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http://mechecapstone.blogs.unr.edu/2014-teams/pedal-power/

Final Design Report
ME 451: System Design- Team 4
May 5, 2014
Dr. Geiger

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Abstract

Pedal Power is a bicycle energy generator that will allow both commuter and avid cyclists to charge their devices by converting the kinetic energy of a moving bicycle into usable electrical energy. The device design takes into account the needs of both cycling groups, including durability, weight and size, and universal compatibility. The complete Pedal Power product (Fig. 1) and generator mounting assembly (Fig. 2) are shown below. Complete prototype drawings are detailed in Appendix I.

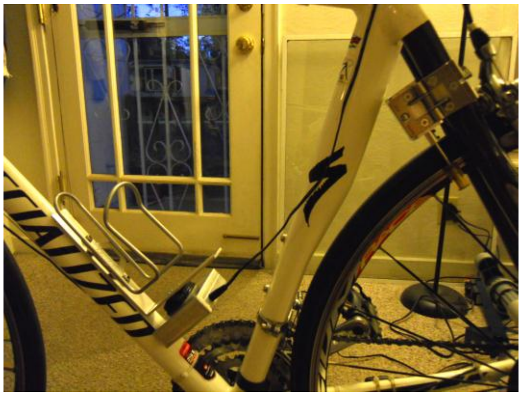

Fig. 1: Pedal Power installed on bicycle.

Fig. 2: Generator mounting assembly.

Two competitors manufacture a similar device, but those products do not adequately address the customer need to charge different electronics. Several design constraints were considered, which include: battery, costs, and the device form factor. Quantitative specifications were developed to meet the objectives and customer needs discussed above.

Engineering calculations were performed early on to ensure that the engineering specifications can be met and to prepare for prototype development. Engineering calculations proved the validity of the design. Results determined that a generator shaft speed of approximately 10,000 RPM is enough to open the charging circuit and charge the battery (Appendix H, Table 1). Proof of concept (POC) testing proved that at 12 MPH, 0.5- 0.75A can be generated at 8V. POC testing also revealed contact issues between the roller and rim, as well as charging circuit lag, thus influenced the spring-loaded generator-mounting hinge design and capacitor addition to the circuit.

Specifications were determined, and four primary functions and their respective sub-functions were identified to aide in prototype designing. The electronics pack was designed to secure all electronic components and connections. The generator mounting assembly ensures constant and reliable contact with the rear wheel and also includes a disconnect function.

The components shown above were individually machined using 6061 Aluminum (with the exception of the prefabricated hinge and universal clamp). Component assembly was completed by hand. The electronics pack components were secured with silicon adhesive, and the generator assembly was fastened together with stainless steel screws. Thorough testing took place after the assembly process to ensure that Pedal Power met the customer expectations and design specifications. A testing summary is shown in Table 3, Prototype Testing and Result at the end of the report.

Personal Statement

As a member of the Pedal Power group my position in the team was lead designer. My job revolved around the iterative design process by which we acquired our final tangible prototype. The drawings were made using a 3D CAD design software named SolidWorks. The software provides a template which enables the user easily produce drawings including measurements which our group used in the fabrication process. Being the basis for all design drawings, the software enabled our group to take our concepts and produce an electronic model to test its practicality without having to spend hundreds of dollars producing the part and then testing its practicality.

One of the requirements for the prototype was to develop a mechanism which would keep the polyurethane rubber wheel fully engaged with added pressure against the part of the bicycle wheel in order to prevent slippage. Additionally, the same part of the mechanism had to also be manually adjustable so that the cyclist could disengage the device at their leisure. By having the polyurethane rubber wheel engaged and the motor producing power the rider would be able to feel slight resistances due from the parasitic load of the motor. Having a disengagement mechanism would allow for the cyclist to remove that resistive load when there is no need to further charge the battery; additionally, disengaging the motor and stopping the production of power serves as an additional method in further protecting the battery from being over charged in case the charging circuit were to fail. The original designs I made were really intricate and involved integrating and manufacturing a spring coil. There were several flanges and cuts to reduce the weight of the overall device. The design was sound but after the group met with the machinist it was found that the tools and equipment available to manufacture the product would be very expensive not to mention time consuming. This meant I had to streamline and simplify the design to make it easily manufactured. Ultimately, this lead to the remaining designs requiring a lot of forethought to keep simple yet functional. Our plan make a spring coil was replaced by an off the shelf spring hinge clamp. Because the designs were straightforward the group was able to take advantage of the machines in the Engineering departments labs to produce the parts and thus save on cost. Taking the designs to final finished products really helped merge the bridge between design and manufacturing.

A part of our device that required a handful iterations was the generator case which would protect the DC motor from any impact and from water. Originally, I designed were two pieces that would come together and encase the motor. This would have required a gasket. The new design we ended up producing involved shelling out a solid piece of aluminum.

The majority of my role consisted of ideation and creation of drawings. I also partook in some of the manufacturing process, assembly, testing.

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Design Problems and Objectives

Cyclists often face dead electronics when using their bicycles and are away from a power source. We have many portable electronics that require frequent charging or battery replacement to remain functional, including: cell phones, tablets, laptops, flashlights, GPS devices, and cameras. When these devices exhaust their stored energy without a means to charge them, they are essentially useless. Finding a solution to this problem is the focus of this project, while tailoring the product design to the cyclist.

Cyclists need a product that converts the kinetic energy of a moving bicycle into electrical energy for charging electronics. Although their needs are somewhat different, two primary customer bases have been taken into consideration: the sports enthusiast and the commuter. Individuals who cycle for exercise, excitement, and the thrill of sport differ from those who ride for transportation needs. Sports enthusiasts will want a product designed for durability and performance, while the transportation base will require a product focused on endurance or longevity. Although both groups ride similar equipment, their needs are different enough to warrant different design criteria. The House of Quality describes the customer requirements and their relative importance (Appendix A, Figs. 1-3) [1].

We have identified a number of qualitative design objectives in order to meet the needs of both customer groups. Because the primary goal is to provide power to recharge other products, a useful amount of charge must be supplied. The first action that the customers will take with our product is installation. As such, the product must be easy to install on any number of bicycle frame geometries and configurations. For both sport and basic transportation, the product must be lightweight and compact. Both customer groups will also require a degree of durability.

Several problems were identified while creating the design objectives for the device. First, engineering analysis will need to confirm that enough energy can be generated to reasonably charge a device. Second, the weight and size of the device will be of concern to cyclists. Many serious cyclists spend considerable money on lightweight and aerodynamic bicycles. A bulky and heavy attachment will deter a significant portion of our customer base. Third, the device will be used by different types of cyclists, including mountain bikers. The rigors of mountain riding will require a durable product that can withstand shock, rain, dirt, and mud. Finding a mounting location to ensure universal compatibility with different frame types will prove challenging. Lastly, the generator can create significant drag on the cyclist, so a disengagement mechanism will be designed. It is important to note that no patents have been filed that will further limit our product.

Several specific constraints were identified that can be divided into three main categories: battery, cost, and device. The most pressing constraints will concern the charging capabilities of the device. Battery limitations are its degradation over time, maximum capacity, and charge time. The battery used will slowly lose capacity, so a high quality unit is necessary to minimize performance decline. Also, it must be able to store enough energy to charge an electronic device, such as a cellphone, GPS, or flashlight. The battery must to be able to charge quickly at full generator output so that the consumer can use their device relatively quickly.

Cost constraints include the development and manufacturing cost of the device, as well as the price point, which must remain competitive with similar products. Our team must keep production costs low to ensure an attractive profit margin.

The major constraints regarding the actual device are electromechanical efficiency, size, and bicycle frame geometry for mounting. The amount of power that can be provided to the battery is directly based upon the generator’s ability to convert mechanical energy into electrical energy. The device must remain small in order to fit into the preferred location on a bicycle. Finally, actual bicycle frame design limits possible attachment points. Since one device will fit multiple styles of bicycles (full-suspension mountain, road, and hybrid), research will be conducted to determine the optimal mounting location.

It is important to determine how well competitor’s products meet our customers’ requirements. Some of the parameters that were used as a basis for comparison are portability, location, specifications, and connection. For portability, every device is relatively small; however, only the Atom by Siva Cycles is completely removable from the generator, which is a design specification that we will pursue. We will use the rotation of the rear wheel, not the wheel hub, to generate energy. Both the Siva Atom and Shimano Dynamo use the rotation of the wheel hub for energy production, which is a disadvantage when compared to our preferred mounting location as they do not allow for disengagement and are a constant drag on the cyclist. The Atom only has a battery capacity of 1300mAh, while the Dynamo is limited to powering a headlight. Both products are shown below in Figs. 1 and 2.

Fig. 1: Siva Atom bicycle generator.

Fig. 2: Shimano Dynamo hub generator.

