into two main categories: product goals and learning goals. At the most basic level, we wanted to build a phone case that was able to charge a smartphone without the need for an electrical outlet or external power source. To accomplish this, there were many more small goals that we had to tackle.

First, we had become educated on the type of technology that we were creating and the competing products on the market. Charging requires electricity, so we aimed to have a solid understanding of the circuitry required to make our product possible. This included the physical building of circuits, in addition to theory and design. The final goal was to design and build the circuit on our own, without assistance from a company, or a student or professor of electrical engineering. Additionally, we set a goal to design and build our own generator system to produce electricity using electromagnetic induction. To better understand the competition and industry as a whole, we aimed to analyze five companies in the charging and case industry. This included the technology used and the business plan that the company used to successfully market their product.

We had goals for the performance of our charging device and the case’s ability to protect the phone and the product’s internal components. The main protective goal of the case was to be able to withstand a drop of 2 meters and still maintain full functionality, while also showing minimal damage, and protecting the phone adequately. Additionally, it was critical that our device was able to produce enough power to charge the phone. Based on the output specifications of wall outlet chargers, we aimed to produce at least 0.5 Watts of energy to charge the device. With an output of at least this much, our case would be able to effectively provide enough power to charge a phone in any situation. Last, we wanted our case to be no thicker than 0.6 inches. This value was chosen so that the product is thin enough to be appealing and desirable to consumers. We set out to achieve a set of challenging, but accomplishable, goals for our senior design project, and we feel that we have accomplished them adequately.

2. System Overview – The Big Picture

2.1 System-level Overview

The entire system consists of a simple snap on case design that incorporates a crank wheel and gear train that transfers mechanical energy to a small electric generator. This generator uses the principle of magnetic induction, moving magnets over a copper wire to create a voltage difference across its terminals, and induce a current in the wire. The current induced in the copper wire is then used to charge the phone. In order to achieve a desirable RPM at the generator shaft, a gear train was incorporated to achieve a final drive ratio of 1:48. Our objective in designing this product was to create a portable case that the everyday consumer can use to extend the life of his/her phone's battery without the need to carry separate accessories with him/her.

2.2 Customer Needs and System Requirements

In order to establish realistic customer needs, smartphone users from differing demographics were surveyed. We strove to dive deep into the mind of our targeted customer base, to learn exactly what they need and are looking for, through our research and interview process. We opted to venture away from the popular research method of a mass survey. As students who are often asked to do surveys, we know first hand that the answers provided by third parties are not often thought out and usually done as fast as possible. Instead, we opted to explore the option of personal interviews, to gain a more in depth and personal perspective of the customer. To truly understand our customer, we opted to interview three different demographics of outdoor enthusiasts, an older man, young college student, and a United States marine. To engage them we tried to ensure that they are the focus of the interview. We told little about our product in order to receive the most open feedback possible. We also emphasized the outdoor activities engaged in by the customer. We asked about situations and experiences that they brought up in conversation in hopes of receiving answers that come from their true needs, rather than hypothetical situations. Overall, our group aimed to receive personal and in depth information from a broad range of demographics in the outdoorsman realm.

As was apparent from the data we collected, our potential customers were most interested in a system that was both efficient and lightweight. All of our interviewees indicated that they used their phones actively for at least 4 hours a day, and that their phones ran out of battery power and that they did not have access to a charger 2 or more times per week. Next on the list was the profile of the case; our customers all required that the design be slim in addition to being lightweight. At the opposite end of the spectrum, we found that, in general, weather resistance was the lowest priority of the system requirements of our design. In between were cost and ergonomics, then noise and aesthetics, followed by the need for the case to be intuitive and have a wide range of compatibility with different phone models. A summary of results and a sample of the survey filled out by the sample customers can be found in *Appendix 4*.

2.3 Benchmarks

Mophie

This device uses a rechargeable lithium polymer battery that extends the life of the iPhone for hours with up to 100% more power. It also features a hard case to protect the phone from the outside environment. (Mophie User Manual)

Flashlight crank chargers

These crank chargers use mechanical energy from a crank to move a magnet in the presence of coiled wires to produce an electrical current. Some of these flashlights feature a USB connector to be able to charge other devices as well. (Lamadrid)

Solio Bolt Charger

This solar charger harnesses the energy of the sun to charge devices equipped with a USB connection. It also features a battery pack that allows you to charge the charger for later use. This device's dimensions are 3.5 x 3.5 x 1 in., and it weighs 5.3oz. (SOLIO BOLT: Battery Pack Solar Charger)

Powerpot thermoelectric charger

The Powerpot is a thermoelectric generator that uses a heat difference between the bottom of the pot and the inside bottom of the pot to produce electrical energy of up to 5 watts. (PowerPot Frequently Asked Questions)

Infinity Cell (Phone Case)

This phone case uses kinetic energy from the movement of a user's body to generate electricity and charge a phone. Although there is no technical data or specifications, it most likely uses the kinetic energy to create induction and charge the phone. (Seo)

A comparison table of these benchmarks can be found in *Appendix 4.1*. Our phone case should be able to compete with these products by meeting requirements of weight, size, capable power, durability, and cost. The main purpose of buying a phone case is to protect the phone from any drops or damage it might take. Our case will provide significant protection as well as the ability to charge one's phone. By minimizing the size and weight of the case, we can further compete with other products such as the Mophie, Infinity Cell, and Solio Bolt charger. If our case is to attract consumers, it must be within the limits of size, weight and cost of these other products.

2.4 Functional Analysis

In order to streamline the development process, the overall project was divided into three subsystems: the power generation system, the physical case housing that encloses it and protects the phone, and the gear train. This was done because the two primary functions of the case will be to charge the phone effectively, and to protect it from light impacts and everyday wear and tear. The power generation and gear train subsystems determined the overall size of the system as a whole, given that the physical housing had to fully enclose and protect not only the phone but the entire power generation system as well.

2.5 System Level Issues

The visual appeal of a product is a critical factor in consumer response and product success. Consumers judge a product on the elegance, functionality, and social significance of the product based largely on visual information. These visual aspects of the product create perceived attributes that center on the wants and desires of the customer instead of their actual needs. Thus, it is important to ensure that our product is visually stimulating and user-friendly. We anticipate our customer base to be a wide range of people, including those who are technically inclined and those who are not. There are many factors to appearance including simplicity, elegance, balance, unity and symmetry. However, aesthetics encompasses much more than simply appearance. It is the combination of beauty in design and usability of the design. We hope to combine these factors, along with product performance and functionality, to make the product desirable for our customers.

2.5.1 Appearance

Our product is designed to accompany modern smartphones, which are often considered to be some of the most beautifully designed products on the market. *Figures 1 through 4* show the progression of our design ideas. *Figure 1* shows the initial design idea for the phone case, incorporating a wheel to spin the magnet over a coil. *Figure 2* shows more functional detail and subcomponents of this initial idea from a side angle. *Figures 3 and 4* show the progression to practical design of the case around a generator subsystem. *Figure 3* shows the very first sizing prototype, designed around a bulky, cobbled together generator system. Careful redesign and rethinking of the integration of drive and power systems led us to redesign the case for a more aesthetically pleasing and efficient design, as seen in *Figure 4*.

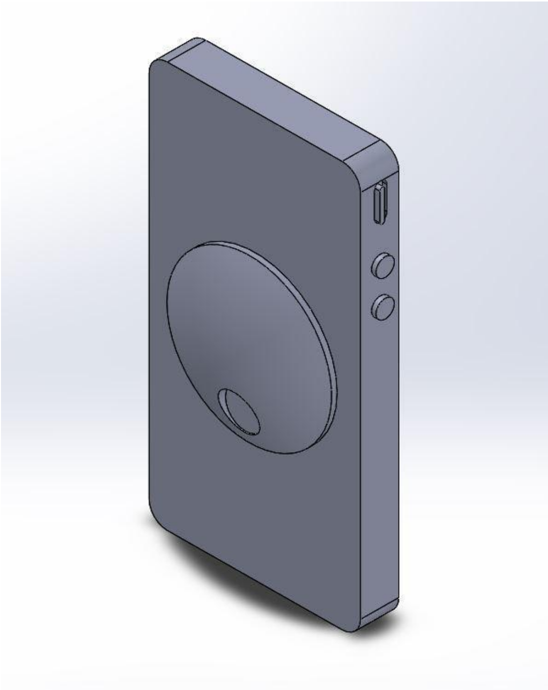

Figure 1: ¾ Rear view of the initial rotary magnet design

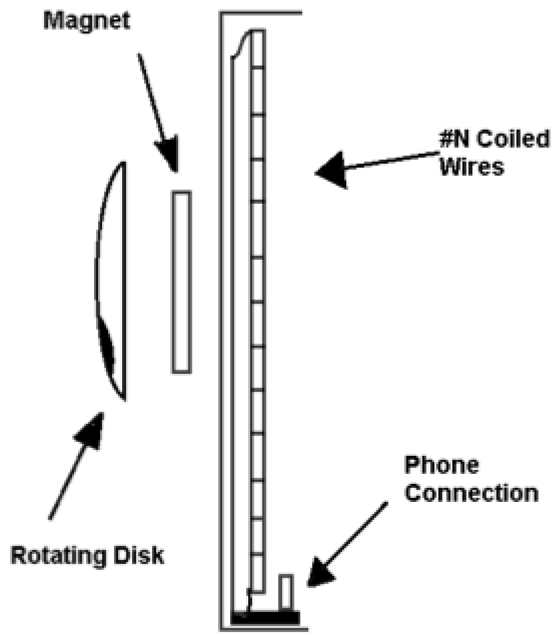

Figure 2: Preliminary design idea for a rotary magnet setup

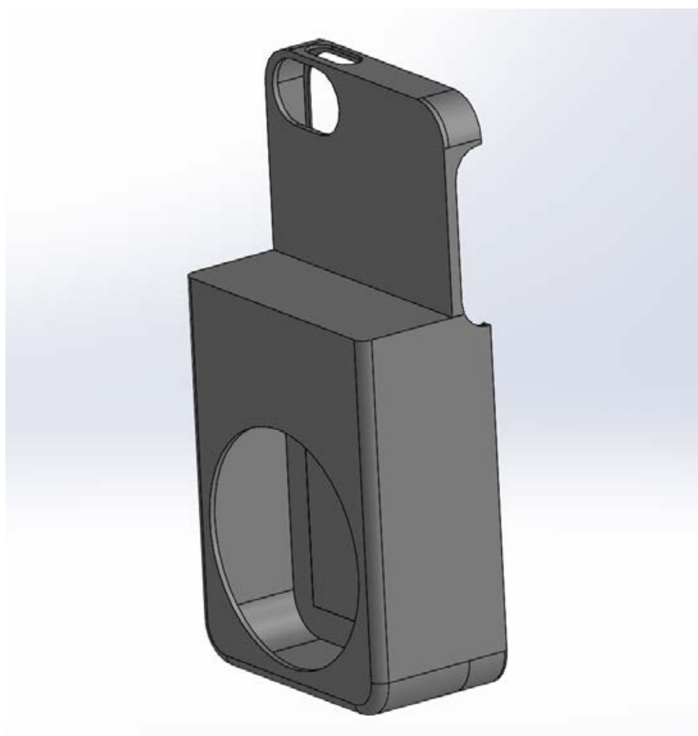

Figure 3: Outside design of Revision 1: first fitment prototype

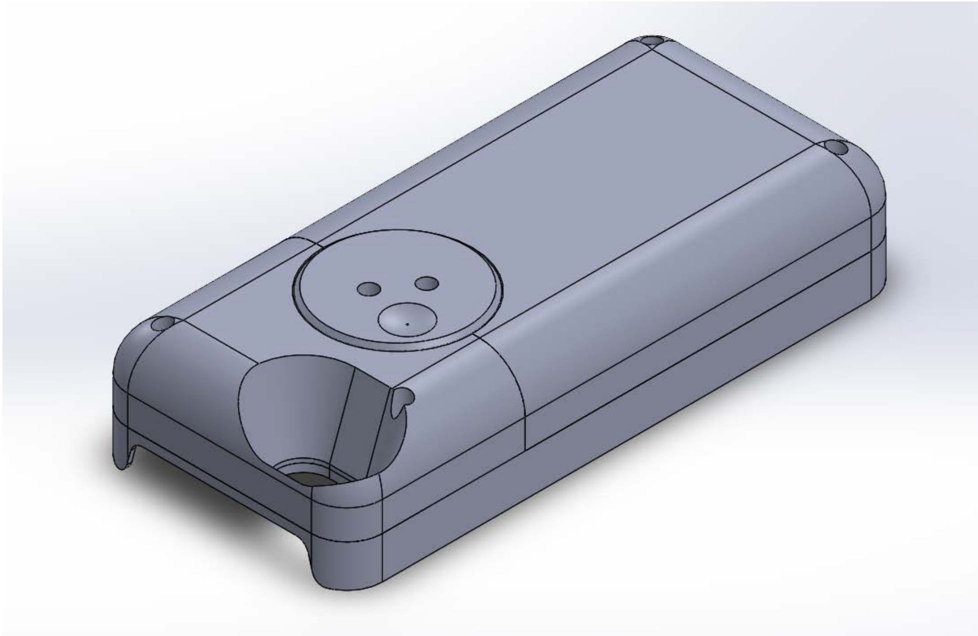

Figure 4: Revision 3: final case design based on sizing prototypes and gear train design

The initial prototype was very large and unwieldy as it housed a very unrefined generator subsystem. Subsequent design iterations aimed to make the design more elegant and aesthetically pleasing while also improving strength characteristics and minimizing material use. We aim for our design to be simple, elegant, balanced, united, and symmetrical. An outline of how we plan to achieve these milestones in design is presented below.

2.5.2 Simplicity

- The design only has one interface for the user to use: the indented button on the wheel used to spin a gear train that drives a generator and generates energy
- The rest is a sleek outer casing used to protect a phone.

2.5.3 Elegance

- Modern elegance is found in minimalism and simplicity.
- Our designs have been designed to only perform one function to reduce size and clutter.

2.5.4 Balance/Symmetry

- The disc design is symmetric on all sides with the exception of the indented finger groove.
- No part of the design has excessive features

The above-mentioned aspects of appearance of our case create a visually pleasing product. It can also be noted that our design is influenced by functionality. In addition to being aesthetically pleasing, the design efficiently uses space to house and protect our product's interior components.

2.5.5 Intuitive Usability and Functionality

Our case design is not only intended to be aesthetically pleasing. In addition to being an attractive case for one's smartphone, it is intended to be highly practical and very easy to use. Turning a wheel on the back of the case is a very simple movement and makes the case functional for virtually any user.

- Our design features only one moving part: the crank wheel. This simple design makes operation intuitive: simply crank to charge the phone.
- The design serves to charge a smartphone and also protect it from minor damages.
- The hard outer casing provides protection for the phone and internal components of the case in the event of a drop or crush.
- The drive system is efficient and satisfying to use without creating unnecessary strain on the user for an acceptable output.

2.5.6 Installation

- Our case is designed to snap on to a smartphone snuggly and securely.
- The designs feature a male charging pin that fits directly into the charging slot of a smartphone.

The intuitive nature of our case lets the user visually detect how the case functions. The indented button used to turn the crank wheel can be used with a single finger and will not strain the user. Furthermore, the low speed required to turn the crank yields usable power to charge a phone, allowing for any user to effectively use the product. In addition to excellent functionality, the case design retains an aesthetically pleasing design and still provides adequate protection for the phone and internal components.

2.6 Team and Project Management

2.6.1 Challenges and Constraints

In terms of project management, challenges and constraints that pertained to our project lay mostly in ethical behavior and actions in social interactions, within and without the team, and product development. Our team was obligated to act within the ethical limitations we had set ourselves in order to compete fairly and not only within our legal limitations. Most importantly, this meant that we respected intellectual property that is not ours, and that we did not fabricate crucial data or information that pertains to the development and manufacture of our final product.

2.6.2 Budget

Our budget did not pose a major issue to the development of our product. Given the scale of our project, even very generous estimates indicated that our spending would not exceed the amount we had budgeted for the project. Because the cost of materials was low and the physical size of our final product did not require much material, fabricating several prototypes did not incur large costs. Of the $500.00 grant that we received from Santa Clara University we only used $210.33.

