



Pedal Phone Charger Final Report



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Table of Contents

List of Figures	3
List of Tables	4
List of Nomenclature	5
Executive Summary	6
Chapter 1: Introduction	7
Customer Background and Needs	7
Problem Definition	7
Objective/Specification Development	8
Project Management Plan	8
Chapter 2: Background	10
Existing Products	10
Current State of the Art Technology	12
Specific Technical Data	13
List of Applicable Standards	13
Chapter 3: Design Development	14
Discussion of Conceptual Designs	14
Concept Selection	20
Supporting Preliminary Analysis	21
Proof of Concept Analysis and Testing	22
Chapter 4: Final Design	24
Solid Model	25
Detailed Design Description	25
Analysis Results	28
Cost Analysis	32
Material, Geometry, Component Selection	32
Wiring Diagrams	33
Safety Considerations	34
Maintenance and Repair Considerations	34
Chapter 5: Product Realization	35
Manufacturing Processes	35
Future Manufacturing Considerations	40
Chapter 6: Design Verification	41
Test Descriptions	41
Design Verification	43
Chapter 7: Conclusion and Recommendations	47
APPENDIX	49
Appendix A: Decision Matrix and Quality Function Deployment Diagram	50
Appendix B: SolidWorks Drawings	52
Appendix C: List of Vendors, Contact Information Pricing	55
Appendix D: Vendor supplied data sheets	66
Appendix E: Detailed Supporting Analysis	67
Appendix F: EES Code for Shaft Sizing	76
Appendix G: Gantt Chart	80

List of Figures

Figure 1: The American Red Cross MICROLINK FR160 by Eton	10
Figure 2: The Trademark Deluxe Solar Power Charger Bag Cell Phone from Kmart	11
Figure 3: The Revolve Electronics xeMicro Hybrid USB Charger and Battery Backup also from Kmart.....	11
Figure 4: YoGen MAX foot powered charger (concept)	12
Figure 5: First-generation "squeeze phone" hand-squeeze-powered generator	14
Figure 6: Improved squeeze phone model	15
Figure 7: Ergonomics study on the original squeeze phone design	16
Figure 8: Concept sketch showing the first developments in harnessing foot power	17
Figure 9: Subsequent foot-powered design, inspired by bicycle riding	18
Figure 10: A concept sketch by Anthony that was popular with communities in India	19
Figure 11: Treadle power is a common and historically effective method of turning foot motion into rotation for machinery	20
Figure 12: Drill motor from DeWalt drill.....	22
Figure 13: Set-up of drill motor in drill press	22
Figure 14: Set-up of small wind generator in drill press prior to testing	23
Figure 15: Adapter machined to hold stator in lathe	24
Figure 16: Set-up for stator and rotor testing in lathe	24
Figure 17: Detailed SolidWorks Model	25
Figure 18: Maximum stresses in the connector link	29
Figure 19: Maximum stresses in the crank and crank shaft	30
Figure 20: Maximum stresses in the pedal reinforcement.....	31
Figure 21: Alternator, Bridge Rectifier, LM317T, Cell phone load	34
Figure 22: Using the spade bit to manufacture counterbore holes	35
Figure 23: Turning the rotor adapter	36
Figure 24: Pouring the concrete in the flywheel mold	37
Figure 25: Grinding the links	38
Figure 26: Final Assembly	38
Figure 27: Assembling the housing	39
Figure 28: Team SolNAK after testing.....	39
Figure 29: The voltage output test setup	44
Figure 30: Foot force test setup	45
Figure 31: Proof of concept test setup	46
Figure 32: Quality Function Deployment Diagram (QFD)	51
Figure 33: Vendor Drawing Sheet for 72 tooth sprocket from McMaster-Carr.....	66
Figure 34: Vendor Drawing Sheet for 14 tooth sprocket from McMaster-Carr.....	66
Figure 35: Gantt Chart created in Microsoft Project	80

List of Tables

Table 1: Design results, after FE analysis was performed on the model.	28
Table 2: Test description and Requirement Summary Table.....	41
Table 3: Test results summary table.....	43
Table 4: Summary of trial run results for foot force required test	45
Table 5: Decision Matrix	50
Table 6: Complete Bill of Materials	65

List of Nomenclature

AC - Alternating current, characterized by a sinusoidal change in voltage. AC voltages are expressed in RMS values.

DC - Direct current: the type of power that electronics and batteries use to function. Provides a steady voltage.

QFD - Quality Function Deployment: a method for determining driving design factors

Rotor - Also referred to as a flywheel on most two-wheeled vehicles. This device includes magnets and is designed to be placed on the main crankshaft of a motorcycle or scooter to provide power for its electrical systems.

Stator - the *static* component of the motorcycle generator: this consists of groups of coils that face the inside of the rotor. Magnets passing over the coils produces AC power.

USB - Universal Serial Bus: an emerging standard for cell phone power charging and connectivity. USB power is generally 5VDC and 0.5A.

Executive Summary

The pedal powered phone charger was developed as a joint mechanical-electrical engineering senior project.

The device design was conceived to meet the energy needs of rural populations in India. These communities have cell phones but lack access to reliable grid power, especially during monsoon season. The charger is designed to be affordable, durable, and easily repairable for each owner family. It uses off-the-shelf components and is intended to be replicated by backyard manufacturing startups in developing countries.

Its purpose is to efficiently transfer human foot motion via a treadle, four-bar-linkage, and sprocket-chain step-up to drive a rotor & stator generator from a common gas scooter. The single-phase alternating current from the generator is passed into an electrical circuit to be rectified and stepped up to the necessary voltage for charging a phone by USB power.

Preliminary research and testing indicates that USB chargers tend to be rated to deliver 5V of potential and 550 mA-1A of current. Initial testing of the scooter generator gave 4.5V and 1A at 450 RPM; charging cell phones at relatively low speeds is within the capabilities of the generator. The linkage and drivetrain have been designed such that 120 RPM input (a comfortable brisk pedal rate) shall yield 600 RPM at the second shaft. 600 RPM at the rotor excites the stator coils sufficiently, producing enough power to charge a cellphone.

Testing results of the charger show that it met all design requirements and it is capable of charging a cellphone easily under human power alone. Further work with the electrical system is needed to integrate a battery and solar panel into the project. Nevertheless, the mechanical aspects of this project were completed to the satisfaction of the team.

Chapter 1: Introduction

Customer Background and Needs

Cell phones play a significant role in village life in India, much as they do in fast-paced western lifestyles. People use these phones to connect across vast distances in hilly terrain that would otherwise be expensive and timely to traverse. Indian brides leave their home village upon marriage and can only hope to see their family only every few years. Aside from voice calls, cell phones provide the evening entertainment consisting of videos and games on their small screens. And during travel, whether it is walking or on a bus, young Indians of all walks of life love to blast the latest Bollywood beats on their phone's loudspeakers. Phones are easily more important than many other possessions in Indian villages because of the wide range of purposes they serve.

Background research started with a look into the customer, who lives in the rural communities of India. 70 percent of India's 1.15 billion inhabitants live in rural villages across India. While these people often work long hours farming and live in cramped, poor conditions, almost every household owns at least one cell phone. Many communities only have access to electricity for a few hours a day, and often the power can be cut during the evening when families are spending time at home together. The frequency of power cuts increases during monsoon as storms wreak havoc on rickety power lines. The only way to avoid power outages is for villagers to purchase costly battery backup inverter systems costing upwards. To charge their phones during power outages, villagers are forced to congregate at those houses owning inverters in the hopes that the owners there will share their battery backup.

Problem Definition

The goal of this project was to design and build a human and solar powered cell phone charger for rural communities in India. Most of rural India does not have access to reliable electricity, yet cell phones play a very significant role in daily life: they provide communication, entertainment, and even social status. It is critical for villagers to have their phones working even when the power is not.

The group for this interdisciplinary project was a team of mechanical and electrical engineering undergraduate students. All students working on this project were also fulfilling their senior project requirement for undergraduate degree. The project integrated both mechanical and electrical systems to provide reliable and convenient charging for these cell phones. This project allowed both disciplines of engineering student to work with technologies that they had

not previously covered in their academic courses and learn to integrate them into a unique system design.

The project was also a way for Cal Poly students to use their engineering abilities to help people from around the world. With the success of this project, designs of this cell phone charger could be used for other applications as well, such as in disaster relief kits or in other countries where such technologies are emerging.

Objective/Specification Development

The formal list of objectives and specifications was developed throughout Fall Quarter. Both Nicole and Krista did extensive research of the rural Indian population, in addition to electrical requirements, human factors and small solar systems. Meanwhile, Anthony spent the quarter in India doing field research, talking to local villagers in rural areas and to manufacturers in Delhi. The desired objectives of the customer were formed mostly from Anthony's field research, while the list of specifications was formed based off of Nicole and Krista's data collection. Once the list was completed, the team developed a Quality Function Deployment diagram that integrated the desired objectives of the customer and the specifications (please see Appendix A for complete QFD). The QFD showed the relationship between the objectives and the specifications, and which particular objective or specification was more critical.

Project Management Plan

The responsibilities of each team member were assigned by individual skill and location at the time. The role titles that each member had were as follows:

Krista Schmidt, Mechanical Engineering Department—Team Coordinator

Nicole Hensley, Mechanical Engineering Department—Cost Account Manager

Anthony Ruh, Mechanical Engineering Department—Lead Manufacturer

Joe Garcia, Electrical Engineering Department—Electrical and Photovoltaic Systems

Krista, as team coordinator, was the team member mostly in charge of documentation of project progress. With a team of four, she has a more managerial role in that she ensured that all four team members worked together to test and build the design. She monitored the team's progress with respect to deliverables, making sure the team stayed on schedule. She also aided Nicole and Anthony with the analysis, the manufacturing, and the testing of the design.

Nicole, as cost account manager, was in charge of the materials and fabrication of the prototype. She worked to keep the team within budget as well as oversee the design of the prototype with the knowledge of cost and available parts. Nicole assisted Anthony and Krista with the analysis, actual manufacturing and testing of the prototype.

Anthony, as lead manufacturer, was responsible for working on the SolidWorks model of the design. Being the team member with the most experience working in the machine shop, he provided his expertise and guidance to Nicole and Krista in testing as well as manufacturing. He assisted Nicole and Krista with the mechanical analysis in addition to assisting Joe with researching the electrical systems.

Joe Garcia joined the team at the beginning of winter quarter 2012. Joe was in charge of the power system design and integration of the power system with the generator, as well as the size and housing requirements. Joe also helped with incorporating the photovoltaic system into the power system. He was in charge of the electrical systems as the rest of the team moved into the building and testing phase.

Chapter 2: Background

Existing Products

Many products exist that could potentially meet some of the needs of the customer. Many of the simple or low-cost renewable energy chargers either solar or human powered, not both, while the few that include both power sources are sophisticated and expensive. The project seeks to combine multiple energy sources in a single, affordable package.



Figure 1: The American Red Cross MICROLINK FR160 by Eton

The American Red Cross MICROLINK FR160 (see Figure 1) has both a small solar panel and a hand crank charger, but is far too complicated for the team's application. It has a radio, flashlight, earphone jacks, a back-up rechargeable battery and a USB phone-charging jack. It also retails for \$39.95 in the United States and is therefore more expensive than the rural customer would be able to afford without dedicated savings.



Figure 2: The Trademark Deluxe Solar Power Charger Bag Cell Phone from Kmart

The Trademark Deluxe Solar Power Charger Bag (see Figure 2) is by far the most economical renewable energy charger that was found, at \$10.99 from Kmart. It fits the idea of simple and affordable but it only runs on solar power, which is not acceptable for the customer. It also needs a specialty adapter for each type of phone it charges and does not come with all the types used in India.



Figure 3: The Revolve Electronics xeMicro Hybrid USB Charger and Battery Backup also from Kmart

The Revolve Electronics xeMicro Hybrid USB Charger (see Figure 3) is very simple and easy to use but only runs off of hand power. It is also very expensive at \$39.95 from Kmart.



Figure 4: YoGen MAX foot powered charger (concept)

The YoGen MAX pedal charger (see Figure 4) uses a treadle motion to charge a laptop or other device. YoGen was working on trying to keep the device low cost and release was scheduled for 2009. Research indicates that this product never came on the market and the company became insolvent.

Current alternate energy technology available to rural villagers is all solar-panel-based. Solar powered LED lights are a common sight in the villages. They come from non-governmental manufacturing organizations like Kavita Solar, D'Light, and Cosmos Ignite Innovations, which are all based in Delhi. These manufacturers also all provide lights that double as phone chargers. These chargers often start at Rs.1000 and can cost as much as Rs.1600 (~\$20-30). To put this into perspective, this could mean as much as a whole month's wages for a lower-caste family. Despite this, solar charging products sell well in rural areas. They often feature a combination adapter that can fit six common makes of phones. Their batteries are large enough to charge multiple phones, though they take all day to charge and require foresight to stay topped-up. Leaving these devices out in the village is also an invitation to have them stolen. Larger units often have a separate solar panel to increase the photovoltaic surface area. Until now, mechanical charging aids have not been successful in these markets because of their high cost, flimsiness, or difficulty of use.

Current State of the Art Technology

In terms of hardware, phones used in rural India are commonly older styles than those used in the United States. Most all have a candy-bar-style form factor characteristic of older Nokia models. Rural villagers do not use smartphones, though their cell phones are still quite

sophisticated. The phones are capable of delivering pictures, movies, and music to their users via color screens and loudspeakers. The leading cell provider in India is Airtel, followed by companies like Vodafone and Tata DoCoMo. The most popular phones in rural India are Nokia, Samsung and Sony Ericsson. Other, Taiwanese companies like G'Five and Lava produce similar phones at lower prices, and many are designed to accept Nokia chargers and batteries.

The goal of this project is to produce an extremely low-cost and durable phone charger that is powered by human foot power and serviceable within India with basic electrical and mechanical training. The internal mechanism is critical in reliably converting manual input into electrical power by passing magnets through coils of wire. Added pluses include the ability to function fully off one or more power sources, including solar, human, and hydroelectric input. Ideally a single user could operate the device while he or she is also using the phone with one hand.

Specific Technical Data

For the charger to operate on USB power and charge a cell phone there are several technical specifications that have to be met. The output to the phone must be 5 volt at 0.5 to 1 amperes. Therefore, the power required to charge the phone is equal to 2.5 to 5W. This must be constant DC power, as fluctuation or oscillation in the power signal will cause the phone to not charge properly.

List of Applicable Standards

Even though the team did extensive research, SolNAK was unable to find many applicable standards that exist for the device. This is mostly due to the fact that this type of mechanism does not exist. However, if this device were to go into production in India it would need to be certified safe by UL India Private Limited, a company affiliated with Underwriters Laboratories Inc. SolNAK seeks to design the pedal charger to UL standards so that very few modifications would have to be made to commercially produce the device.

Chapter 3: Design Development

Discussion of Conceptual Designs

The first quarter of senior project the team spent time doing background research and brainstorming concept ideas. The ideas sketched and described below are a culmination of the team's brainstorming efforts.

The first concept design and the basis of the project was a device from Anthony and Krista's Mechanical Engineering Design II project (see Figure 5). This device uses a squeeze motion to move a rack and pinion and produce power. The phone would be attached to the rack and pinion housing creating a very compact design. Solar panel would be located on the back of the mechanism housing to allow for charging when the device is not being charged by hand.

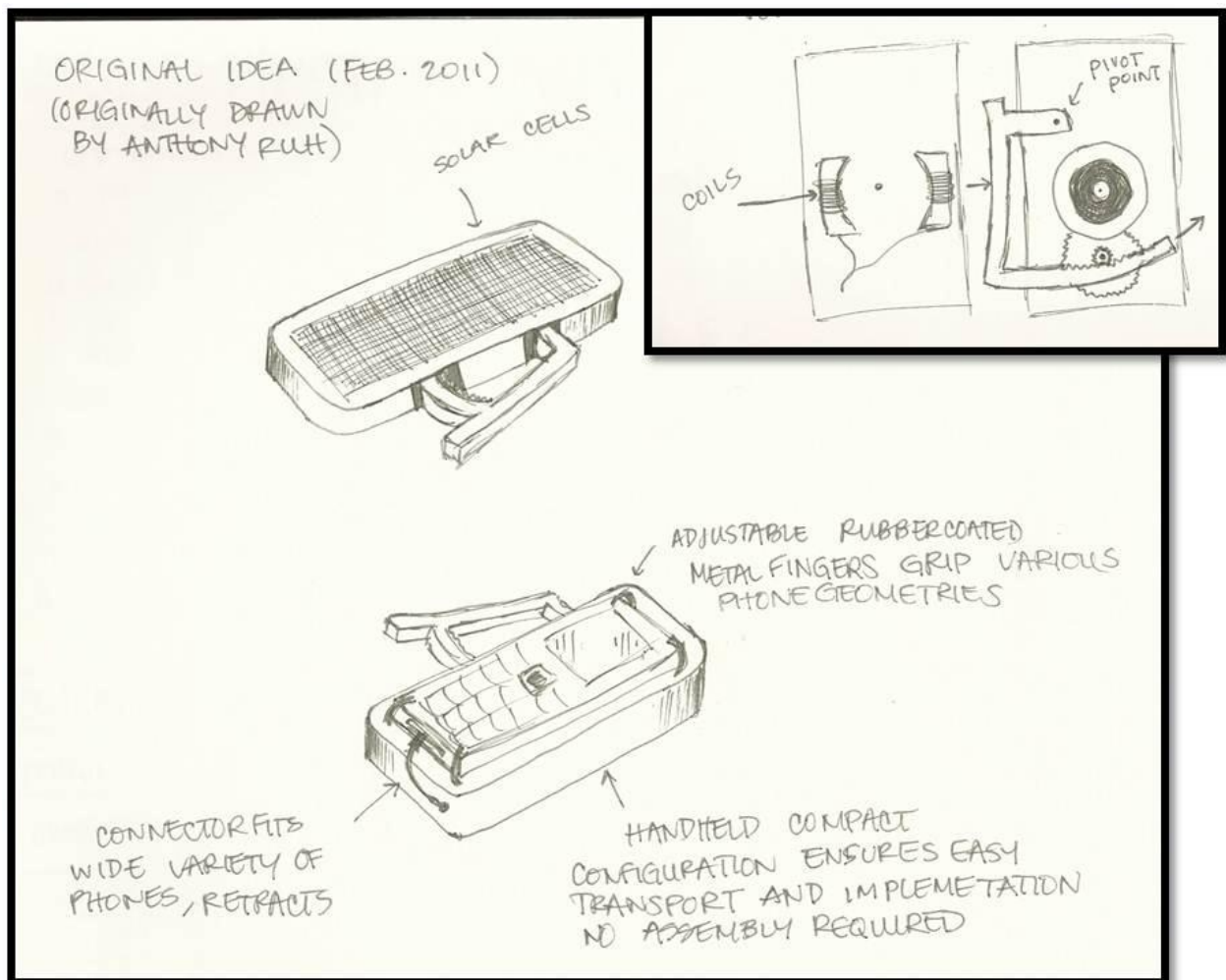


Figure 5: First-generation "squeeze phone" hand-squeeze-powered generator

The design continued to be improved from the original sketch. The design pictured in Figure 6 is a modification of the first concept. The lever is modified to be more ergonomic and provide equal force from all fingers. The phone is now connected with an external USB adapter so that it can be placed farther away from moving parts to reduce the background noise heard from the user from the rack and pinion gearing. The solar panels are moved to the front panel so that they can be operational when the device is being charged with the hand power, as the front is not covered by the operator's hand. There are also more solar panels as well as a second electric generator.

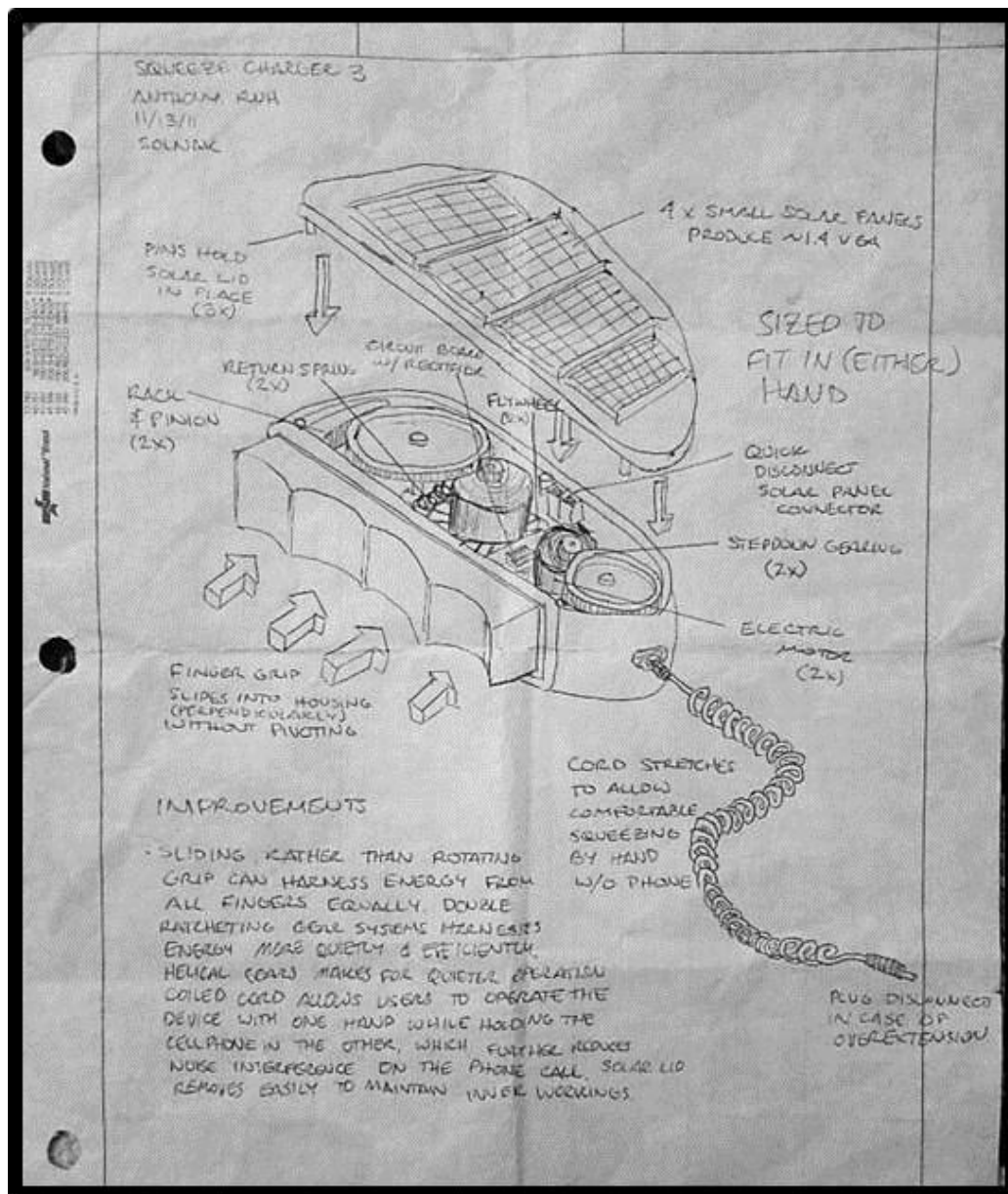


Figure 6: Improved squeeze phone model

The next concept (see Figure 7) was developed after talking with Dr. Niku about the ergonomics of a hand-powered device. It was found that the squeezing motion of the other two previous designs was one of the hardest motions to sustain, changing the motion to a handle crank allows for the user to produce power more comfortably. This design also has an added ergonomic handle for your other hand to provide stability to the device while in use. The handle also allows the solar panels to be unobstructed by shading that may occur from fingers that may wrap around the edge of the other previous devices.