Quantitative engineering specifications have been developed to ensure that the product meets previously discussed objectives and the customer need. It is important to note that the competition’s design and specifications played a role in developing specifications for our device.

The engineering specifications are listed below:

1. Water resistance will be tested using the IPX4 standard. Shock resistance will be tested using a one-meter drop test.
2. To be useful, the device will be able to charge most common devices at least 50% over the course of an hour. A 2500mAh battery capacity will meet this

requirement.

3. The device will take no longer than 30 minutes to install for an average cyclist.
4. The mounting mechanism must be able to make a one-time adjustment to fit frames from 1.0-2.0 inches in diameter by using the included tool.
5. Tamper-proof fasteners will be used to deter theft, and the proper tool bit will be included to ensure easy installation.
6. We have identified a maximum size of 8 inches wide, 12 inches long, and 6 inches thick. The weight of the entire product must be less than five pounds.
7. A poll will be taken to ensure that the design of the product is held as favorable by at least 50% of participants.

Detailed Design Documentation

After design specifications were developed, the next step was to identify the primary functions and sub-functions of the design and choose the best design concepts to fulfill these requirements (Appendix B, Fig. 1).

We have identified four major functions that the design must incorporate in order to be usable:

1. The ability to install the apparatus onto a wide range of bicycle platforms and frame geometries
2. Have the capability to reliably convert rotational energy into electrical energy
3. Provide a way to store a usable amount of electrical energy
4. Supply a way to output stored energy to a variety of devices

Our focus centers on designing a product that is convenient and practical to use. It became evident that most other electricity generating systems have little universal compatibility across different cycling platforms. We will severely limit our customer base if we do not design and market a universal mounting system for multiple bicycles.

The mounting mechanism must allow the generator to maintain contact with the rear wheel to ensure uninterrupted and reliable power generation. It is important to find a generator that can handle the proper rotational velocity, is durable enough to resist shock and moisture, and will not overheat.

Possessing the ability to store the generated energy in a battery for later use was found to be a major customer need. Other apparatuses are only able to charge a device while the bicycle is in motion, which significantly reduces the practicality of the device. Not only must the system have the ability to store energy, but also enough power must be stored to charge a device to 50% of capacity.

In order for the battery pack to charge a variety of different electronics, a common power output is necessary. This will allow both commuters and sports enthusiasts to charge devices that are important to them. All of the above primary functions were developed to solve the problem, meet customer objectives, and stay within our design specifications.

Sub-functions were created to illustrate specific design parameters that must be met to satisfy the primary functions. The ability to install the apparatus onto different bicycles includes a fastening feature. Another sub-function concerns the variable speed of the bicycle, which directly correlates to the output of the generator while satisfying the demands of the charging system. Producing energy requires that the generator have constant contact with the rear wheel, which is another sub-function. The proper roller material is paramount in ensuring that wear and slippage does not occur. To ensure functionality and convenience, being able to remove the battery from the bicycle and continue charging a device is an important sub-function concerning energy storage. A USB enabled output port and a voltage regulator is a necessary sub-function, which will allow the charging of a broad array of electronics.

The following prototype components were developed using the primary and sub-functions as an outline. In order to define leading designs for each function, our team used the Pugh's Method decision making process [1]. Finalized designs are discussed below and the total scores for each item are displayed in Appendix C, Fig. 1. The generator mounting assembly and enclosure is shown below in Figs. 3 and 4. Detailed engineering drawings and photos are presented in Appendix I, with the installed device shown in Appendix I, Fig. 1.

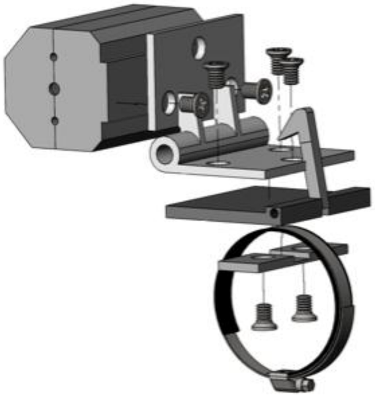


Fig. 3: Complete generator enclosure and mounting assembly.

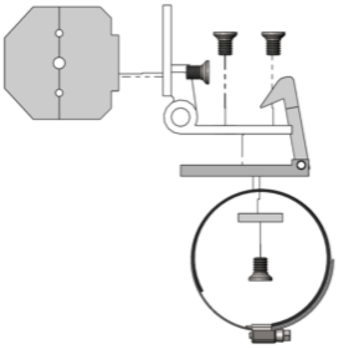


Fig. 4: Generator enclosure and mounting assembly side profile.

A direct-drive generator was chosen to ensure reliable electricity generation, due to its simplicity and overall reliability. Quantitative specifications were identified that require water, dirt, and shock resistance. To ensure that these are met, a durable generator enclosure was designed. Figure 5 shows how the generator housing, spring hinge, and latch plate attach. Figure 6 depicts the generator housing, complete with output shaft exit with room for silicon grease and fastener holes.

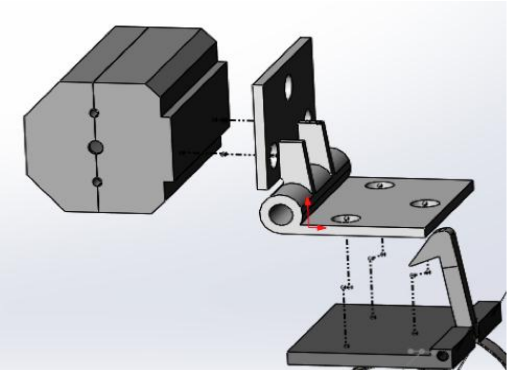


Fig. 5: Generator enclosure, spring hinge, and clamp base connections.

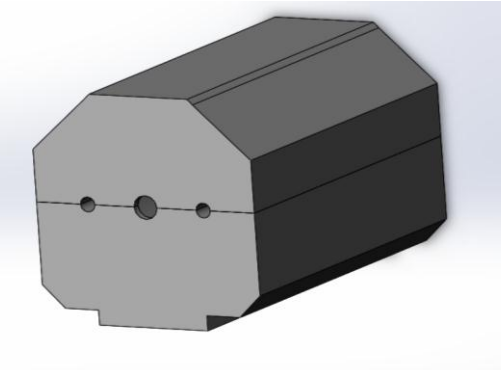


Fig. 6: Generator enclosure front view.

A latching mechanism was developed to disengage the generator to decrease drag while the cyclist is pedaling uphill. When not in use, the generator and polyurethane contact wheel can be rotated away from the bicycle wheel and latched in place with the retaining hook shown. A prefabricated spring-loaded hinge connects the generator enclosure to the latch base plate (Fig. 8) which allows the polyurethane roller to maintain constant contact with the rim interface. The latch system components are shown below in Figs. 7-8, with drawings displayed in Appendix I, Figs. 4-7.

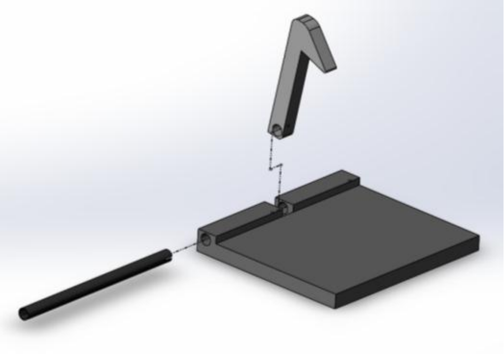


Fig. 7: Clamp base, appendage, and tension pin.

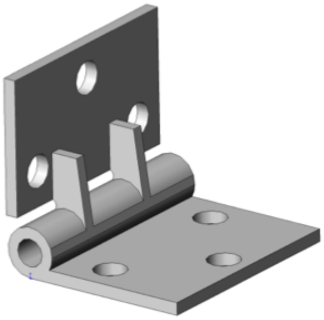


Fig. 9: Universal clamp with foam padding.

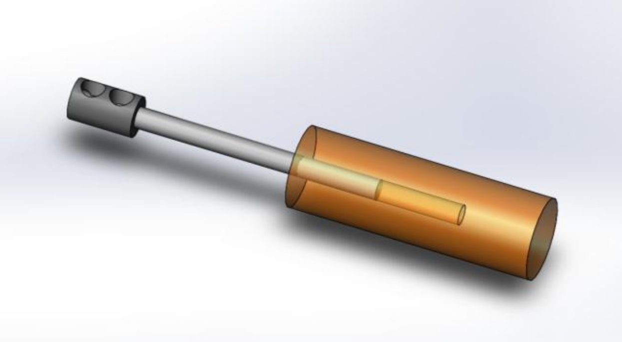


Fig. 10: Generator extension shaft with polyurethane roller wheel.