See *Appendix 5.2.*

2.6.3 Timeline

Again, the scale of the project gave us ample time to complete it, though we still made use of all the time we could in order to test and optimize each subsystem. By the end of 2013 we had initial design plans for our subsystems, and had begun to source parts to fabricate initial prototypes. In the beginning months of 2014 we had prototyped revision 1 of our case and power housing, and had assembled a prototype for our initial magnet-coil design. Testing our initial design prototype pointed us in a different direction, and we began to redesign the generator subsystem from the ground up. At the end of February, FEA analysis of revision 1 of the case design was conducted. The results guided the next redesign, with the key focus being on reducing the corners and unsupported area on the back face of the case. With the generator system redesigned and a new gear train design in the works, the case was redesigned to be more aesthetically pleasing as well as more practical; revision 2 was 3D printed for physical testing of fitment. Beginning in Spring, new generators were sourced, and testing was conducted on their potential power production. Initial tests on the new generators in March returned promising numbers. In March, the gear train design was finalized around the potential generators, and the case design was fine tuned to ensure fitment of the assembled subsystems; revision 3 was determined to be the final iteration of the case design. Preparation for the Santa Clara Senior Design Conference 2014 was begun. Further testing was conducted on the generators at the end of April and beginning of May. Generator theory was verified, and the generators were determined to have high efficiency - a very desirable trait. Conference presentation material was finalized in the first days of May and presented on May 8, 2014. Following the Senior Design Conference, the final prototype was manufactured and assembled with all components installed. Once built, the Senior Design Thesis paper was written, edited and submitted on June 11, 2014.

See *Appendix 5.1*.

2.6.4 Design Process

Our approach to our design relied heavily on the feasibility of power output and the ergonomics of the case itself. Calculations showing the necessary power needed to charge a smartphone proved that our size constraint was not an issue in designing a system to charge a smartphone. Based on initial calculations, our design revision 1 should have worked. When it came to practical testing however, our prototype with the hand-wound coil proved to be insufficient. At this point it was determined that a professionally wound coil was required in order for our design to succeed. From an analysis of basic DC electric motor theory, and practical testing of available small DC electric motors, it was determined that a high quality, small electric motor could serve as a generator. A new set of calculations (*APPENDIX 2*) was conducted for the new generator setup selected. Based on these calculations, we found a range of generators that would prove suitable. The main constraint here was to select a generator that would not add excessive bulk to the rear of the phone case. In selecting potential generators, the maximum height was limited to 12.7 mm, as it was determined that material could be removed from the top of the generator shaft if needed. The next constraint was the diameter of the generator housing: this aspect was limited to 35 mm. Within these constraints, a selection of generators with the highest potential voltage per RPM were chosen. Ranging from 1200kv to 2100kv, the generators were all determined to produce useable voltage from an acceptable input RPM without excessive gearing to increase output speed in the gear train. Once efficiency was determined to be acceptable, the gear train design was finalized to provide a final drive of 1:48, increasing an average input of 90 RPM to 4320 RPM at the generator shaft.

2.6.5 Risks and Mitigation

By determining theoretical power generation for the type of generators that were selected, excessive testing was avoided. Research and initial calculations allowed us to select the generators that would best suit our purpose without physically testing them. We were able to select the most powerful generators without compromising the size of the case, and the overall product. In addition to this, conducting FEA analysis on CAD models of our prototypes allowed us to determine weak points in our designs without needing the materials or time required for physical drop testing of our designs. This also allowed us to select a material for the case of our product without the need for multiple prototypes of different materials.

In addition to the risks associated with design and testing, we were faced with the risks of running over budget or running out of time. Given that our product is a physical object, one of the greatest risks we faced to staying on schedule was the time taken to acquire parts. This was an issue for our group as the first generators we ordered were delayed several weeks in arriving. Although we did run into this issue, we were able to minimize the amount of time we were set back by completing other work that did not require us to physically possess the parts.

2.6.6 Team Management

In order to maintain an effective team dynamic, we strove to effectively and efficiently communicate with each other. By maintaining open communication among team members, we ensured that all ideas were considered, so that we could put together the best, most effective final product. In order to do this, in making decisions we worked to reach a consensus among ourselves so that our decisions and progress with the project was cohesive and effective. To avoid conflict within the team we all made a conscious effort to treat everyone’s differing viewpoints respectfully, regardless of our own opinions. By working to enforce these ideals, we were able to ensure smooth and efficient team interactions and product development.

3. Subsystems

3.1 Plastic Housing

3.1.1 Role

The plastic housing of our phone case plays the critical role in the durability and protection our case provides for both the phone itself and the internal components of our energy generation system. The case must not break on its own, and it must protect the internal components. Thus, we chose materials and structure that provides ample protection, while remaining slim and lightweight for functional purposes.

<u>Size and Protection Requirements</u>

Maximum Case Dimensions

- Thickness: 20 mm
- Width: 65 mm
- Height: 130 mm
- Weight: 100 grams

Drop Test Specifications

- Average Height (Male) ~ 1.75 meters (5’ 10”)
- Case must remain intact after a drop from 1 to 2 meters
    - Provide adequate protection for the phone when dropped from same height

3.1.2 Challenges and Solutions

The largest problem we faced with our housing piece was combining size, durability, and effectiveness. It would be simple to build a large and heavy case that provides plenty of protection and is very unlikely to fail. However, this is not our aim. To create a case that provides protection, while being elegant, slim and light is much tougher. The solution defies what would seem obvious, use less plastic. Much of the harm done to smart phones when dropped is due to shock and vibration. To reduce this problem, material will be added at regions of high stress. This greatly reduces the necessary thickness of the plastic.

To reduce the weight, a proper polymer must be chosen and molded into our case shape. Through our research, the best polymer choice for a mass-manufactured case is polycarbonate. It is used on other smartphone cases, such as Speck and Otter Box cases. Its combination of strength and minimal weight is a perfect fit for our need. Cheaper materials with less strength are also available, but will not properly satisfy our needs. Additionally, there are stronger and more lightweight materials available that are much too expensive and are not necessary for our needs. For prototyping our case we chose to 3D print the housing revisions in order to reduce cost and time needed between design revisions. The 3D printer uses ABS-M30 plastic material. It is a popular material in the field and has proper material properties to successfully protect the phone and internals of the power generation system. More importantly, the difference in performance between ABS-M30 and polycarbonate is minimal. ASTM test D256 showed the izod impact performance of polycarbonate to be 12.0 ft-lbs/in, while ABS-M30 had a performance of 5.3 ft-lbs/in. Furthermore ASTM test D790 found the flexural modulus of polycarbonate to be 345,000 psi, and 350,000 psi for ABS-M30. (*Fortus Material Specs* 1, *Curbell Plastics* 1) The initial housing created a compartment for the power generation system that is 22.86 x 58.42 x 76.2 mm in size.

The housing subsystem underwent three design iterations. The first design was made as a sizing prototype and can be seen below in *Figure 5*.

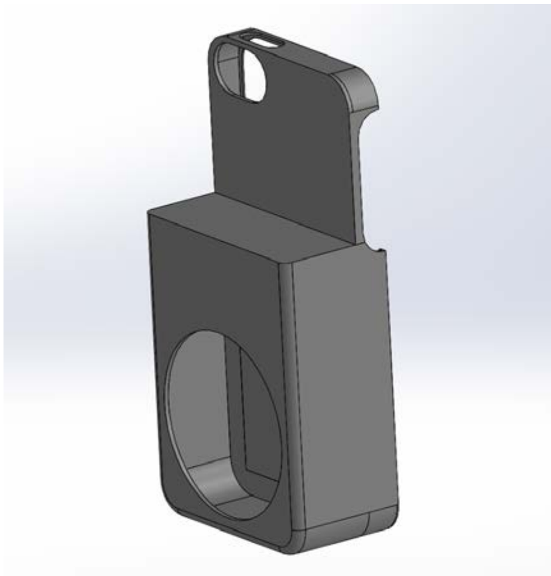

Figure 5: Housing design Rev. 1

Important aspects of this design include the large disk hole for user input, along with proper adherence to Apple’s design drawing for features such as case size, camera holes, and button locations. The case was tested using a finite element analysis method on SolidWorks, with images of the results shown in *Appendices 6.6-6.8*. Important results include the maximum deformation, which was found to be .918 mm on the back face of the case. This highlighted that the case is acceptable to our predetermined standards and highlights the most likely region to have failure, the back face. Thus, there was a need to reduce the amount of unsupported area on the back face. This led to our second sizing prototype, revision 2 of our case, which can be seen below in *Figure 6*.

Figure 6: Housing design Rev. 2

Revision 2 features a reduced flat surface on the back of the case in order to better distribute stress on the back of the case. Furthermore, it is redesigned to be more ergonomic and have improved weight distribution. The case also features improved fixturing on the interior of the case for gears and the power generation system. This case was a big upgrade from the original design, but was not perfect. It needed to be reduced in size and made to be a bit longer to fit the lightning connector to attach to an iPhone. These improvements were made in the final housing design, which can be seen in *Figure 7*.

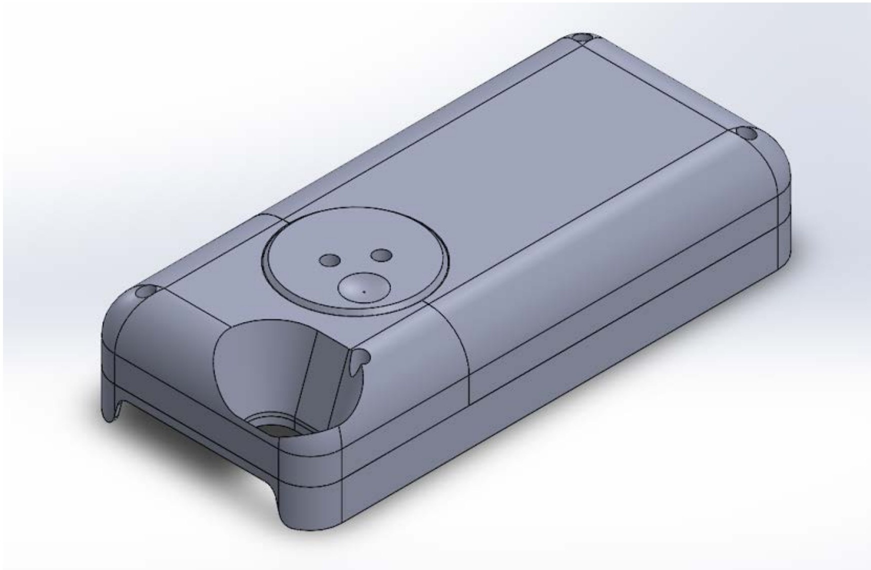

Figure 7: Housing design Rev. 3

The third revision of the housing is the final housing to be used for the project. The housing is longer than previous cases to allow more space for connecting the power generator to the phone, along with an improved camera hole and redesigned fixtures for an updated power generation and gear system. The third revision of the housing underwent an additional finite element analysis, which proved the design to be successful. The results from the finite element analysis can be found in *Table 1*. The maximum deflection for design revision 3 also occurred on the back face and had a magnitude of 1.15 mm. That is acceptably within our preset limits and is an improvement on previous designs, despite the large amount of deflection. This is due to the minimal increase in deflection in comparison to the large increase in unsupported back face surface area.

3.1.3 Testing Methods

To validate our findings, we needed to test our phone case. Ideally we wanted to conduct a simple drop test. We planned to first drop the case from a height of one meter above the ground onto a cement surface. We would observe our findings for each drop and repeat for five drops at this height. This was meant to imitate it falling out of the user's pocket. We wanted to then repeat the test for a height of two meters to imitate a fall when the user is holding his or her cell phone. This test was to be repeated with a sample phone in the case and the drop's effect on the phone was to be observed. For our purposes, a finite element analysis was performed to imitate the drop tests. This was done to reduce the cost and time of manufacturing multiple housings.   The results of the finite element analysis showed that our housing will not fail a drop test, and can be found in *Table 1*. As mentioned in Section 3.1.2, the maximum deflection of the final housing was 1.15 mm and did not fracture. This is well within the allowable limits and proved the housing design to be successful in protecting both the case's components and the phone itself.

3.2 Power Generation System

3.2.1 Role

The power generation system built internally into our phone case is responsible for creating energy to provide power to the phone's battery when running low. There are many of options of how to do so. In the market today there are phone cases with back-up batteries, solar panels, and wireless charging options. We are choosing to explore a new method: electromagnetic induction. Electromagnetic induction utilizes a magnet moving at high rate speed over a coil of wires to produce a current and voltage. The following are the benchmarks for power production, and the amount we aim to produce.

<u>iPhone 5 Battery/charger specifications</u>

- 1440 mAh (5.45 Wh)
- 3.7 V
- Advertised max standby time: 225 hours
    - As advertised idle power draw: ~0.025 W
- Wall charger power output: 5 W (5 V, 1 A)
- PC USB charger output: 2.5 W (5 V, 0.5 A)

In order to charge the phone we must overcome idle power draw

- Required case power output to trickle charge: ~0.5 W to 1 W

3.2.2 Challenges and Solutions

The largest problem faced with the electromagnetic induction system is discovering the method that creates the most energy for the phone. The two best options for optimal energy generation are spinning a disk over the coil of wires, or spinning a set of magnets around a stator. To create the maximum amount of energy, the magnet needs to be moving at the highest speed possible over the coils in one direction. Given the small scale of our product, spinning a circular disk over the coils, along with a gear system, appeared to be the best option. The spinning magnetic disk is the most common method used by power generation systems on a small scale, most notably flashlight crank chargers. Our first generation of the power generation system featured this type of system. The system featured a disk magnet and wire coil, both 1.25 inches in diameter. The system was tested and found to produce an insufficient amount of power, with results shown and discussed in Section 4. We found this to be because our wire coil was hand coiled. So, we decided to purchase a small-scale induction generator. We chose the Outrunner generator, as explained below, due to its high output and thin profile. The generator is three phase and can be seen below in *Figure 8*.

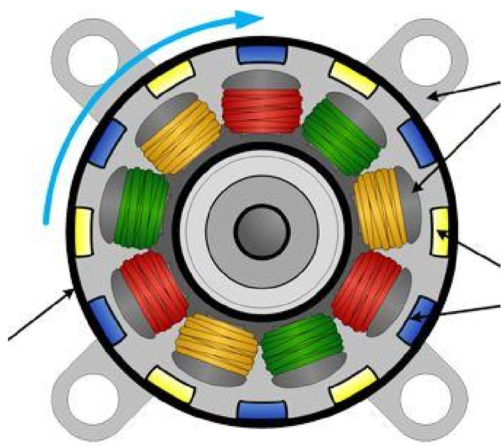

Figure 8: Outrunner motor schematic (Gornek)

The coils of magnetic wire are in the center of the motor, with each phase colored differently (red, yellow, and green). This is the motor's stator and it is fixed in place. The magnets are spun around the outside of the coils with alternating poles as represented by the yellow and blue rectangles on the diagram above. The system was tested and several different sizes proved to generate enough power: 1200kv, 1700kv and 2100kv. The results for the testing of the Outrunner motor can be seen in Section 4. The 2100kv motor was selected as the final generator choice due to its unique combination of thin profile and power generation ability, from results of testing performed and explained below.

3.2.3 Testing Methods

To discover which method of induction is best, we needed to test our system. It was done in two ways, with and without the gear train attached. The independent generators were spun at a low RPM of 600 to get baseline power generation values to compare to theory and determine the efficiency of each generator. These results can be found in *Appendices 6.3-6.5,* efficiencies and other general information are shown in *Table 1* below.

Table 1: Relevant specifications for selected outrunners

	Turnigy 3020	HD2910	C2403
Kv (rpm/v)	1200	1700	2100
Weight (g)	25	21.2	17
Total Length (mm)	21	22	17
Diameter (mm)	30	29	30
Efficiency	0.90	0.85	0.945

We applied a user input to the system at 90 RPM and measured the amount of energy produced by the combined gear train and power generation system. The data was collected using LabView, with a simple block diagram to translate the results from an attached data acquisition unit. We repeated the tests with different generator set ups, and differing gear ratios. More in-depth discussion of testing can be found in Section 4.

3.3 Gear System

3.3.1 Role

To achieve the desired speed of the magnet, we required a system that maximizes the user's input to achieve a higher speed at the generator shaft. There are a few methods to accomplish this, however, few are applicable on the small scale that our product requires. Options available to us included torsion springs, a wind-up mechanism, or gears. Given the limited amount of space available, torsion springs and wind-up methods became less feasible. Thus, gears emerged as the simple and most effective method of increasing magnet speed. This was verified by the aforementioned crank flashlight example, where gears are heavily utilized to amplify the speed of the magnet's rotation.

3.3.2 Challenges and Solutions

The use of gears to amplify speed creates three major variables that we had to determine.