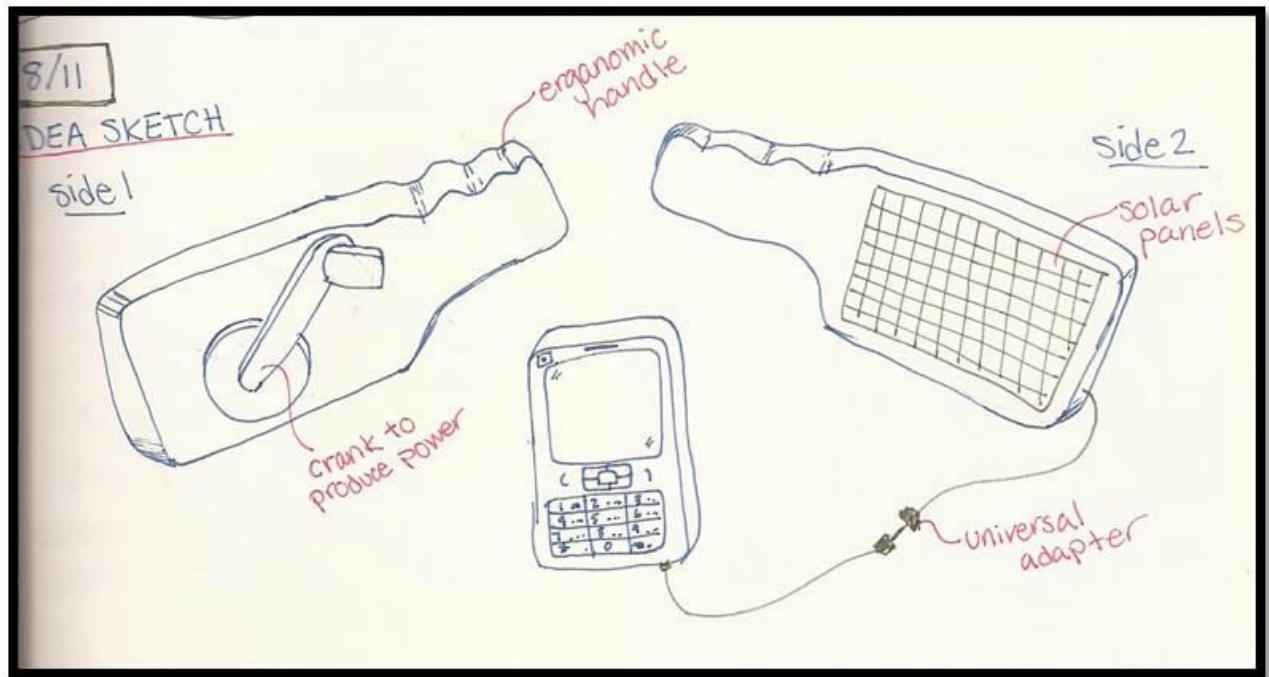


Figure 7: Ergonomics study on the original squeeze phone design

Ideas involving foot power were also developed. The idea shown in Figure 8 was created after discussing human factors with Dr. Niku due to the fact that the leg and foot muscle group is stronger when compared to the hand and arm muscle groups. This idea would use a pedal and solar panel connected in parallel to charge the phone either individually with solar or foot power that could be used in conjunction with one another to provide power to the phone simultaneously.

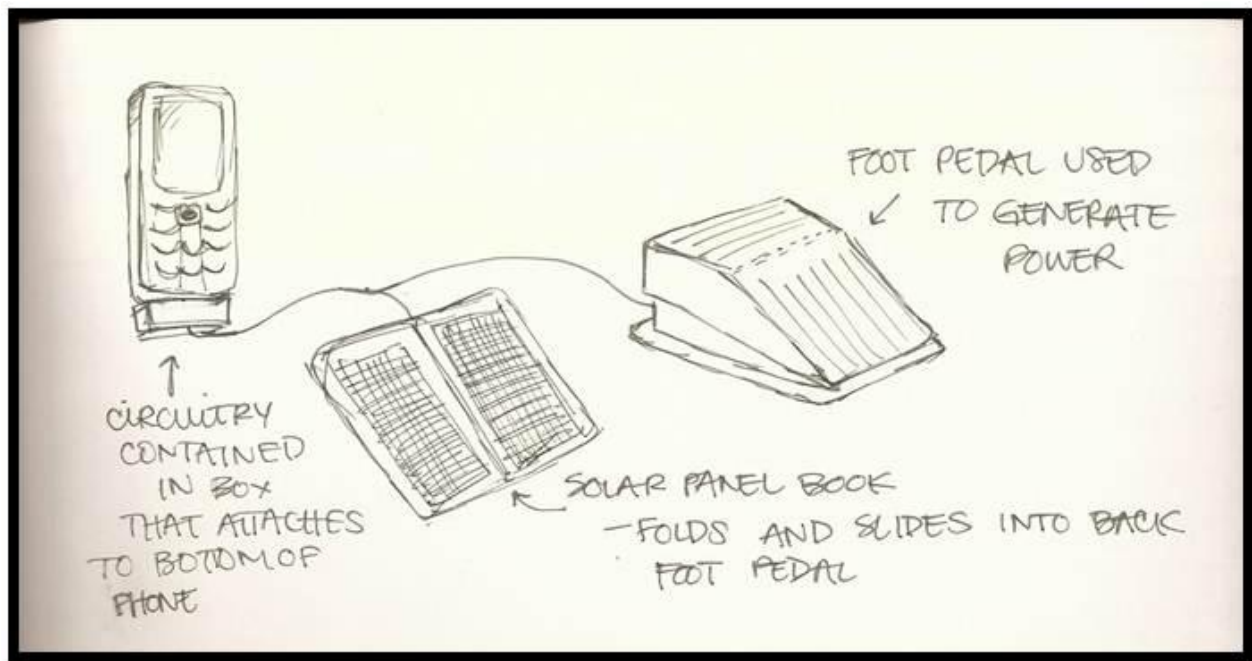


Figure 8: Concept sketch showing the first developments in harnessing foot power

Another foot powered idea was similar to a bicycle pedal mechanism (see Figure 9). The user would sit on a chair of the floor and strap their feet onto the pedals on either side of the device. The pedal motion would be as easy to maintain as riding a bike. The solar panels would be mounted on top of the housing for the mechanical and electrical system to allow for unobstructed solar energy collection.

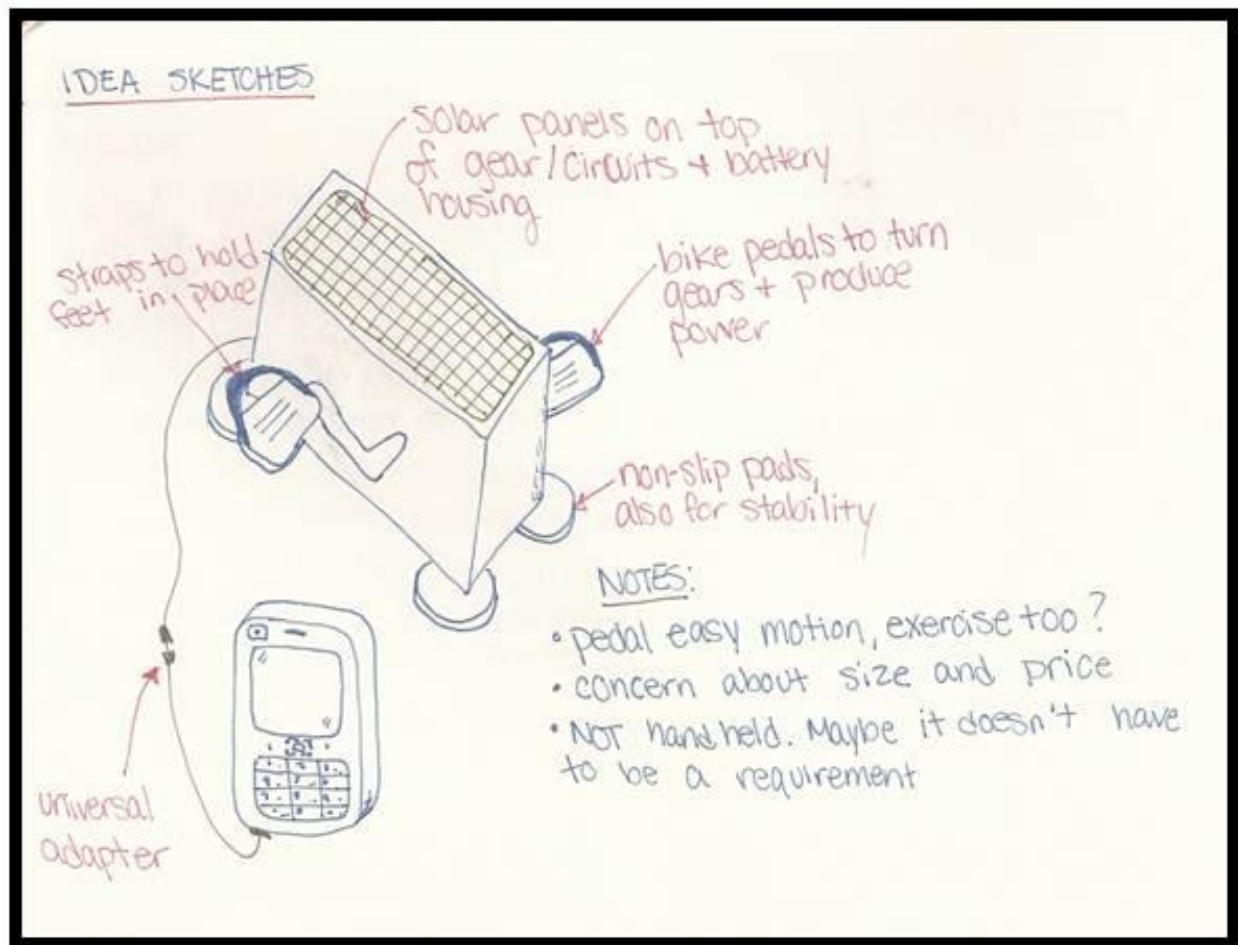


Figure 9: Subsequent foot-powered design, inspired by bicycle riding

The device concept seen in Figure 10 would not be able to collect energy from both foot and solar power at the same time but was very attractive because of the compact design. The pedal would operate when the device was folded in half and would produce power when the operator applied and released pressure to the pedal with their foot. When the operator wanted to use the solar part of the device it would be unfolded and left out in the sun to collect solar energy and charge the phone.

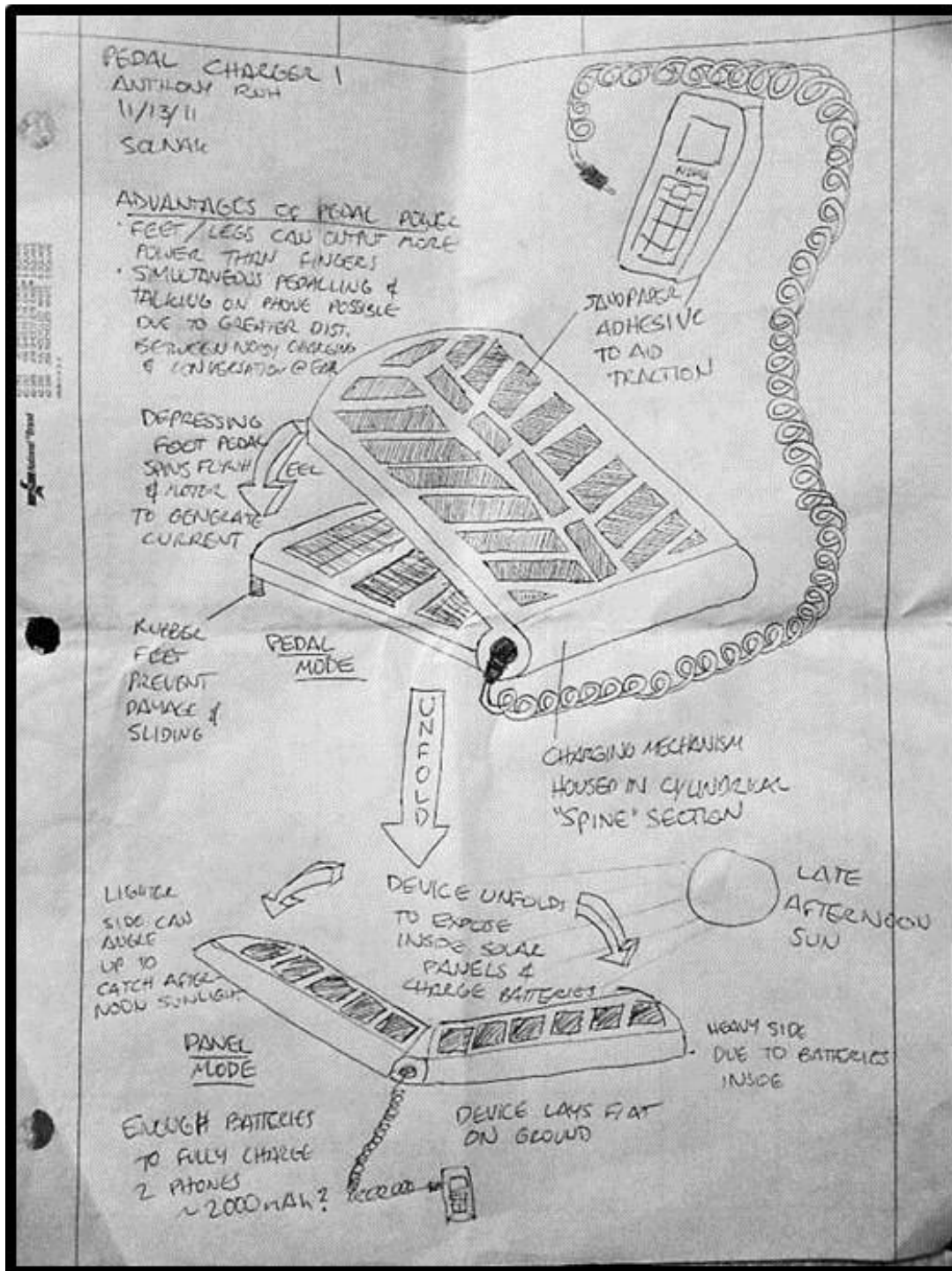


Figure 10: A concept sketch by Anthony that was popular with communities in India

The last concept is based on the design of an old-fashioned sewing machine treadle. The pedal is connected to a flywheel, which powers gearing to a generator. The generator powers the cell phone. This design could also be modified to include as solar panel attachment.

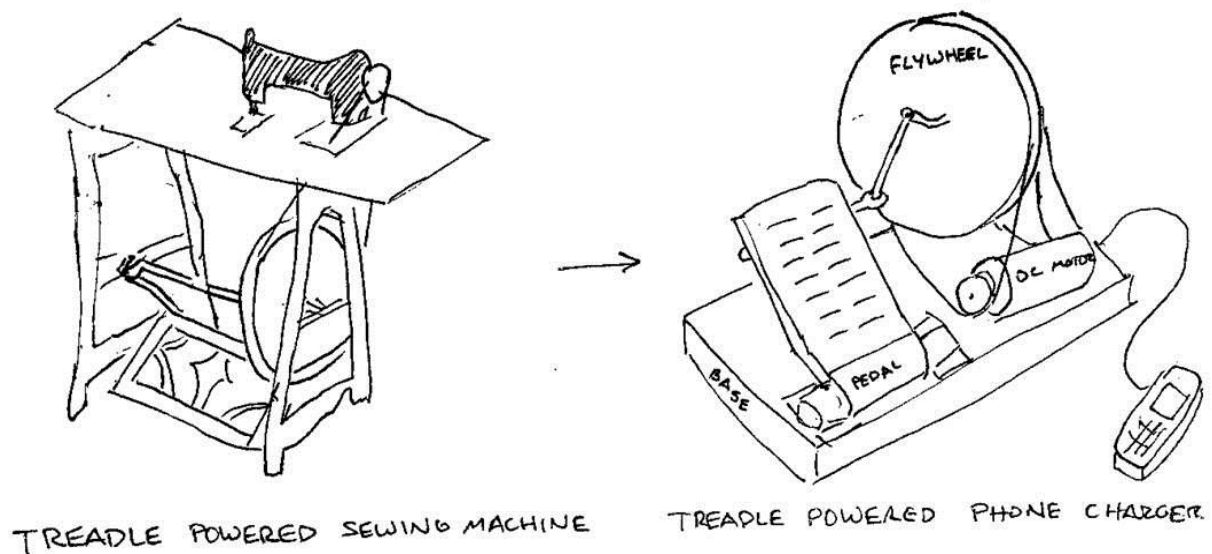


Figure 11: Treadle power is a common and historically effective method of turning foot motion into rotation for machinery

Concept Selection

The concept selection process began by constructing a decision matrix for the top four designs and a Quality Function Deployment (QFD) diagram. Both are listed in Appendix A. The decision matrix was an extremely useful tool in comparing the different mechanisms that were a possible solution in creating a successful design. The four mechanisms that were compared were a rack and pinion, a bicycle design, a treadle design and the hand crank design that was originally proposed. The categories of durability, simple design and ease of use were given the highest weight with regards to importance. When compared in the decision matrix, the mechanism with the highest rating was the treadle design.

The QFD diagram provided valuable information through determining design characteristics that were of higher importance than others. As seen in the relative weight row at the bottom of the QFD, the two design characteristics that had a higher weight of importance were the housing size and the link material selection. This assisted with the design process in determining which design characteristics were most critical. The link material that was eventually selected was steel, due to cost, durability and availability. The importance of the housing size led to the selection of a more compact design to minimize the size.

Once it was determined that the housing size (compactness) and the link material were the more critical components, the decision matrix was modified to reflect values of higher weighted importance for both the durability factor as well as the compact factor. This revised decision

matrix is the one presented in Appendix A. With these changes, the treadle design still proved to have the highest favorable rating.

The greatest obstacle that was faced during the process of concept selection was choosing an appropriate method of power generation. It was extremely challenging due to the fact that alternative power generation is a very new field, and there is little documentation available. Initially, the team was researching the idea of using a motor as a generator by running it in reverse. Through the testing of a drill motor and further research including contacting various companies that manufacture small DC motors, it was determined that using a motor would be an inefficient method to generate power (please see Proof of Concept Analysis and Testing section). The next concept that was approached was using a small generator, for example a generator built for a small wind turbine. At first this seemed to be the answer because a generator was found where the value given for power output at a particular speed was exactly what the preliminary analysis proved was required. However, the generator also proved to be an inefficient method of power generation (please see Proof of Concept Analysis and Testing section). Toward the end of Winter Quarter, SolNAK was able to connect with an electrical engineering team, Yuri and Ervin Castillo, whose senior project was creating a manual on how to rewire an alternator to produce a desired power output. This led the focus to small alternators. While the electrical engineering team was using a car alternator in their manual, it was decided that a smaller alternator from a motorized scooter would be more appropriate for the concept design. Testing a stator and rotor from a GY6 motorcycle proved that it would be an effective choice for alternative power generation (please see Proof of Concept Analysis and Testing section).

Supporting Preliminary Analysis

The goal of the team's analysis was to break the model into a simplified system. A steady state analysis was performed on the system looking at just the torque from the generator and the torque from the four bar linkage system on the flywheel, with the flywheel rotating at a constant speed (Appendix E). From this point, reasonable values were chosen for the link lengths, the materials, the applied forces etc. and formulated equations to find the relationship between different parameters and the resulting torques. Preliminary calculations to find out if the foot force required to pedal the device would be able to be feasible to sustain for the required time to charge a phone. Slight modifications to the four bar linkage design were necessary after the first iteration of calculations produced much too high or torques for a human to easily sustain.

Another approach that was used to try and determine the relationship between input rotational speed and output voltage and power, and the necessary size of the flywheel was

Simulink. After the schematic was created, it was decided that in order the size the flywheel, the specifications of the power generation were required. Thus, the Simulink diagram was more beneficial later on in the design process once those specifications were determined.

Proof of Concept Analysis and Testing

There were several tests performed in the process of deciding on a suitable method for power generation. During the first test, the team recorded the voltage and current of a DeWalt DW995 drill motor (see Figure 12) at different rotational speeds. The voltage across a load was observed and the current was recorded as the rotational speed was steadily increased using a drill press (see Figure 13). The results from this test were that the voltage was too low and the current was too high. Additionally, the speed required to get the power to reach a reasonably close value was too high for what the design was capable of.



Figure 12: Drill motor from DeWalt drill

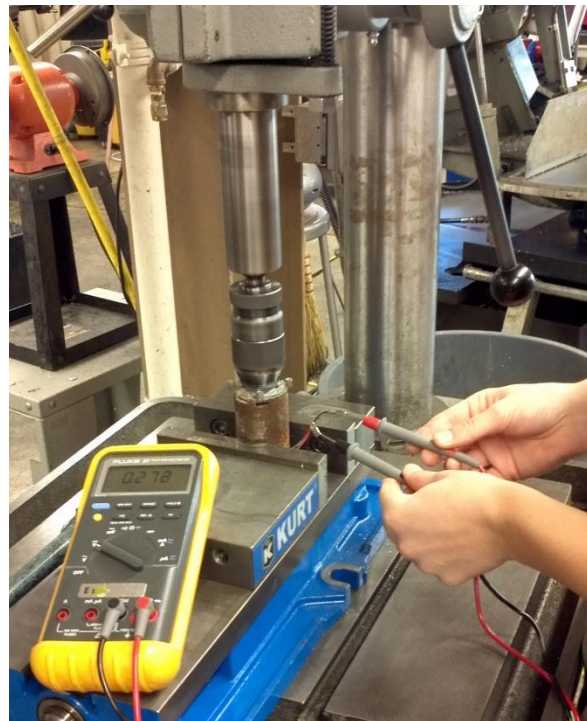


Figure 13: Set-up of drill motor in drill press

The second test was very similar to the first in the purpose as well as the setup, however a small generator was tested instead of a drill motor (see Figure 14). While the values found for power were significantly closer to the necessary value to charge a cell phone. After only 10 seconds of running and a reduced speed, the generator was extremely warm to the touch. From this it was concluded that the generator was not at all appropriate for the extended duty cycles necessary to charge a cell phone.



Figure 14: Set-up of small wind generator in drill press prior to testing

The third test performed led to the selection of a stator and rotor from a GY6 engine. A fixture was designed to hold the stator steady while the rotor was turned in a lathe chuck (see Figure 15). As seen in Figure 16, the rotor was clamped into the chuck with very small clearance. The machined fixture allowed for the placement of the stator inside of the rotor while keeping the protruding wires from impeding motion. From this procedure it was demonstrated that precise concentricity between the stator and the rotor is not necessary for the components to work properly, as long as they do not physically touch during rotation. The results from testing the stator and the rotor proved to meet the required parameters. A reasonable voltage of 3.6 volts was reached at the relatively low speed of 360 rpm. With a simple gearing ratio added, the required input speed from the pedal could be reduced and the speed that the rotor is rotating at could be increasing, therefore increasing the output voltage. This data confirmed the decision in using the stator and the rotor.