For the function of device attachment, a universal worm clamp style attachment was selected. The inside of the clamping surface was fitted with a foam sleeve to protect composite bicycles and oversized frames. The clamp shown in Fig. 9 meets the design requirements for universal compatibility with frame sizes from 1.0-2.0 inches in diameter. To satisfy the universal compatibility objective, a polyurethane roller that is connected to a generator shaft extension was selected. The roller contacts and rotates along the metal rim of the bicycle wheel to maintain consistent rim contact (Fig. 10).

The electronics pack assembly (Fig. 11) contains the charging circuit, battery, USB connector, and generator power connector to provide protection against the elements, while ensuring portability and universal connectivity. The mounting location of the electronics pack was chosen to ensure protection and convenient access. An L-shaped mounting bracket (Fig. 12) is attached to the universal water bottle cage mounting posts to allow use of the existing water bottle cage. The electronics pack attaches to the bracket with a prefabricated quick release mechanism. Detailed drawings are shown in Appendix I, Figs. 13-15.

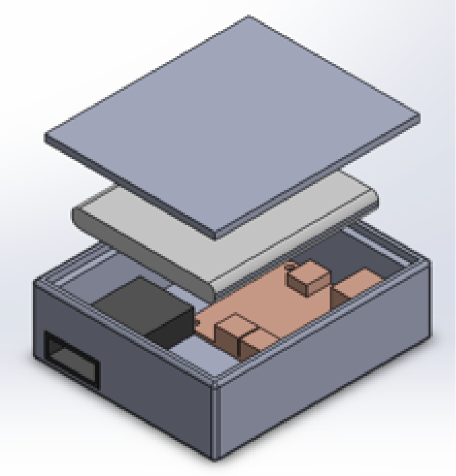


Fig. 11: Electronics pack assembly.

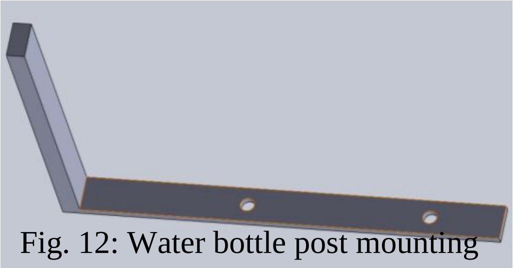


Fig. 12: Water bottle post mounting bracket.

Selecting the appropriate battery pack was crucial in maximizing the performance of the device. Lithium-polymer batteries have the best performance, and the availability of off-the-shelf circuits makes its incorporation simple. A 2400mAh cell was chosen because it will meet our charging requirements (charge a common cellphone 50% in one hour).

All of the previously listed components have been chosen to meet the product objectives and engineering specifications. Primary objectives include: providing a useful amount of charge, easy and simple installation, universal compatibility across different cycling platforms, and reliable operation. Complete engineering drawings, models, and photos are shown in Appendix I.

Engineering calculations were performed to ensure that engineering specifications would be met and to prepare for POC development. The following information provides a summary of numerical results-- assumptions, annotations, and complete equations are presented in Appendix D. Tabulated results are displayed below in Table 1.

The primary concern of the engineering calculations and analysis centered around the ability of the generator to produce enough voltage and current to the charging circuit at a reasonable cycling speed. The rotational velocity of the rear wheel is 165 RPM, using a bicycle velocity of 12 MPH. The diameter of the connecting wheel between the generator shaft and bicycle wheel is 3/8 in. Given a generator shaft speed of 10,000 RPM, the generator will produce 0.5 to 0.75 Amps at 8V, which is well within the charging circuit specifications.

Table 1: Engineering Analysis Results.

Tabulated Engineering Analysis Results					
Assumed Speed (MPH)	Wheel Diameter (m)	Contact Wheel Diameter (In)	Wheel Velocity (RPM)	Generator Shaft Velocity (RPM)	Current (A) at 8 V
12	0.622	3/8	165	10,000	0.5-1

During every step of the design process, customer impact was considered. The product was designed for sports enthusiasts and commuters, making aesthetics, safety, cost, and installation key factors to be considered.

Aesthetics

In order to keep the bicycle streamlined, the location and size of the generator and battery pack were important. Protruding components out of the sides of the bicycle would add unwanted drag and a greater chance of damage in a crash. To keep the battery pack and charging circuit out of the way, a single sealed electronics pack was designed.

Safety

Because a lithium-polymer battery was used, the product needs to protect the battery pack. The circuit was chosen to prevent overcharging, and the case for the battery pack was designed to be weatherproof and shockproof.

Cost

The product was designed to compete with two other products already on the market and was given a price point to match. The most expensive part of the product was machining the electronics pack and generator casing. Although comparable devices retail for about $100, our product will retail for around $75, which will attract a larger customer base.

Installation

There are two main components to install: the electronics pack and the generator assembly. Both were designed to be quick and easy to install. The generator will be attached to the frame by a universal worm clamp, and the electronics pack will be mounted to a water bottle post mounting bracket.

Human Factors Considered

Two key factors for the interaction between the user and system were considered in the design: the drag from the generator and the removal of the battery pack. The generator creates drag when engaged, which makes pedaling more difficult for the rider. To compensate for this, the generator is designed to disengage from the wheel when the user does not want to generate electricity. Concerning the battery pack, a quick release system will be used to allow for easy installation and removal.

Fabrication and Materials

Several parts required fabrication, which include: a generator mounting assembly, generator housing, electronics pack, and electronics pack mounting bracket. The universal clamp used to attach the generator to the rear triangle, the quick release for the electronics pack, and spring-tension generator hinge were selected from prefabricated components. All Pedal Power drawings, as well as 3-D models and complete product photos, are shown in Appendix I.

Initially, manufacturing was to be completed by a professional machine shop. After consulting with staff in the Palmer Manufacturing Lab (PML), our team chose to manufacture all components in-house. Fabricating the necessary components ourselves provided several advantages, including:

1. Greater quality control over fabrication process
2. Reduced manufacturing costs by 75%
3. Completion time reduced by two weeks
4. Provided design team with hands on machining experience

5. Reduced the cost of engineering drawing errors

Choosing to use the PML was a successful decision that resulted in a professional, well-designed and fabricated product.

The prefabricated components were purchased at various hardware vendors locally and online, such as Ace Hardware and McMaster-Carr, and availability is plentiful for small production needs. For the prototype construction, milling individual components was effective. High demand production will warrant future investigation into various molding techniques.

All machined components were built from 6061 Aluminum bar stock (12x3x1.5 in). Although drawings were reviewed by the machinist before fabrication, building components in the PML allowed our team to constantly verify fitment and clearances of the various components. This proved especially helpful when choosing tolerances and fasteners, as the machinist has considerably more experience than our design team.

Aluminum is the standard material used in high-end bicycles, as it is lightweight, yet strong. It was necessary to employ this material to meet the customers' requirements, as shown in the House of Quality (Appendix A) [1]. Although the material is not outrageously expensive, milling components with a large void, such as the electronics pack, wastes material. Using a molding process to fabricate the separate components would lower production costs and possibly allow for a higher performance material to be used. Although avid cyclists would likely pay more for the product to be fabricated from a more exotic material such as titanium or carbon fiber, costs must be kept to a minimum for this product to avoid losing recreational cyclists as customers.

Table 2 below displays the major component cost analysis. A complete bill of materials is provided in Appendix E, Table 1. The top of the table lists materials, their prototype costs, and the costs associated with building 10,000 units. The bottom segment of the table lists various items donated for the duration of the project, which were used for the proof of concept and final prototype testing.

Table 2: Manufacturing Component Budget.

Major Component Cost Analysis				
Item	**Vendor**	**Vendor #/ID**	**Prototype Cost**	**Mass Production Cost (10,000 Units)**
Li-Po Battery	Adafruit	ID: 328	$ 14.95	$ 7.00
Li-Po Battery charger	Adafruit	ID: 259	$ 12.50	$ 5.00
Generator (hobby motor)	RadioShack	#: 273-256	$ 5.99	$ 2.00
Polyurethane Rod	McMaster-Carr	8784K19	$ 15.17	$ 3.00
Universal Clamp	Ace Hardware	-	$ 2.99	$ 2.00
Generator Latch Plate	Palmer Mfg. Lab	-	Donated	$ 6.00
Mounting Hinge with Spring	Hardware Source	-	$ 9.99	$ 3.00
Water Bottle Bracket	Palmer Mfg. Lab	-	Donated	$ 5.00
Electronics Pack	Palmer Mfg. Lab	-	Donated	$ 10.00
Generator Housing	Palmer Mfg. Lab	-	Donated	$ 4.00
Aluminum Stock	McMaster-Carr	8975k315	$ 32.75	$ 5.00
GoPro Mounts	Walmart	-	$ 19.99	$ 1.00
Items Possessed				
Cycle Roller	-	-	$ 350.00	-
Bicycle	-	-	$ 1,600.00	-
Voltmeters	-	-	$ 50.00	-
Rheostat	-	-	$ 3.00	-
Speedometer	-	-	$ 10.00	-
Digital Oscilliscope	-	-	$ 350.00	-
Labor	-	-	$3,000	$ 5.00
Cost of materials needed			$ 114.33	**$ 58.00**
Cost of all materials			$ 5,477.33	
			Note: These cost does not include minor components.	