First, we needed to design a gear configuration that maximized the velocity of the magnets. Planetary and spur gears are the most common on a small scale, so we explored both options. A spur gear train proved to be the optimal choice for our application. This was due to the fixtures for the axles being too close together on the housing to be fixed at both ends and still allow planetary gears to mesh. Second, gears are the main source of noise for small-scale systems that implement gears because of due to material choice, and poor tolerances. Gear design is often very generic, and to reduce costs, they are manufactured with larger tolerances and cheaper materials. This can be avoided by choosing higher quality materials and designing for closer tolerances. Lastly, we needed to reduce the thickness of the gears to keep the profile of the case thin. This was ultimately accomplished with stepped gears, which allowed us to greatly reduce the space required for a full gear train and still achieve a satisfactory final drive ratio.

The gear train began with a simple two gear system that produced a 1:5 gear ratio. As the needs of the power generation system changed, the gears changed to satisfy these needs. The final gear train system can be seen below in Figure 9, where it is mounted on axles in the final revision of the housing.

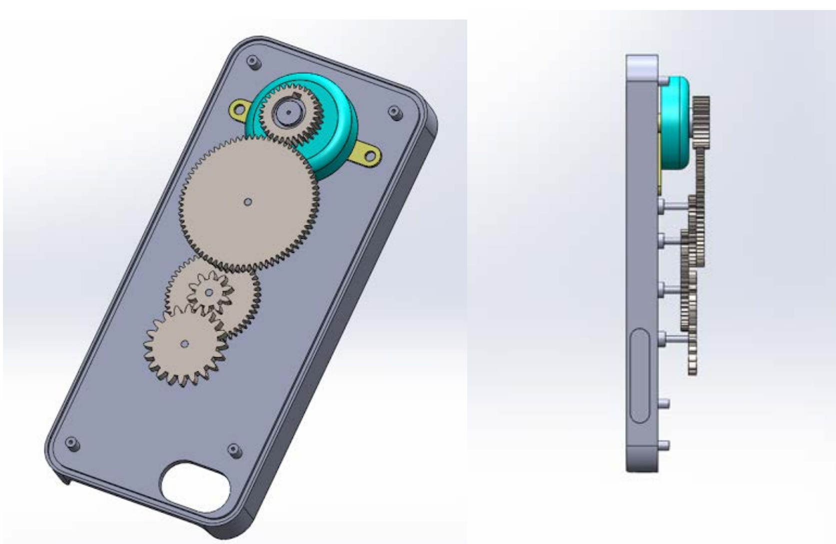

Figure 9: Final gear train design

The final gear train depicted above features 4 stepped gears, in addition to the final gear mounted on the generator, working in conjunction to create 1:48 final drive ratio. The ratio was chosen by a calculation that provided us with 2 volts of generated power from a user input of 90 RPM. The 2100kv motor means that the motor must be spun at 2100 RPM to produce 1 volt. Thus, to achieve 2 volts, the motor must be spun at 4200 RPM. When 4200 is divided by the user input of 90 RPM, it calculates to a minimum gear ratio of 1:47. A 1:48 ratio was chosen to allow room for a reduced user input speed and system inefficiencies.

3.3.3 Testing Methods

The gear train will be tested in conjunction with the power generation system. The system will be configured and spun at a constant user input speed of 90 RPM. While being spun, the gear train will be observed for multiple forms of failure and error. These areas include noise, gear fitment, axle stability and tooth strength. The gears will be tested individually, in pairs, and as a whole system.

4. System Integration, Test and Results

4.1 Housing

To test the housing, a finite element analysis was performed in order to reduce cost and time of remanufacturing. The environment chosen was meant to be similar to that of the average user. The product will be used in both cold and hot environments, so an air temperature of 22 degrees Celsius was chosen as a point halfway between the two extremes. Extremes were not tested because the facilities provided did not have the capability of reaching extreme temperatures. The nature of the force is meant to imitate the housing hitting a hard cement surface from the height of a pocket (1 meter) and ear (2 meters) at different angles. The force was calculated with the assumption that the acceleration of gravity is 9.81 m/s^2. The cement is assumed to have no elasticity and that the effect of air on the rate of falling could be neglected. The angles chosen to analyze were the back corner of the housing, side edge, and flat on the back of the case.

The ANSYS program and SolidWorks were used to perform the FEA analyses for these forces and angles on the housings. For revision 1, the part was created in Solidworks and then imported into ANSYS for analysis. Revision 1 of the housing design was evaluated on ANSYS, while revision 3 was evaluated on SolidWorks. This was done to gain exposure to both evaluation programs.

The housing case was analyzed as if the phone were in the case, and the case was fully assembled. The phone added rigidity to the case and acted as a fixture in the tests, mitigating bends, twists, or deformation. The case was analyzed by applying impact forces to simulate the drop of the case at points 1, 2 and 3, seen in *Figure 10*. These points are the most likely to hit when dropped and provide worst case scenarios of impact.

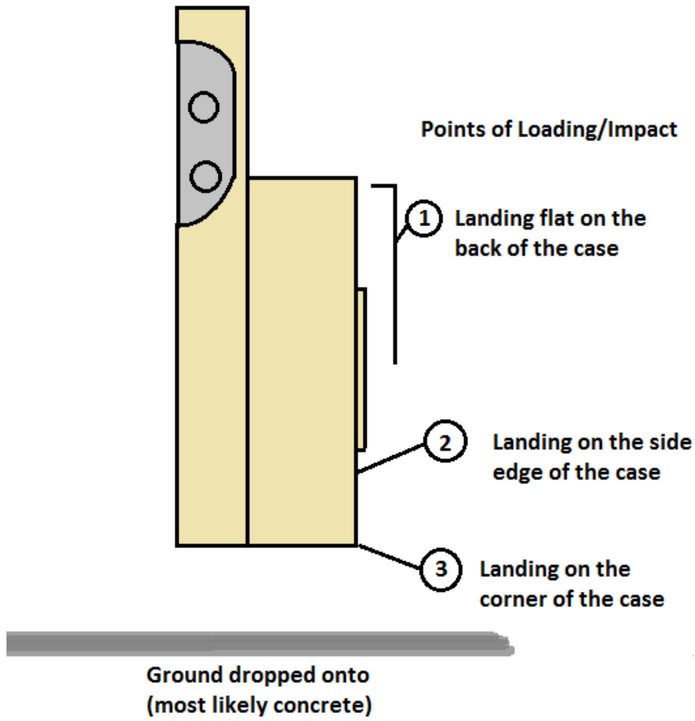

Figure 10: Diagram Showing the Three Points of the Case Being Analyzed (Revision 1 Depicted)

We expected the housing to deform differently at each of the three impact positions (corner, side edge, and back face). Each point faced differing benefits or drawbacks due to the internal components. In some places, such as the side of the case and the back face, the internal components added structure and rigidity to the housing, improving its characteristics under impact loading. However, the internals added weight, which increased the force that the housing was subjected to. This was most evident in the corner of the housing, where the weight was a factor, but the internals did not improve the structure or rigidity. At all locations of applied force we expected two potential modes of failure: elastic deformation and impact fracture. Elastic deformation was expected where the material was thinner and more easily warped. In areas where the housing material was thicker, we expected failure to occur as an impact fracture. The thin areas included the center of the back face, while the thick areas being tested were the corner, side edge, and rim of the back face.

We expected the housing to undergo maximum deformation when a force was applied to the back face of the housing because the face has the largest and thinnest surface without support, spanning 58.42 x 76.2 mm on housing revision 1. For the back face, it was considered a failure if it deflected over 2 millimeters in the center of the face, or one on the edges. 2 millimeters was chosen because of the clearance between the housing and internal components. Factures at any part of the back face were considered a failure. We expected no fractures on the back face, but given the thin nature of the face we expected deflection at the center to exceed the allowable amount. The impact force was applied to the smallest surface area at the case's corners where there is also very little added structure from internal components. Because of this, we expected a large amount of deformation but no fracture. For the corner impact, it was considered a failure if the corner of the case deformed anywhere more than 3 millimeter or if a fracture occurred. 3 millimeters was chosen because of the clearance between the housing and internal components. The side of the housing protects the phone and power generation system more tightly, so deflection of over 1 millimeter or a fracture was to be considered a failure. We did not expect the side to fail.

Finite element modelling of our case component revealed that the case was not likely to fail when dropped from 1 m and 2 m heights in each of the three different likely scenarios: flat on the back of the case, flat on one side edge, and directly on the bottom corner. Visual results of the FEA testing can be seen in *Appendices 6.6-6.11* for both revision 1 and revision 3 of the housing. When an increased load was applied, the graphic remained unchanged, but the maximum deformation and maximum principal stresses increased, as can be seen in *Table 2* below.

Although the structure is relatively rigid, especially when attached to a phone, there is still a need for more structural rigidity in order to protect the internal components. As we can see from the graphics depicting deformation, in extreme cases, the deformation can impede the operation of our system by binding or crushing. As we predicted, the back face saw the most deformation when subjected to the impact load in both revisions of the case. This was the greatest cause for concern for us, as this face will be interfacing with the manual crank that drives the magnet-coil power generation. Not only does it interface with the crank, this face also encases the internal components, and a crack or bend can result in reduced protection from physical forces as well as dust and moisture.

Given the small scale of our deformation, it is safe to assume that our design is robust enough to protect our components granted we reinforce it strategically and slim our design down to reduce waste material and minimize free-floating, unsupported surface area. It is possible that integrating our internal components may increase structural rigidity by reinforcing weak areas of our design with fasteners, bearings, axles and the like. Conversely, the small internal components could prove to be weak, fail and/or be displaced from its desired position.

Table 2: Deformation results of the three points analyzed from heights of 1m and 2m.

-	**Drop Test From 1 meter**		**Drop Test From 2 meters**	
-	Design Iteration 1	Design Iteration 3	Design Iteration 1	Design Iteration 3
Corner Deformation [m]	2.44E -2 [mm]	1.02E -2 [mm]	4.89E -2 [mm]	2.04E -2 [mm]
Side Deformation [m]	4.34E -2 [mm]	3.84E -2 [mm]	8.68E -2 [mm]	7.68E -2 [mm]
Back Deformation [m]	4.59E -1 [mm]	5.74E -1 [mm]	9.18E -1 [mm]	1.15 [mm]

Our results proved our case design to have high integrity and strength. Our primary concern was that the housing would suffer fail from a fracture, but the testing reassured us that our design would not fail. However, the FEA analysis highlighted some issues we have. The housing underwent elastic deformation from every force and at all locations it was applied. The maximum deformation was found to be 9.18E-1 mm for revision 1 and 1.15 mm for revision 3 on the back of the housing when dropped from a height of two meters. The results appear to get worse as design iterations went on, but this is not the case. The mass of the system increased, along with height of the flat back surface, so the deformation was expected to increase. This, however, was not of much concern to us, as the new design also incorporated a row of axles along the center of the case. These axles would act to reinforce the unsupported area of the rear face. Thus, the finite element analysis proved our housing to be successful.

4.2 Power Generation System and Gears

The power generation system and gears were tested in the Santa Clara University Instrumentation Laboratory. The data from the experiment was gathered using a simple block diagram on the computer program, LabView. The LabView program interpreted a signal gathered by a data acquisition unit, plotting the voltage and current data for further analysis. LabView was chosen because it is highly accurate and commonly used in the professional field. The ambient conditions were the same as the FEA analysis, 22 degrees Celsius. We expected the system in the first power generation test to produce 1.2 volts based on Faraday's Law calculations.

The first test performed evaluated the voltage created by the primary 1.25 inch diameter magnet and coil configuration of the power generation system. A constant speed of 90 RPM was inputted to the 1:5 gear train that drove the spinning magnet. This was chosen to imitate the average input speed of a user. The results proved to be very poor, with almost no voltage being able to be read by the LabView system. As a plan B, an externally purchased gearbox with a 1:87 gear ratio was connected to a small purchased generator. The drive gear was spun at a constant speed of 90 RPM. The results proved much more successful, with the LabView system detecting and plotting values of up to 4 volts of output voltage from the system. The LabView plots from the tests can be found in *Appendices 6.1* and *6.2*. Though the original test configuration proved unsuccessful, the second part of the test provided positive results and a sense of direction moving forward.

A second test was performed to make a choice of outrunner motors. The test featured no gear system, as it was meant to evaluate the efficiency of the motors and accuracy of the kv value provided by the manufacturers. Three outrunner motors were tested, a 1200kv, 1700kv and 2100kv motor. The outrunner motors were spun at a constant speed of 600 RPM. The motors were expected to have a high efficiency and theoretical values of .5 volts, .35 volts, and .29 volts for the 1200kv, 1700kv, and 2100kv motors, respectively.

The difference in output from each of the motors was large, with the 1200kv motor producing up to 0.5 volts and the 2100kv motor producing up to 0.3 volts. The LabView plots for the tests can be found in *Appendices 6.3-6.5*. The results showed a high efficiency as they were close to the theoretically expected results based on the kv rating of each motor. The results proved the experiment to be successful, as each motor demonstrated a high efficiency in the experimental results as seen in *Table 1*. Due to these results, the thinner, 2100kv motor, was chosen to be implemented in the final system design.

5. Cost Analysis

As is very obvious from our budget we did not exceed our overall budget or spend more than the money we were granted by Santa Clara University's School of Engineering. The cost of producing several prototypes was significantly less than expected, and the overall cost of our project was greatly overestimated. Although we did run over budget in a few areas, we had ample reserves in other areas where we had spent little more than 5% of the budget we had allotted.

The ability to 3D print our housing prototypes rapidly meant that we avoided not only long turnover times to receive prototypes from a manufacturer, but also that a large portion of our budget was left free to fill in where we needed it. Where we had initially anticipated expenditures of more than $100 solely for prototyping the case housing, we spend only $6.39 on material used to make axles.

The portion of our budget designated for power generation components was the closest to going over budget. Although we initially anticipated a cost of roughly $120 for magnets and $30 for coils to be used in our magnet-coil setup, we only spent $35 on magnets and $21.19 on wire for the coils. After initial tests concluded that this setup was not viable, we chose to use outrunner generators. Costing roughly $15 each, the total for the assortment of generators we purchased ended at $73.35, $33.35 over the $40 we initially allocated. This portion of the budget was initially allocated for miscellaneous parts, but was reallocated for the purchase of our generators. Another area we ran over our initial estimates for was the gearing. Initially allocated a budget of $34, we spent a total of $40.71 on gears and other parts for the gear train. Although these two areas went over budget, the remaining money allocated for the purchase of magnets and coils was sufficient to cover these costs.

In the final two areas of the budget we did not spend more than a fraction of the total allocated to each. In the power transfer area of the budget for example, only $14.16 of the $41 allocated were spent. In addition to this, much of the testing equipment we required was available for use in the instrumentation lab free of charge. We had initially budgeted to purchase much of our own testing equipment, allocating $85 for test rig parts, and miscellaneous wiring and electrical components for test rig and prototype construction. The ability to test in the instrumentation lab at Santa Clara University meant that we only spent $19.53 purchasing miscellaneous wiring and electrical components to build our circuits.

In final production, many of the parts we purchased would be available at wholesale, manufacturer prices. For example, if purchased in bulk, the 2100kv generator we selected for use in our prototype could cost as little as 8 or 9 dollars, instead of the $16.84 unit price we purchased it at. This pricing would also apply to wiring and electrical components as well. Rather than spending about a dollar per resistor, capacitor, or rectifier, the prices for these components quickly drop to somewhere between 10 and 20 cents when they are purchased in very large bulk orders. In addition to this, initial exploration into the manufacture of gears showed that professionally prototyped gears would cost as much as $20 each, whereas a bulk order of at least 1000 gears would cost only $2-3 per gear. Overall the cost of producing the final product can be reduced greatly by purchasing in bulk for mass market manufacturing. Where the prototype cost us roughly $40 for the components to construct a single prototype, by buying in bulk the overall cost can be reduced to about $15; more than a 50% decrease in the cost of production.

See *Appendix 5.2*.

6. Business Plan

6.1 Abstract

Most people who have a cellular phone can admit that their phone battery has died on them from too much use. Like us, these people know how terrible the feeling of not being able to contact anyone for any reason can be. This situation can apply to many circumstances whether someone is lost, needs help, or just simply wants to make a phone call. This is why we have created a manual charging phone case so that users may charge their phone where ever and whenever at their convenience. Our product is different from other charging cases because it gives the opportunity to create battery life without an external power source. Our product gives users the peace of mind that their phone battery will not die and will be able to make phone calls in emergency, distress, or everyday situations.

6.2 Introduction

Our team consists of three senior mechanical engineering students who have all experienced having our phones die on us because of constant use. This has driven us to create a device to manually charge our phones without the use of an external power source. The ownership of the business is split equally, with equity divided three ways amongst us.