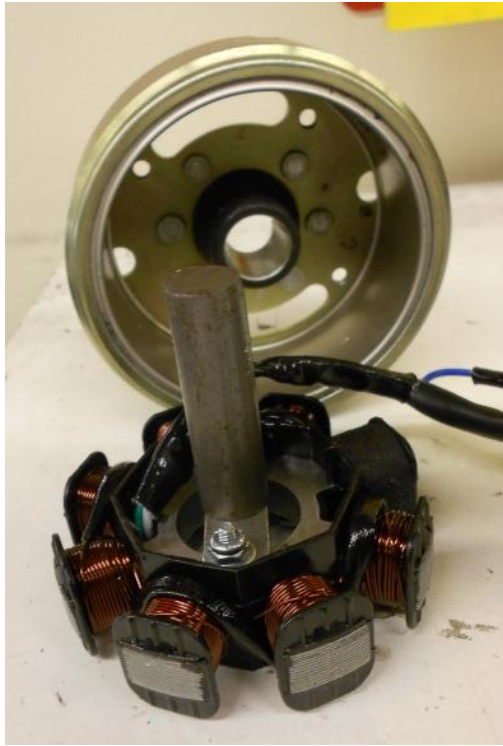


Figure 15: Adapter machined to hold stator in lathe

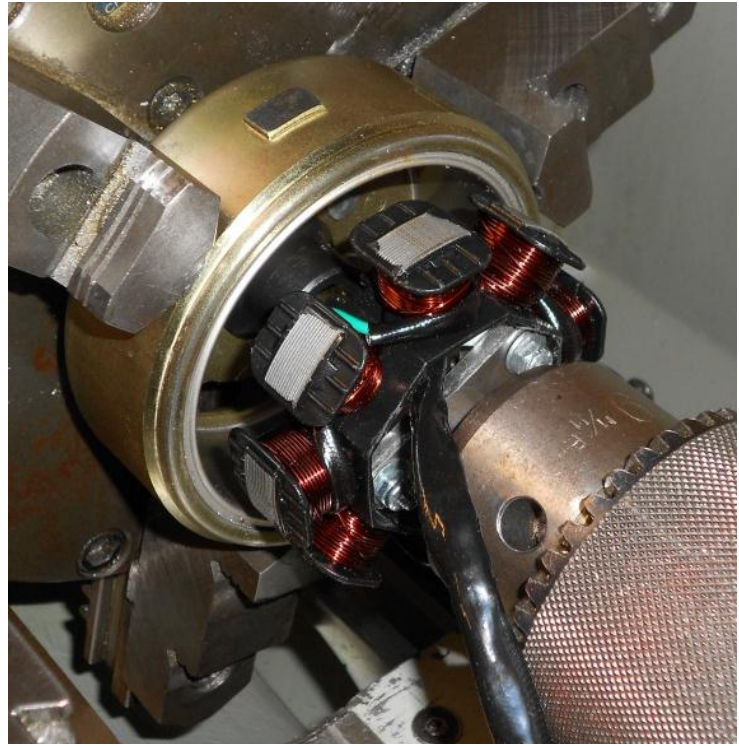


Figure 16: Set-up for stator and rotor testing in lathe

Chapter 4: Final Design

Solid Model

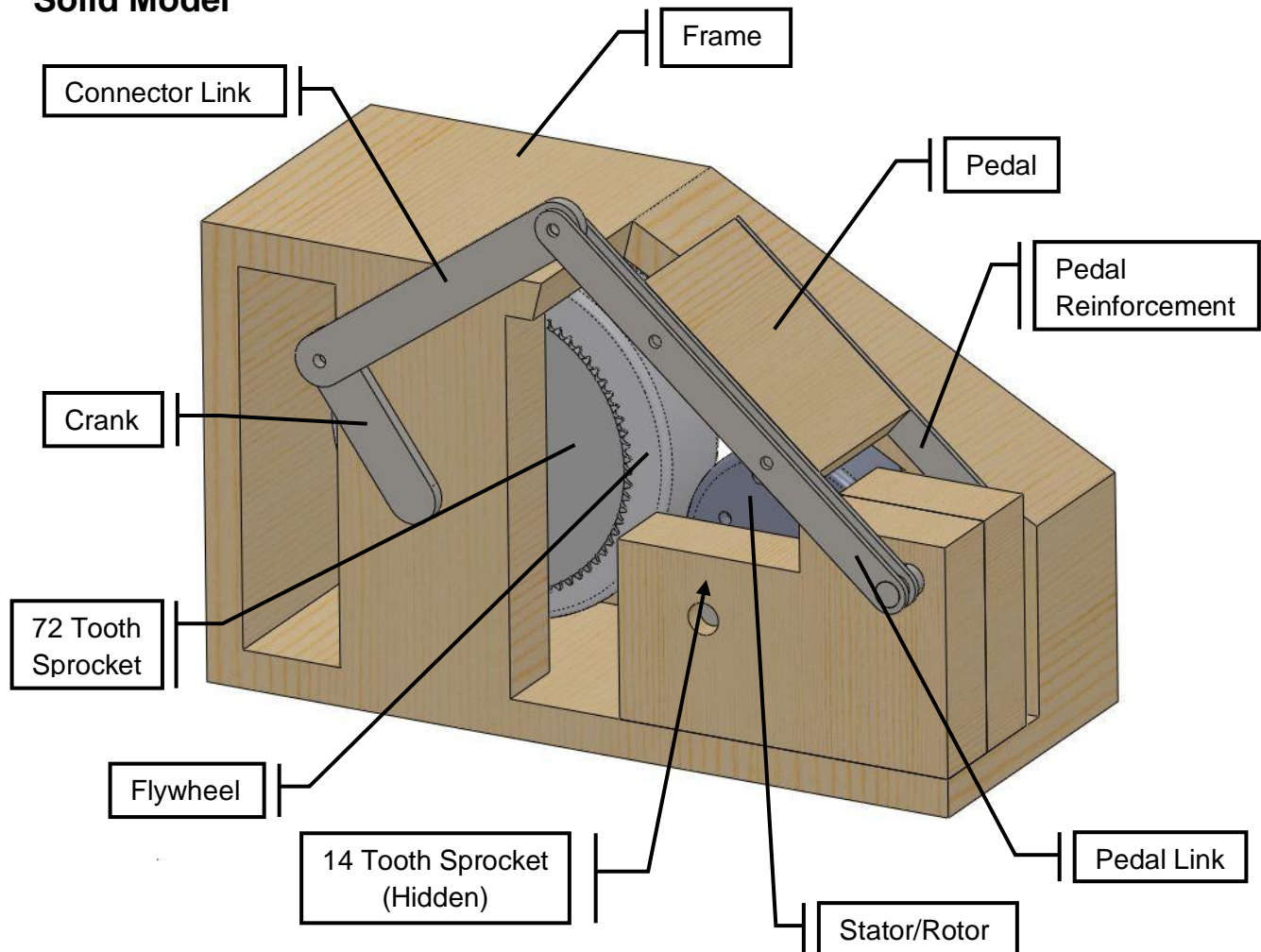


Figure 17: Detailed SolidWorks Model

Detailed Design Description

The design was developed with a focus on low-cost materials and high-manufacturability. Dimensions were chosen to create a device that is safe and sturdy, and whose components are easily substituted to maximize the design's adaptability. Most all of the parts are easily produced with a saw and a drill; those that are not shall be easy to manufacture in a basic machine shop or, failing that, mass produced quickly and cheaply. The focus behind the charger's design is that not only will it be marketed and used in poor communities, but that it will also be produced in them as well. In this way, the charger can benefit the community throughout its life cycle.

The base is comprised of a large flat board. This iteration has a base of poplar, but any similar base material may be used. All of the shaft mounts double as frame members and are constructed of widely available basic planks. In this case, the 2 x 4 surrounding the rotating components provide both support and protection to the mechanism. Scraps from the $\frac{3}{4}$ " wood used in the base will be used to fashion side and top coverings for the flywheel and charger mechanism inside.

The driving component of the device, the pedal, is located in the top left corner of the device. It has been situated so that its pivot is in line with the crankshaft, which improves the device's range of motion for ease of force input. For operation by a user sitting on the ground, the device would ideally have the pedal closer to ground level instead of being elevated four inches; though lowering this would vastly increase the size of the design. Steel bar stock bolted through the width of the pedal provides rigidity and reduces stress and torsion on the wood during pedaling. On the drive side, the steel bars transmit most of the force from the user's foot through the frame, pivoting on a half-inch round bar welded through the ends and resting on bronze bushings press-fit in the frame. These bushings are less costly than bearings for this relatively low-stress pivot position. Extended bar sections on the left side of the pedal comprise the pedal link, which transmits the forces through the linkages towards the charging system.

After the pedal, the connector link and crank link transmit forces and torques to the rotating components. The links are all produced easily from $\frac{1}{4}$ "x1" bar stock on a chop saw and drill press and finished with a grinder. Small brass inserts of a standard size are press-fit into the pivot holes (5 total) to reduce friction on the components and extend service life. The crank link length has been doubled over previous design dimensions to provide extra torque to the system, which will help in driving the high-speed rotor system. Short sections of $\frac{1}{4}$ " round steel are used as connector links and held in place with retaining rings and $\frac{1}{4}$ " washers.

The crank link is welded to the half-inch round steel bar serving as the crankshaft. The crankshaft rotates between two economy, sealed, flanged bearings press-fit into upright 2 x 4 members. The half-inch bar was selected for durability and economy. It also contains weldments to reinforce the flywheel, as well as space for the large sprocket. It is long enough to span the width of the machine. The half-inch shaft also does not require keyways to mate to the selected ANSI sprockets, reducing the need for specialty parts or machining.

On the crankshaft are the first two components of the rotating mechanism: the flywheel composed of concrete and the versatile large sprocket. The flywheel is cast of concrete inside a cutout base of a large liquid container (in this case, a seven-inch diameter bleach bottle was used). The bleach bottle section serves both as the mold and as a component in the final design

to ensure flywheel structural integrity during operation. The use of low-cost, easy-to-cast concrete for the flywheel was inspired by a corn-grinder project from ME 329 Mechanical Engineering Design II, in which a concrete grinding stone was successfully used to pulverize corn.

The sprockets and corresponding ANSI $\frac{1}{4}$ " pitch roller chain were selected from McMaster-Carr for the wide range of sizes available. A 5-to-1 ratio of steel-finished bore sprocket was used to transmit the highest shaft speeds possible to the generator. The sprockets simply slide onto the shafts and are held in place by set screws. No keyways are used or needed for smaller shafts such as this, which keeps part cost and complexity low. The chain is sized to length between the two sprockets and held together with a removable connecting link. Chain tension was set during construction, where the position of the shafts themselves removed slack in the chain line. This was determined to be the best way to keep costs and project complexity to a minimum. The drivetrain is covered on the upper side by a formed section of $\frac{3}{16}$ " steel screwed into the base. This shroud protects the drivetrain from damage while shielding the user from moving parts.

The rotor and stator pair, which converts the mechanical rotation into an alternating current, is the final component of the mechanical system. They were sized from a standard, 150cc scooter engine design, the GY6, a common design worldwide that may be adaptable to other similar scooter power generators. A generator from a two-wheeled vehicle was desirable because of their prevalence and affordability in developing areas around the world. These devices work by passing rotating magnets around a series of stationary coils, thereby producing single-phase alternating current. The design is desirable because, unlike DC motors or generators, its operation does not rely on contact between any moving parts (such as brushes and commutators). Further, it is developed for long duty cycles and its coils will not heat up from the current, as those in previously tested DC motors did. The stator coils will be attached by bolts into the 2" x 4" walls, while the rotor's tapered shaft will be secured by a woodruff key on a custom-machined steel adaptor, held in place on the $\frac{1}{2}$ " shaft by set screws. This adaptor will be the most complex component to be manufactured, though it only requires the use of a hand-mill and lathe. It could easily be produced in a machine shop in medium cities in these developing countries.

From the stator, the electrical current passes through the electrical system to be rectified and regulated into a DC current that cell-phones can accept without any other charger adapter. A USB power port is provided in addition to multi-plug adaptors to fit a wide range of cell phone types. Users will be able to charge their cell phones readily without worry of damaging sensitive electronics, thanks to the power-regulating circuitry of the machine.

Analysis Results

The calculations that supported the final design were completed through techniques including finite element analysis. While the FE code was performed on a previous model configuration, the four-bar link geometry differed little in the final prototype design. The FE code showed that the design should include two pedal links side-by-side, in order to reduce the load on each link and to put the connecting pin in double shear. The dimensions of the steel for the pedal links was determined to be appropriate, as specified in Table 1. The abstract of the report, published on March 14, 2012 by Anthony Ruh and Krista Schmidt, provides details on the findings from the ABAQUS analysis:

Worst-case static and dynamic load tests on a pedal-powered electricity generator were conducted with ABAQUS/Standard using 20,840 elements and 175,547 degrees of freedom on the five idealized main components of the assembly. The linkage was connected with idealized, non-deformable hinge joints. Convergence studies of each isolated part in pure bending or tension were performed to determine the appropriate mesh size. As this product is being developed for rural areas of India, it is critical that the device be both durable and constructible from a wide range of locally available materials. The 50 lbf static load design study indicated that the pedal link thickness should be increased to $\frac{1}{4}$ ". All other materials and dimensions are suitable for the design.

Further, the FE code showed that the initial design thickness for the steel crank and connector links of 1" wide by $\frac{1}{4}$ " thick were appropriate for the model. The maximum stress concentration in the principal material directions was found to be 2200 psi in the pedal link and 1100 psi in the connector link. The crank link's maximum stress was found to be 560 psi. These numbers were within carbon steel's (1018) limits of 32 kpsi from table A-22 in Shigley's *9th Ed*. In-plane stress magnitude at the interface between the crank and the crankshaft indicated that a weld would be suitable to keep the parts from rotating relative to each other.

Table 1: Design results, after FE analysis was performed on the model. Lengths are measured center-to-center.

Crank	Connector Link	Pedal Link (2x)
1" x $\frac{1}{4}$ " x 3" L	1" x $\frac{1}{4}$ " x 6" L	$\frac{3}{4}$ " x $\frac{1}{8}$ " x 9" L

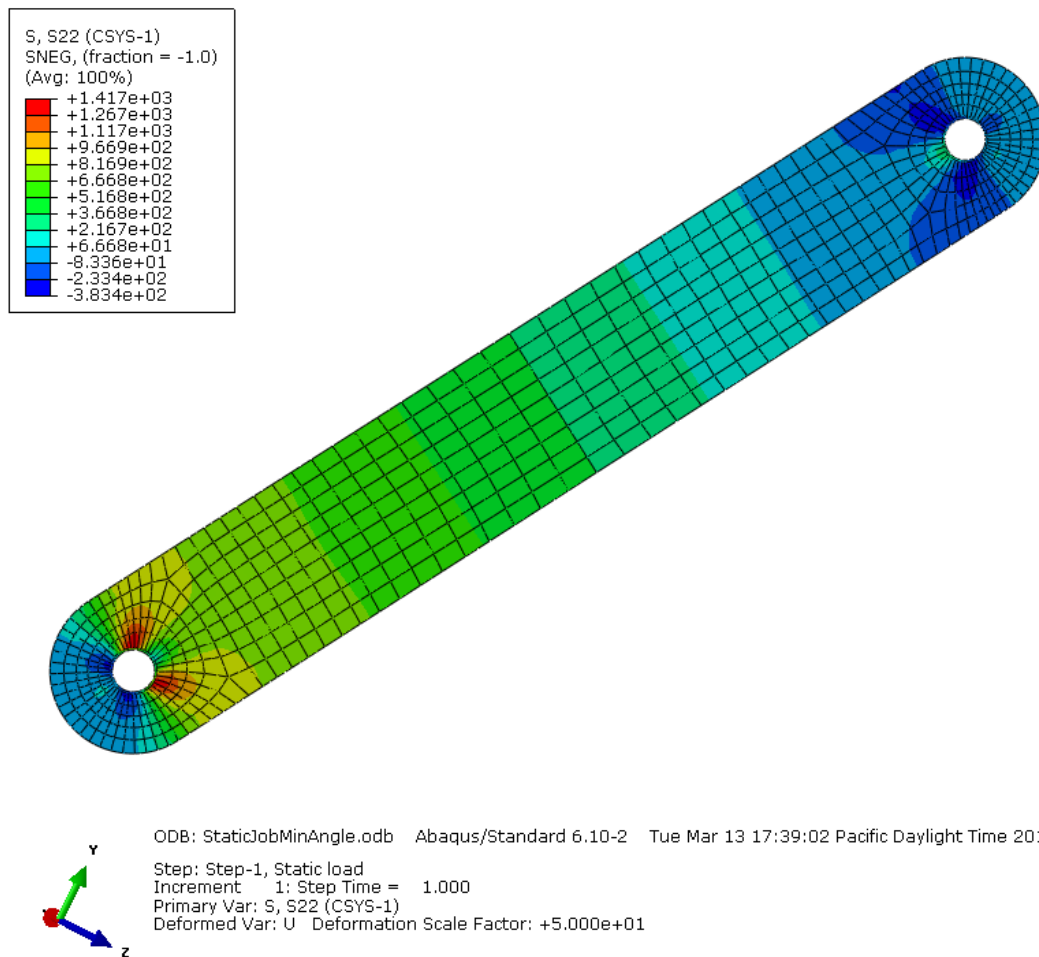


Figure 18: Maximum stresses in the connector link at the lower locking point of the mechanism

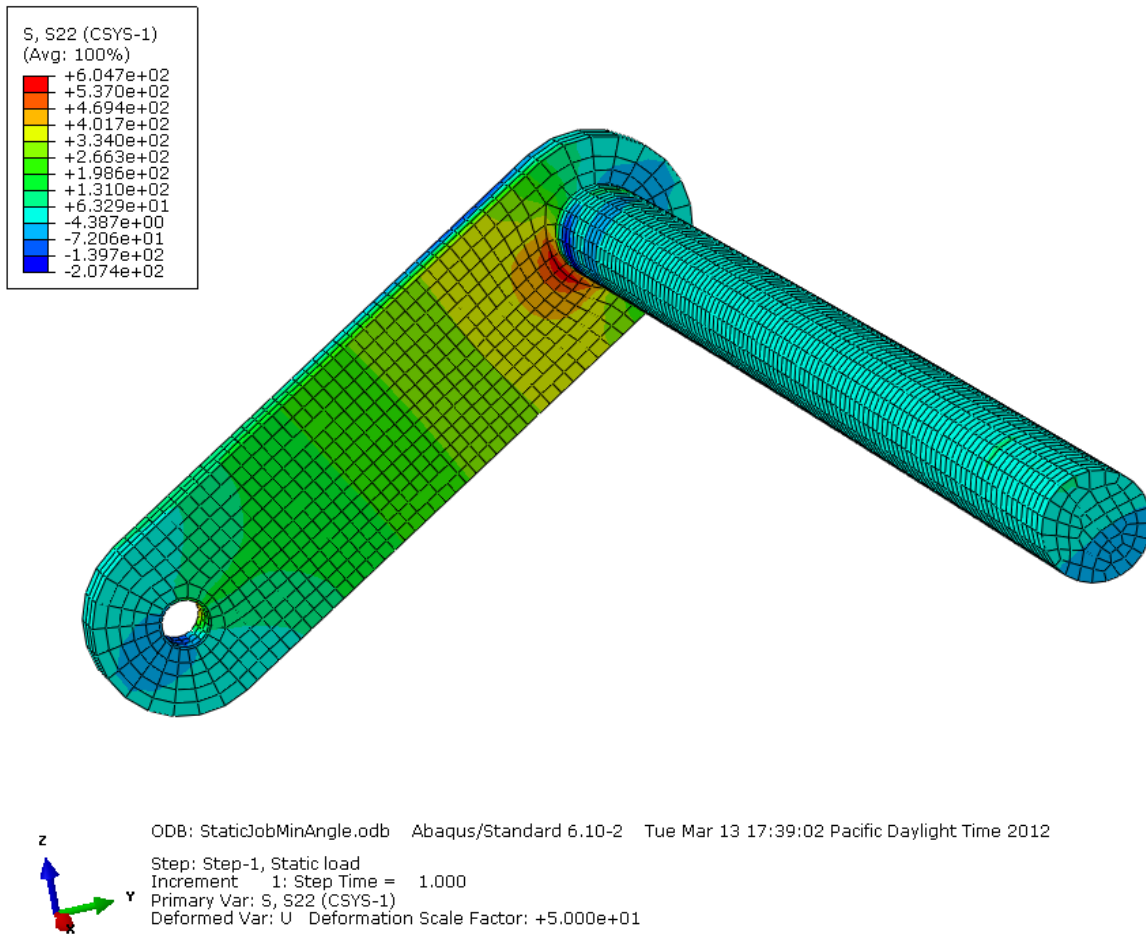


Figure 19: Maximum stresses in the crank and crank shaft at the lower locking point of the mechanism

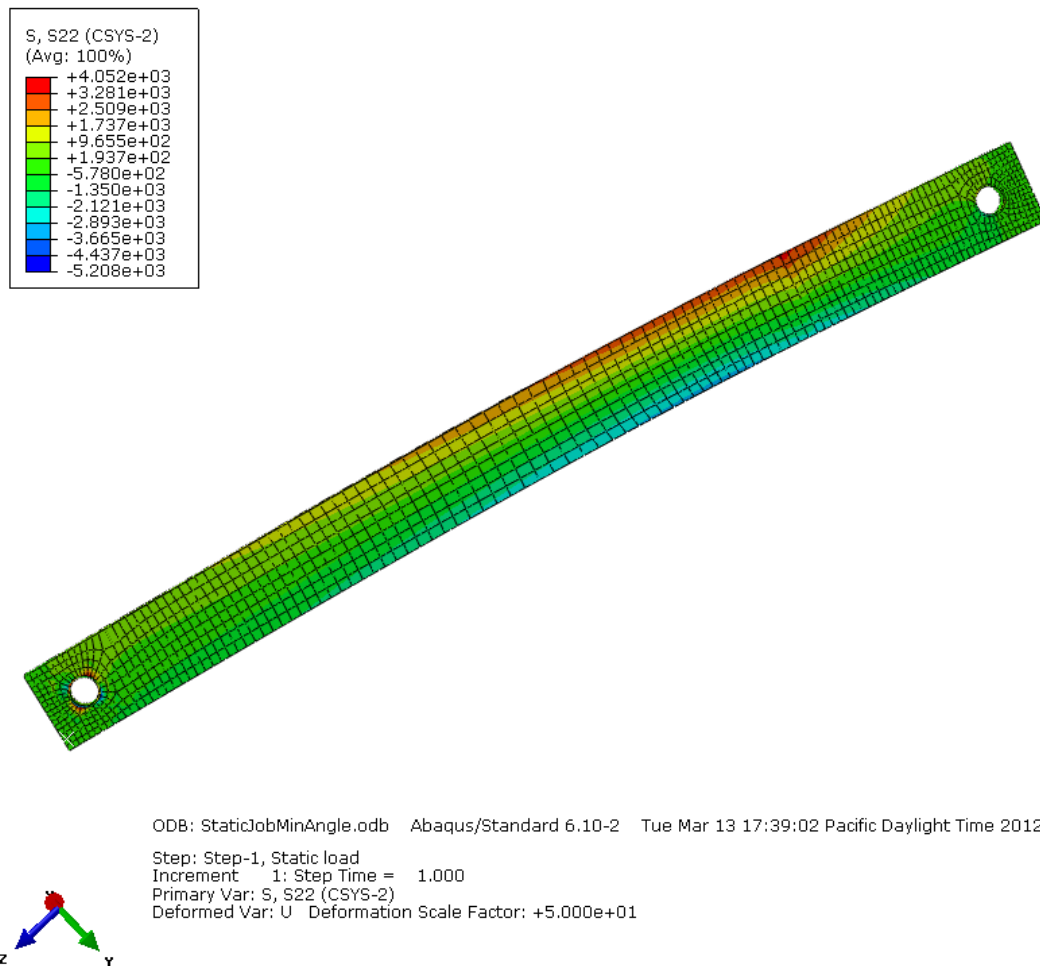


Figure 20: Maximum stresses in the pedal reinforcement at the lower locking point of the mechanism

The process for determining the different shaft diameters was written out using the methodology found in Shigley's *Mechanical Engineering Design 9th Ed* (Appendix E). These equations and processes were entered into Engineering Equation Solver in order to facilitate changing parameters and producing the correct shaft sizing more efficiently (Appendix F). From this analysis, it was determined that a ½ inch steel shaft for the crankshaft would be sufficient to withstand the loads and speeds of the machine. All shaft sizing included a factor of safety of at least two since the device needed to be durable and safe for rural applications. It was also determined that concrete would be an optimal material for the flywheel with respect to weight, cost and workability.