The average device price from competitors is approximately $100. Our design team has a target retail price of $75. The total prototype cost was $154.08. Note that the costs incurred below do not include minor components. However, the expected mass production cost for 10,000 units is $65.00, well below the target retail price. The extra cushion will allow for profit, marketing, and other costs to factor into the price.

Assembly

Final assembly of all manufactured components went smoothly. Preliminary assembly and mock-ups took place throughout the manufacturing process to ensure proper alignment between components.

The electronics pack was completely assembled after all necessary testing was complete. The USB connector was secured in its port and sealed using JB Weld epoxy, and the power cables were soldered directly to the Adafruit charging circuit (Fig. 13). The charging circuit was glued to the electronics enclosure surface with nonconductive silicone glue, and the generator power connector was sealed as well. A 1μF capacitor was then soldered across the power input terminal. The battery pack was glued to the top plate with silicone adhesive. Once all of the internal glue cured, the top plate was sealed with silicone glue. All corners were rounded and the exterior casing was polished (Fig. 14).

Fig. 13: Electronics pack internal view.

Fig. 14: Electronics pack external view.

The generator enclosure and mounting bracket required the most assembly, shown in Fig. 15. First, the generator was fastened into the enclosure with two stainless steel screws. The extension shaft was then installed and secured with two setscrews. The polyurethane wheel was center drilled and pressed onto the extension shaft. Next, one side of the spring hinge was fastened to the generator case using two stainless steel screws. The latch base plate was attached to the other side of the hinge using three stainless steel screws. On the backside of the latch plate, a thin retaining bar was notched to allow the stainless steel worm clamp to sit flush against the latch plate, and then fastened. The inside surface of the worm clamp was fitted with foam padding. The water bottle post bracket was simply installed underneath the water bottle cage on the bicycle.

A GoPro quick release mount was fastened to the free side using the three predrilled holes (Fig. 16). The adhesive end of the mount was attached to the electronics pack.

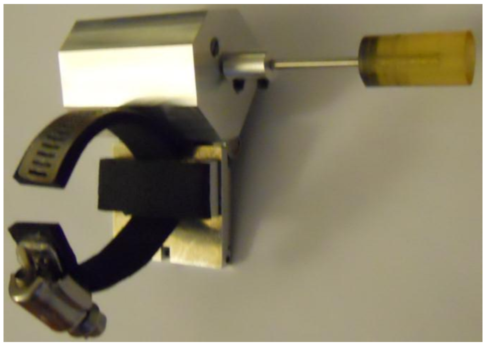


Fig. 16: Water bottle post mounting bracket and quick-release mechanism.

Fig. 15: Generator enclosure, extension shaft and wheel, and mounting bracket.

The complete generator assembly was attached to the top of the rear triangle of the bicycle using the adjustable worm clamp. The generator power cord was soldered to the generator terminals, the generator backing plate was secured with silicone adhesive, and the power cord hole was sealed.

Proof of Concept

A summary of the proof of concept is presented below, and will allow for comparison to the final prototype testing data. The product's success was determined by its ability to convert rotational energy into stored electrical energy. Because of this, the POC focused on two primary areas: energy generation and energy storage.

Testing focused on the ability of the generator to provide enough voltage and amperage to the charging circuit in order to charge the battery. The circuit requires a voltage range of 5-12V and an amperage range of 100-1200mA in order to charge a lithium-polymer battery (see Appendix H for charging circuit and battery datasheets). The generator must output a minimum of 5V at 100mA to charge the battery. According to the available data for the motor, the generator can produce the required power at a range of 10,000 to 15,000 RPM (Appendix H). According to the engineering analysis, this range can be achieved with a riding speed between 10 and 18 MPH (Appendix D).

A testing platform was built in order to verify the engineering calculations. A summary of the process is discussed here. Detailed POC assembly and instructions are presented in Appendix F. A detailed bill of materials is shown in Appendix E, Table 2. The platform consisted of a bicycle mounted to a stationary cycling stand (Fig. 17). A cycling computer was used to measure the rear wheel velocity. The generator was then attached to the rear triangle of the bicycle, so that the generator wheel contacted the rear tire. Using a multi-meter allowed us to measure the voltage and amperage output of the generator as the bicycle was pedaled for speeds ranging from 11-20 MPH in 1 MPH increments. To better understand the voltage and amperage output at various speeds, the data was plotted to obtain an application specific power curve (Fig. 18). Refer to Appendix G for complete POC testing data and results.

Fig. 17: POC testing setup.

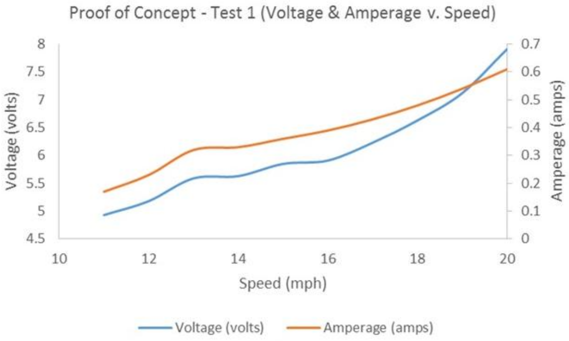


Fig. 18: Voltage and amperage vs. speed plots.

Figure 18 confirms that enough power can be generated to charge the battery. However, initial testing uncovered one problem; for the charging circuit to “open” and begin charging the battery, a minimum of 100mA is required. Unfortunately, the bicycle had to reach a speed of approximately 17 MPH before the initial 100mA can be achieved. After the circuit opens, the bicycle speed can be lowered to as little as 11 MPH before the current dropped below the charging circuit’s threshold. POC testing provided insight into necessary design changes to ensure that the customers’ needs and product specifications are met.

Prototype Testing and Results

The bicycle generator and charger/battery unit required scientific testing of design parameters to ensure that objectives and specifications were met. Eight design specifications were tested to verify a fully functional product. Table 3 below summarizes the results, with detailed explanations following.

Table 3: Prototype Test Results Summary.

Design Specification	Testing Method	Duration	Outcome
IPX4 (10 L/min, 100kpa for 5 min)	2 GPM showerhead	10 min	Fully operational
1 meter concrete drop test	2 meter carpet drop test	3 times	Fully operational
50% capacity charge in 1 hr	Connect cellphone to electronics pack	1 hr	55% increase in charge
30 minute installation time	5 team members install on separate bicycles	Varies	Meets spec
Theft deterent	Attempt to remove device	N/A	Difficult to remove
Weigh less than 5 lbs	Weigh on scale	N/A	3.7 lbs
Footprint smaller than 8" wide, 12" long, 6" high	Measure with calipers	N/A	Meets spec
Desirable product	Survey	N/A	63% would purchase

The specifications for water resistance were chosen based on the IPX4 standard. The standard states that the device will withstand 10L/min of water at a pressure of 80-100 kPa for five minutes. To simulate this test, the electronics pack and generator assembly were placed under a showerhead with a flow rate of 2 GPM for 10 minutes. The components were immediately installed on the bicycle, and the bicycle was ridden for ten minutes to energize the generator and electrical components. A cellphone was then connected to the device and successfully charged.

The parameter set for durability requires full device functionality after being dropped from a distance of one meter onto concrete. Seeing that we only have one prototype due to budget and time constrains, the drop test was modified. The electronics pack and generator assembly were dropped from a distance of two meters onto carpet three times each. The components were immediately installed on the bicycle, and the bicycle was ridden for ten minutes to energize the generator and electrical components. A cellphone was then connected to the device and successfully charged.

The charge time parameter was set to prove that the product would charge a small electrical device with a capacity of 2400mAh up to 50% in an hour. Although this parameter is also dependent on the charging capabilities of the actual device to be charged, we feel that it validates a useful and practical device. The bicycle and attached Pedal Power product was ridden for 30 minutes. A cellphone was then plugged in with a battery charge of 15%. After one hour, the battery life registered 70%, a 55% increase in charge.

The installation time specification requires that Pedal Power can be installed by a novice cyclist within 30 minutes. All five team members, with differing levels of experience, attached the product to two different bicycles and were timed for both installs (Table 4). This test also verifies that the device can be installed on different platforms, as a Specialized Allez road bicycle and Trek Rumblefish mountain bicycle were tested.

Table 4: Installation Times.