Today people are using their phones more and more to get data, send data, and overall be more connected with the world. With the heavy reliance on ones phone to connect them to everything, peoples phone batteries cannot last a full day given one full charge. This creates a need for those who use their phones substantially and do not always have a power outlet or means of charging their phone at any given moment. Our product attaches to a smartphone via a snap case and will charge a phone through a user's manual input by spinning a turn style disc. The snap case will act just as any other phone case does by protecting the phone but also includes our power generation technology. Our product competes with similar cases by meeting similar size constraints, aesthetics, and ergonomics all while cutting costs and meeting customer requirements.

6.3 Goals and Objectives

Our vision is that our product will create peace of mind to travelers, people in natural disaster situations, emergency situations, or anyone who might use their phone enough to run out of charge. We have met our goal by testing our power generation system in the laboratory and getting optimal results for providing power to charge a cell phone battery. Furthermore, we wanted our case to be rugged. It must act just as any other case does by first and foremost protecting the phone itself. Through finite element analysis we calculated that the case will be able to withstand drops from a normal pocket height of 1 meter and a high talking height of 2 meters. The future plans for our technology are that it will be sold and marketed in outdoor stores everywhere and used by whoever needs some extra charge.

6.4 Description

Our case is designed to attach to a phone via a snap case and utilizes a disc interface on the back for the user to power our case and charge their phone. Attached to the back of the case is our power generation design that turns user mechanical energy into electrical energy. The turn style disc interface is attached to a gear train that spins up an electric motor generator to create energy. The gear train was designed after testing the generator in the laboratory to create the optimal amount of energy needed to charge a phone. The generators energy then flows through our circuit board and into the charging port to charge the phone. Our circuit board is executed to work so that a user can spin the disc interface either left, right, or back and forth. However, the most efficient use is by constantly turning the disc in one direction. Since our case design has never been implemented before our product will be protected by a patent.

6.5 Competition

Our design separates itself from the competition because it allows users to manually charge their phone at their convenience rather than use another power source. Other cases that allow users to charge their phones are the Mophie, Solio Bolt Charger, and PowerPot Thermoelectric Charger. These accessories and others alike are either bulky, expensive, require another charged battery, or simply cannot work at all times. The Mophie operates by adding an extra battery pack to the phone extending the life of its charge. This extra battery however, still needs to be charged via an outlet before use. This makes the Mophie useless when dead or not near an outlet. The next competitor, the Solio Bolt Charger, uses solar energy captured by the sun to charge the phone. The problem with this solution is that the sun isn't always available and the device is bulky and inefficient. The PowerPot uses heat by means of fire to create energy. This solution is dangerous and challenges a user to contain a fire when it is not always readily available. The PowerPot is also very big and can be cumbersome to carry being around 6 inches tall and 6 inches round. For these reasons we have created our Manual Charging Case to combat the bulky, expensive, dangerous, and challenging ways to charge a phone without an outlet. You can see in *Table 3* that the price of our case cuts the competitions price almost in half every time.

Table 3: Price of the Manual Charging Phone Case versus competitors

-	Manual Charging Phone Case	Mophie	Solio Bolt Charger	PowerPot
Cost	$50	$80-$120	$100	$150-$220

6.6 Marketing and Sales

6.6.1 Customer Profile

Potential customer markets included the common outdoors men and women, travelers, people on the go, and people in disaster or emergency situations. During our research we conducted personal interviews with potential customers ranging from the older outdoors man to the college student. In these interviews we informed the interviewees just a little about our product to ensure open feedback and asked what types of requirements they were looking for in a phone case that provides extra energy. We found that most people are looking for a lightweight and efficient charging case for their phone. In addition to that, people wanted the case not to be too bulky so that it was not a burden to fit into a pocket or use. The least of their worries were the intuitiveness, range of compatibility with different phone models, and ergonomics. In our outside market research we found that 58 percent of Americans own a smartphone. (Mobile Technology Fact Sheet) On top of that, 75 percent of smartphone owners use a protective case on their phones. Furthermore, 49.2 percent of Americans ranging from age 6 to older, participated in outdoor activities in 2013. Taking these figures into account for solely the outdoors consumer group, at most 21.4 percent of outdoors people would think about using our case on their phones.

6.6.2 Marketing Strategy

Our market strategy is to sell our product through outdoor retail stores such as REI, Cabelas, and Bass Pro. Stores such as these promote an active lifestyle which is our biggest market to capture. We will also advertise our case by attending outdoors and sporting events. This will gain our popularity among our targeted consumers. Once we gain attention and demand in our target outdoors market we can move onto other retail stores for mass marketing of our case. In addition to selling in retail stores we would create a website to reach our customers through an e-commerce business. This way we advertise through the internet and consumers can buy and see our product without having to go to the store.

6.6.3 Sales

In terms of putting a face to our product, we will hire representatives to publicize our product at social events such as local concerts, festivals, outdoor events, and sporting events to get our brand and product well known. At first we will give out a couple free cases so that hype can build and our product can be recognized. Once our product has reached a certain peak and is well known these representatives will turn into vendors seeking out retail stores to sell our product. Our sales team will largely contribute to growing the company and advertising to the public.

6.7 Manufacturing and Costs

The Manual Charging Phone Case consists of several subsystems that make up the case as a whole. These subsystems include the case housing, power generation, gear train, and circuitry. We plan to manufacture our case housing by injection molding polycarbonate plastic pieces. Our generator is outsourced from a retailer, Hobby King, who creates highly efficient electric generators. For our gear train, it will be made out of light-weight aluminum and custom manufactured to fit our case. The circuit contained in our case will also be outsourced by a custom circuit manufacturer.

For the first prototyping stage we plan to produce 1000 cases. Once all of our parts have been delivered, the prototyping will start with assembly by hand. The three of us owners will hand assemble the first prototypes. With all the pieces in inventory the time to assemble one case will be 15min. This means that between the three of us we will be able to assemble 1000 cases in about 2 weeks. Once we reach some profit we will be able to hire assembly workers to assembly the cases. Then further into the future once we have sold tens of thousands of cases we will look into research and development of our own motors and improving on the design and optimization for our specific use.

With production of our first prototypes the cost of manufacturing will be high. We predict a cost of around $35 dollars a unit including shipping. This means to startup our business it will cost us around $40,000. This is due to not being able to manufacture items such as our generator, gears, circuits, and injection molded case in bulk amounts. The first prototypes will be sold at $50 a unit to the consumer. With a retailer taking 10% of the sale we produce a profit margin of 20%. As we further perfect and optimize our design we can plan to produce a higher volume of our cases. Once we can order in bulk from our manufacturers we predict the cost of production to significantly decrease to around $15 a unit.

6.8 Service and Warranty

We have run finite element analysis on our case to ensure that it will endure the abuse of everyday use and drops from both the hip and head. We are confident with our product that it will last a year in the consumer's hands therefore we do not anticipate for a high rate of returns. This is why we provide a one year warranty protecting the case internals provided that it is not abused beyond everyday normal use. We will replace any broken cases within the warranty free of charge with exchange of the broken case. After the warranty is expired we will still replace the case at a reduced fee to the original price. We do this because anything else in the case that is not broken is still valuable to us; whether that be the gears, generator, circuit, or housing. The cost of replacement beyond warranty is $15 not including shipping and handling.

6.9 Financial Plan

Our biggest key driver for the Manual Charging Phone Case is our high gross margins and return on investment. In the prototype stage if we sell all of our 1000 prototypes we will have a gross margin of 20% and a return on investment of 42%. Our high return on investment in these first stages is due to the three of us doing all of the work and not paying for a huge facility or employees. We will limit our assets and work between the three of us to cut business costs. Looking further down the road, in a couple of years when we are mass producing our case and the cost of production is lowered to $15 a case, we will be producing a gross margin of 70% percent. By this time we will have a warehouse for delivery, assembly, storage, shipment, and service. After paying for rent, employees, packaging, equipment, supplies, advertising and promotion, utilities and all of our assets our return on investment will be around 25%.

7. Engineering Standards and Realistic Constraints

7.1 Team and Organizational Ethics

To work in an ethically effective team environment the team must have a good dynamic of communication and work collaboration. Our team has committed to work ethically with each other by agreeing to meet each week at a designated time that works for everyone's schedule, including our advisor. We ensure full respect and ethical collaboration in meetings between team members by upholding Santa Clara’s ASG Code of Ethics and Values. Instilling these guidelines and values into our team work provides a true procedure to work ethically among our team members and as students of Santa Clara University. These values involve:

- Incorporating fair collaboration by reserving judgment of others until all relevant information has been accessed.
- Adapting your communication style to the situation at hand.
- Seeking integrity in work and taking ownership of results and decisions made by that work.
- Strive to reach a consensus that the whole team can agree on.
- Treat all viewpoints with respect, even if you do not personally agree with them.
- Prepare for meetings by reading the respected materials and showing up on time.
- Actively participating and using responsive communication in meetings.

By following these rules we can ensure that our team is acting ethically within our team and as members of Santa Clara University. Our team strives to provide a fair product. That means if at any point we cannot ensure the integrity or fair compensation for our product we will no longer be involved in the research of the project. This way we can be certain that our product does not fall into any category of destructive or unjust technology.

7.2 Social Ethics

Our team stands behind our research and product, ensuring the integrity of our calculations and work. The people that buy our product will be certain that the product is ethically fair. Our product does not involve the use of data, confidential information, user responsibility with said data or confidential information, or anything that could potentially cause concern for the user by using the product. Our social ethics involvement mainly comes from the concern of pollution and fair trade. Has the product been manufactured in an environmentally safe manner and was it in a fairly compensated transaction?

These ethical obligations for our team take precedence over legal freedoms in the development of our product. Potentially, we could obtain a manufacturer that charges much less because they pay their workers unfairly. Furthermore, that manufacturer could be producing these materials in a harmful manner to the environment and legally it would be ok. However, our team has taken the values of fair trading and providing an environmentally safe product to our customers into the design of our product. This way we can ensure users that our product has reduced the effect of pollution and unfair compensation within product design.

7.3 Product Development Ethics

Our product, along with its research, development, and manufacturing must be done ethically. The focus on ethics must begin from the project's inception: research. Research is a concept rarely associated with ethics, especially for a product of our type. In the area of research, the most important aspects from the perspective of ethics are knowledge, truth, and avoidance of error. Examples of this are prohibitions against fabricating, falsifying, or misrepresenting research data. We must hold ethical norms to ensure that we are held accountable to the public. To ensure that the data is not altered in any way, we must take ownership of our findings and associate them to our group or personal name. Additionally, we are accountable to the public to provide truthful data so they are not fooled into purchasing or endorsing our product falsely.

To ensure our research and development is ethical, we must specify our guidelines for research morality. First, we must show complete transparency in our research and findings. We are willing to share all our findings and methods truthfully, whether positive or negative for our final product. We also will show respect for the sources, locations, and equipment used to conduct our exploration. We will provide citations where data or data acquisition processes have been borrowed from others, along with the instruments used to gather our information. Similarly, it is important that our group strives to validate the credibility of our sources. The sources we base our findings on must have the support of a reliable group, company, journal, or university so that we can have confidence beyond the realm of our personal knowledge in our findings.

As we develop the product, we must be mindful of the amount of design iterations we implement. With more steps, more money and material is needed. If we are able to minimize the number of prototypes we build, we will be more honest to our investors. We will maximize their investment, rather than wasting their money. Additionally, the reduction in material use has benefit to the environment. Less material will be needed to take from the world around us, strongly benefitting nature.

8. Conclusions

The project has proven to be a success at its completion. A successful housing, power generation system, and gear train were produced and assembled into a prototype. Each subsystem, and the system as a whole, met the goals that our group put in place from the outset of our project. The housing was proven to not fail under expected impacts, through multiple finite element analyses, with a maximum deflection of 1.15 millimeters when dropped on its corner from a height of 2 meters. Diagrams of this can be found in *Appendices 6.6* through *6.11*. The power generation system is able to produce ample voltage as can be seen in *Appendices 6.1* through *6.5*. The desired voltage was 2 volts and the final outrunner power generation system in combination with a gear train is able to produce that. The gear train's five spur gears are able to produce a 1:48 gear ratio in the small space of 9 mm x 4 mm x 1 mm. As a complete system, the fixtures and fittings are all correct and the system works as designed. Furthermore, the case fits an iPhone 5 perfectly, adhering to Apple's design drawings with precision. The complete size and weight of the system also is within the desired range of our expected customers, as deciphered by surveys of this group. During the project, group dynamics proved to be an important a critical and successful factor to completion. The group worked in a professional and dynamic way to succeed and develop for group work in the future. The project's cost remained low in all areas and adhered to the budget. Moreover, the cost per prototype, and expected mass production cost landed in the desirable range, with the cost per prototype at $35 and mass-manufacturing cost per unit at $15. This enables the product to be sold at a highly competitive price. To conclude, despite many obstacles, the Induction Phone Charger Case proved to be a success in all areas.