Cost Analysis

The team has a budget graciously provided by the mechanical engineering department of a maximum of \$500. Of that \$500 the team has spent \$363. The only components left to purchase are a few electrical system parts and the solar panels. This should cost no more than \$100, bringing the grand total for the project to just under \$475. The mechanical system prototype has material components totaling to a value of \$173.23. The other \$189.77 was spent on other items, such things as testing apparatuses. Additionally, in the process of manufacturing the system, problems were encountered that required addition material and parts to be purchased and fabricated to ensure device integrity. Also, due to minimum purchase requirements on some items, such as a bag of washers or the length of wood, extra material had to be purchased to get the necessary components for construction. For a list of device components purchased and pricing see Appendix C.

Material, Geometry, Component Selection

For the material selection the team chose to make the design out of inexpensive materials that could be found in India. The entire housing is made out of wood, while the shafts, bearings, sprocket and chains are all made of steel. Steel was chosen because of its high strength and durability, while also being very inexpensive. Using wood for the housing is very appropriate since it just needs to provide a barrier between the high-speed gearing and the user and will not experience much stress. The flywheel will be made of concrete because it has the mass properties that the system requires, while also being very inexpensive and easy to work with.

Calculations to size the generator and flywheel shafts were done before the team could complete the design of the system. They were able to apply the knowledge, processes and equations that they learned from Shigley's *Mechanical Engineering Design 9th Ed*. The calculations were completed using lengths from the SolidWorks model and speeds obtained from testing done on the stator and rotor (please see Appendix E: Detailed Supporting Analysis for the detailed calculations). The pedaling speed was based on reasonable human pedaling frequency of around 120 RPM. The stator and rotor testing determined that a 5:1 gear ratio was needed to obtain the necessary power. After calculations were complete and checked all the equations were put into EES so that modifications could be made, with quick results. From the analysis the team chose to use ½ inch shafts for both the generator shaft and the flywheel shaft. This gives the design a comfortable factor of safety of 2.

Preliminary calculations on the four bar linkage have been done to assess if the torque required to operate the foot pedal is sufficiently small for a human to overcome easily. The team used an online four bar linkage simulator as well as their SolidWorks model to determine if the appropriate range of motion could be achieved with the design.

Wiring Diagrams

The circuit design was completed by electrical engineering senior, Jospeh Garcia, who developed the circuit to the specifications of the system. Fine tuning of the ciruit design is ongoing and will be completed as Joesph's senior project in fall of 2012.

The LM317T is a linear voltage regulator. Linear voltage regulators dissipate heat in order to set the desired output voltage. The following is used to set V_{out} :

$$\begin{aligned}V_{ref} &= 1.25V \\V_{out} &= 1.25 V \left(1 + \frac{R2}{R1}\right) \\5V &= 1.25 V \left(1 + \frac{R2}{240}\right) \\R2 &= 720 \Omega\end{aligned}$$

The LM317T requires a reference voltage, set by R1. A value in between 100 Ω - 1 k Ω is most often used, and a value of R1 = 240 Ω results in the reference voltage of 1.25V. R2 is calculated using the equation for voltage division, and we find a value of 720 Ω to output a constant 5V. A 1 μ F capacitor is added in parallel to the load resistors for output smoothing.

Our alternator generates about 7-9 V open-circuit after rectification. Efficiency is calculated:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{out} * I_{out}}{V_{in} * I_{in}}$$

The reason efficiency is sacrificed for a stable output is because various issues are presented when trying to deal with a varying DC voltage input. DC-DC circuits need a constant input voltage. It is likely that the generator is capable of producing an excess of power for charging phones, in which case it will be used to charge a backup battery or dissipated as heat via a resistor. The simulations that were performed resulted in either too much or too little voltage depending on the input voltage so it was decided that a linear voltage regulator was the best option for this application.

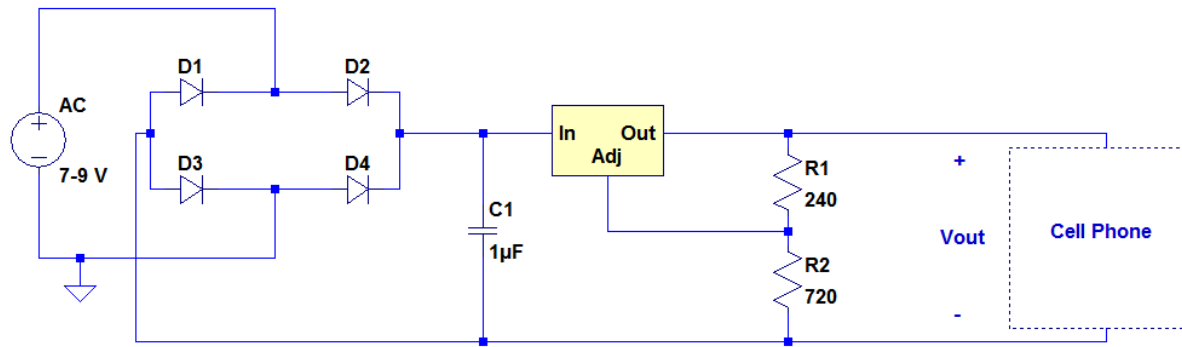


Figure 21: Alternator, Bridge Rectifier, LM317T, Cell phone load

Safety Considerations

There are several safety issues that had to be considered while the team was in the design process. On the electrical side, the charging circuit had to have voltage and current regulation. Having the voltage and current regulation will protect the circuit as well as the phone charging from overloading that could occur from the user putting too much power into the device from excessive pedaling or from high solar irradiance. This safety feature will also protect the user from being exposed to unnecessarily high voltages or currents that could potentially be harmful. On the mechanical side, there are high-speed shafts and gearing that have to be encased in a housing to prevent injury to the user.

Maintenance and Repair Considerations

Since the purpose of the design to so be used in rural India, the team wanted most parts to be easily found and serviceable in India. One of the design considerations going into this project was to make the device as durable as possible so that it would not have to be repaired often. When the device did break down, if ever, the team wanted the device to be a simple enough design so that the user could do most of his or her own repairs with minimal training or knowledge of the system.

Chapter 5: Product Realization

Manufacturing Processes

The manufacturing of the device took place in April and May, 2012. Most work was done in the Mustang '60 machine shop as well as several work days taking place in the Aero Hanger. Since Anthony was the only one in the group with a yellow tag certification, he did all the lathe, mill, and welding work, while Krista and Nicole assisted with all other aspects of the manufacturing process.

To begin the assembly, each wood piece was cut using a tablesaw or a vertical band saw. A drill press was used to create counterbore through holes in the 2 x 4's using a $\frac{5}{8}$ " drill bit and a spade bit, respectively (see Figure 22). The bearings were secured in the counterbores of the 2 x 4 with epoxy. To attach the 2 x 4's to the base, brackets on the inside corners as well as wood screws are driven up through the bottom, which were pre-drilled and screwed in using a cordless drill and clamps.



Figure 22: Using the spade bit to manufacture counterbore holes

The two most complicated parts, the rotor adaptor and the flywheel reinforcement, were manufactured on the mill and the lathe by Anthony. In Figure 23 below, Anthony is drilling the generator shaft hole in the rotor adaptor using a lathe in the Aero Hangar. Both the rotor adaptor and the flywheel reinforcement contain set screw holes that were drilled and tapped by Anthony as well. The flywheel reinforcement had rebar welded to it after it was

manufactured on the lathe. The rebar was also welded in various places to ensure that it did not move within the concrete flywheel.



Figure 23: Turning the rotor adapter

Once the flywheel adapter was complete, Krista and Nicole manufactured a mold to cast the flywheel out of concrete (See Figure 24). For the mold base, they used a piece of poplar wood remaining from the wood bought for the housing. A counterbore was drilled into the base using a spade bit to fit the portion of the flywheel adapter that would be sticking out of the side of the flywheel. The set screw holes were covered with tape to ensure that no concrete would get inside. A section of a bleach bottle was used for the circumference of the flywheel. The concrete was poured carefully to make certain that the concrete reached under the reinforcement rebar and filled the mold's corners.



Figure 24: Pouring the concrete in the flywheel mold

The shafts and the links all required used an abrasive chopsaw to cut the length and grinding to round the ends of the links and remove burrs (see Figure 25). The holes for the connector pins were drilled and lined up as closely as possible. Brass bushings were press-fit into the holes before their centers were reamed out to ensure a clean, tight fit. The ends of all links were rounded on a grinding wheel for safety and aesthetics. The crank link and pedal links were then carefully welded to their respective shafts to ensure their perpendicularity. Welds were ground down in regions where the shaft interfaced with bushings or bearings in order to prevent interference. The links were connected with small $\frac{1}{4}$ " pins, washers, and retaining rings.



Figure 25: Grinding the links

Once all parts were manufactured, the shafts were carefully aligned and the chain was tensioned manually by slight adjustments of the 2x4 placement (see Figure 26 for assembly). Screw holes were pre-drilled and a Phillips head screwdriver was used to fasten the wooden components of the frame together.



Figure 26: Final Assembly

Finally, a housing was constructed around the device to enclose the rotating parts of the device. The housing was secured with a latch on one side and a hinge on the other to make the rotating machinery easily accessible for maintenance and repair.



Figure 27: Assembling the housing



Figure 28: Team SolNAK after testing. From left to right: Joseph Garcia, Anthony Ruh, Krista Schmidt, and Nicole Hensley

Future Manufacturing Considerations

During manufacturing, the team discovered multiple areas of improvement in both planning and the production process. In translating the computer solid model into a physical wooden model, it was apparent that the warping and the expansion of the wood were not factors that could have been accounted for on the computer, and a number of parts had to be sanded down or done over. The production of the flywheel was also vulnerable to distortion of the bleach container mold. Any shifting in the plastic would yield imperfections in the flywheel, though at the target 100RPM, the wobble is negligible. If the problem exacerbates, the team still has the option of improving its circularity by sanding the flywheel as it is rotated in the mechanism. A spade bit was used to drill the large bearing recesses on the 2x4's, and it was difficult for the team to center the bit. A jig for drilling would have greatly increased the accuracy of drilling, thereby aiding in shaft alignment. Finally, during the assembly of the generator shaft, the team found that the order in which the components were slid onto the shaft and placed in the device was critical, and that there was one specific order to accomplishing everything. A manual will have to be produced detailing this process before the device would be able to be mass-produced.

Chapter 6: Design Verification

Test Descriptions

The following is a list of requirements that were set for the device during the ideations phase of the project. Each has an appropriate test that must be completed to ensure the device meets the objectives set out by the team:

Table 2: Design verification test description and requirement summary table

Test	Test Description	Requirement
Voltage Output	Leads from the stator were attached to a multimeter	5 Volt Minimum
Current Output	Used a 10 Ω resistor load and the multimeter measuring current in series to simulate cell phone load	1 Amp Maximum
Weight of Device	Placed on a calibrated scale	20 lbs Maximum
Foot Force Required	A spring scale was attached to pedal and pulled perpendicular to pedal until pedal began to move	10-20 lbs Range
Flywheel Size	Measured with a ruler	8 in. Diameter Max
Pedal Size	Measured with a ruler	6 in. Length Min
Exterior Housing Size	Measured with a ruler	1000 in ³ Max
Proof of Concept	Stator wires connected to a 6 Volt, 0.5 Amp light bulb and pedaled to see if light was produced.	Device lights 6V/0.5A bulb

Test plans were developed for each parameter and are detailed as follows:

Voltage Output Test

The voltage test requires that the device be able to produce a minimum of 5 volts at the output. The voltage output test is a critical test for the device to pass since 5 volts are required to charge a cell phone. To measure the voltage the electrical leads from the stator were attached to a multimeter to measure output AC voltage.

Current Output Test

The current output test requires that the device produce a maximum of 1 Amp. This requirement is due to the fact that the electronics in the circuit as well as the phone itself cannot withstand currents much larger than 1 Amp. The optimal range for device operation is between 0.5 and 1 Amp. To measure the current output the electrical leads from the stator were attached to a 10 ohm resistor and the multimeter in series with each other. The 10 ohm

resistor simulated the load the cell phone would have on the system and the multimeter measured output AC current.

Device Weight Test

The device weight requirement states that the charger should not weigh more than 20 lbs. This requirement is due to the fact that the device is designed to be relatively portable. To test the weight of the device, it was simply placed on a scale to measure its weight in pounds.

Foot Force Test

The foot force test requires that the device pedal should not operate when an initial force below 10 pounds is applied to the pedal. The requirement is a safety consideration so that those not actually meaning to pedal the device, such as young children, could not hurt themselves. The device should also not be so difficult that it could not be pedaled by the average adult, so a 20 pound maximum force to operate was also factored into the design. To test the force applied to the pedal, a spring scale was attached to the pedal and force was applied to the pedal by pulling on the spring scale perpendicular to the pedal until the pedal began to move. The maximum force applied to the pedal, before motion, from the spring scale was the foot force required to operate.

Pedal Size Test

The pedal size requirement states that the foot pedal shall be at least six inches in length. The pedal size is important for the device user's comfort, since a very small pedal would be hard to place a foot on. Additionally, if the pedal is too short then the device would be difficult to pedal since the required moment arm from the top of the pedal to the pedal pivot needs to be at least six inches to overcome the torque from the stator and rotor assembly. The pedal was measured to make sure it was within the proper design requirement.

Flywheel Size Test

The device flywheel size requirement states that the flywheel shall be no larger than 8 inches in diameter. This is so the device can remain small and lightweight. After the flywheel was cast out of concrete, it was measured to ensure that it was within the required dimensions.

Housing Size Test

The housing size test requires that the device exterior housing size should not exceed 1000 cubic inches. This requirement establishes a metric for portability and compactness. The computer solid model volume was measured to confirm that this requirement was met.

Proof of Concept Test

Since the mechanical system was complete long before the circuit for charging an actual cell phone was complete, the team developed the proof of concept test. The proof of concept test was to show that the output from the device could produce enough power to charge a cell phone. To determine this, the device's stator wires were connected to a 6 Volt, 0.5 Amp light bulb. The device was pedaled to see if the power produced by the charger would be enough to light the bulb. If the device could keep the light bulb lit, then it could charge a phone with similar power requirements.

Design Verification

The following is a list of the various tests performed and the results, ensuring that the design was sufficient in all the necessary requirements:

Table 3: Design verification test results summary table

Test	Test Description	Requirement	Test Result	Pass / Fail
Voltage Output	Leads from the stator were attached to a multimeter	5 Volt Minimum	10 Volts	Pass
Current Output	Used a 10 Ω resistor load and the multimeter measuring current in series to simulate cell phone load	1 Amp Maximum	0.5 Amps	Pass
Weight of Device	Placed on a calibrated scale	20 lbs Maximum	20 lbs	Pass
Foot Force Required	A spring scale was attached to pedal and pulled perpendicular to pedal until pedal began to move	10-20 lbs Range	14.12 lbs	Pass
Flywheel Size	Measured with a ruler	8 in. Diameter Max	6.25 in.	Pass
Pedal Size	Measured with a ruler	6 in. Length Min	7 in.	Pass
Exterior Housing Size	Measured with a ruler	1000 in ³ Max	700 in ³	Pass
Proof of Concept	Stator wires connected to a 6 Volt, 0.5 Amp light bulb and pedaled to see if light was produced.	Device lights 6V/0.5A bulb	Light bulb lit	Pass

Voltage Output Test

The voltage output test was run three times for several minutes each time. Once the system was being pedaled at steady state it produced between 8 and 12 Volts of open circuit AC power. Averaging the values together the device produced 10 Volts AC in the open circuit.

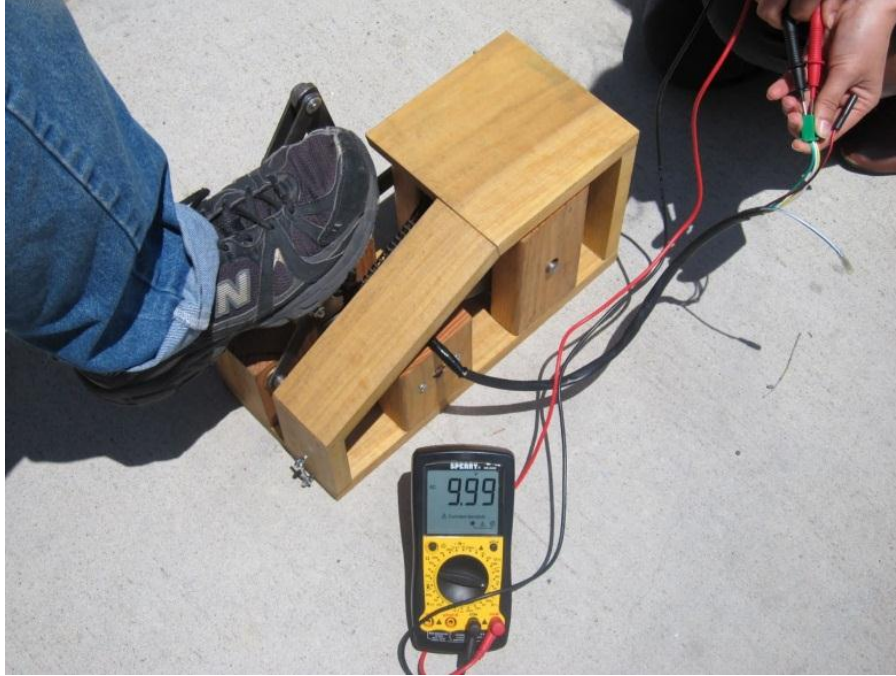


Figure 29: The voltage output test setup

Current Output Test

The current output test was conducted with a demonstration circuit including a diode bridge rectifier and a capacitor in parallel with the 10 Ohm dummy load. The AC input current from the positive and negative leads of the stator was converted to DC power while the capacitor helped even out fluctuations in the voltage. A measured drop in the range of 4.9-5.2 volts indicates that the charger and circuit produced a current of just under 0.5 amperes. This indicates that the circuit is capable of charging a phone. It also falls well below the maximum current limit of 1 amp.

Device Weight Test

The device was weighed with a standard bathroom scale in the Mustang '60 shop. The team calibrated the scale for accuracy before weighing the device to ensure accurate results. It was determined that the device weight was 20 pounds.

Foot Force Test

The foot force test was completed three times with each run averaged to find an accurate value for the force required to operate. The average foot force required to operate the device is 14.1 pounds. Table 4 summarizes the test runs.

Table 4: Summary of trial run results for foot force required test

Run	Force (lbs)
1	14.6
2	13.9
3	13.9
AVERAGE	14.1



Figure 30: Foot force test setup

Pedal Size Test

The pedal size was measured to be 7 inches long from the pedal mount blocks to the tip of the pedal.

Flywheel Size Test

The flywheel's measured diameter averaged $6\frac{1}{4}$ ", falling well within the requirements.

Housing Size Test

The housing was measured to have a size of approximately 700 cubic inches.

Proof of Concept Test

The proof of concept test was run several times, all with the same result. Once the pedal began to move, the light bulb lit up. Once the device was at a steady state speed, the light continued to stay lit the entire time the device was pedaled. The device was proved to work. Once the circuit is complete we should be able to charge an actual cell phone.



Figure 31: Proof of concept test setup

Chapter 7: Conclusion and Recommendations

After manufacturing and testing the design, the team determined that the design of the Sole Power device meets all requirements set out at the beginning of the project, except for the cost to produce. However, the device is a one-of prototype and therefore much more expensive to make than the exact same device would be if it were mass produced in a factory in India. Since all materials used to manufacture the charger are relatively cheap and readily available in India, the team is confident that the final product could be manufactured and sold for a reasonable price that would enable many Indian citizens to afford it.

During the manufacturing and testing phases of the project, the team came up with a few modifications to the existing design that could improve the overall functionality or safety. The following modifications should be implemented in future iterations of the design: A chain tensioning system for the sprocket chain, a spring or mechanism to avoid stalling at the locking point of the 4-bar four bar linkage, and a housing to encase the 4-bar linkage system. The process we used for tensioning the chain was to just align the shafts to the proper distance and screw each 2 x 4 down. This process, while effective, provides a challenge if the chain ever needs re-tensioning. Using an idler for chain tensioning would be a better choice for future designs. While pedaling the device during testing, we discovered that the 4-bar linkage system would sometimes get stuck at its locking point; putting a spring under the pedal to make it impossible for the device to stall this point should be implemented in the future. Finally, a housing should encase the 4-bar linkage for safety reasons. The prototype did not have this feature for simplicity, as well as for showcase purposes. If the team encased the 4-bar linkage in a housing, it would be harder to show the internal workings of the device. Had the team had more time and money for the design, these three aspects could easily be introduced into the prototype.

Over the course of the entire project the team learned several important lessons about working with a team to design and build a project from start to finish. First of all, even though the team was small, scheduling times to meet and work on the project all together proved more difficult than previously thought, especially during the third quarter of the project when there was not a designated class time to meet. During the manufacturing phase, the team learned that no matter how many calculations and drawings are produced of a system there will almost always be unexpected problems that will be encountered in the assembly, such as warping and expansion of materials. During the design phase of the project the team discovered that their initial guesses of sizing calculations were often quite accurate and many of the problems that arose during manufacturing were often solved very quickly with solutions that required very few actual design calculations. This fact initially surprised them, as they discovered their

engineering intuition was much more developed than they previously thought.

In conclusion, the team should be able to address the needs of these rural villagers with an appropriate technology charger. It is recognized that cell phones are a vital part of village life, and that their use is often hampered by power cuts or lack of sunny weather, or both. The goal is to have this product mass-produced and introduced into the rural homes of India and other nearby countries. It's a low-cost, low-tech project that takes little initial investment and meets the needs of an enormous market with almost unlimited beneficiaries. The pedal charger will empower the humanitarian side of engineering, and provide accessible technological aid for the other, often-neglected 90% of the world's citizens. With this project, the team will demonstrate that Cal Poly students are proud and responsible world citizens.