Team Member	Specialized Road Bicycle Installation Time (min)	Trek Mountain Bicycle Installation Time (min)
1	10	15
2	17	20
3	7	12
4	20	25
5	15	18
Average Time (min)	**13.8**	**18**

To deter theft, Loctite Blue 242 thread sealant was used in the universal clamp drive screw. Although this method does not eliminate theft, it will increase the difficulty of removing the device with a screwdriver, but still allow the consumer to make adjustments if necessary.

The product weighs 3.7 pounds and has a footprint of 4.25in x 5.00in x 7.25in when all components are laid side by side.

To ensure a desirable product, a survey was distributed on two online forums targeted specifically to cyclists, Bikeforums.net and Cyclechat.net. The survey found that 63% of respondents would be interested in a product that “charged a detachable battery booster for phones, tablets, etc. while you ride.” The survey can be found in Appendix J.

Although all of the outlined specifications were verified with the test results listed above, our design team wanted to prove that the design changes made to the POC were warranted and successful. The POC showed that to meet our objective of providing useful and reliable power, the roller wheel must maintain constant contact with the rear rim. We employed a spring hinge to ensure that the wheel always contacts the rim. We also chose a polyurethane rod as a roller wheel, as it is ductile yet durable. The second problem found during initial testing concerned the speed required to initialize the charging circuit. Initially, the bicycle had to be ridden up to 18 mph before adequate amperage could be generated to begin charging. Once charging began, the resistance in the circuit dropped, which increased the amperage and allowed a riding speed of 10-12 mph while still charging. To overcome this problem, a capacitor was placed across the power input to the charging circuit (brown disk shown in Fig. 13). The capacitor provides an initial spike of current to open the charging circuit.

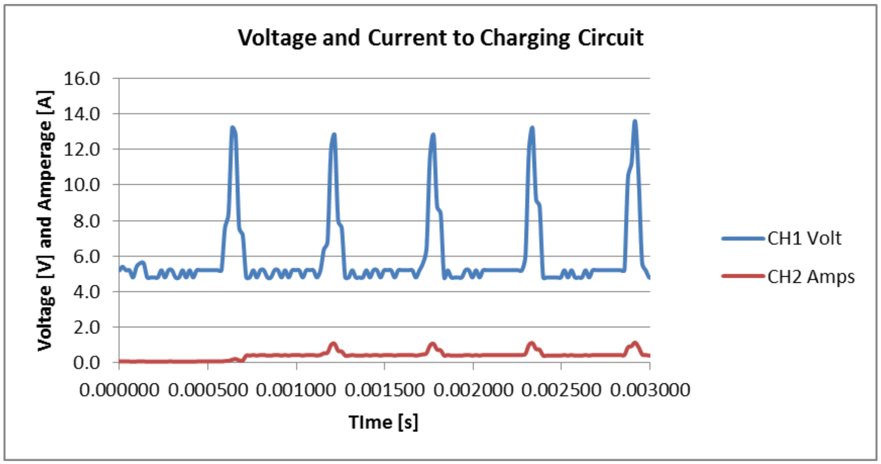


Fig. 19: Voltage and amperage output to charging circuit.

Figure 19 shows the data output from an oscilloscope as the capacitor provides the initial 0.1A current to initiate charging. Notice that the mean voltage remains constant. However, the current rises from a mean value of approximately 0.006 Amps to 0.4 Amps at about the 0.55ms mark, which is the moment that the charging circuit initializes. This happens at approximately 12 mph, showing that the capacitor effectively solved the problem and lowered the speed required to begin charging.

Alternate Designs

Many different design concepts were debated before the leading candidates were determined. Three main areas of the product were discussed: generator, battery, and mounting setup.

Several different types of generator connections were originally considered, including direct drive, gearbox, and belt-drive. Engineering calculations verified that a direct drive generator would be adequate.

Three types of batteries were considered: nickel-metal hydride, lithium-ion and lithium-polymer. Lithium-polymer batteries were chosen for their superior energy density and the availability of pre-made charging circuits.

The battery, charging circuit, and generator needed to be mounted to the bicycle. Originally, components would be mounted inside of a water bottle shaped case, which would preclude the use of the water bottle cage. An improved design allowed full water bottle cage functionality.

The generator mounting location presented many options. The location must allow for universal compatibility across multiple platforms, as well as enable easy installation. The rear triangle was chosen to meet these requirements.

A quick-disconnect switch was initially designed to disconnect the generator/ rear wheel interface. This design was modified to a latching mechanism on the generator bracket to reduce clutter, costs, and complexity.

Ethical and Safety Concerns

While no ethical concerns exist for team Pedal Power, our team is committed to responsibly using resources. Internal components are not user serviceable, and all aluminum components are recyclable. Present manufacturing techniques require excess material, however, mass production molding would reduce waste considerably.

The greatest safety concern regarding our product pertains to the lithium-polymer battery pack. A specially selected circuit designed for lithium-polymer batteries will properly charge the battery pack, avoiding thermal runaway. The battery pack is protected from the environment and shock. However, the consumer will be instructed to periodically check the battery pack for damages to prevent accidental fire. All electrical components were properly insulated to protect the user from accidental shock.

Timeline and Team Management

A timeline was created to ensure that the design process remained on schedule and that the final prototype was completed before the end of the course. An in-depth discussion and timeline are presented in Appendix K. In our first meeting of the fall semester, we determined the manner in which we would function as a team, as well as the responsibilities of each individual team member. In terms of keeping the team focused and motivated, the team leader spent the beginning of every meeting checking up with individuals on the progress of their assigned tasks. He would also contact each member throughout the week, reminding them of their responsibilities and due dates for their assignments. The responsibilities of each team member are as follows:

- Andrew Childress: Designated team leader in charge of compiling all reports/tasks, leading team meetings, managing team members throughout the design process, completing assigned tasks, and turning in all finalized reports/tasks.
- Aaron Stone: Designated team website and assignment editor. In charge of editing all reports/tasks, purchasing components, completing and editing website assignments, and completing designated report/task assignments.
- Joshua McGuire: Designated team lead researcher in charge of researching current products similar to our own, researching materials and components to be used for project, lead contact with the PML staff, and completing designated report/task assignments.
- Luis Garcia-Perez: Designated team lead designer in charge of overall design of our project, charged with drafting design sketches, and completing designated report/task assignments.
- Ryan Stemmerik: Designated team secretary in charge of taking meeting minutes, creating documentation for materials and designs, planning testing and implementation of components, and completing designated report/task assignments.

Conclusion

The complete prototype design, which includes the generator bracket assembly and electronics pack, serves to meet the customer's need, quantitative design objectives, and engineering specifications. These requirements are summarized with the primary functions, which include: device installation across a wide range of bicycles, having the capability to convert kinetic energy into electrical energy, storing the generated energy, and supplying a way to output stored energy to a variety of devices. Competitor research, engineering calculations, POC testing, and a structured revision process ensured that the finalized design detailed in the Detailed Design Documentation was complete and operational.

The components that formed the final prototype were machined individually or prefabricated from various manufacturers. Our design team manufactured all Aluminum components in the PML, which allowed us to observe and scrutinize the fabrication process closely. Component fitment and operation was continuously verified during the manufacturing process to ensure a smooth assembly process.

After complete assembly, testing began to verify that all engineering specifications and product objectives were achieved. Our team also tested the design improvements made since the POC to verify their validity and effectiveness. All engineering specifications were met or exceeded. Design changes, namely a spring hinge for the generator and capacitor addition to the circuit, greatly improved the performance and reliability of the Pedal Power device.