9. Appendix

Appendix 1: Bibliography

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Appendix 2: Calculations

Appendix 2.1: Design Calculations

Based on a final input speed of 4320 @ generator shaft

$$\frac{\text{RPM}}{kv} = V_e$$

<u>2100kv</u>

$$\frac{4320\ rpm}{2100\ rpm/V} = 2.06\ V$$

<u>1700kv</u>

$$\frac{4320\ rpm}{1700\ rpm/V} = 2.54\ V$$

<u>1200kv</u>

$$\frac{4320\ rpm}{1200\ rpm/V} = 3.6\ V$$

Appendix 2.2: Efficiency Calculations

$$\frac{Actual}{Theoretical} = \eta\ (Efficiency)$$

<u>2100kv @ 600 RPM</u>

$$\frac{.27}{.2857} = 0.945$$

<u>1700kv @ 600 RPM</u>

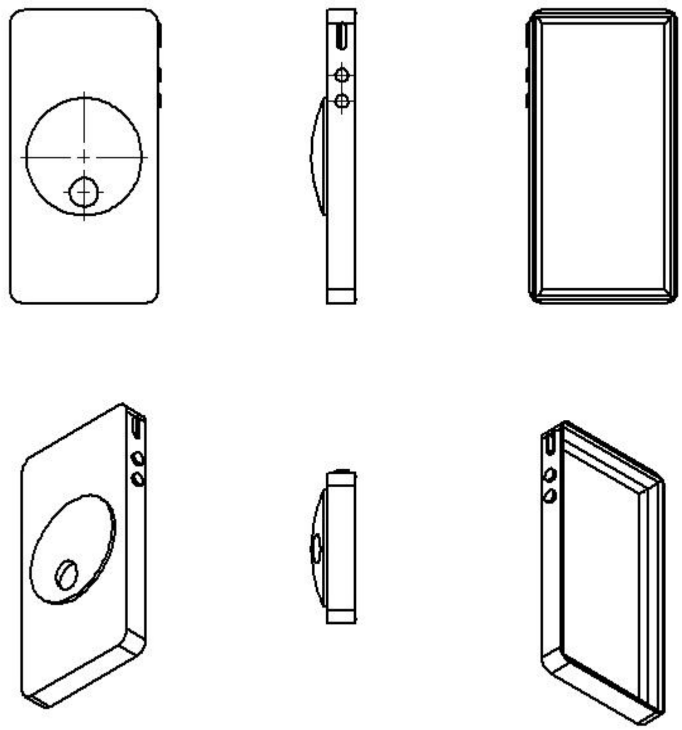
$$\frac{.30}{.353} = 0.850$$

<u>1200kv @ 600 RPM</u>

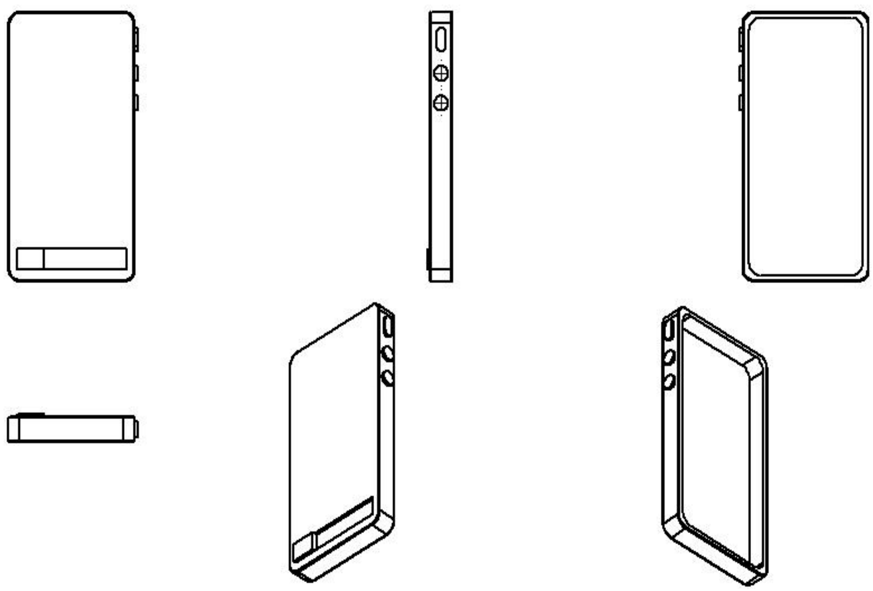
$$\frac{.45}{.5} = 0.9$$

Appendix 3: Design Sketches & Detail Design Drawings

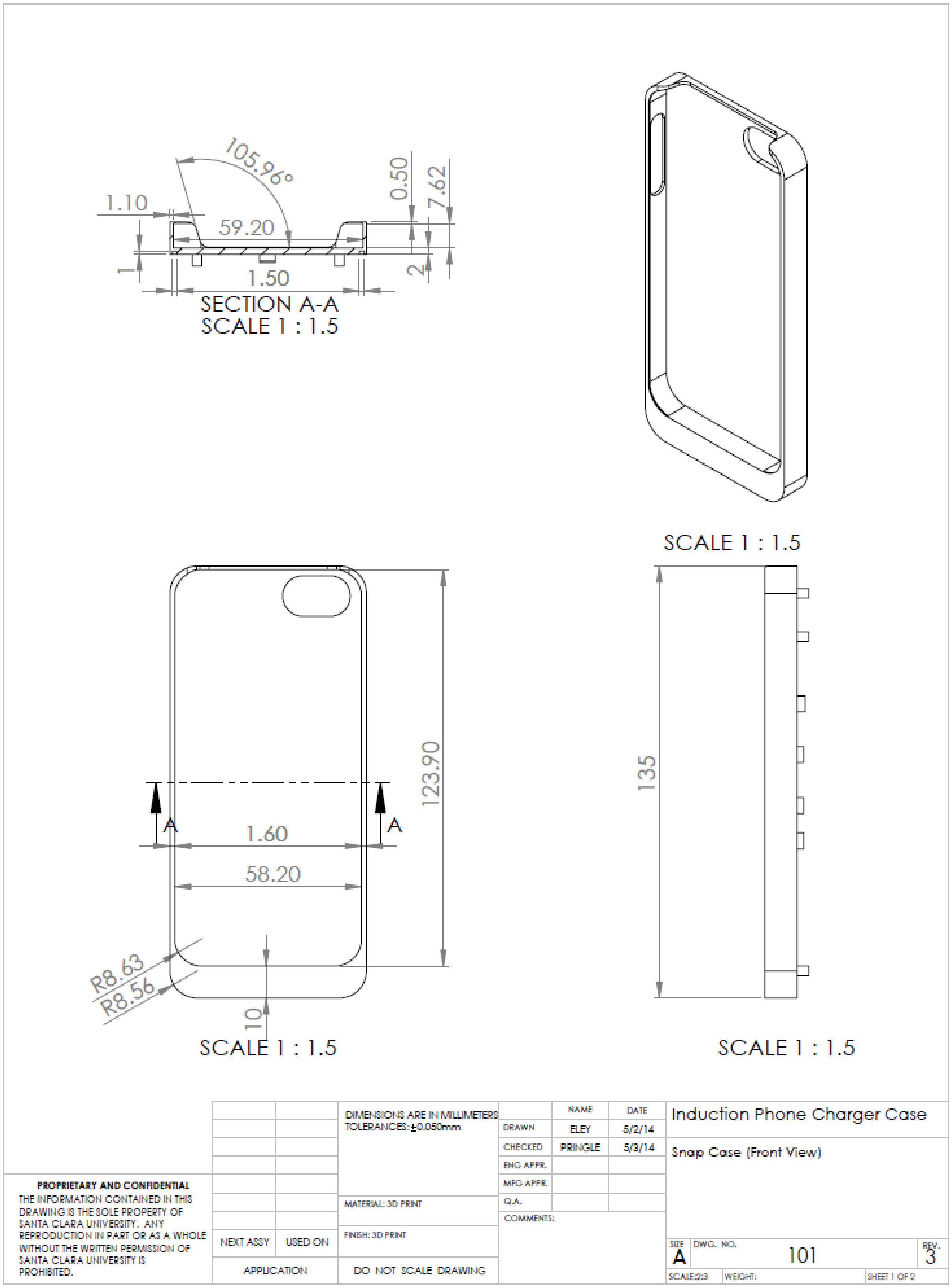
Appendix 3.1: Drawings of a conceptual rotary magnet setup



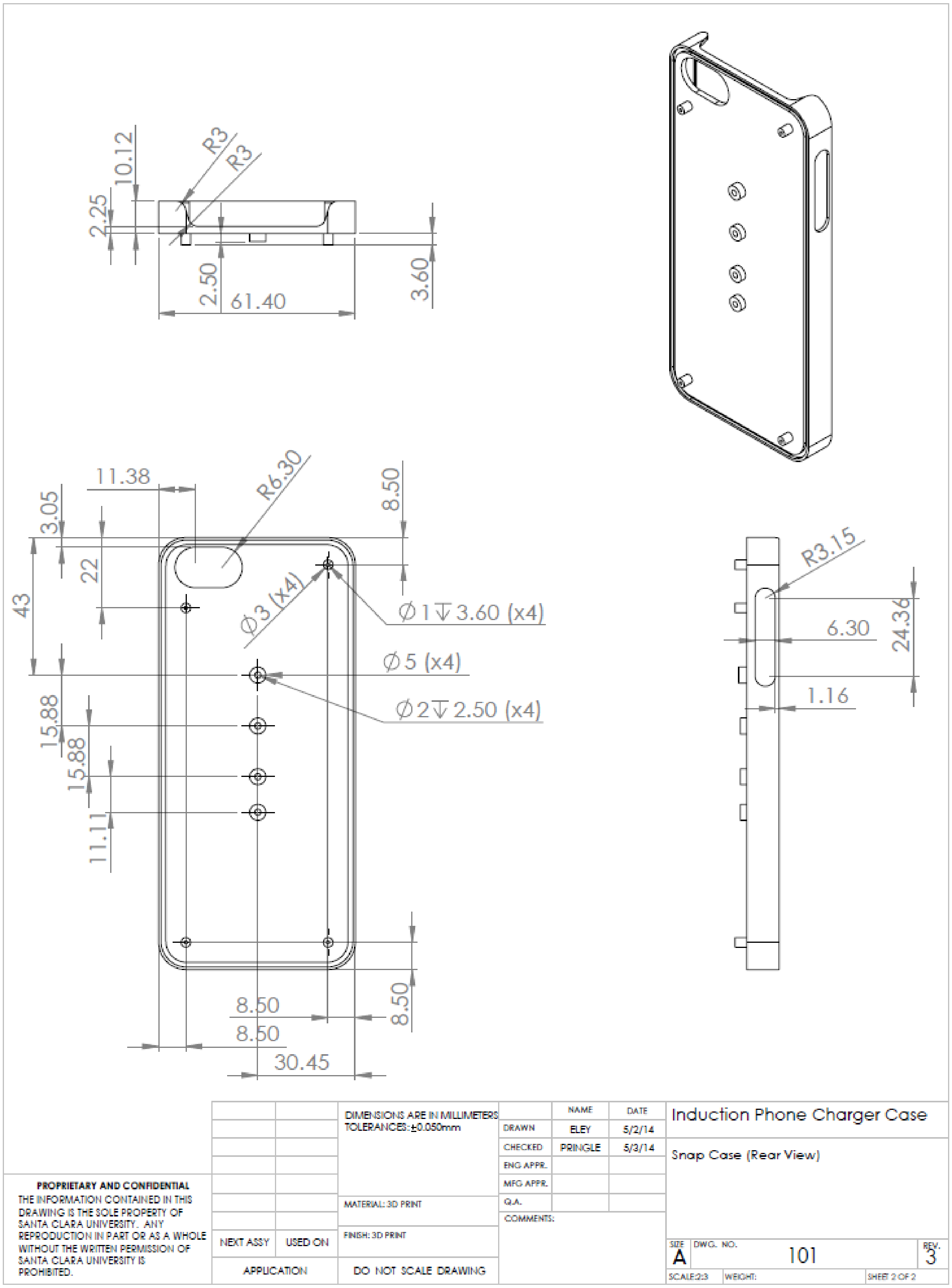
Appendix 3.2: Drawings of a conceptual slider magnet setup



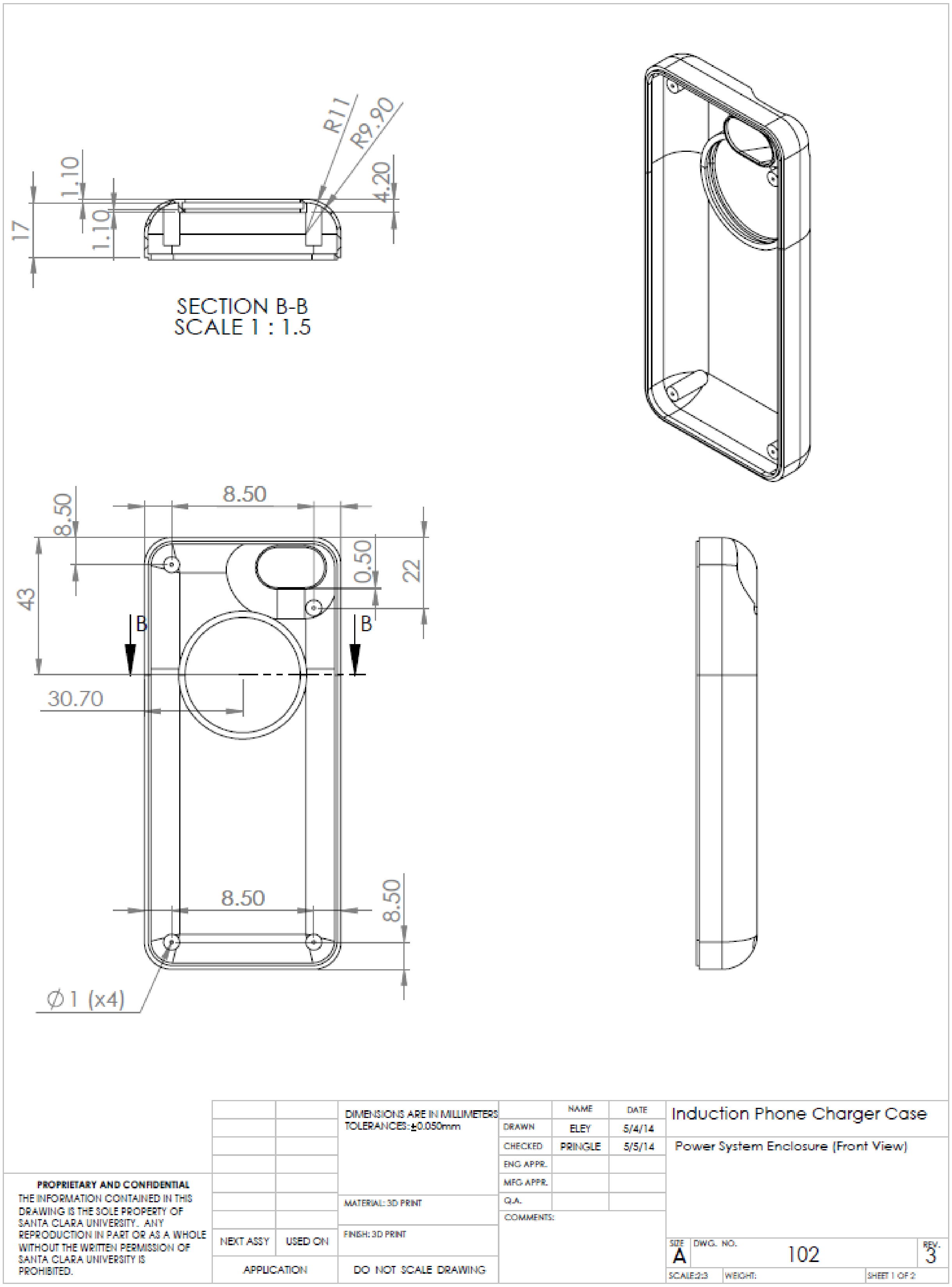
Appendix 3.3: Snap Case Drawings (Front View)



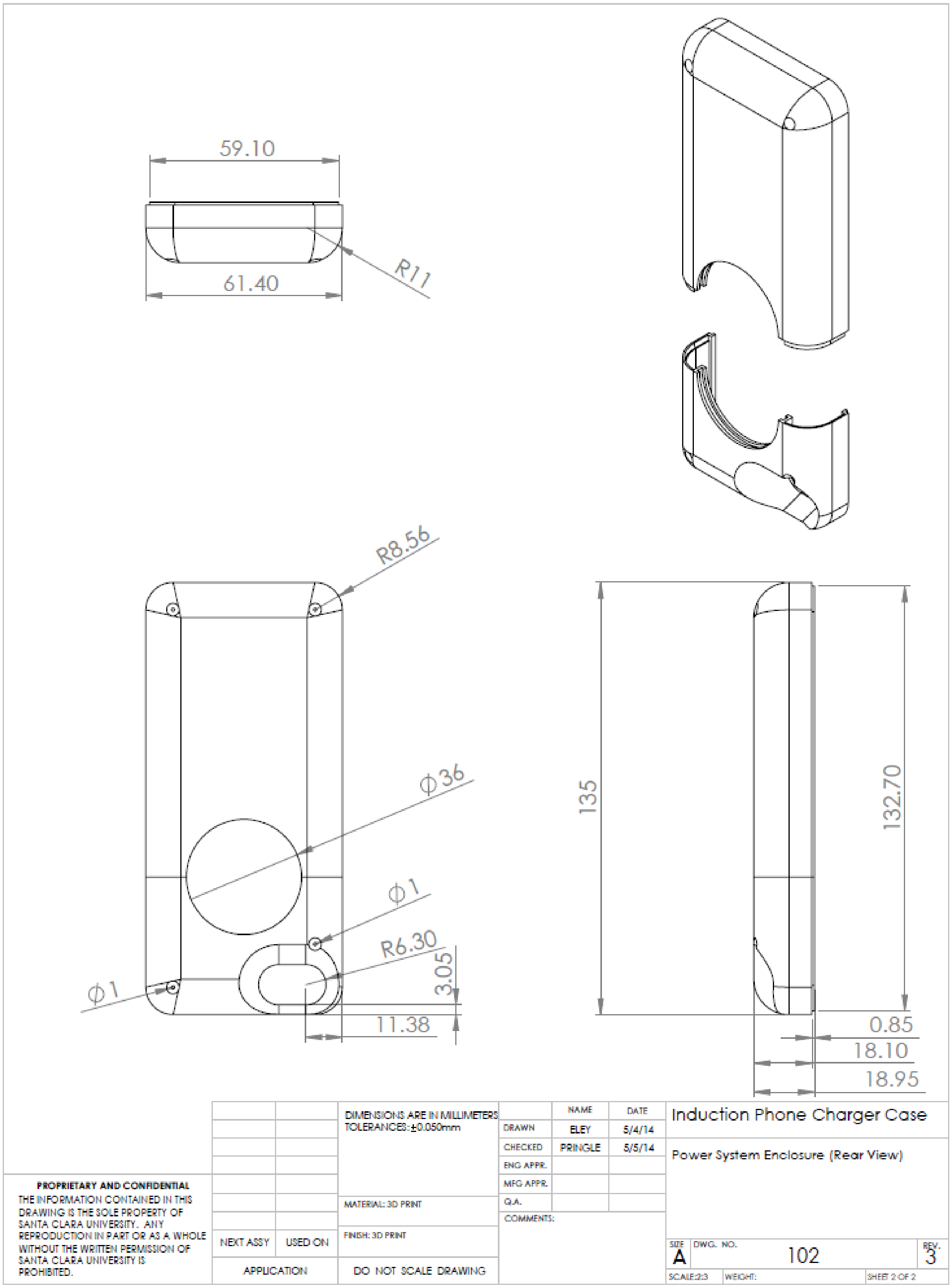
Appendix 3.4: Snap Case Drawings (Rear View)