APPENDIX

Appendix A: Decision Matrix and Quality Function Deployment Diagram

Table 5: Decision Matrix

Concept Idea	Ease of Use	Simple Design	Manufacturability	Compact	Readily Available Parts	Durability	Ease of Repair	Price	Total (%)
Weight (% total)	10	5	15	20	10	20	5	15	100
Rack and Pinion	1	1	1	4	1	1	1	1	40.00
Hand Crank	2	3	2	3	2	2	2	4	63.75
Bicycle	3	2	4	1	4	3	4	2	67.50
Treadle	4	4	3	2	3	4	3	3	78.75

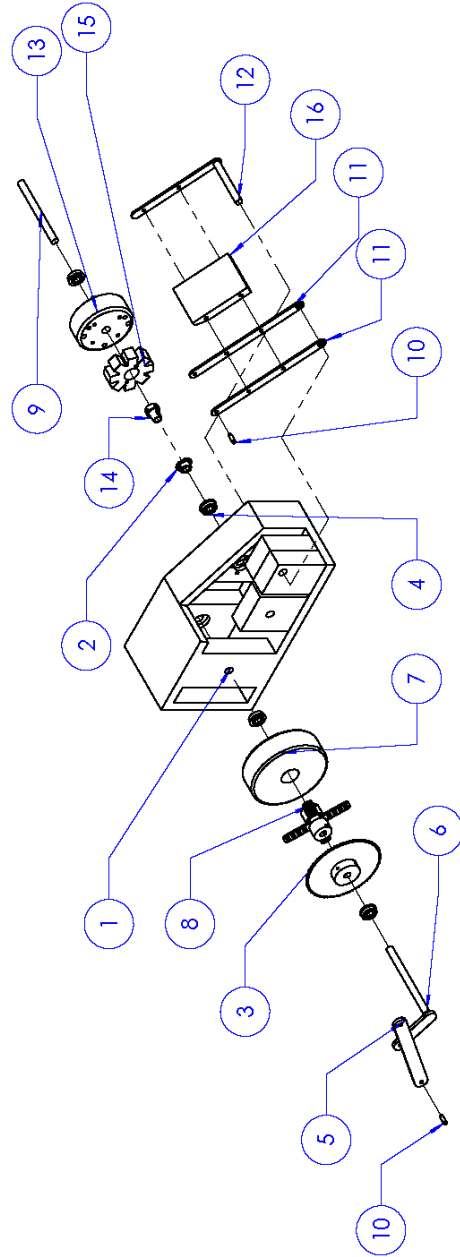
Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
△	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
-	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	D demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Column #													
					Direction of Improvement: Minimize (▼), Maximize (▲), or Target (X)													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
					Voltage Output (V)	Current Output (A)	Weight (lbs)	Minimum Foot Force (lbs)	Link Material Selection	Pedal Size (in)	Flywheel Diameter (in.)	Housing Size (in³)	Solar Panel Selection	Voltage Regulation (V)	Universal Adapter	Sale Price (\$)	Ergonomic	Steps to Operate (#)
1	9	12.0	3.0	Adaptable for Multiple Phones	○	○							▲	○	○			
2	9	4.0	1.0	Durable (child proof)			○					○		○				○
3	9	16.0	4.0	Compact			○			○	○	○	▲		▲	○	▲	
4	9	16.0	4.0	Easy to Manufacture			○		○	▲	▲	○	▲		▲	○		
5	9	16.0	4.0	Cheap in price					○	○	○	○	○	▲	○	○	○	
6	9	12.0	3.0	Simple Instructions (Pictures)												▲		○
7	3	4.0	1.0	Aesthetically Pleasing					▲			○	▲			▲	○	
8	9	4.0	1.0	Easy Portable by one Person			○	○		○		○	▲				○	
9	9	8.0	2.0	Water Resistant					○				○			▲		
10	9	8.0	2.0	Safe	○	○	○				▲	▲		○				
11																		
Target or Limit Value					5V	1A	20 lbs	10 lbs	Steel	6.0 in	8 in.	1000 in³	N/A	Max Voltage of 7 V	N/A	\$50	N/A	5
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)																		
Max Relationship Value in Column					9	9	9	3	9	3	3	9	9	9	9	9	9	9
Weight / Importance					108.0	108.0	264.0	12.0	316.0	124.0	120.0	308.0	268.0	160.0	188.0	264.0	112.0	120.0
Relative Weight					4.4	4.4	10.7	0.5	12.8	5.0	4.9	12.5	10.8	6.5	7.6	10.7	4.5	4.9

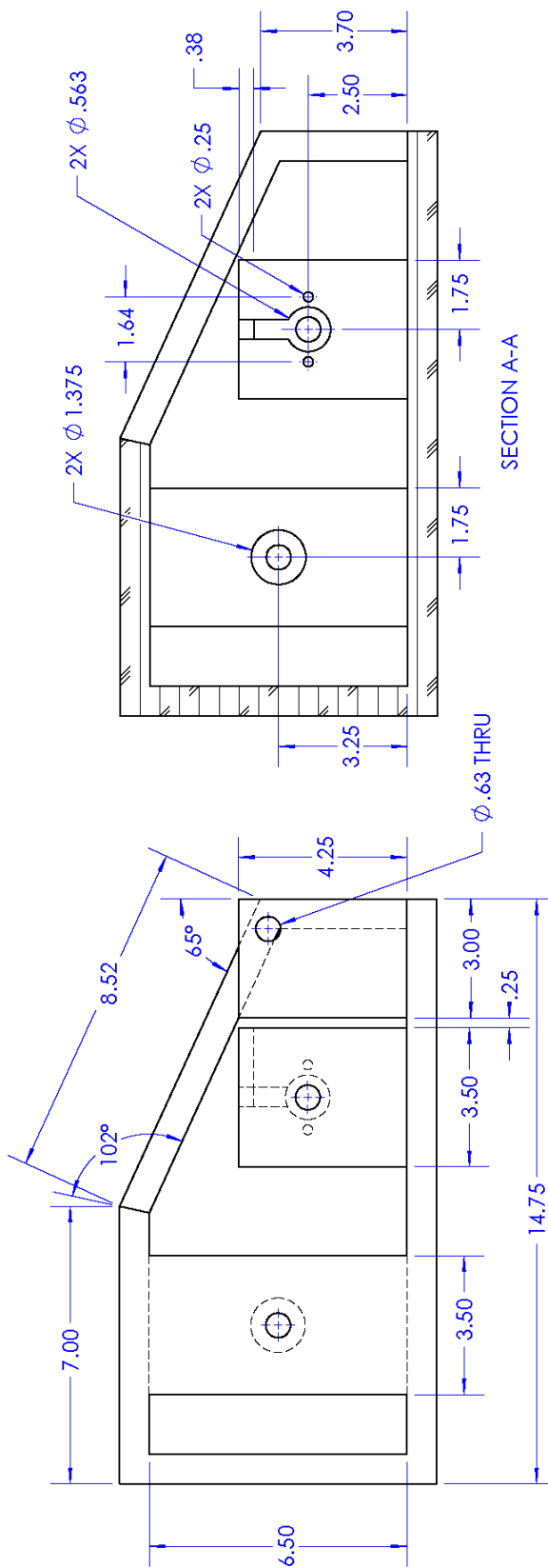
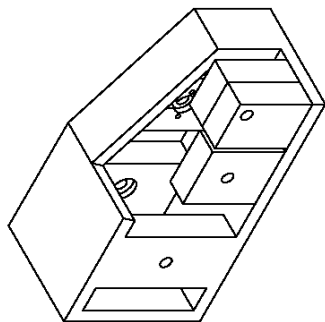
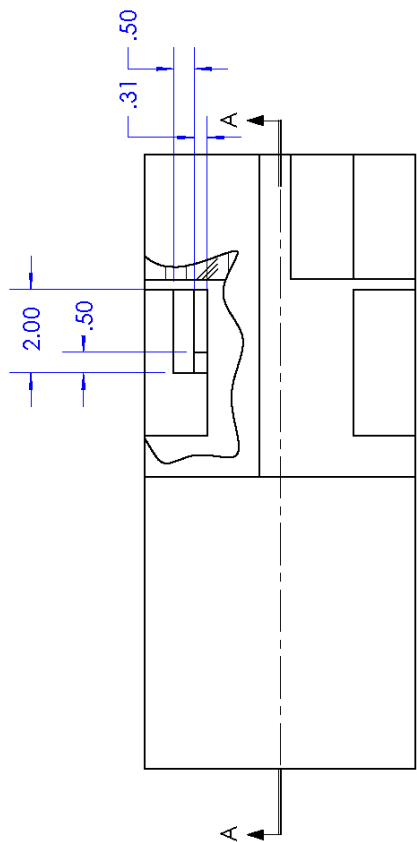
Figure 32: Quality Function Deployment Diagram (QFD)

Appendix B: SolidWorks Drawings

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base	Wood Frame, 2x4's and cut 1x12	1
2	2737T107	ASTM #25 14t 1/2"bore sprocket	1
3	2737T361	ASTM #25 72t 1/2"bore sprocket	1
4	6384K361	1/2" ID sealed flanged bearing	4
5	ConnectorLink	1/4"x1" bar stock	1
6	Crankshaft	1/2" round welded to 1/4"x1"bar	1
7	Flywheel	plastic container, concrete, steel	1
8	FlywheelReinforcement	1 3/8" round with 3/4"x 1/8" arms	1
9	GeneratorShaft	1/2" round, generator shaft	1
10	LinkPin	1/4" round steel with snap ring grooves	2
11	PedalLink	pedal link, 1/8"x3/4" bar	2
12	PedalReinforcement	1/8"x3/4" bar	1
13	Rotor	8 pole 187qmi, for 150cc GY6 motor	1
14	RotorAdaptor	1" Round steel, machined	1
15	Stator	8 pole 187qmi, for 150cc GY6 motor	1
16	PedalPlatform	1x4 poplar	1



 	SCALE: 1:8	DRAWN BY: ACR	TITLE: Charger Assembly	
	TOLERANCE: ±.05, ±.001	DATE: 5/26/2012	MATERIAL: N/A	
	UNITS: Inches	CHECKED: NMH, KKS	DWG #: 0	
	NEXT ASSY: N/A	DATE: 5/26/2012	FILENAME: ChargerAssembly	
	5	4	3	2



SECTION A-A



SCALE: 1:4

TOLERANCE: $\pm .05, \pm .001$

UNITS: Inches

NEXT ASSY: Charger Assy

DRAWN BY: ACR

DATE: 5/26/2012

CHECKED: NMH, KKS

DATE: 5/26/2012

TITLE: Base

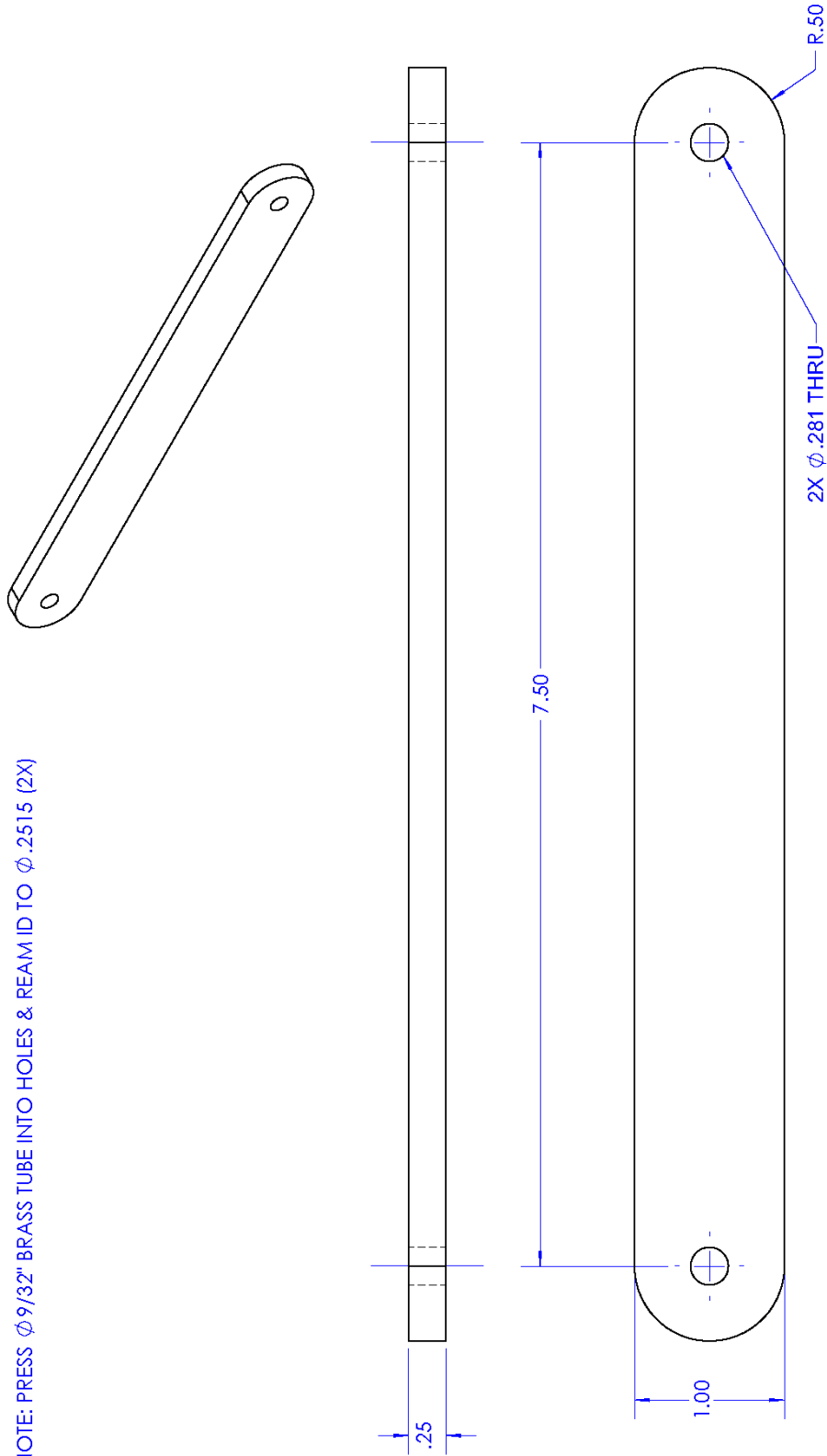
MATERIAL: 2x4 Pine & 1x12 Poplar



DWG #: 1

FILENAME: Base

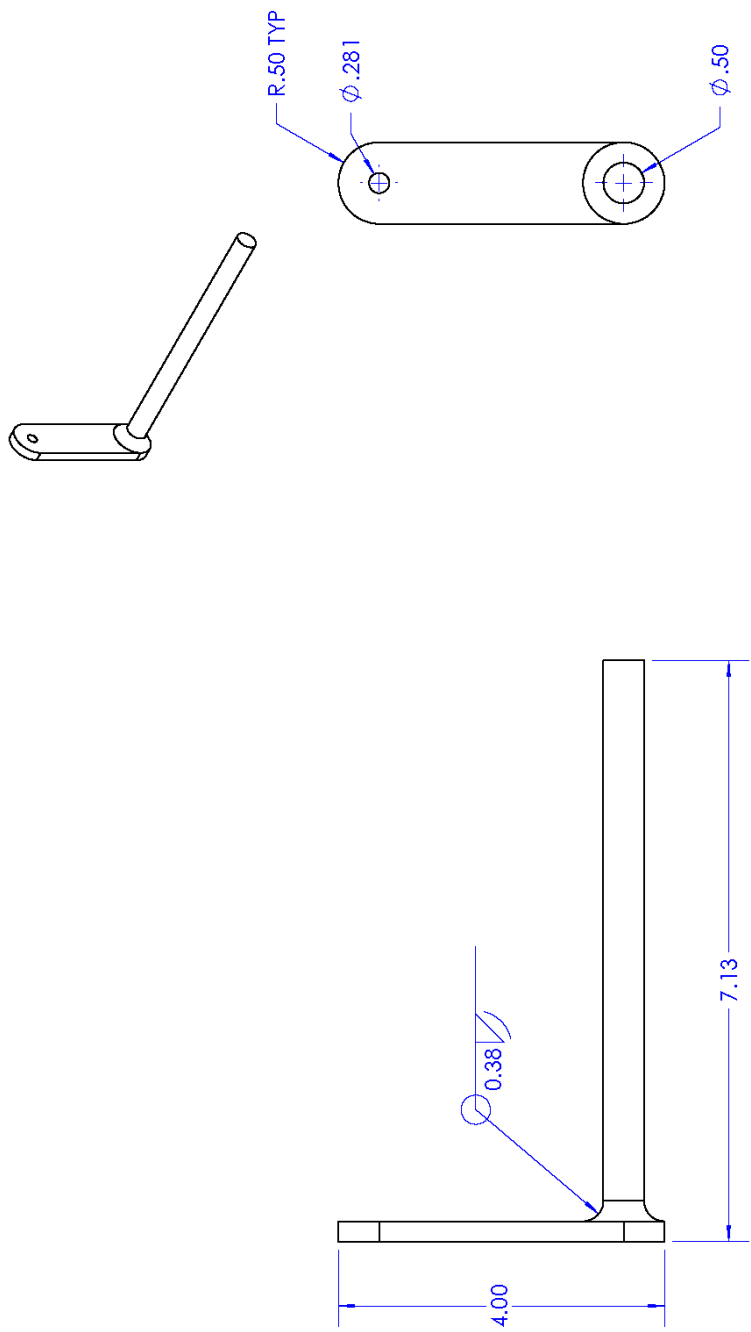
5 4 3 2 1


NOTE: PRESS $\phi 9/32"$ BRASS TUBE INTO HOLES & REAM ID TO $\phi .2515$ (2X)



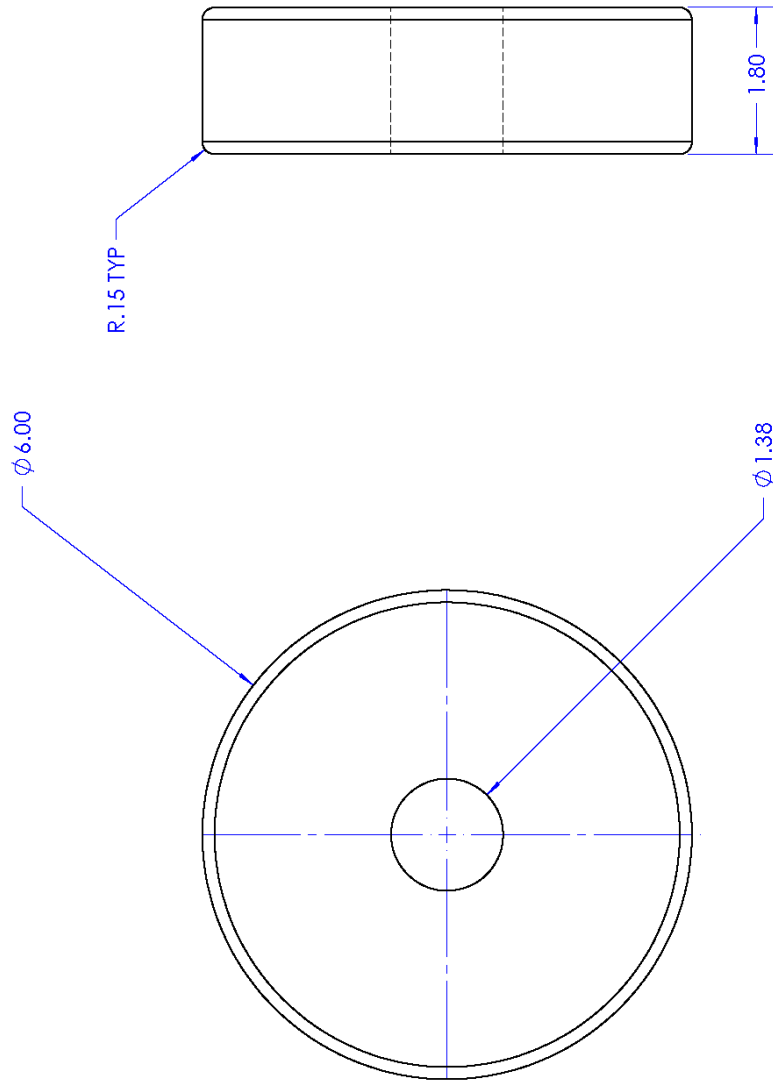
 	SCALE: 1:1	DRAWN BY: ACR	TITLE: Connector Link	
	TOLERANCE: $\pm .05, \pm .001$	DATE: 5/26/2012	MATERIAL: 1"x1/4" steel bar stock	
	UNITS: Inches	CHECKED: NMH, KKS	DWG #: 5	
	NEXT ASSY: Charger Assy	DATE: 5/26/2012	FILENAME: ConnectorLink	
5	4	3	2	1

NOTE: PRESS ϕ 9/32" BRASS TUBE INTO HOLES & REAM ID TO ϕ .2515



	SCALE: 1:2	DRAWN BY: ACR	TITLE: Crankshaft	
	TOLERANCE: $\pm .05, \pm .001$	DATE: 5/26/2012	MATERIAL: 1/2" round & 1"x1/4" bar (steel)	
	UNITS: Inches	CHECKED: NMH, KKS	DWG #: 6	
	NEXT ASSY: Charger Assy	DATE: 5/26/2012	FILENAME: Crankshaft	
5	4	3	2	1

NOTES: 1. TO BE CAST IN 96 oz CLOROX BLEACH BOTTLE SECTION
 2. THE BOTTLE SECTION IS TO BE LEFT AROUND THE DIAMETER TO ADD TO BOTTLE INTEGRITY
 3. THE FLYWHEEL IS TO BE CAST IN MORTAR AROUND PART #3, FLYWHEEL REINFORCEMENT