Acknowledgements

Team Pedal Power would like to thank the following individuals for their meaningful contributions, insight, and support for the duration of the design project:

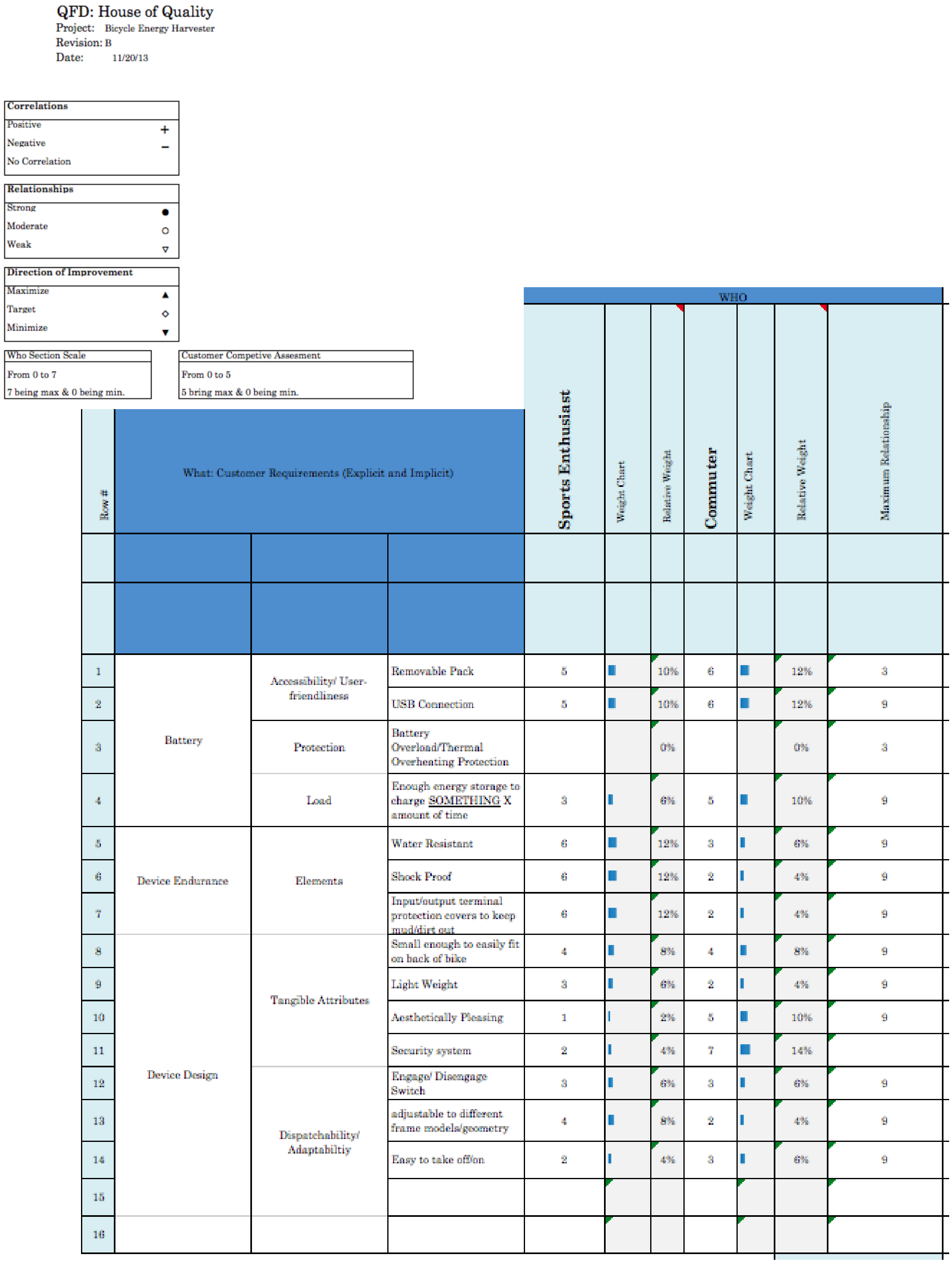
- Dr. Emil Geiger- Course Instructor, provided technical insight and writing feedback, and spent time meeting with the design team to troubleshoot and provide foresight into possible future problems.
- Johnson Wong- Course Teaching Assistant, assisted in purchasing and general course questions.
- Greg Childress- Technical Editor, provided editing feedback on all design reports.
- Tony Berendsen- Palmer Manufacturing Lab Machinist, provided guidance on design drawings and manufactured various device components.

References

[1] Ullman, David, "House of Quality," in *The Mechanical Design Process*, E. A. Jones, Ed. USA: McGraw-Hill, 2003. Pp. 143-166, 108.

Appendix A

House of Quality



QFD: House of Quality
Project: Bicycle Energy Harvester
Revision: B
Date: 11/20/13

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▿

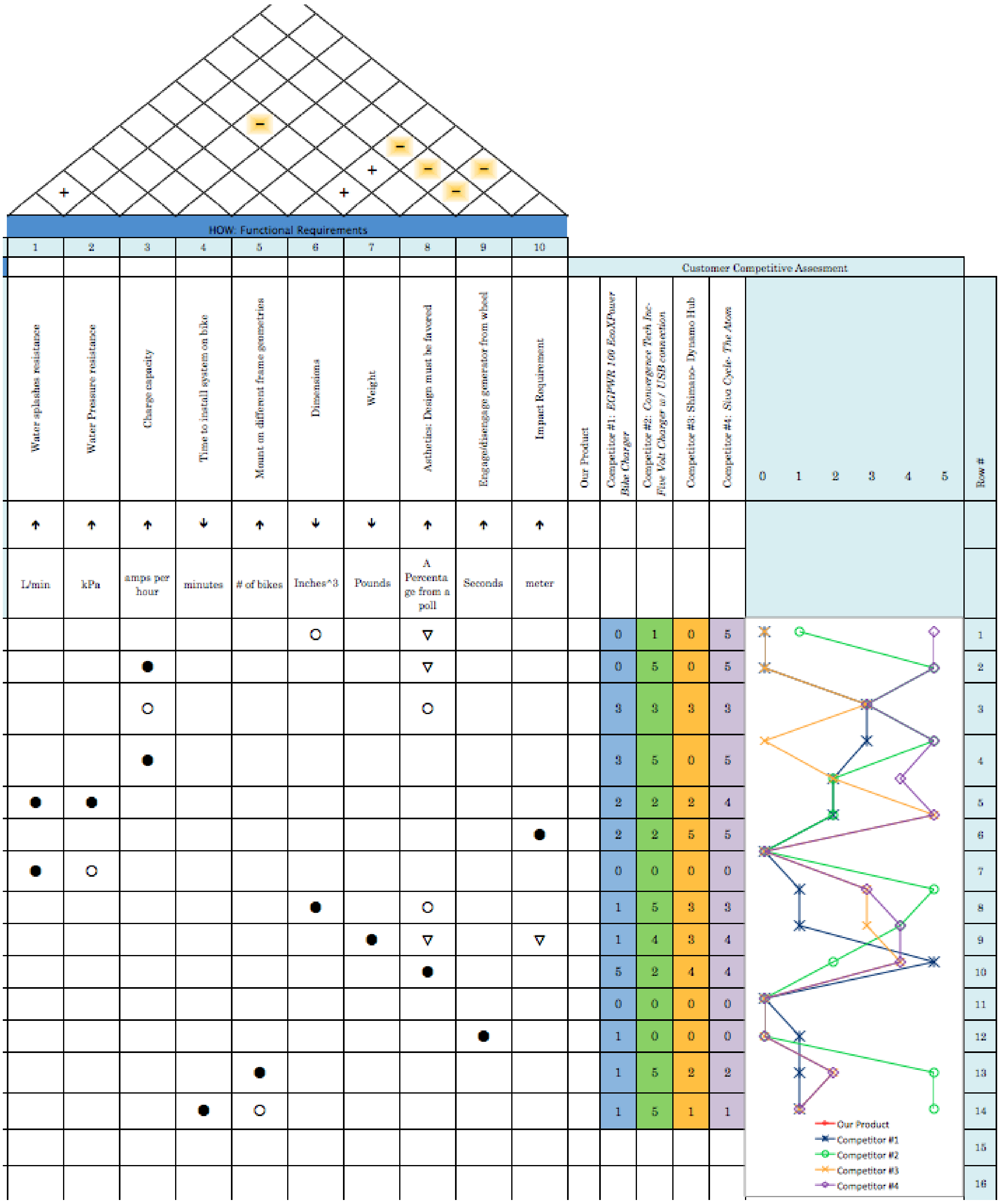
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Who Section Scale
From 0 to 7
7 being max & 0 being min.

Customer Competive Assesment
From 0 to 5
5 bring max & 0 being min.