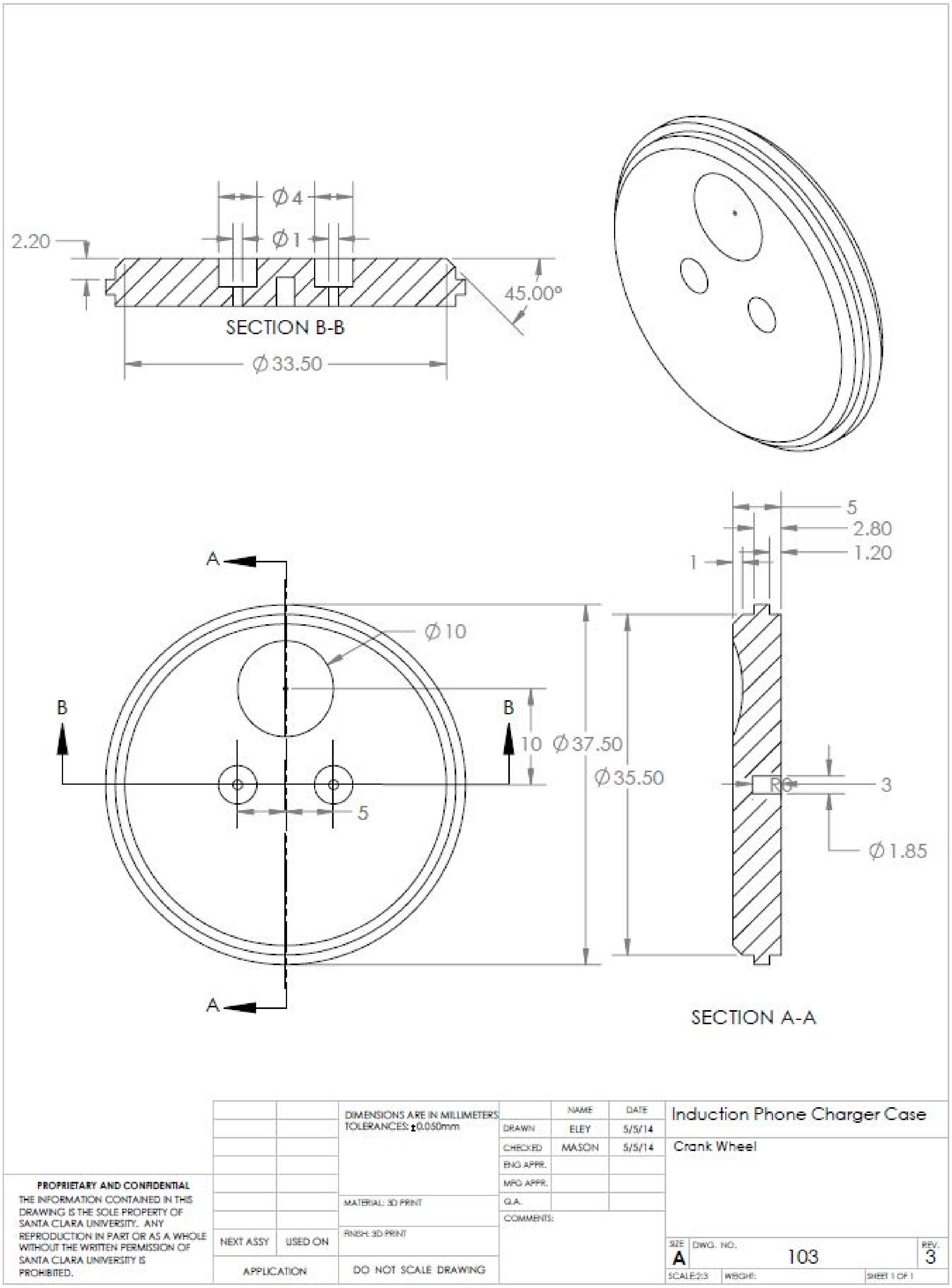
Appendix 3.5: Power Enclosure Drawings (Front View)



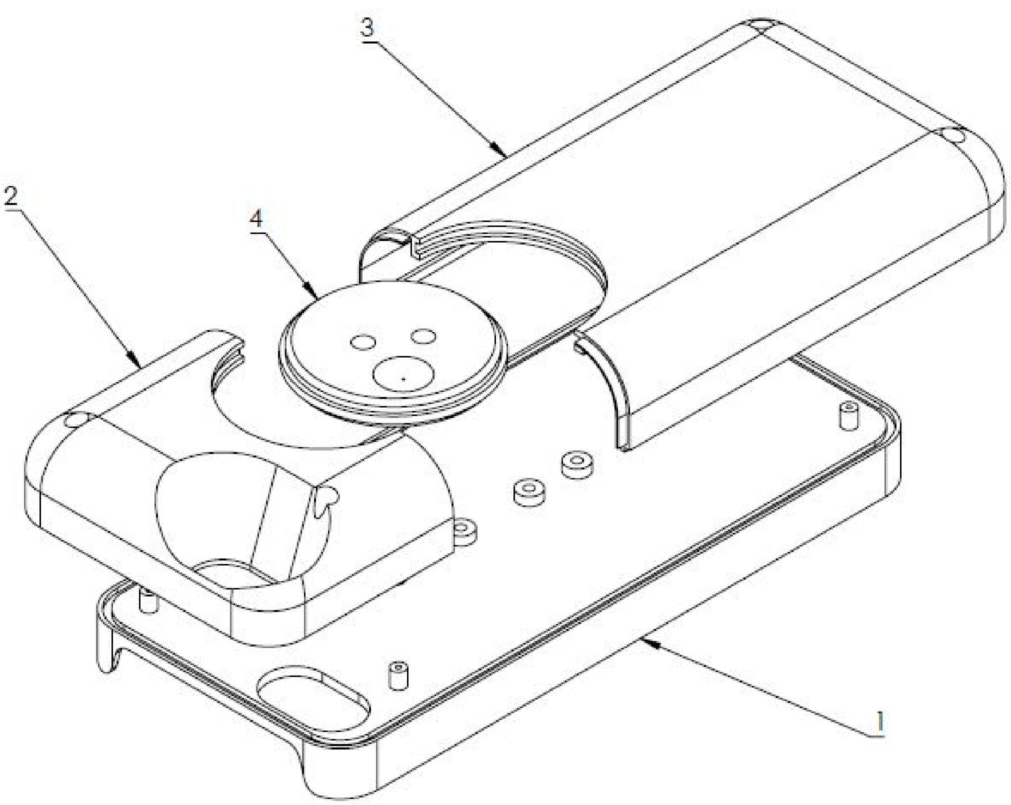
Appendix 3.6: Power Enclosure Drawings (Rear View)



Appendix 3.7: Crank Wheel Drawings



Appendix 3.8: Detail Assembly Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	101	Snap Case	1
2	102	Power Housing Upper	1
3	103	Power Housing Lower	1
4	104	Crank Wheel	1

PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY | USED ON

APPLICATION

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: ±0.050mm

MATERIAL: 3D PRINT

FINISH: 3D PRINT

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ELEY	5/7/14
CHECKED	MASON	5/7/14
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Induction Phone Charger Case

SIZE A | DWG. NO. | REV. 3

SCALE:2:3 | WEIGHT: | SHEET 1 OF 1

Appendix 4: Product Design Definitions

Appendix 4.1: Product Benchmark comparisons

Characteristic/ Parameter	Parameter Units	Design Criticality	Design Target	Mophie Juice Pack	myCharge Freedom 2000	Solio Bolt Charger/Battery
Size	inches	High	2.45in x 5.15in x 0.60in	2.49in x 5.49in x 0.59in	2.5in x 5.2in x 0.60in	3.5in x 3.5in x 1.0in
Mass	ounces	High	3.5 oz	2.44 oz - 3.14 oz	3 oz	5.3 oz
Power Output	watts	High	0.5 W - 1 W	~ 5 W	5 W max	5 W max
Strength/Durability (Drop Test)	feet	Medium	6' - 8'	-	-	-
Ergonomics		TBD	-	-	-	-
Shelf Life/Time Constraint	hours	Low	Indefinite	~ 270 hrs	~ 300 hrs	Daylight
Cost	dollars	Low	$20.00	~ $20-$30	~ $25	~ $25
Price	dollars	Low	$40.00	$79.95 - $119.95	$79.99	$70.00

Appendix 4.2: Needs Metric Matrix

Needs Metrics Matrix	Sustainability (kWh)	Weight (oz/gram)	Size (cm^3)	Time to Use (sec)	Energy Production (kWh)	Drop Height Before Break (m)	Product Materials Dollars/oz/gram)
Light enough to be carried for extended individuals		x					x
Small enough to be carried for extended distances			x				
Cost effective for average phone							
Intuitive to use				x			
Durable enough to withstand wear and tear						x	x
Can be operated with limited dexterity			x				
Provides enough energy to fulfill need	x				x		
Can withstand harsh climates and conditions							x

Appendix 4.3: Customer Needs Interview Feedback

Older Outdoorsman (Mark Pringle)

- Uses phone 4-6 hours a day
- Aesthetic appeal very important
- Ergonomics less important but the case must function correctly
- Wants a case that can provide some protection(scratches) , but not bullet proof
- Engages in surfing, hiking, skiing, sailing, backpacking, flying, and biking
- Phone runs out of power 2+ times a week
- Lightweight is most critical aspect
- Not very thick but provides some protection
- Some type of waterproofing for the case would be nice

Young Outdoorsman, Andrew Noonan

- Uses phone 6+
- Engages in hiking, back packing, camping, rock climbing, kayaking, and many other outdoor activities.
- Must provide enough energy to charge while on outdoor trips
- Lightweight so to not add any weight to travel packs
- Must be able to withstand the elements and everyday use(weather, drops, falls, scratches)
- Easy to use/doesnt take a long time
- Phone runs out of power 2+ a week
- Sealed so that the phone itself does not get dirty (dust/dirt resistant)

· Aesthetically appealing is not too concerning

<u>Responses from 1st Lt. Pascual Eley, USMC</u>

How many hours a day do you actively use your phone?

<2 hours 2 hours – 4 hours **<u>4 hours – 6 hours</u>** >6 hours

How important is the aesthetic appeal of your phone case?

1 2 **<u>3</u>** 4 5

How important are the ergonomics of your phone case?

1 2 3 **<u>4</u>** 5

What degree of protection do you expect from your phone case?

Looks cool, doesn't do much

Protects the back from scratches and the screen from most contact

Impact and scratch resistant (I should be able to drop it 6 feet without consequence)

<u>Bulletproof. And waterproof. And fireproof. Just make it everything proof.</u>

How often does your phone run out of power on the go?

Every day

<u>2+ times a week</u>

Once a week

Once a month

What kind of outdoor activities do you engage in? (If any)

Frequently outdoors - in the field

Hiking, running, biking, working out

What are the most important selling points for a phone case that you would buy?

Protection of the phone

Reduced weight

Slim design

Appendix 4.4: Summary Table of Survey Information

System Requirements	Mark Pringle	Pascual Eley	Andrew Noonan
Lightweight	1	4	3
Slim	3	5	2
Efficient	2	1	1
Intuitive	6	9	7
Weather Resistant	10	7	6
Cost	9	3	5
Aesthetics	4	8	9
Ergonomic	7	2	8
Noise	5	6	10
Compatibility	8	10	4

Appendix 5: Timeline of Work & Final Budget

Appendix 5.1: Timeline of Work

Fall Quarter:

Week 1: Form and organize team

Week 2: Project proposal

Week 3: Project concept brainstorming and form and begin work on preliminary design report

Week 4: Preliminary Design Review Presentation and Paper

Week 5: Team dynamics reflective essay

Week 6: Complete solidworks modeling of initial prototype

Week 7: Customer needs report

Week 8: Begin conceptual design report and complete draft

Week 9: Build mock up and edit conceptual design report

Week 10: Design presentation and slides

Finals: Edit and complete design notebook, layout drawings, design portfolio binder, and team member evaluations

Winter Quarter:

Weeks 1-4: Detailed design and construction of test rigs and prototypes

Weeks 5-10: Testing and initial fabrication/iterations

Spring Quarter:

Weeks 1-5: Continue testing, finalize iterations

Weeks 6-10: Completion of testing, final iterations, completion of thesis and final design report

Appendix 5.2: Final Budget

Final Budget

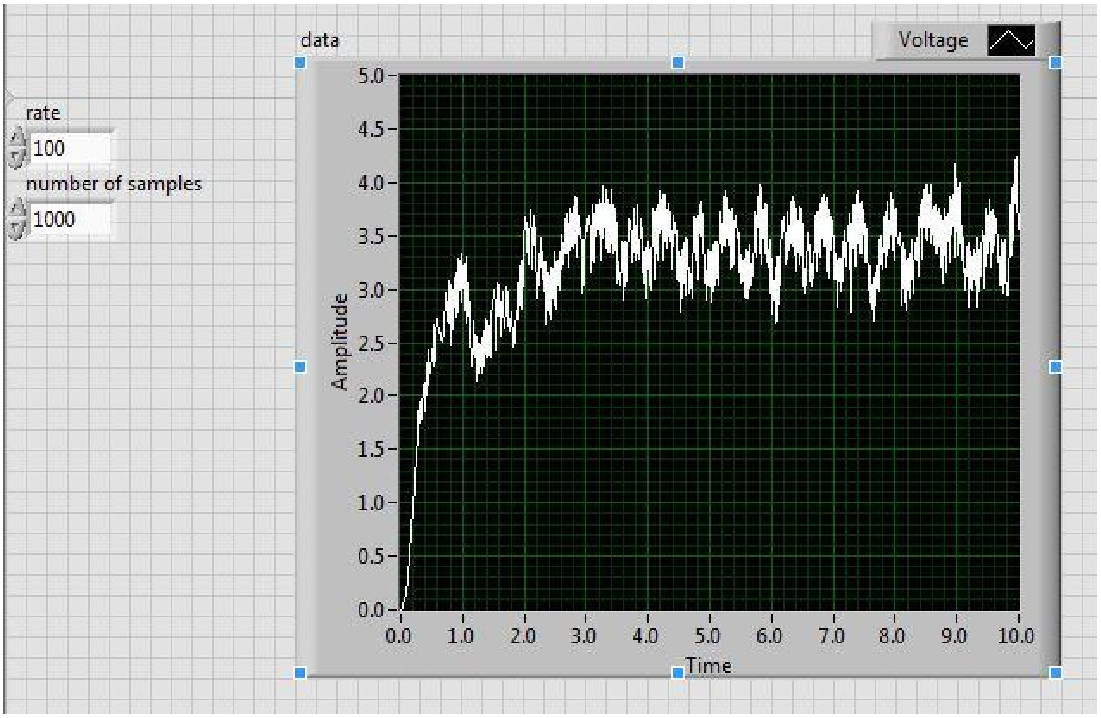
TEAM	Induction Phone Charger Case
Date	20-May-14

INCOME					
Category	**Source**	**Sought**	**Committed**	**Pending**	
Grant	School of Engineering	$ 500.00	$ 500.00		
					any pending funding
	TOTAL	**$ 500.00**	$ 500.00	$ -	$ 500.00

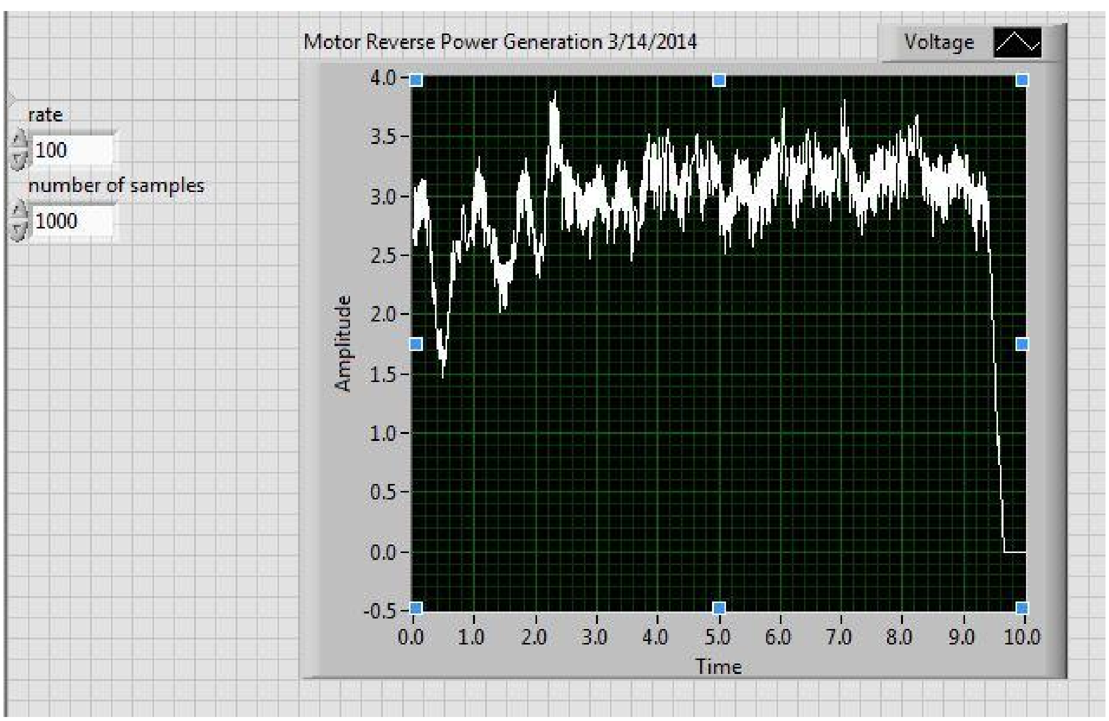
EXPENSES					
Category	**Description**	**Estimated**	**Spent**	**Pending**	
Housing	3-D Main Housing	$ 60.00	$ -		
	3-D Disk	$ 30.00	$ -		
	Axles	$ 12.00	$ 6.39		
	Rubber Lining	$ 30.00	$ -		
Power Generation	Magnet	$ 120.00	$ 35.00		
	Copper Wire (Coil)	$ 30.00	$ 21.19		
	Gearing	$ 34.00	$ 40.71		
	Misc	$ 40.00	$ 73.35		
Power Transfer	Assorted Wiring	$ 10.00	$ -		
	Power Adapter	$ 22.00	$ 14.16		
	Capacitor	$ 9.00	$ -		
Testing	Wood	$ 25.00	$ -		
	Misc Fasteners	$ 20.00	$ -		
	Misc Wiring/Parts	$ 40.00	$ 19.53		
	TOTAL	**$ 482.00**	$ 210.33	$ -	$ 210.33
	Net Reserve (Deficit)		$ 289.67	$ -	$ 289.67