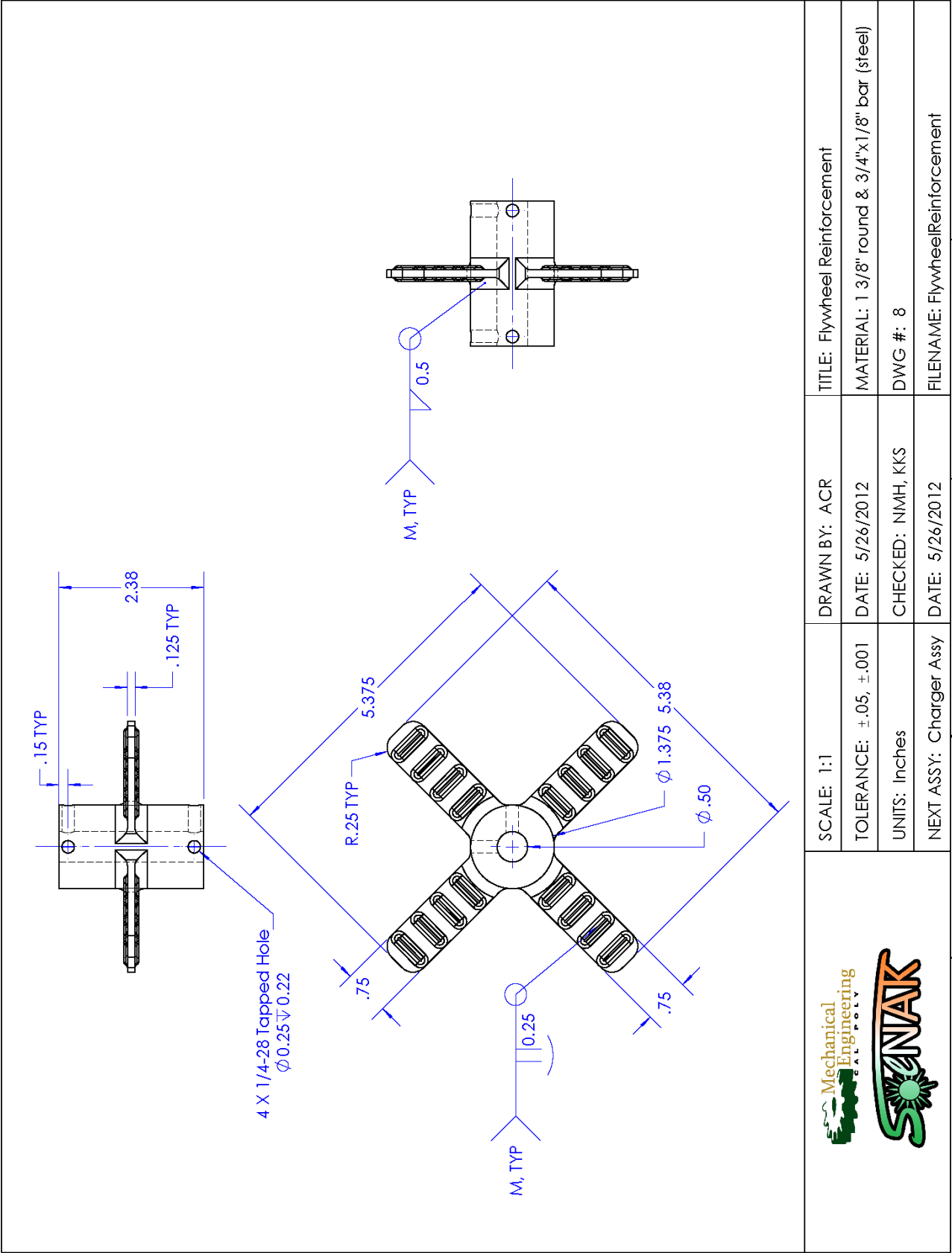


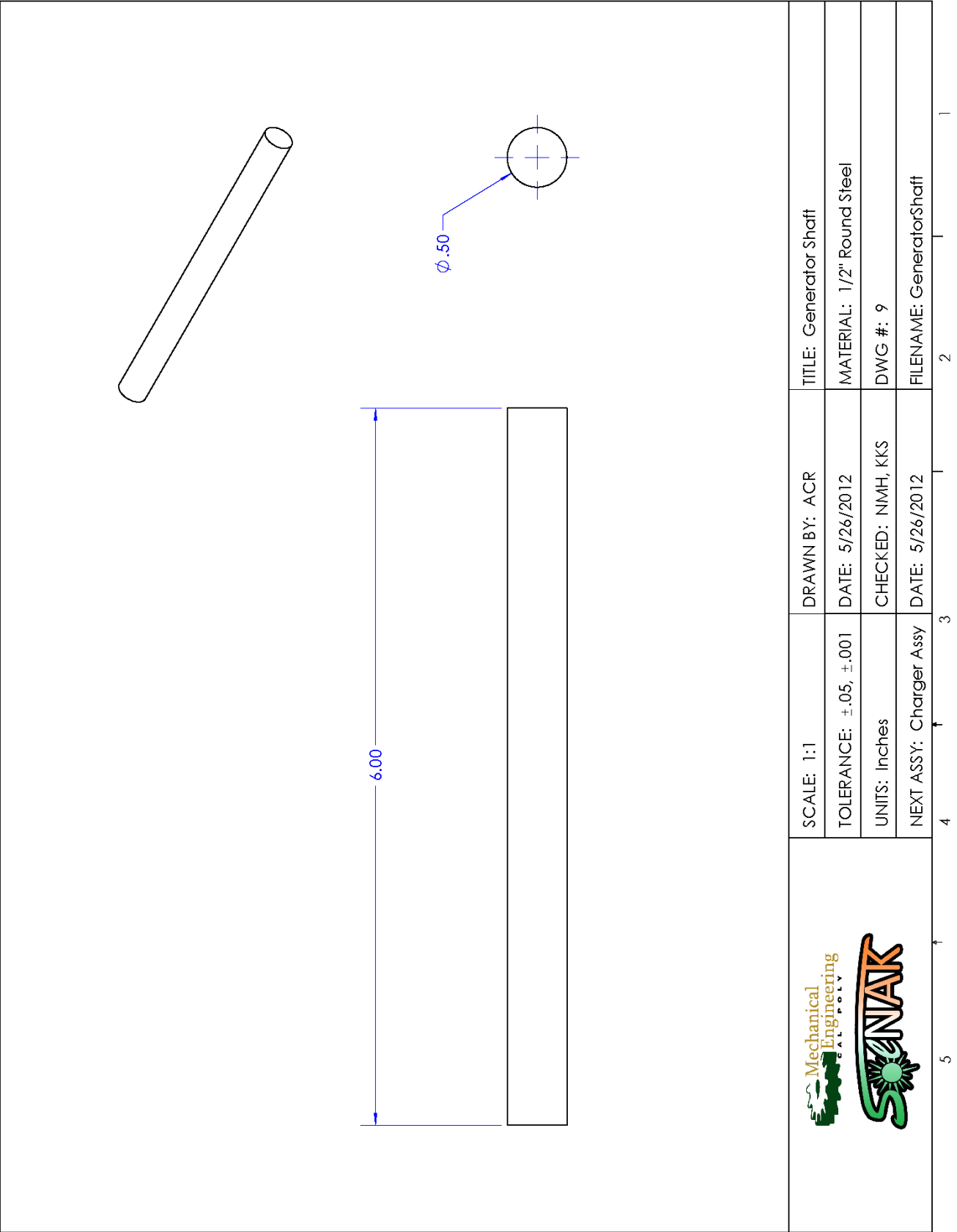
SCALE: 1:2
 TOLERANCE: ± 0.05 , ± 0.001
 UNITS: Inches
 NEXT ASSY: Charger Assy

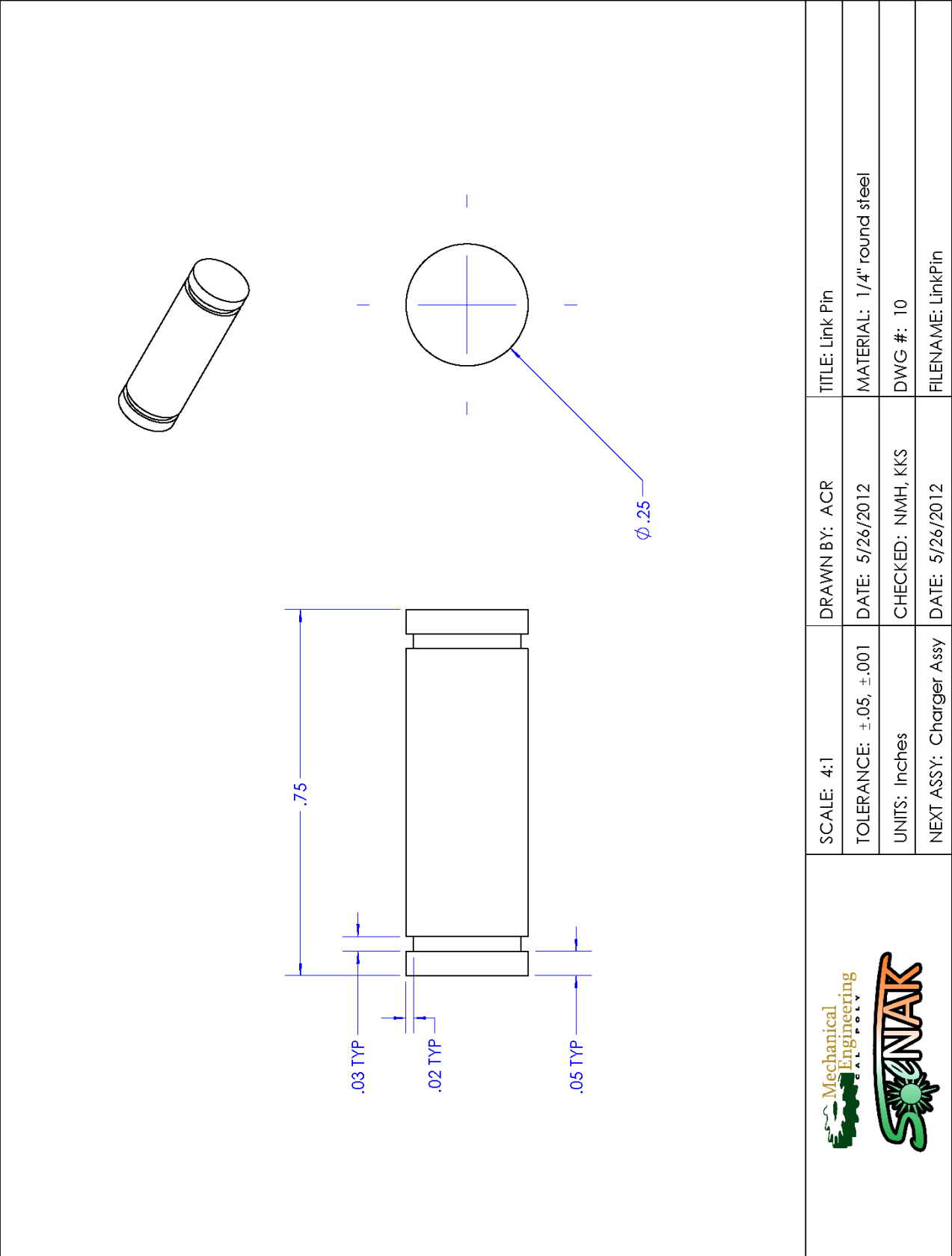
DRAWN BY: ACR
 DATE: 5/26/2012
 CHECKED: NMH, KKS
 DATE: 5/26/2012

TITLE: Flywheel
 MATERIAL: Mortar
 DWG #: 7
 FILENAME: Flywheel

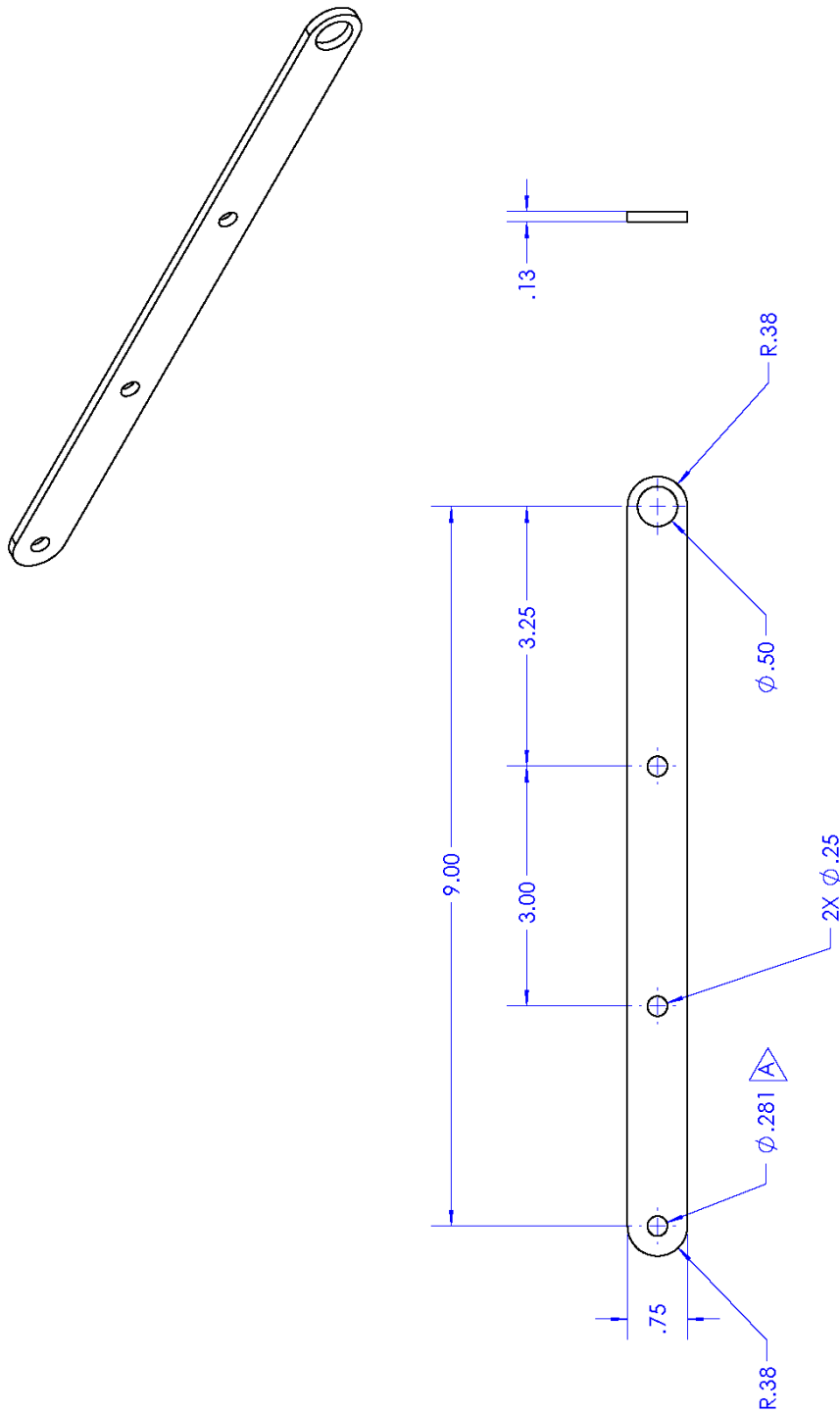
5 4 3 2 1





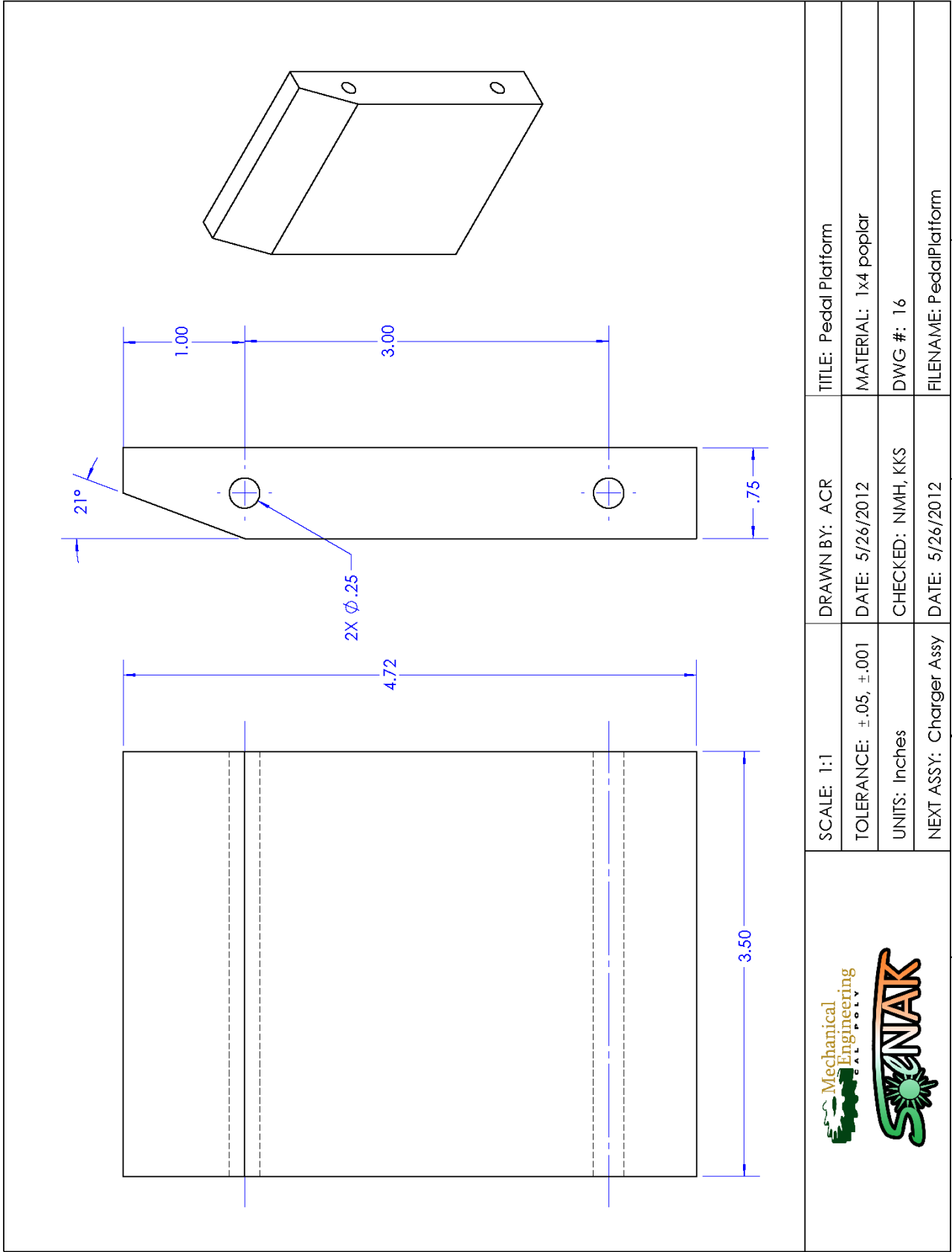


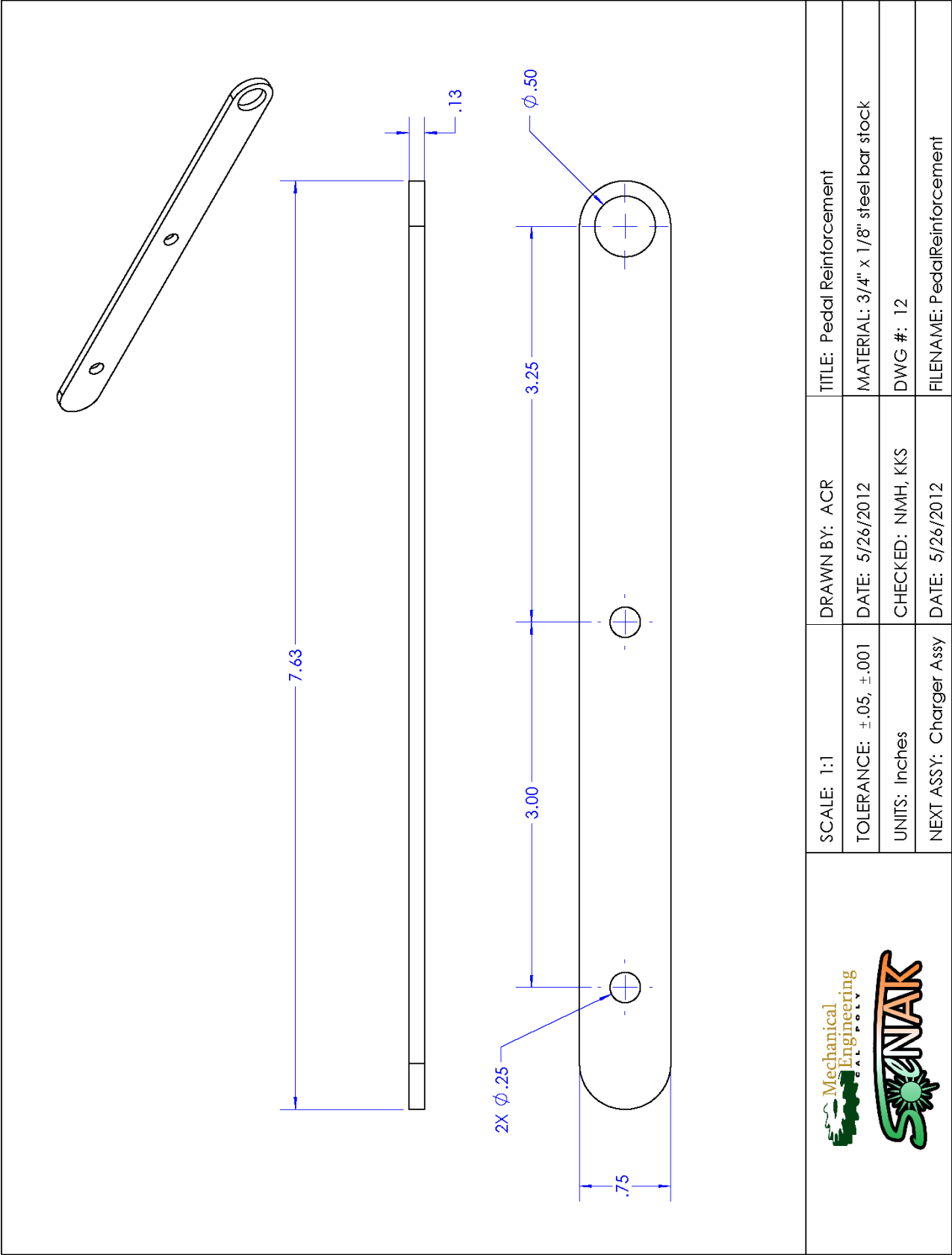


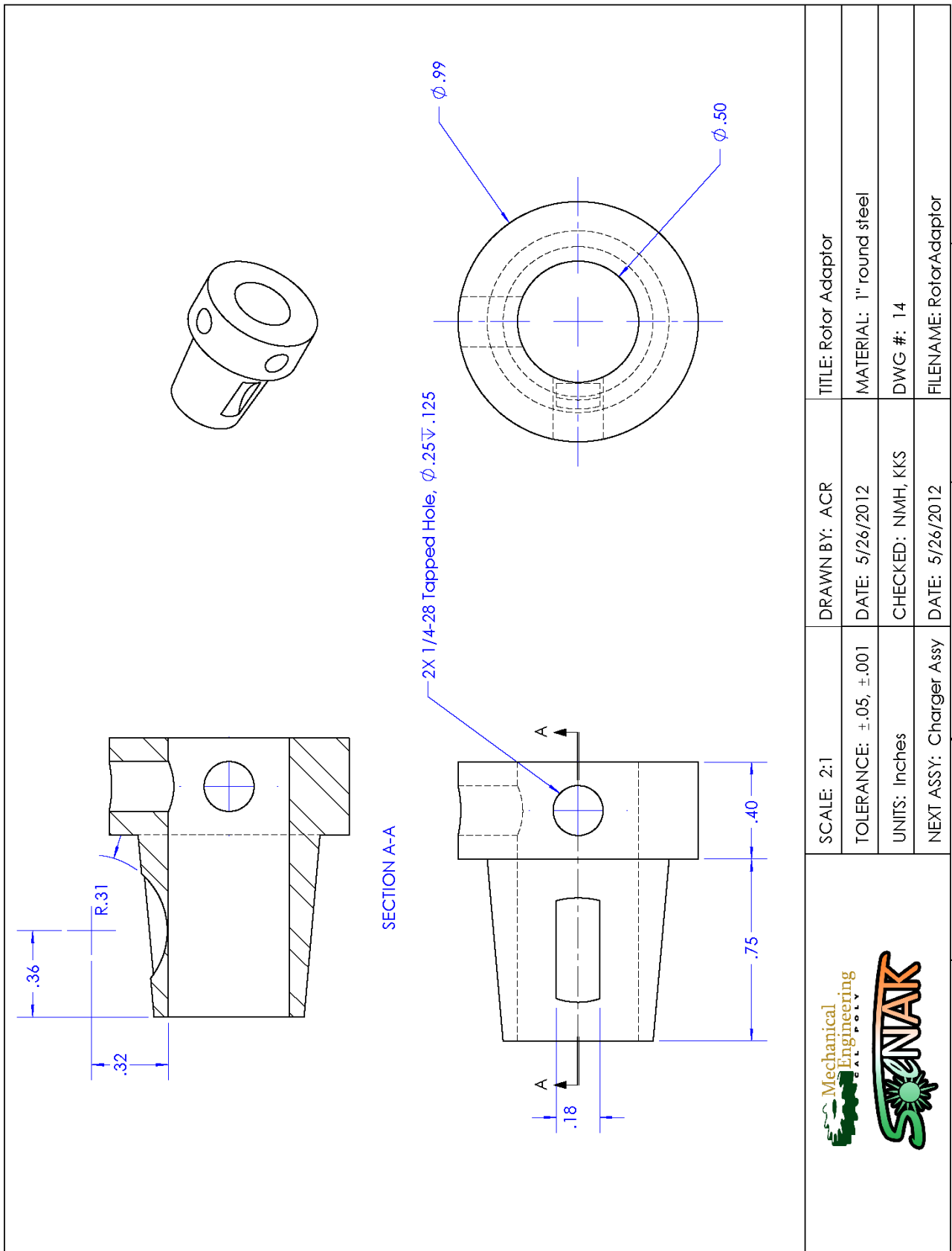
NOTE:  PRESS $\phi 9/32$ " BRASS TUBE INTO HOLES & REAM ID TO $\phi .2515$