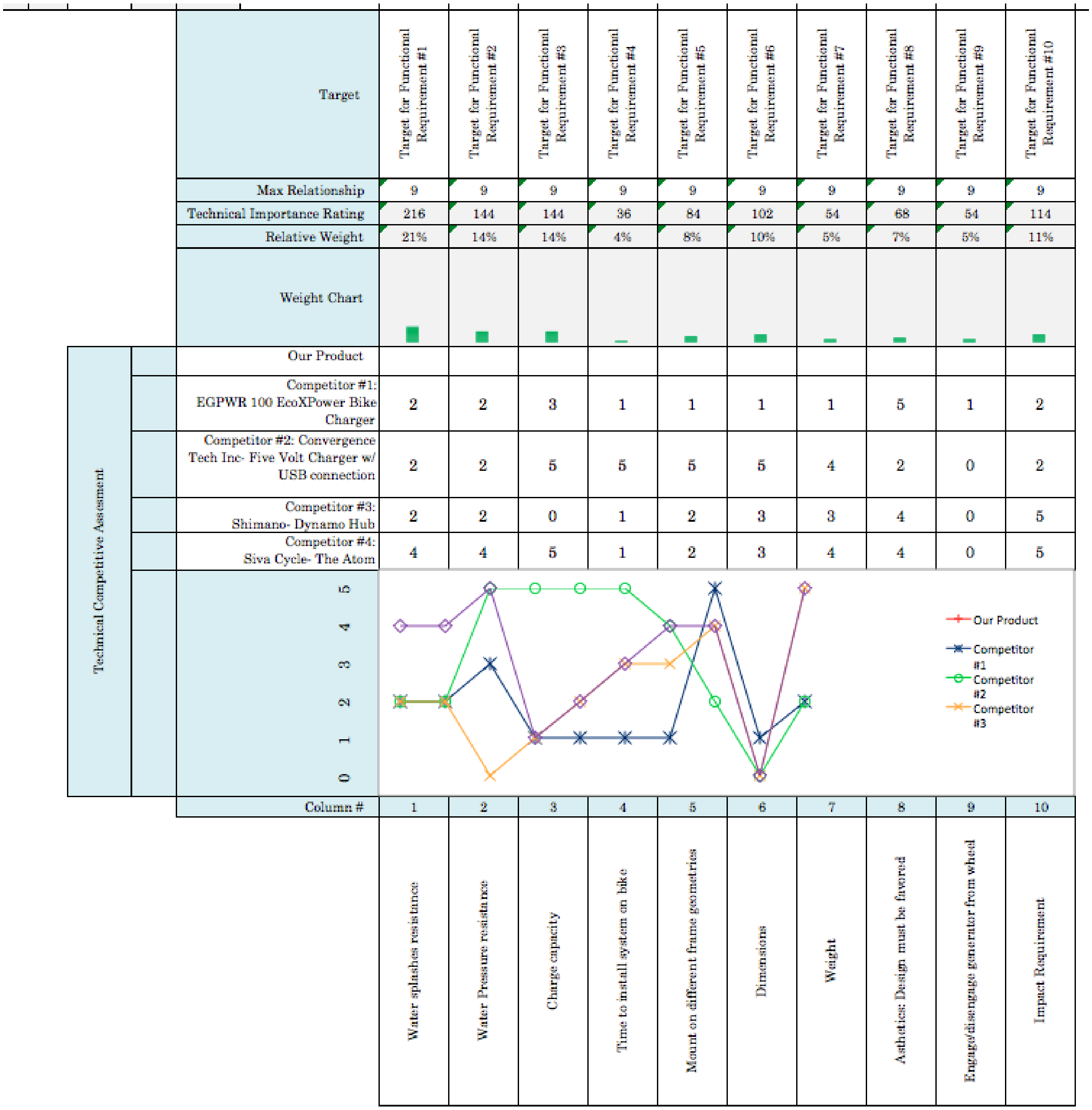
				WHO						
Row #	What: Customer Requirements (Explicit and Implicit)			**Sports Enthusiast**	Weight Chart	Relative Weight	**Commuter**	Weight Chart	Relative Weight	Maximum Relationship
1	Battery	Accessibility/ User-friendliness	Removable Pack	5	▮	10%	6	▮	12%	3
2			USB Connection	5	▮	10%	6	▮	12%	9
3		Protection	Battery Overload/Thermal Overheating Protection			0%			0%	3
4		Load	Enough energy storage to charge SOMETHING X amount of time	3	▮	6%	5	▮	10%	9
5	Device Endurance	Elements	Water Resistant	6	▮	12%	3	▮	6%	9
6			Shock Proof	6	▮	12%	2	▮	4%	9
7			Input/output terminal protection covers to keep mud/dirt out	6	▮	12%	2	▮	4%	9
8	Device Design	Tangible Attributes	Small enough to easily fit on back of bike	4	▮	8%	4	▮	8%	9
9			Light Weight	3	▮	6%	2	▮	4%	9
10			Aesthetically Pleasing	1	▮	2%	5	▮	10%	9
11			Security system	2	▮	4%	7	▮	14%	
12		Dispatchability/ Adaptabiltiy	Engage/ Disengage Switch	3	▮	6%	3	▮	6%	9
13			adjustable to different frame models/geometry	4	▮	8%	2	▮	4%	9
14			Easy to take off/on	2	▮	4%	3	▮	6%	9
15										
16										

Fig. 1: Who vs. What for House of Quality.



HOW: Functional Requirements										Customer Competitive Assesment					
1	2	3	4	5	6	7	8	9	10						
Water splashes resistance	Water Pressure resistance	Charge capacity	Time to install system on bike	Mount on different frame geometries	Dimensions	Weight	Asthetics: Design must be favored	Engage/disengage generator from wheel	Impact Requirement	Our Product	Competitor #1: *EGPWR 100 EcoXPower Bike Charger*	Competitor #2: *Convergence Tech Inc- Flux Volt Charger w/ USB connection*	Competitor #3: Shimano- Dynamo Hub	Competitor #4: *Siva Cycle- The Atom*	Row #
↑	↑	↑	↓	↑	↓	↓	↑	↑	↑						
L/min	kPa	amps per hour	minutes	# of bikes	Inches^3	Pounds	A Percentage from a poll	Seconds	meter						
					○		▽				0	1	0	5	1
		●					▽				0	5	0	5	2
		○					○				3	3	3	3	3
		●									3	5	0	5	4
●	●										2	2	2	4	5
									●		2	2	5	5	6
●	○										0	0	0	0	7
					●		○				1	5	3	3	8
						●	▽		▽		1	4	3	4	9
							●				5	2	4	4	10
											0	0	0	0	11
								●			1	0	0	0	12
				●							1	5	2	2	13
			●	○							1	5	1	1	14
															15
															16

Fig. 2: What vs. How for House of Quality.



Target	Target for Functional Requirement #1	Target for Functional Requirement #2	Target for Functional Requirement #3	Target for Functional Requirement #4	Target for Functional Requirement #5	Target for Functional Requirement #6	Target for Functional Requirement #7	Target for Functional Requirement #8	Target for Functional Requirement #9	Target for Functional Requirement #10
Max Relationship	9	9	9	9	9	9	9	9	9	9
Technical Importance Rating	216	144	144	36	84	102	54	68	54	114
Relative Weight	21%	14%	14%	4%	8%	10%	5%	7%	5%	11%
Weight Chart										
Our Product										
Competitor #1: EGPWR 100 EcoXPower Bike Charger	2	2	3	1	1	1	1	5	1	2
Competitor #2: Convergence Tech Inc- Five Volt Charger w/ USB connection	2	2	5	5	5	5	4	2	0	2
Competitor #3: Shimano- Dynamo Hub	2	2	0	1	2	3	3	4	0	5
Competitor #4: Siva Cycle- The Atom	4	4	5	1	2	3	4	4	0	5
Column #	1	2	3	4	5	6	7	8	9	10
	Water splashes resistance	Water Pressure resistance	Charge capacity	Time to install system on bike	Mount on different frame geometries	Dimensions	Weight	Asthetics: Design must be favored	Engage/disengage generator from wheel	Impact Requirement

Fig. 3: How Much Portion for House of Quality.

Appendix B

Primary and Sub-Functions

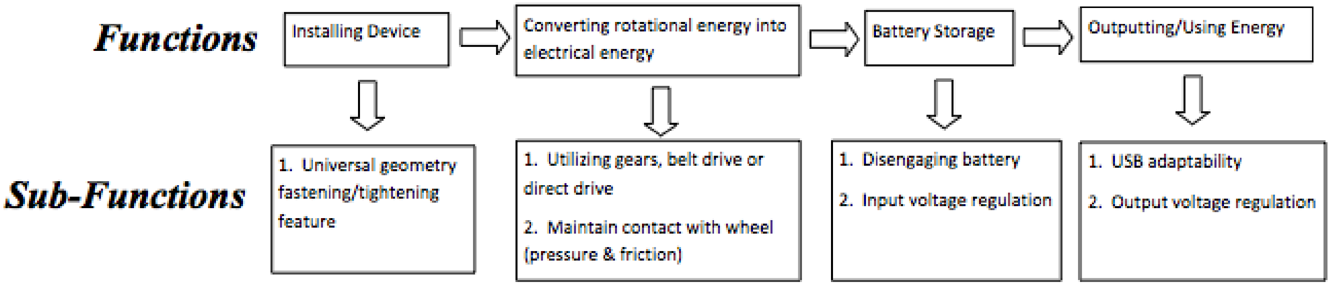


Fig. 1: Primary functions and sub-functions displayed in a graphical format.