Appendix 6: Experimental Data

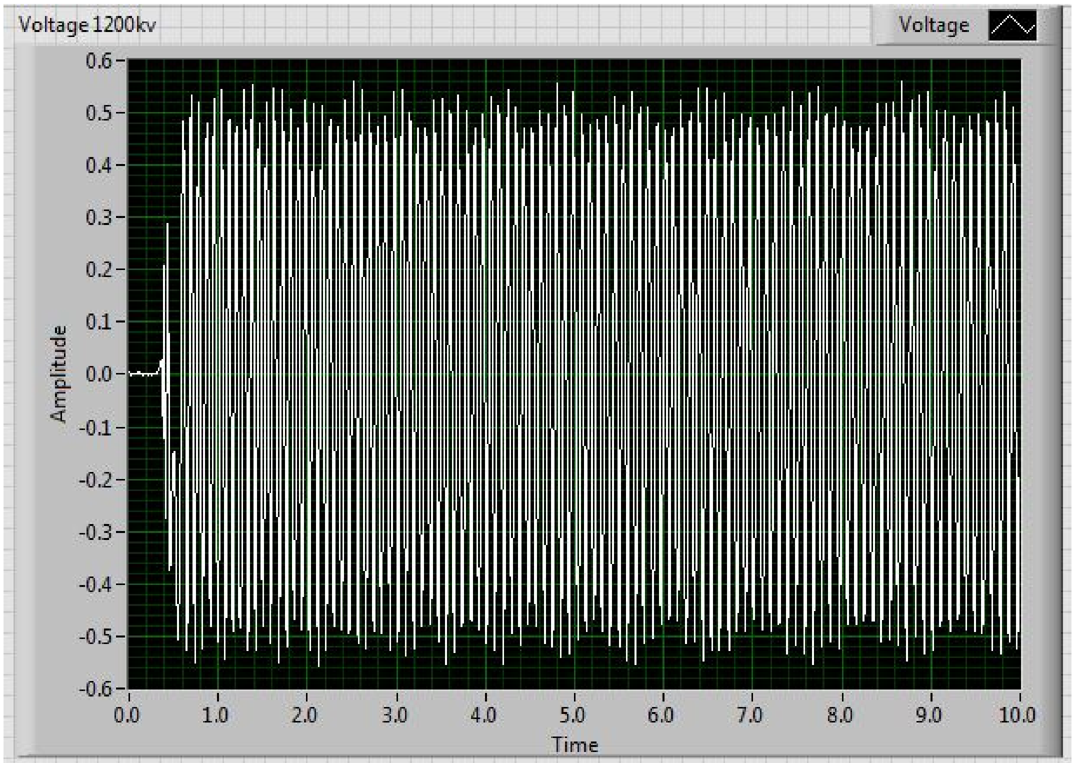
Appendix 6.1: 60 RPM through factory gearbox to store-bought hobby motor



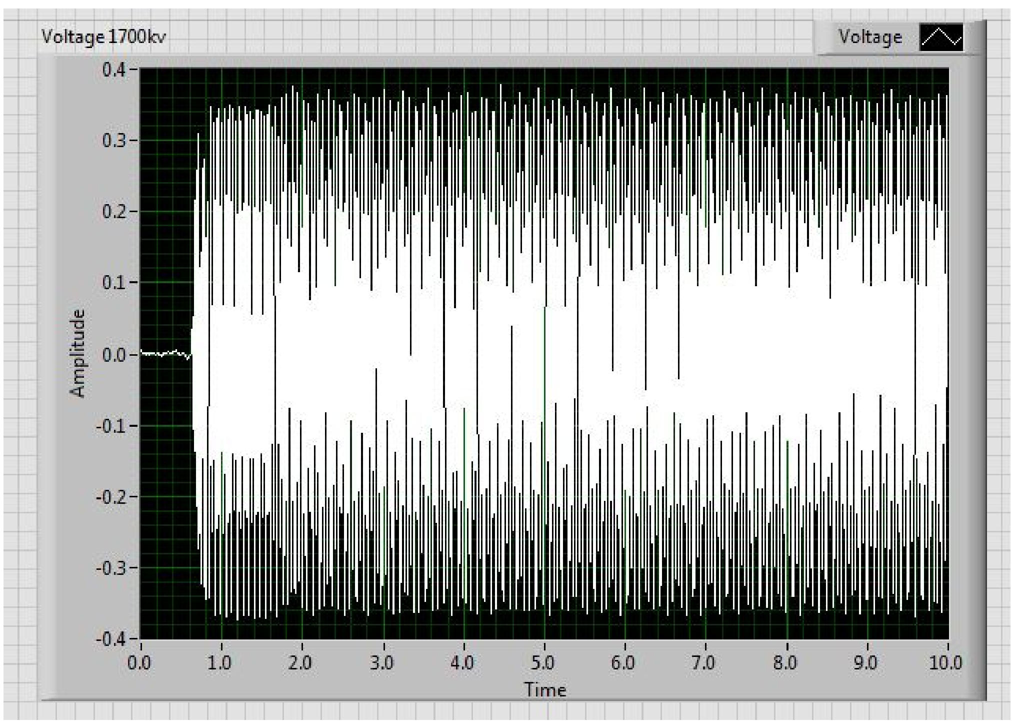
Appendix 6.2: 60 RPM through factory gearbox to second store-bought hobby motor



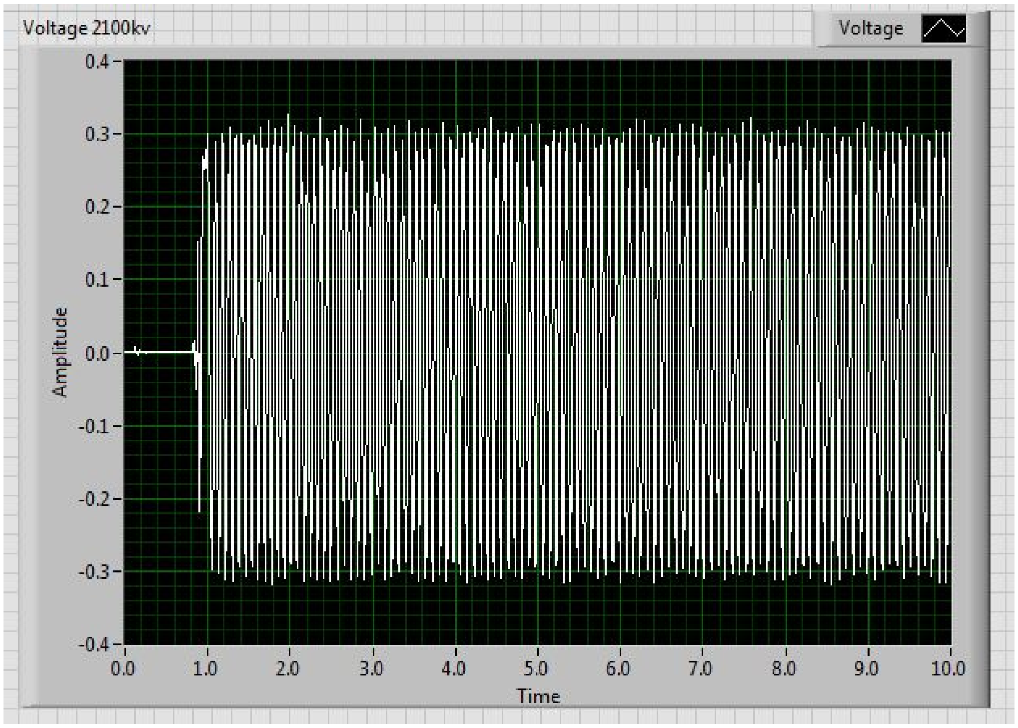
Appendix 6.3: 600 RPM directly to output shaft of 1200kv outrunner



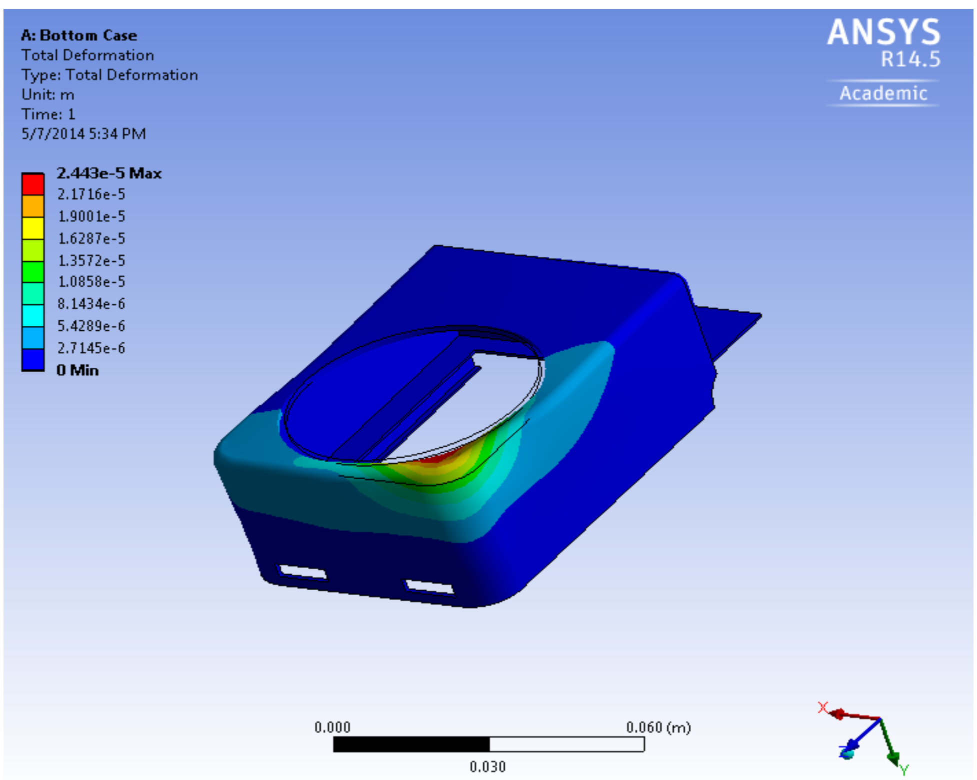
Appendix 6.4: 600 RPM directly to output shaft of 1700kv outrunner



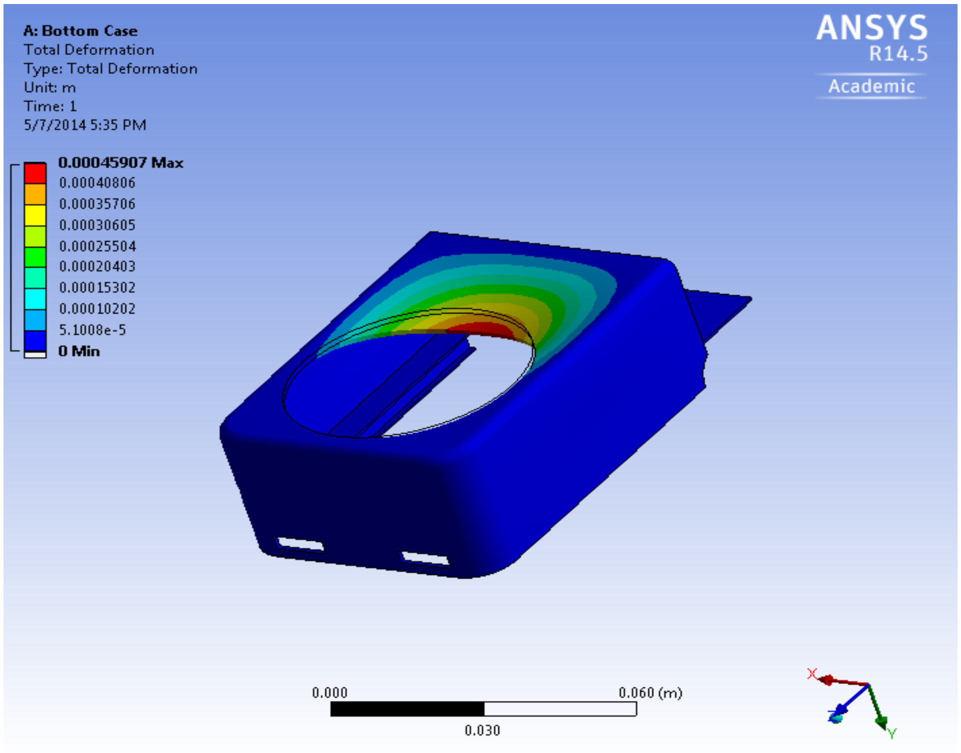
Appendix 6.5: 600 RMP directly to output shaft of 2100kv outrunner



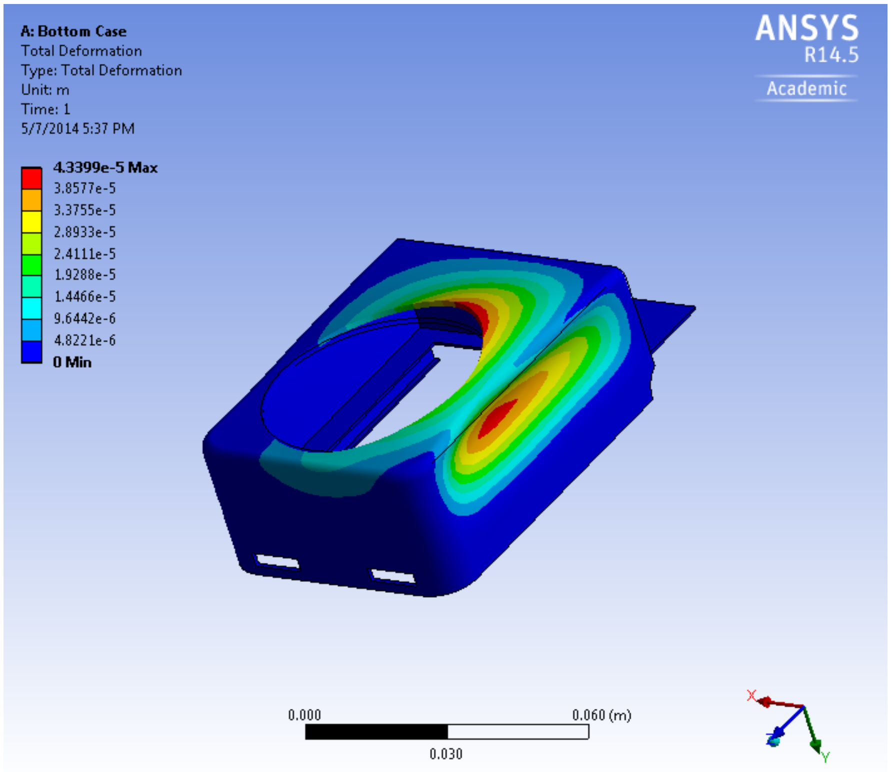
Appendix 6.6: FEA Deformation for Corner Impact (Rev 1)