 	SCALE: 1:2	DRAWN BY: ACR	TITLE: Pedal Link	
	TOLERANCE: $\pm .05, \pm .001$	DATE: 5/26/2012	MATERIAL: $3/4" \times 1/8"$ steel bar stock	
	UNITS: Inches	CHECKED: NMH, KKS	DWG #: 11	
	NEXT ASSY: Charger Assy	DATE: 5/26/2012	FILENAME: PedalLink	
5	4	3	2	1







Appendix C: List of Vendors, Contact Information Pricing

Table 6: Complete Bill of Materials

Item	Quantity	Unit Cost	Cost	Source
Wood				
1x12 Poplar (/ft)	2	\$3.07	\$6.14	Home Depot
1x4 Poplar (/ft)	2	\$1.47	\$2.94	Home Depot
2x4 Pine (/ft)	2	\$0.32	\$0.64	Home Depot
Steel				
1/4" Round (per 6")	1	\$0.55	\$0.55	Home Depot
1/2" Round (/ft)	2	\$1.92	\$3.84	Home Depot
1" Round (8290T181) /in	2	\$0.87	\$1.74	McMaster-Carr
3/4"x1/8" Bar (3ft)	1	\$4.21	\$4.21	Home Depot
1"x1/4" Bar (/ft)	1	\$2.43	\$2.43	Home Depot
Brass				
9/32x12" Hollow Rod (0.253"ID)	1	\$2.49	\$2.49	Beverly's
Concrete				
10 lb Mortar	1	2.99	\$2.99	Ace Hardware
Drive Components				
GY6 Rotor/Stator 8 pole 1 phase	1	\$35.99	\$35.99	EBAY:az1imports
72T #25 Steel 1/2" Bore Sprocket (2737T361)	1	\$22.51	\$22.51	McMaster-Carr
14T #25 Steel 1/2" Bore Sprocket (2737T107)	1	\$6.41	\$6.41	McMaster-Carr
4' #25 (1/4" pitch) roller chain (6261K284)	1	\$14.92	\$14.92	McMaster-Carr
#25 connecting link	1	\$0.96	\$0.96	McMaster-Carr
Clorox bleach bottle (96oz)	1	\$1.99	\$1.99	Home Depot
Fasteners & Other Components				
1/2" Bearings	4	\$4.06	\$16.24	Ace Hardware
1/2" Bronze bushings	2	\$0.93	\$1.86	Ace Hardware
2 1/2" x 1" Simpson Strong Tie GA 1 Angle	4	0.99	\$3.96	Ace Hardware
1/4" Washers (bag)	2	\$1.18	\$2.36	Home Depot
1/4" Retaining ring (outside)	3	\$0.52	\$1.56	Home Depot
1/4-20 nuts	1	\$1.18	\$1.18	Home Depot
1/4" washers (bag)	1	\$1.18	\$1.18	Home Depot
#6 x 5/8" Screws	1	\$1.18	\$1.18	Home Depot
Hex Bolt 1/4-20 x4 1/2" (ARC)	2	\$0.36	\$0.72	Home Depot
1 1/2" x1" hinge	1	3.59	3.59	Ace Hardware
3"x3/8" Flat brace	2	\$3.59	\$7.18	Ace Hardware
1 1/2" Corner Brace set	1	\$3.59	\$3.59	Ace Hardware
Hook-Eyelet clasp	1	\$2.59	2.59	Ace Hardware
1/4" outside retaining ring	4	\$0.25	\$1.00	Home Depot
1 1/2" Deck Screws	12	0.01	0.12	Ace Hardware
Woodruff Key	1	0.97	0.97	Ace Hardware
Electrical Components				
TBD				
Subtotal	\$160.03			
Tax	\$13.20			
Total	\$173.23			

Appendix D: Vendor supplied data sheets

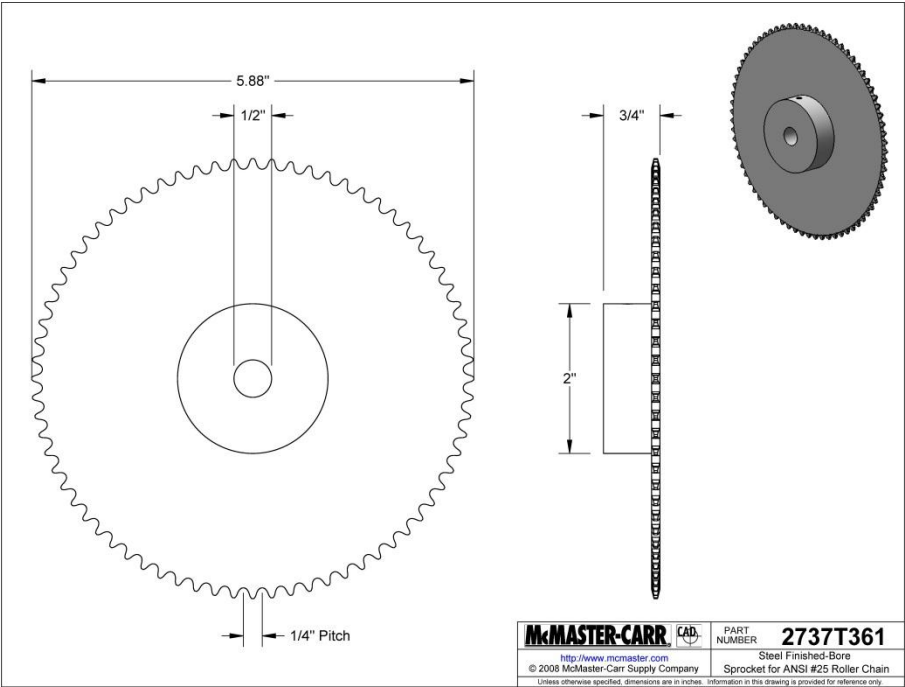


Figure 33: Vendor Drawing Sheet for 72 tooth sprocket from McMaster-Carr

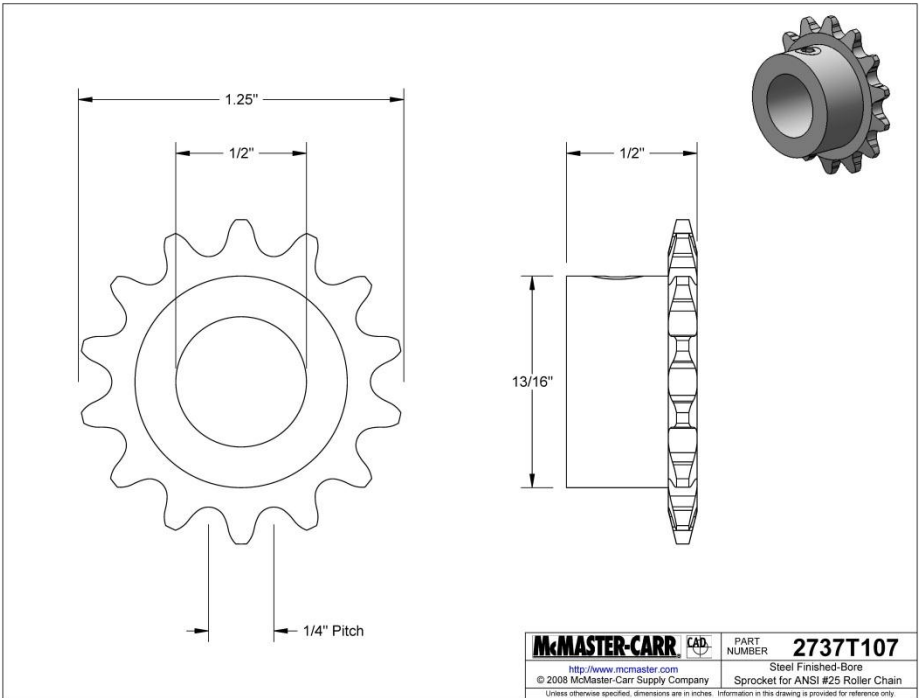
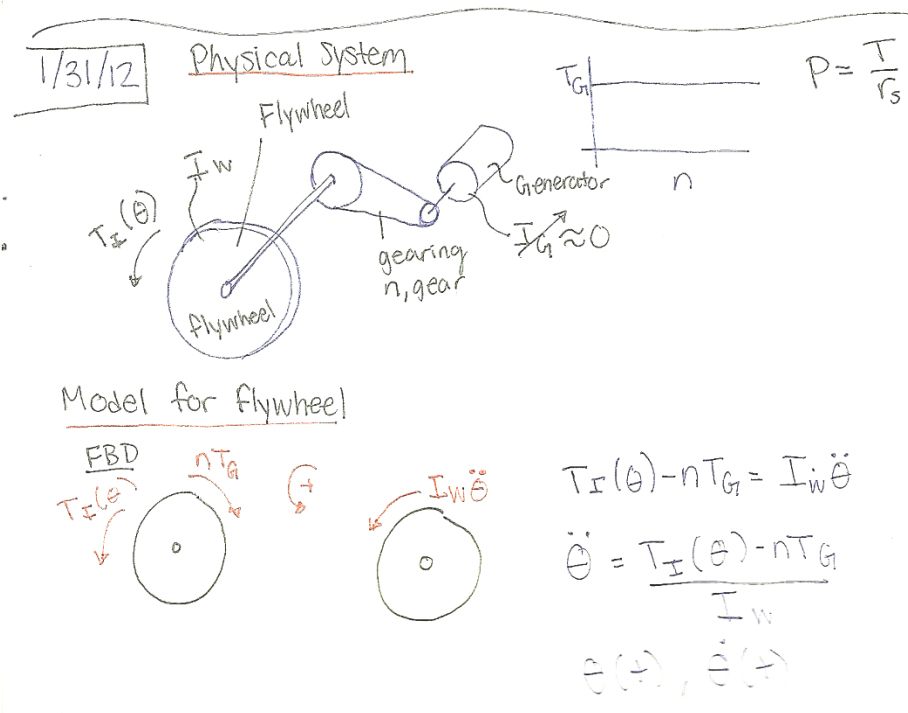
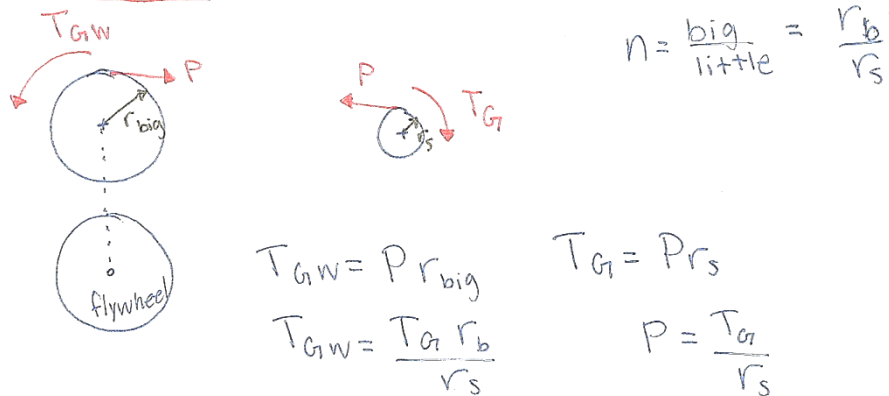


Figure 34: Vendor Drawing Sheet for 14 tooth sprocket from McMaster-Carr

Appendix E: Detailed Supporting Analysis



Model for gearing



Estimate Calculations

$T_I(\theta) \rightarrow$ some sort of sine wave

$$T_I(\theta) = A \sin(\omega t)$$

assuming $\sim 120 \text{ rpm}$ for the speed of wheel

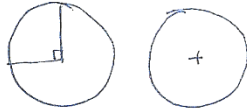
$$\omega = 120 \frac{\text{rev}}{\text{min}} \cdot \frac{2\pi \text{ rad}}{\text{rev}} \cdot \frac{1 \text{ min}}{60 \text{ sec}} = 4\pi \frac{\text{rad}}{\text{sec}}$$

$$T_I(\theta) = T_{\max_{ss}} \sin(4\pi t)$$

$T_{\max_{ss}}$ = max steady-state torque on the wheel from the 4-bar linkage

2/2/12

FLYWHEEL



Assume:

$$\omega_0 = 120 \text{ rpm} = 4\pi \text{ rad/s}$$

T_p is constant from $\theta = 0$ to $\pi/2$

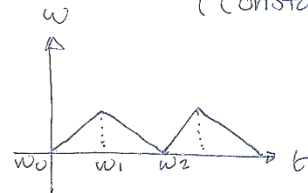
$$T_p - T_G = I \ddot{\theta}$$

To get up to speed

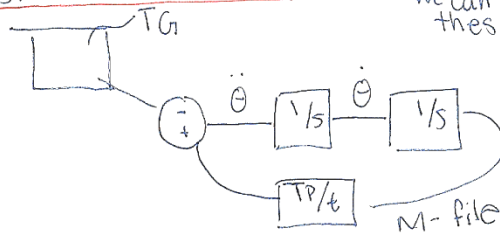
$$\frac{1}{2} I \omega^2 = N \int_0^{\pi/2} T_{pi} d\theta - N \int_0^{2\pi} T_G d\theta$$

\uparrow desired speed \uparrow # of cycles \uparrow initial torque \uparrow torque of generator (constant)

we can change these



SIMULINK MODEL



SIMPLER MODEL

$$\frac{1}{2} I \omega^2 = N \left(\int_0^{\pi/2} T_{pi} d\theta - \int_0^{2\pi} T_G d\theta \right)$$

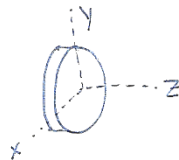
Start-up

$$N = 4 \text{ (revs to steady)}$$

$$\omega = 55 \text{ revs} = 4\pi \text{ rad/s}$$

Find: I, T_G, T_p

Flywheel is assumed to be a solid cylinder



$$I_z = \frac{1}{2} m r^2$$

Solidworks part

$$\text{Volume} \approx 45 \text{ in}^3 = 7.374 \times 10^{-4} \text{ m}^3$$

$$\rho_{\text{cast carbon steel}} = 0.28 \frac{\text{lbs}}{\text{in}^3} = 7.75 \text{ g/cm}^3$$

$$\rho_{\text{concrete are}} = 1.1 \text{ g/cm}^3$$

$$r = 4 \text{ in} = 10.16 \text{ cm}$$

$$\frac{1}{2} I \left(4\pi \frac{\text{rad}}{\text{s}} \right)^2 = 4 \left(\frac{\pi}{2} T_{pL} - 2\pi T_G \right)$$

1st iteration:

assume carbon steel:

$$I = \frac{1}{2} (7.374 \times 10^{-4} \text{ m}^3) (7.75 \times 10^3 \frac{\text{kg}}{\text{m}^3}) (0.1016 \text{ m})^2$$

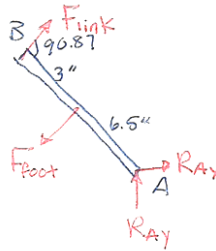
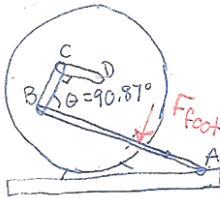
$$I = 0.0295 \text{ kg-m}^2$$

Continued Analysis on simpler model

1st Iteration:

Carbon steel $I = \frac{1}{2} (7.374 \times 10^{-4} \text{ m}^3) (7.75 \times 10^3 \frac{\text{kg}}{\text{m}^3}) (0.1016 \text{ m})^2$
 $I = 0.0295 \text{ kg} \cdot \text{m}^2$

Finding T_{pedal} :

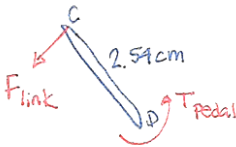


$$\sum M_A = 0$$

$$F_{\text{foot}} (6.5'') + F_{\text{link}} \sin(90.87'') (9.5'') = 0$$

$$F_{\text{link}} = \frac{F_{\text{foot}} (6.5'')}{\sin(90.87'') (9.5'')}$$

$$F_{\text{link}} = 0.6843 F_{\text{foot}}$$



$$\sum M_D = T_{\text{pedal}} = (0.6843 F_{\text{foot}}) (0.0254 \text{ m})$$

$$T_{\text{pedal}} = 0.01738 F_{\text{foot}} \text{ N} \cdot \text{m}$$

$$4\pi I = T_{\text{pi}} - 4T_G$$

$$4\pi \frac{1}{2} (0.0295 \text{ kg} \cdot \text{m}^2) = (0.01738 F_{\text{foot}}) - 4T_G$$

$$0.3707 - 0.01738 F_{\text{foot}} = -4T_G$$

$$T_G = 4.345 \times 10^{-3} F_{\text{foot}} - 9.268 \times 10^{-2}$$

(N·m)

(N)

Motor Calculations

$$H = Tw$$

$$\frac{5 \text{ W}}{0.75} = 6.667 \text{ W}$$

losses from
DC to DC

$$\frac{6.667 \text{ W}}{0.6} = 11.11 \text{ W}$$

losses from
motor

needed input at
motor

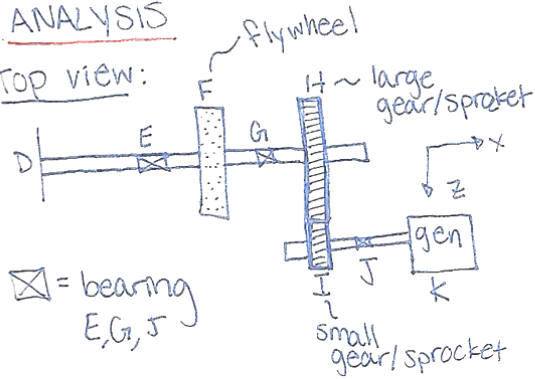
$$11.11 \text{ W} = 1 \times 10^{-7} \text{ W}^2 + 4 \times 10^{-5} \text{ W}$$

$$W = 10,342 \text{ RPM} = 1083 \text{ rad/s}$$

$$T = \frac{H}{W} = \frac{11.11 \text{ W}}{1083 \text{ rad/s}} = 0.01026 \text{ N} \cdot \text{m} \leftarrow \text{torque at input of generator}$$

ANALYSIS

Top view:



Known:

Forces/Torque at D
Torque at K
gear/sprocket ratio @ K
(2:1)
for now
shaft material (steel)
flywheel material (concrete)

Assumptions:

- Weight of sprocket/gears neglected
- flywheel size = 8 in \varnothing , 2 in wide for first iteration

Calculations:

$$H = T\omega$$

$$H_K = 20 \text{ W} \leftarrow \text{assumed output from generator from manufacturer at 240 rpm}$$

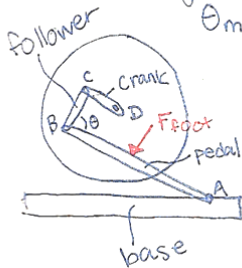
$$T_K = \frac{H}{\omega} = \frac{20 \text{ W}}{8\pi \text{ rad/s}} = \frac{5}{2\pi} \text{ N}\cdot\text{m} = 0.796 \text{ N}\cdot\text{m}$$

with gear ratio:

$$T_H = (2)T_K = 2\left(\frac{5}{2\pi} \text{ N}\cdot\text{m}\right) = 1.592 \text{ N}\cdot\text{m}$$

TORQUE from 4-bar

Pedal length = 9.5" with force applied at 6.5" up pedal
 $\theta_{\text{max torque}} = 90.87^\circ$



Assume: $F_{\text{foot}} \approx 50 \text{ N}$

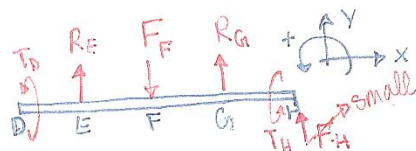
from equations on 2/4/12

$$F_{\text{crank}} = \frac{F_{\text{foot}} l_{\text{to force}}}{\sin \theta l_{\text{pedal}}} = \frac{(50 \text{ N})(6.5")}{\sin(90.87^\circ)(9.5")}$$

$$F_{\text{crank}} = 34.214 \text{ N}$$

$$T_D = F_{\text{crank}}(l_{\text{co}}) = (34.214 \text{ N})(0.0254 \text{ m})$$

$$T_D = 0.869 \text{ N}\cdot\text{m}$$



preliminary lengths along shaft:

$$l_{DE} = 1.5 \text{ in} \quad l_{FG} = 2.5 \text{ in}$$

$$l_{EF} = 2.5 \text{ in} \quad l_{GH} = 2 \text{ in}$$

$$T_D = 0.869 \text{ N}\cdot\text{m} \quad T_H = 1.591 \text{ N}\cdot\text{m}$$

F_F = weight of flywheel

$\rho_{\text{concrete}} \approx 2.3 \text{ g/cm}^3$ heat transfer book T-A3

$$\gamma = \rho g = (2.30 \text{ g/cm}^3)(9.81 \text{ m/s}^2) = (2.30 \frac{\text{g}}{\text{cm}^3}) \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 (9.81 \frac{\text{m}}{\text{s}^2})$$

$$\gamma = 22563 \frac{\text{kg}}{\text{m}^3 \text{s}^2}$$

$$F_F = \gamma (V_F) = (22563 \frac{\text{kg}}{\text{m}^3 \text{s}^2}) (\pi (4 \text{ in})^2 (2 \text{ in})) \left(\left(\frac{0.0254 \text{ m}}{1 \text{ in}} \right)^3 \right)$$

$$F_F = 37.17 \text{ N}$$

F_H is neglected in the y direction

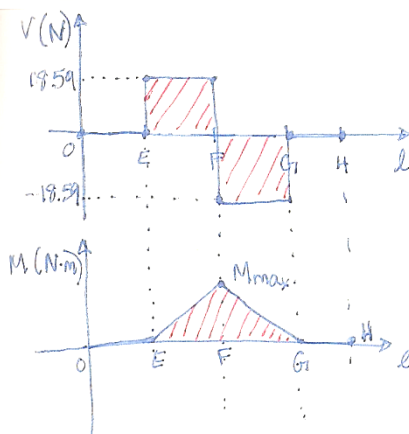
$$\sum M_E = 0$$

$$-F_F(l_{EF}) + R_G(l_{EF} + l_{FG}) = 0$$

$$R_G = \frac{F_F(l_{EF})}{l_{EF} + l_{FG}} = \frac{(37.17 \text{ N})(2.5 \text{ in})}{(2.5 \text{ in} + 2.5 \text{ in})} = 18.59 \text{ N}$$

$$\therefore R_E = 18.59 \text{ N}$$

Shear diagram (V)



$$M_{\text{max}} = (18.59 \text{ N})(2.5 \text{ in}) \left(\frac{0.0254 \text{ m}}{1 \text{ in}} \right)$$

$$M_{\text{max}} = 1.180 \text{ N}\cdot\text{m}$$

$\sigma_{\text{all}} = 210 \text{ MPa}$ (Plain steel 1020 HR carbon steel)

$$\sigma = \frac{Mc}{I} = \frac{M_{\text{max}} \left(\frac{d}{2} \right)}{\frac{\pi}{64} d^4}$$

$$210 \text{ MPa} = \frac{(1.180 \text{ N}\cdot\text{m}) 32}{\pi d^3}$$

$$d = 3.85 \text{ mm} \rightarrow 0.152'' \rightarrow \text{minimum diameter} = \underline{\underline{3/16''}} \text{ due to bending}$$

check due to Torsion

$$T_{TOTAL} = T_D + T_H = 0.869 \text{ N}\cdot\text{m} + 1.591 \text{ N}\cdot\text{m}$$

$$T_{TOTAL} = \underline{2.460 \text{ N}\cdot\text{m}}$$

$$\tau_{all} = \frac{T r}{J}$$

$$\tau_{all} = 0.577 S_y = 0.577(380 \text{ MPa}) = 219.26 \text{ MPa}$$

$$J = \frac{\pi}{32} d^4 \leftarrow \text{for solid cylinder}$$

$$\tau = \frac{T_{TOTAL} \left(\frac{d}{2} \right)}{\frac{\pi}{32} d^4}$$

$$219.26 \text{ MPa} = \frac{(2.460 \text{ N}\cdot\text{m}) (16)}{\pi d^3}$$

$$d = 3.85 \text{ mm} \rightarrow 0.152'' \rightarrow \underline{3/16}'' \text{ minimum diameter due to torsion}$$