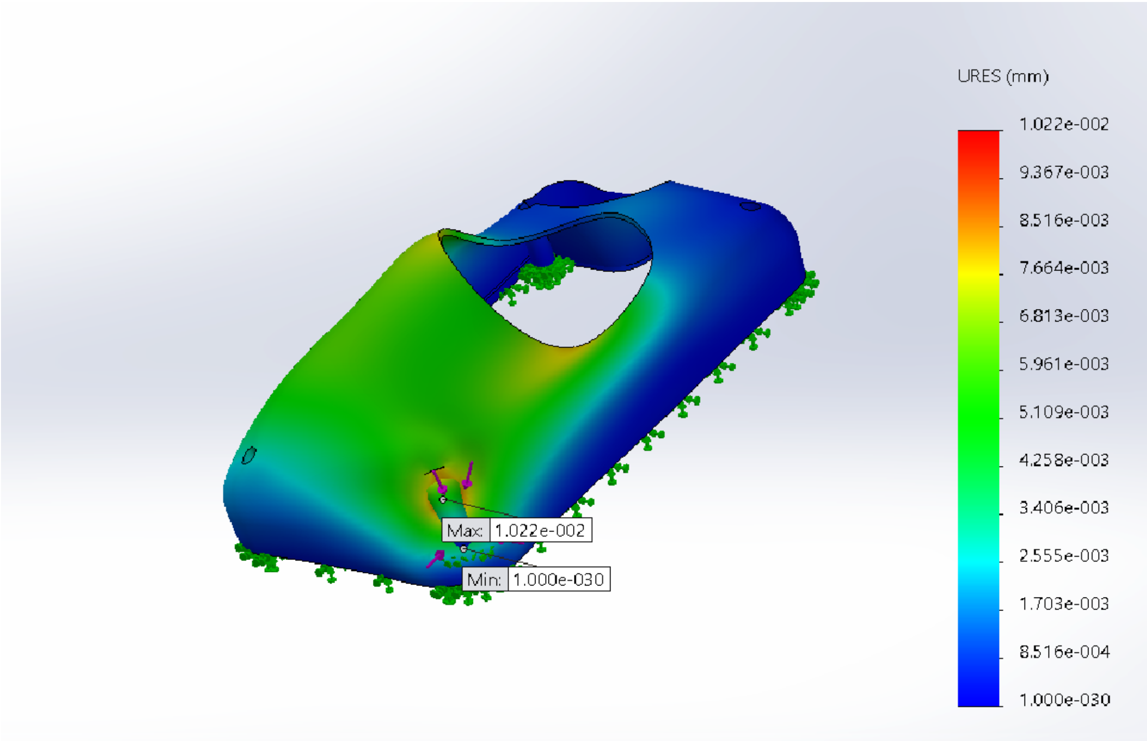
Appendix 6.7: FEA Deformation for Back Impact (Rev 1)



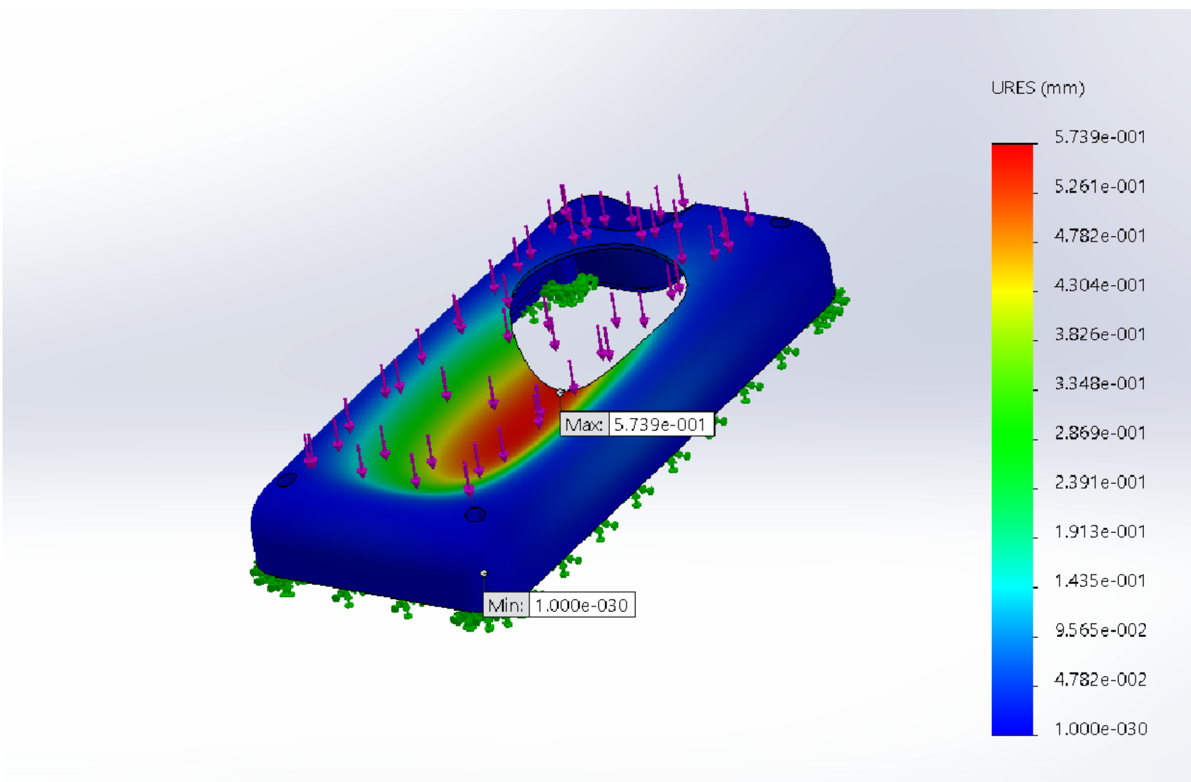
Appendix 6.8: FEA Deformation for Side Impact (Rev 1)



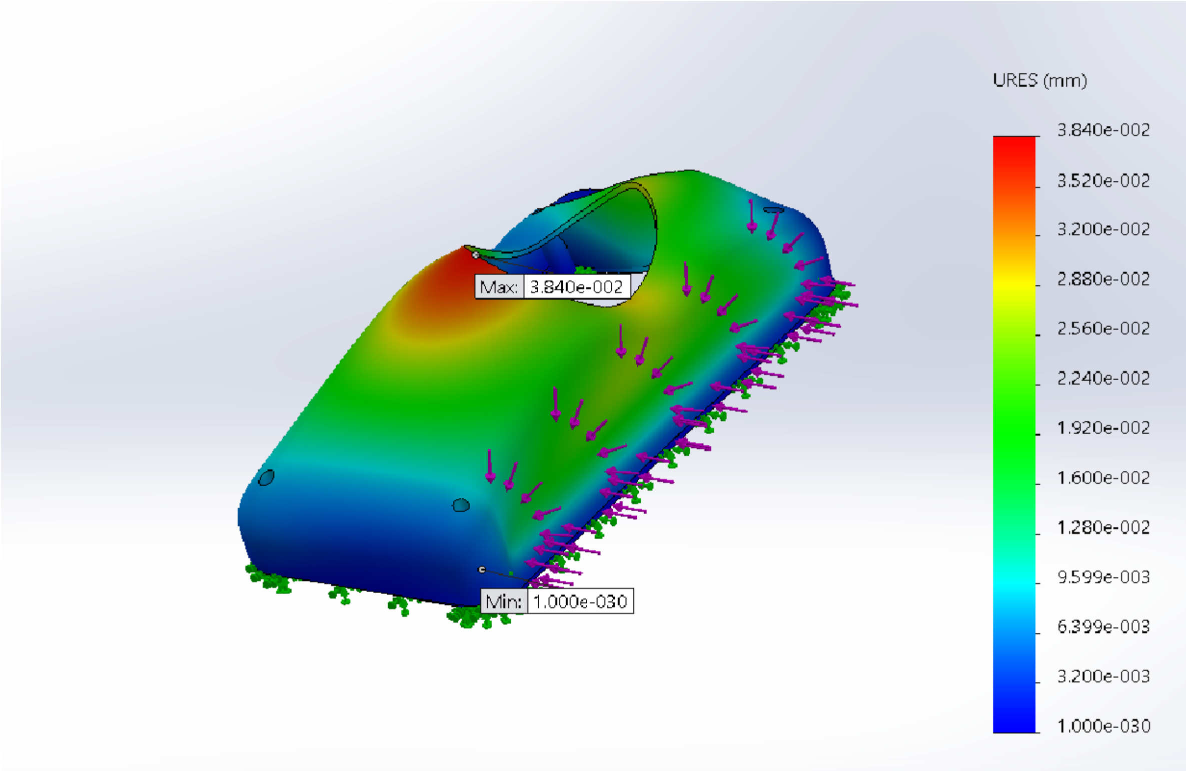
Appendix 6.9: FEA Deformation for Corner Impact (Rev 3)



Appendix 6.10: FEA Deformation for Back Impact (Rev 3)



Appendix 6.11: FEA Deformation for Side Impact (Rev 3)



Appendix 7: Conference Presentation Materials

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Manual Charging Phone Case

Dante Eley
B.S. Mechanical Engineering
Nikko Mason
B.S. Mechanical Engineering
Cameron Pringle
B.S. Mechanical Engineering

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Introduction and Goals

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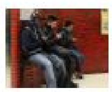
Our Project

The Idea Sources



- Information and data usage
- Everything is on your phone
- Batteries cannot last a full day on one charge
- There is a need to charge ones phone at anytime

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Problem Statement

- Cellular phones have limited power, and in today's society of increased mobile device usage extra battery life is becoming more and more valuable. Our goal is to develop a simple and cost effective phone case with an integrated mechanical charging device.

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Motivation

Why we chose this project

- Current options for extended battery life are bulky, expensive, and require an outlet
- Strong need for a product that provides power when a plug is not readily available
- Opportunity to exercise engineering and design prowess that is highly applicable to the field

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Benchmarks

What is currently out there

- Mophie Case
  - Case with additional rechargeable battery
- Flashlight/Radio Crank Chargers
  - Case with additional rechargeable battery
- Solio Bolt Charger
  - Independent hardware using photovoltaic cells to provide power
- Infinity Cell
  - Phone case that utilizes kinetic energy from the users movement to charge a phone

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Target Consumer Groups

Who the product is built for

- Outdoors-people
  - Limited access to power when far from civilization
  - Desire: Protection for phone, emergency power
- Commuters and businesspeople
  - On the move/travelling and high phone use
  - Desire: Lightweight and efficient
- People who reside in high risk regions
  - In a disaster with a loss of power phone functionality is critical
  - Desire: Protection and reliability

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Goals

- Design and implement a phone case that can charge a smartphone with a mechanical input
- Provide peace of mind to consumers knowing that their phone will have an independent and reliable source of power in all situations
- Design a durable case that will protect a phone and the internals of the system
- Aesthetically pleasing and ergonomic case

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System Overview

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System Components

The constituents of our device

- Electromechanical system that combines a multitude of electrical and mechanical components
  - Mechanical:
    - Housings
    - Fittings
    - Gears
    - Joints
    - Manufacturing Process
  - Electrical:
    - Induction generator
    - Circuit board
    - Phone connection

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System Function

How it works

- Housing
  - 3D printed plastic case that provides protection and anchoring for internal components
- Power generation
  - Outrunner generator system spun at maximum achievable velocity from a user input using gearing system
  - Circuit designed to allow user to rotate input drive in either direction and provide proper amount of current/voltage to each of phones input terminals

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Complete System Model

Revision 1 – Sizing Prototype

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Complete System Model

Revision 2 – Sizing Prototype

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Complete System Model

Revision 3 – Final System

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Housing

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Housing

Critical system for appearance and protection

- Challenges and solutions
  - Must combine size, weight and durability
    - Material choice: Polycarbonate
    - Design to have varying thickness – reduce in areas of where minimal stress will be applied to reduce weight
  - Impact Protection
    - Design to distribute stress as effectively at all points of impact
    - Reduce sharp edges and line with rubber to reduce shock on phone

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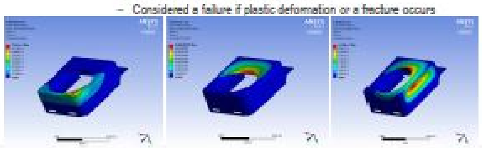
Housing

Finite Element Analysis Rev 1

- Drop Test Simulation
  - Drops from 1m and 2m (pocket and ear)
  - Considered a failure if plastic deformation or a fracture occurs



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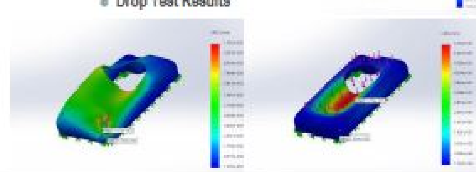
Housing

Finite Element Analysis Rev 3

- Drop Test Results



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Housing

Finite Element Analysis Comparison

-	Drop Test From 1 meter		Drop Test From 2 meters	
-	Design Iteration 1	Design Iteration 2	Design Iteration 1	Design Iteration 2
Corner Deformation [m]	2.44E -2 [mm]	1.02E -2 [mm]	4.89E -2 [mm]	2.64E -2 [mm]
Side Deformation [m]	4.38E -2 [mm]	3.88E -2 [mm]	8.68E -2 [mm]	7.68E -2 [mm]
Back Deformation [m]	4.39E -1 [mm]	9.78E -1 [mm]	9.18E -1 [mm]	1.15 [mm]

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Power Generation

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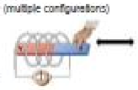
Power Generation

Generates power to charge phone's battery

- Challenges and possible solutions
  - Choose and design the optimal generator
    - Electromagnetic induction generator (multiple configurations)
    - Solar
    - Piezoelectric
  - Size reduction
    - Balance power production and size
    - Multiple induction configurations
      Spinning disk, sliding bar, magnet in tube



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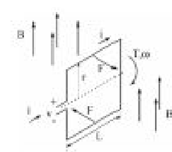
Power Generation

Faraday's Law – How it works

- Coil of wire in the presence of a magnetic field
- Change the magnetic field
  - Strength of magnet
  - Moving towards and away from
  - Rotating the coil or magnet
- Induces a voltage in the coil

$$\text{Voltage generated} = -N\frac{\Delta(BA)}{\Delta t}$$

Faraday's Law



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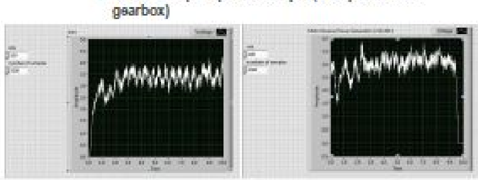
Power Generation

Voltage Generation Test 1

- Constant input speed of 60rpm (1:87 purchased gearbox)



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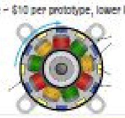
Power Generation

Outrunner generator

- 2100kv outrunner motor
  - Motor qualities
    - Three phase
    - High torque – high amperage produced
    - Low price – $10 per prototype, lower in mass production



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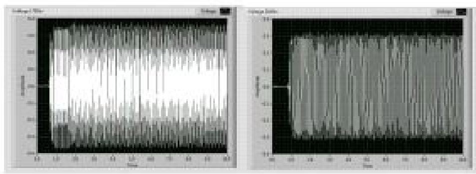
Power Generation

Voltage Generation Test 2

- Motors spun at 600 rpm



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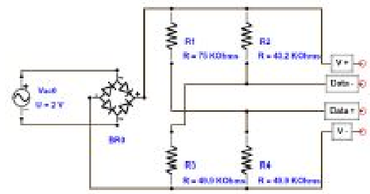
Power Generation

Circuit configuration



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Gears

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Gears

Maximize user's input to create maximum rotational speed of generator (1:48 ratio)

- Challenges and Solutions
  - Design gear configuration with maximum output radial velocity
    - Planetary vs. spur – complex spur design
  - Noise reduction
    - Material selection (plastic vs. metal) – metal
  - Size reduction
    - Minimum gear thickness
    - Case location and complex configuration

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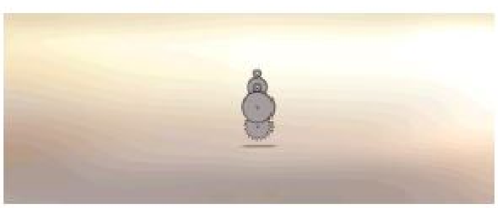
Gears

Final design animation



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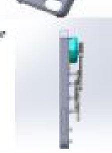
Next Steps

- Print final housing
  - Add lightning adapter
  - Proper fixtures for gears and motor
  - Reduced thickness
- Final assembly
- Full system testing



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The End

Questions?