2/29/12

CALCULATIONS

sprockets:

ustsubaki.com/pdf/110916-sprocket_catalog.pdf

$$d_A = 3.964 \quad d_B = 2.049 \quad d_{sp} = 5 \text{ in}$$

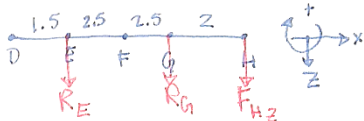
$$F_{Hy} = -\frac{T_H (r_A - r_B)}{d_{sp} r_A} = \frac{-1.591 \text{ N}\cdot\text{m} (3.964 - 2.049) \frac{1}{2} \text{ in}}{(5 \text{ in}) (3.964 \text{ in}) \left(\frac{0.0254 \text{ m}}{1 \text{ in}} \right)}$$

*F_{Hy} incorrect
by factor of 2
forgot to
use r + not d*

$$F_{Hy} = \underline{-3.026 \text{ N}} \quad (\text{we assumed this was negligible in hand calcs but we will add it to the EES program})$$

$$F_{Hz} = -\frac{d_{sp} F_{Hy}}{r_A - r_B} = \frac{-5 \text{ in} (-3.026 \text{ N})}{(3.964 - 2.049) \frac{1}{2} \text{ in}}$$

$$F_{Hz} = \underline{15.802 \text{ N}}$$



$$\sum \mathcal{M}_E = 0 = +R_G(l_{EF} + l_{FG}) + F_{Hz}(l_{EF} + l_{FG} + l_{GH})$$

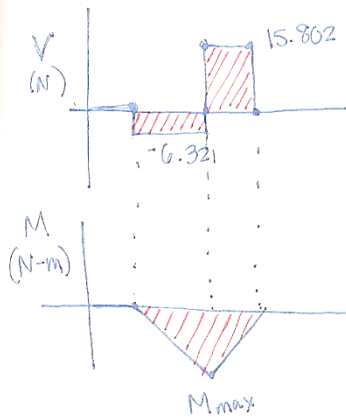
$$R_G = -F_{Hz}(l_{EF} + l_{FG} + l_{GH}) = \frac{-15.802 \text{ N}(2.5 + 2.5 + 2) \text{ in}}{(2.5 + 2.5) \text{ in}}$$

$$R_G = -22.123 \text{ N}$$

$$\sum F_z = 0 = R_G + R_E + F_{Hz}$$

$$R_E = -R_G - F_{Hz} = 22.123 \text{ N} - 15.802 \text{ N}$$

$$R_E = 6.321 \text{ N}$$



$$M_{\max} = (15.802)(2 \text{ in}) \left(\frac{0.0254 \text{ m}}{\text{in}} \right) = 0.803 \text{ N}\cdot\text{m}$$

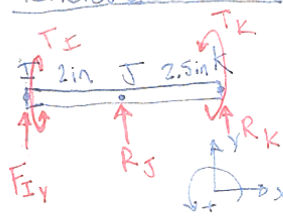
$$\sigma_{\text{all}} = 210 \text{ MPa}$$

$$\sigma = \frac{Mc}{I} = \frac{M_{\max} \left(\frac{d}{2} \right)}{\frac{\pi}{64} d^4} = \frac{32 M_{\max}}{\pi d^3}$$

$$d_{\min} = 3.39 \text{ mm} \rightarrow \underline{\underline{3/16}} \text{ shaft}$$

For factor of safety pick 1/2 shaft
fs of > 2

Generator shaft



$$T_I = \frac{T_D}{\text{sprocket ratio}} = \frac{0.869 \text{ N}\cdot\text{m}}{2}$$

$$T_I = 0.4345 \text{ N}\cdot\text{m}$$

$$T_K = 0.796 \text{ N}\cdot\text{m} \text{ (from previous calcs)}$$

$F_{Iy} = F_{Hy}$ ← transmitted between shafts from chain/gear

$$F_{Iy} = 3.026 \text{ N}$$

$$\sum M_K = 0$$

$$-F_{Iy}(l_{IJ} + l_{JK}) - R_J(l_{JK}) = 0$$

$$R_J = \frac{-F_{Iy}(l_{IJ} + l_{JK})}{l_{JK}} = \frac{-3.026 \text{ N}(2 + 2.5) \text{ in}}{2.5 \text{ in}}$$

$$R_J = -5.447 \text{ N}$$

$$\sum F_y = 0$$

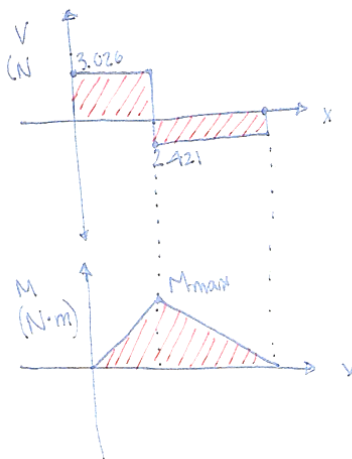
$$F_{Iy} + R_J + R_K = 0$$

$$R_K = -F_{Iy} - R_J$$

$$R_K = -(3.026 + 5.447) \text{ N}$$

$$R_K = -2.421 \text{ N}$$

shear diagram



$$M_{\max} = 3.026 \text{ N}(2 \text{ in}) \left(\frac{0.0254 \text{ m}}{1 \text{ in}} \right)$$

$$M_{\max} = 0.154 \text{ N}\cdot\text{m}$$

$$\sigma_{\text{all}} = 210 \text{ MPa}$$

$$\sigma = \frac{32 M_{\max}}{\pi d^3} = \sigma_{\text{all}}$$

$$d_{\min} = 1.95 \text{ mm}$$

$$d_{\min} = 0.765'' \rightarrow \text{pick } 1/8'' \text{ shaft}$$

TORSION

$$T_{TOTAL} = T_J + T_K = \frac{5}{2\pi} + 0.4345 \text{ N}\cdot\text{m}$$

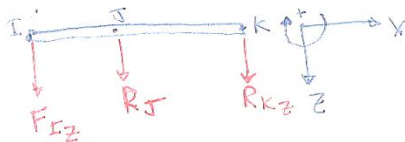
$$T_{TOTAL} = 1.230 \text{ N}\cdot\text{m}$$

$$\tau_{all} = 0.577 S_y = 0.577 (380 \text{ MPa}) = 219.26 \text{ MPa}$$

$$\tau = \frac{T r}{J} = \frac{T_{TOTAL} (\frac{d}{2})}{\frac{\pi}{32} d^4} = \tau_{all}$$

$$219.26 \text{ MPa} = \frac{16 T_{TOTAL}}{\pi d^3} \Rightarrow d_{min} = 3.06 \text{ mm}$$

$$d_{min} = 0.120 \Rightarrow \text{pick } \underline{1/8"} \text{ for minimum shaft diameter}$$



$$F_{Iz} = -F_{Hz} = -15.802 \text{ N}$$

$$\sum M_K = 0 = -F_{Iz}(l_{IJ} + l_{JK}) - R_J(l_{JK})$$

$$R_J = -\frac{F_{Iz}(l_{IJ} + l_{JK})}{l_{JK}} = \frac{15.802 \text{ N}(2 + 2.5) \text{ in}}{2.5 \text{ in}}$$

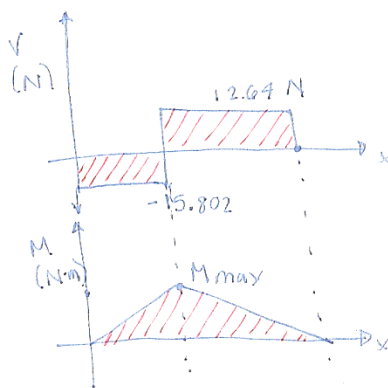
$$R_J = 28.44 \text{ N}$$

$$\sum F_z = 0$$

$$F_{Iz} + R_J + R_{Kz} = 0$$

$$-15.802 + 28.44 \text{ N} + R_{Kz} = 0$$

$$R_{Kz} = -12.64 \text{ N}$$



$$M_{max} = (15.802 \text{ N})(2 \text{ in}) \left(\frac{0.0254 \text{ m}}{\text{lin}} \right) = 0.803 \text{ N}\cdot\text{m}$$

$$\sigma_{all} = 210 \text{ MPa}$$

$$\sigma = \frac{32 M_{max}}{\pi d^3} = \sigma_{all}$$

$$d_{min} = 3.39 \text{ mm} \rightarrow \underline{3/16"} \text{ (Note: handwritten as 3/16, but calculation shows 3.39 mm)}$$

with a factor of safety of 2 pick
Generator shaft to be 3/8"

Appendix F: EES Code for Shaft Sizing

Program to Calculate shaft force and sizes

SoINAK

Nicole Hensley, Krista Schmidt, and Anthony Ruh

3/1/12

Program based off of sample calculations done on 2/26 and 2/29 in senior project notebook

KNOWN

Material for shafts is hot rolled plain 1020 carbon steel

$$\sigma_{all} = 2.1 \times 10^8 \text{ yield strength in MPa}$$

$$S_y = 3.8 \times 10^8 \text{ tensile yield strength in MPa}$$

$$\tau_{all} = 0.577 \cdot S_y \text{ maximum torsional strength}$$

FLYWHEEL

Flywheel is made of concrete

$$\rho_{concrete} = 2300 \text{ density of concrete in kg/m}^3$$

$$D_{fly} = 4 \text{ Diameter of flywheel in inches}$$

$$th_{fly} = 2 \text{ thickness of flywheel in inches}$$

GENERATOR

$$H = 20 \text{ Power input to generator in Watts}$$

$$\omega = 8 \cdot \pi \text{ speed in rad/s, 240 RPM}$$

SPROCKET SIZING

$$n_A = 48 \text{ Number of teeth on larger sprocket}$$

$$d_A = 3.964 \text{ Diameter of larger sprocket in inches}$$

$$n_B = 24 \text{ Number of teeth on smaller sprocket}$$

$$d_B = 2.049 \text{ Diameter of smaller sprocket in inches}$$

$$d_{sp} = 5 \text{ distance of shaft spacing due to sprocket and chain}$$

LENGTHS

Refer to figures in notebook on 2/26 for placement

$$L_{AB} = 9.5 \text{ Length of foot pedal in inches}$$

$$L_{Ato,F} = 6.5 \text{ length from pivot A to the location of applied foot force in inches}$$

$$L_{CD} = 1 \text{ length of crank CD in inches}$$

$$L_{DE} = 1.5 \text{ inches}$$

$$L_{EF} = 2.5 \text{ inches}$$

$$L_{FG} = 2.5 \text{ inches}$$

$$L_{GH} = 2 \text{ inches}$$

$$L_{IJ} = 2 \text{ inches}$$

$$L_{JK} = 2.5 \text{ inches}$$

$$\theta_B = 90.87 \text{ Angle between pedal and connector link in degrees at max torque position}$$

CALCULATIONS

TORQUES

$$T_K = \frac{H}{\omega} \text{ N-m Torque on generator shaft due to generator}$$

$$T_H = \frac{n_A}{n_B} \cdot T_K \text{ N-m Torque on crankshaft due to generator}$$

$$T_D = F_{\text{crank}} \cdot L_{CD} \cdot 0.0254 \text{ N-m Torque on crankshaft due to four bar linkage}$$

$$T_I = T_D \cdot \frac{n_B}{n_A} \text{ N-m Torque on generator shaft due to four bar linkage}$$

FORCES

$$F_{\text{foot}} = 50 \text{ Force of foot in N, perpendicular to pedal located at } L_{Ato,F}$$

$$F_{\text{crank}} = F_{\text{foot}} \cdot \frac{L_{Ato,F}}{\sin(\theta_B) \cdot L_{AB}} \text{ Force of the crank on the crankshaft in N}$$

$$F_{F,y} = -\rho_{\text{concrete}} \cdot 9.81 \cdot \pi \cdot D_{\text{fly}}^2 \cdot t_{\text{fly}} \cdot 0.0254^3 \text{ Weight of flywheel using concrete in N}$$

$$F_{H,y} = -T_H \cdot \left[\frac{d_A - d_B}{d_{sp} \cdot d_A \cdot 0.0254} \right] \text{ Force on crankshaft in the y-direction due to chain tension}$$

$$F_{H,z} = -2 \cdot d_{sp} \cdot \left[\frac{F_{H,y}}{d_A - d_B} \right] \text{ Force on crankshaft in the z-direction due to chain tension}$$

$$R_{G,y} = \frac{-F_{F,y} \cdot L_{EF} - F_{H,y} \cdot (L_{EF} + L_{FG} + L_{GH})}{L_{EF} + L_{FG}} \text{ Reaction due to the bearing at G in the y-direction}$$

$$R_{G,z} = -F_{H,z} \cdot \left[\frac{L_{EF} + L_{FG} + L_{GH}}{L_{EF} + L_{FG}} \right] \text{ Reaction due to the bearing at G in the z-direction}$$

$$R_{E,y} = -(F_{F,y} + R_{G,y} + F_{H,y}) \text{ Reaction due to the bearing at E in the y-direction}$$

$$R_{E,z} = -(R_{G,z} + F_{H,z}) \text{ Reaction due to the bearing at E in the z-direction}$$

$$F_{I,y} = -F_{H,y}$$

$$F_{I,z} = -F_{H,z}$$

$$R_{J,y} = -F_{H,y} \cdot \left[\frac{L_{IJ} + L_{JK}}{L_{JK}} \right]$$

$$R_{J,z} = -F_{I,z} \cdot \left[\frac{L_{IJ} + L_{JK}}{L_{JK}} \right]$$

$$R_{K,y} = -(F_{I,y} + R_{J,y})$$

$$R_{K,z} = -(F_{I,z} + R_{J,z})$$

FINDING MINIMUM DIAMETERS

$$M_{\text{crankshaft},z} = R_{E,y} \cdot L_{EF} \cdot 0.0254 \quad \text{Max moment on crankshaft about z-direction}$$

$$\sigma_{\text{all}} = 32 \cdot \frac{M_{\text{crankshaft},z}}{\pi \cdot \left[d_{\text{crank,bend},z} \cdot \frac{10^{-3}}{0.0254} \right]^3} \quad \text{Finding d in inches based on allowable bending stress in z-direction}$$

$$M_{\text{crankshaft},y} = F_{H,z} \cdot L_{GH} \cdot 0.0254 \quad \text{Max moment on crankshaft about y-direction}$$

$$\sigma_{\text{all}} = 32 \cdot \frac{M_{\text{crankshaft},y}}{\pi \cdot \left[d_{\text{crank,bend},y} \cdot \frac{10^{-3}}{0.0254} \right]^3} \quad \text{Finding d in inches based on allowable bending stress in y-direction}$$

$$T_{\text{tot,crankshaft}} = T_D + T_H \quad \text{Total torque on the crankshaft}$$

$$\tau_{\text{all}} = 16 \cdot \frac{T_{\text{tot,crankshaft}}}{\pi \cdot \left[d_{\text{crank,tors},x} \cdot \frac{10^{-3}}{0.0254} \right]^3} \quad \text{Finding d in inches based on allowable torsional stress}$$

$$M_{\text{genshaft},z} = F_{I,y} \cdot L_{IJ} \cdot 0.0254 \quad \text{Max moment on generator shaft about z-direction}$$

$$\sigma_{\text{all}} = 32 \cdot \frac{M_{\text{genshaft},z}}{\pi \cdot \left[d_{\text{gen,bend},z} \cdot \frac{10^{-3}}{0.0254} \right]^3} \quad \text{Finding d in inches based on allowable bending stress in z-direction}$$

$$M_{\text{genshaft},y} = -F_{I,z} \cdot L_{IJ} \cdot 0.0254 \quad \text{Max moment on generator shaft about y-direction}$$

$$\sigma_{\text{all}} = 32 \cdot \frac{M_{\text{genshaft},y}}{\pi \cdot \left[d_{\text{gen,bend},y} \cdot \frac{10^{-3}}{0.0254} \right]^3} \quad \text{Finding d in inches based on allowable bending stress in y-direction}$$

$$T_{\text{tot,genshaft}} = T_I + T_K \quad \text{Total torque on the generator shaft}$$

$$\tau_{\text{all}} = 16 \cdot \frac{T_{\text{tot,genshaft}}}{\pi \cdot \left[d_{\text{gen,tors},x} \cdot \frac{10^{-3}}{0.0254} \right]^3} \quad \text{Finding d in inches based on allowable torsional stress}$$

EES Sample Solution Set:

Unit Settings: SI C kPa kJ mass deg

$d_A = 3.964$ [in]	$d_B = 2.049$ [in]	$d_{\text{crank,bend,y}} = 0.1085$ [in]	$d_{\text{crank,bend,z}} = 0.09344$ [in]	$d_{\text{crank,tors,x}} = 0.09784$ [in]	$D_{fly} = 4$ [in]
$d_{\text{gen,bend,y}} = 0.1085$ [in]	$d_{\text{gen,bend,z}} = 0.06253$ [in]	$d_{\text{gen,tors,x}} = 0.07766$ [in]	$d_{sp} = 5$	$F_{\text{crank}} = 34.21$ [N]	$F_{\text{foot}} = 50$ [N]
$F_{F,y} = -37.17$ [N]	$F_{H,y} = -6.054$ [N]	$F_{H,z} = 31.61$ [N]	$F_{I,y} = 6.054$ [N]	$F_{I,z} = -31.61$ [N]	$H = 20$ [W]
$L_{AB} = 9.5$ [in]	$L_{A,to,F} = 6.5$ [in]	$L_{CD} = 1$ [in]	$L_{DE} = 1.5$ [in]	$L_{EF} = 2.5$ [in]	$L_{FG} = 2.5$ [in]
$L_{GH} = 2$ [in]	$L_{IJ} = 2$ [in]	$L_{JK} = 2.5$ [in]	$M_{\text{crankshaft,y}} = 1.606$ [Nm]	$M_{\text{crankshaft,z}} = 1.026$ [Nm]	$M_{\text{genshaft,y}} = 1.606$ [Nm]
$M_{\text{genshaft,z}} = 0.3075$ [Nm]	$n_A = 48$ [teeth]	$n_B = 24$ [teeth]	$\omega = 25.13$ [rad/s]	$\rho_{\text{concrete}} = 2300$ [kg/m ³]	$R_{E,y} = 16.16$ [N]
$R_{E,z} = 12.65$ [N]	$R_{G,y} = 27.06$ [N]	$R_{G,z} = -44.26$ [N]	$R_{J,y} = 10.9$ [N]	$R_{J,z} = 56.91$ [N]	$R_{K,y} = -16.95$ [N]
$R_{K,z} = -25.29$ [N]	$\sigma_{\text{all}} = 2.100\text{E}+08$ [Pa]	$S_y = 3.800\text{E}+08$ [Pa]	$\tau_{\text{all}} = 2.193\text{E}+08$ [Pa]	$\theta_B = 90.87$ [deg]	$th_{fly} = 2$ [in]
$T_D = 0.869$ [Nm]	$T_H = 1.592$ [Nm]	$T_I = 0.4345$ [Nm]	$T_K = 0.7958$ [Nm]	$T_{\text{tot,crankshaft}} = 2.461$ [Nm]	$T_{\text{tot,genshaft}} = 1.23$ [Nm]

Appendix G: Gantt Chart

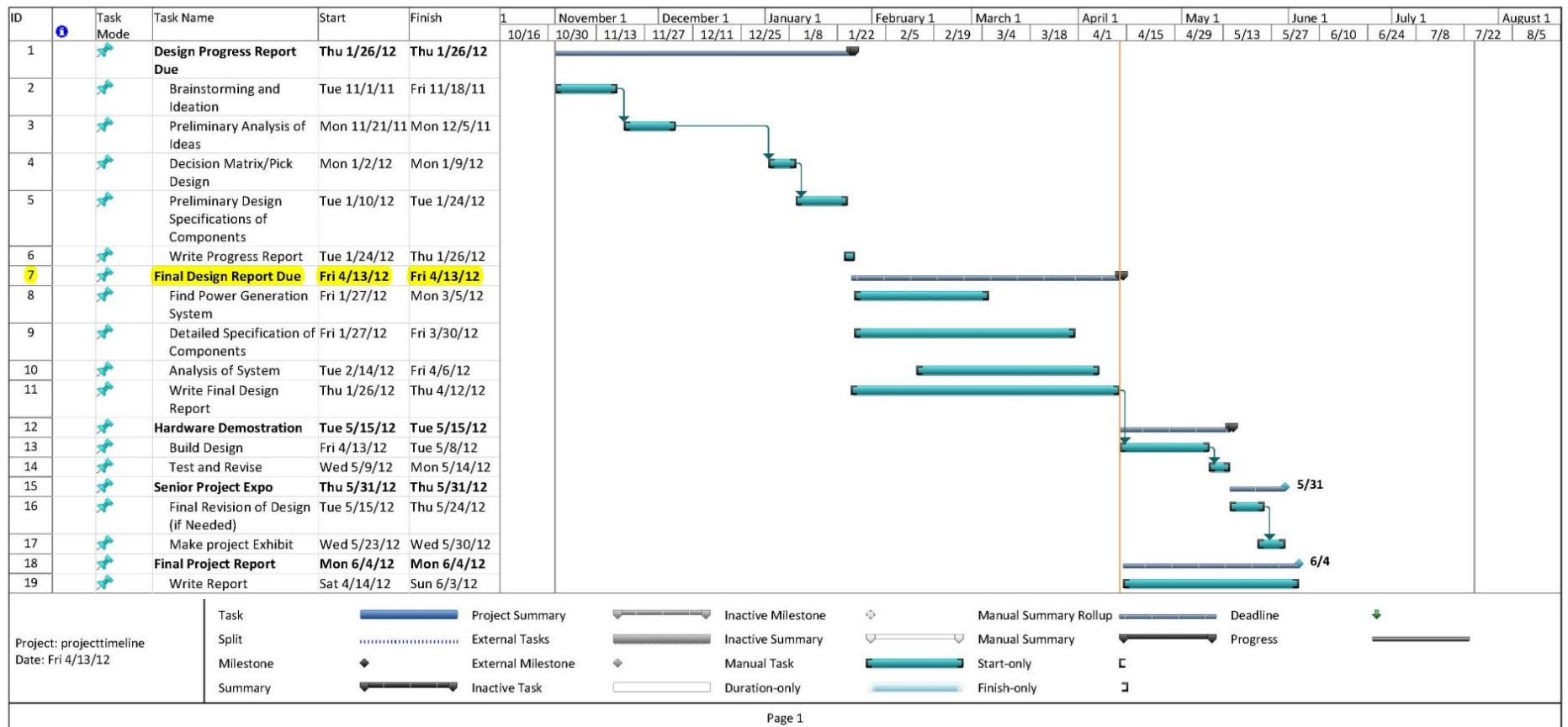


Figure 35: Gantt Chart created in Microsoft Project