Appendix C

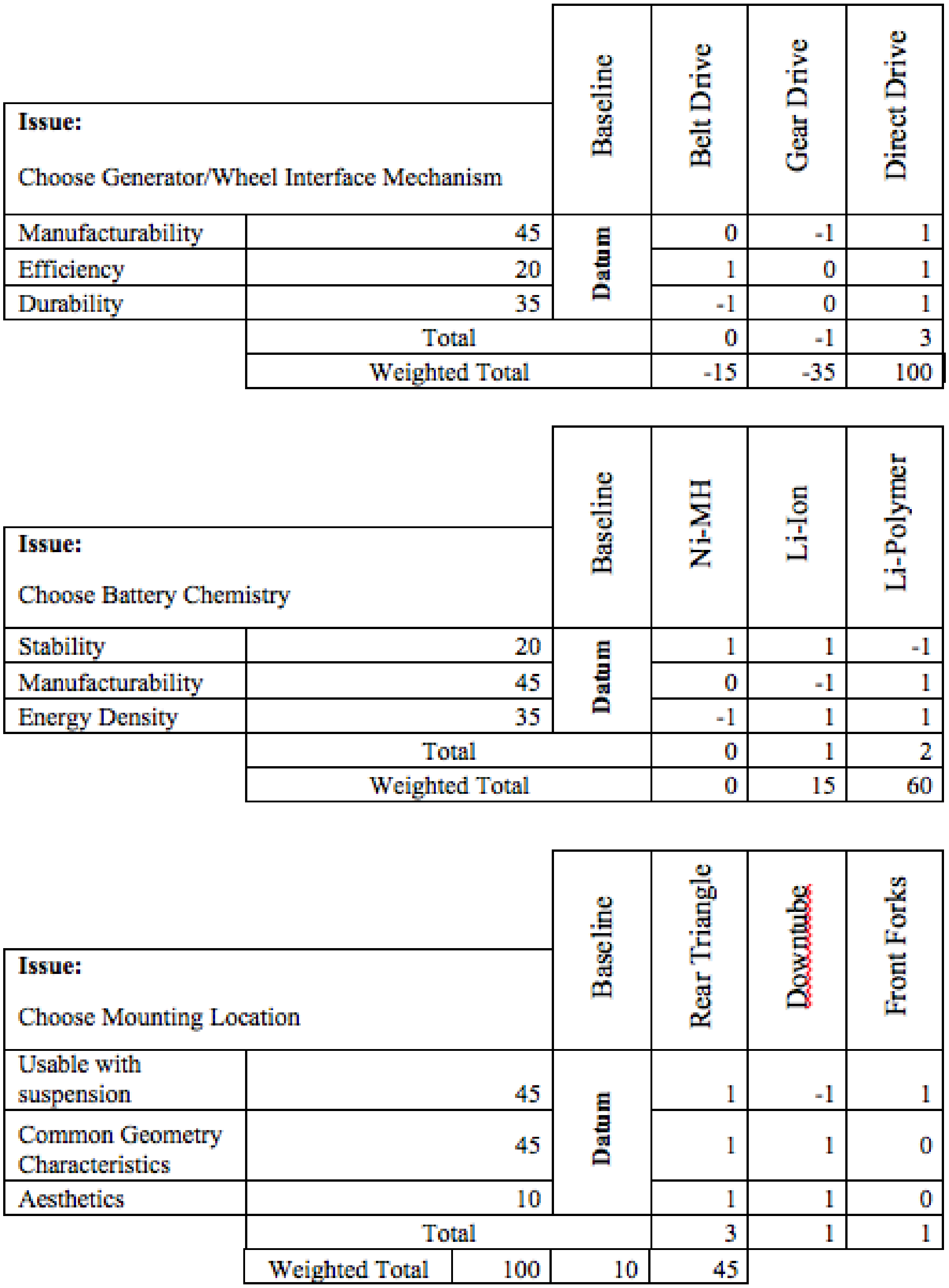
Pugh's Method

The previously developed product functions (universal platform compatibility, reliable energy conversion, energy storage, and common power output) will continue to guide relevant design candidates. To ensure that the functions are continuously met, the team will continue to employ decision matrices using Pugh's Method (Fig. 1).

The design concepts are summarized below:

1. Rubberized pipe clamp generator attachment
2. Direct-drive generator
3. Rear rim/generator interface
4. All inclusive electronics (battery, circuit, USB) mounted in water bottle cage
5. Lithium-polymer battery, 2400mAh capacity
6. Spring-loaded generator disconnect

The following topics were chosen for use in the matrices to drive design concept selection: generator/wheel interface mechanism, battery chemistry, and mounting location. In determining the best generator/wheel interface, the manufacturability, efficiency, and durability were made the criteria. For battery chemistry, sustainability, manufacturability, and energy density were the criteria examined. They were given scores from negative one to one; one meaning the part met the criterion better than datum (the baseline score set at meeting the bare requirement), zero meaning met the criterion as well as the datum, and negative one meaning it did not mean the criterion as well as the datum. The criteria for choosing the mounting location included: usability with suspension, common geometric characteristics, and aesthetics. Throughout each matrix, each criterion was given different weighting factors to normalize the score. Future testing and analysis during the proof of concept phase may change the most attractive design concepts, which will be reflected in the decisions matrices.



Issue: Choose Generator/Wheel Interface Mechanism		Baseline	Belt Drive	Gear Drive	Direct Drive
Manufacturability	45	**Datum**	0	-1	1
Efficiency	20		1	0	1
Durability	35		-1	0	1
	Total		0	-1	3
	Weighted Total		-15	-35	100

Issue: Choose Battery Chemistry		Baseline	Ni-MH	Li-Ion	Li-Polymer
Stability	20	**Datum**	1	1	-1
Manufacturability	45		0	-1	1
Energy Density	35		-1	1	1
	Total		0	1	2
	Weighted Total		0	15	60

Issue: Choose Mounting Location		Baseline	Rear Triangle	Downtube	Front Forks
Usable with suspension	45	**Datum**	1	-1	1
Common Geometry Characteristics	45		1	1	0
Aesthetics	10		1	1	0
	Total		3	1	1
Weighted Total	100	10	45		

Fig 1: Decision matrices for generator/wheel interface, battery chemistry, and mounting location.

Appendix D

Engineering Calculations

The following calculations will ensure that outlined design specifications can be met, and provide analytical data that will later be compared with testing results to ensure proper operation and performance.

Certain system assumptions will be made in order to begin the engineering analysis:

1. Average bicycle speed of 12 mph.
2. Performance will be based on 700c wheel size.
3. Available power for charging consumer devices will be 2400mAh.
4. Battery chargeability is based on 1c performance (c=1 x capacity).

The speed of 12 mph was chosen to reflect a moderate pace on a commuter or mountain bicycle. The 700c wheel is the most common size wheel for commuter bikes, performance road bikes, and many new mountain bikes (known as 29ers). Actual wheel diameter of the 700c wheel is 0.622 m.

All devices that will potentially be charged by our device can be charged to at least half of capacity with 2400mAh. For initial analysis, we will assume a chargeability factor of 1c, or 1 times the total capacity, in this instance 2400mAh. Most off of the shelf circuits can condition and regulate a 5-12V input to charge the battery and are also capable of handling a range of amperage from 100mA to 1.5A. As such, we will need to be able to provide voltage and current in these ranges from the generator.

Most small, high-speed DC motors are capable of supplying between 0.5 and 1.0 Amp at 6V when loaded and given a rotational velocity between 8,000 and 12,000 RPM. The key calculations include the interface between the rotating bicycle wheel and the rotating generator shaft. Assuming a constant velocity of 12 MPH, we can determine the rotational speed of the wheel, given a radius of 0.311 m (Eqns. 1 and 2).

$$Eq. 1 \qquad D \times \pi = \frac{meters}{rev} = 0.622m \times \pi = 1.95407 \frac{m}{rev}$$

$$Eq. 2 \qquad V \times \frac{1\,hr}{60\,min} \times \frac{rev}{meter} = 19312.1 \frac{m}{hr} \times \frac{1\,hr}{60\,min} \times \frac{1\,rev}{1.95407m} = 164.717\ RPM$$

Subscripts *w* denotes values related to the wheel, while subscripts *s* denotes values related to the motor/generator shaft. Again, assuming a nonslip condition at the interface between the wheel and the generator shaft, a simple equation relating the rotational speed to each wheel radius can be used to relate the two wheel rotations (Eq. 3).

$$Eq. 3 \qquad \omega_w \times r_w = \omega_s \times r_s$$

Rearranging Eq. 3 in order to solve for the radius of the generator shaft and using the assumed necessary value of 10,000 RPM at the motor shaft yields the necessary radius needed at the interface between the wheel and the generator (Eq. 4).

$$Eq.4 \quad r_s = \frac{\omega_w \times r_w}{\omega_s} = \frac{164.717\ RPM \times 0.311\ m}{10{,}000\ RPM} = 0.005123\ m$$

This shows that we have a required diameter of 10.2mm or approximately a diameter of 3/8 of an inch for the generator shaft interface with the wheel in order to achieve the proper voltage and current output required for charging.

Appendix E

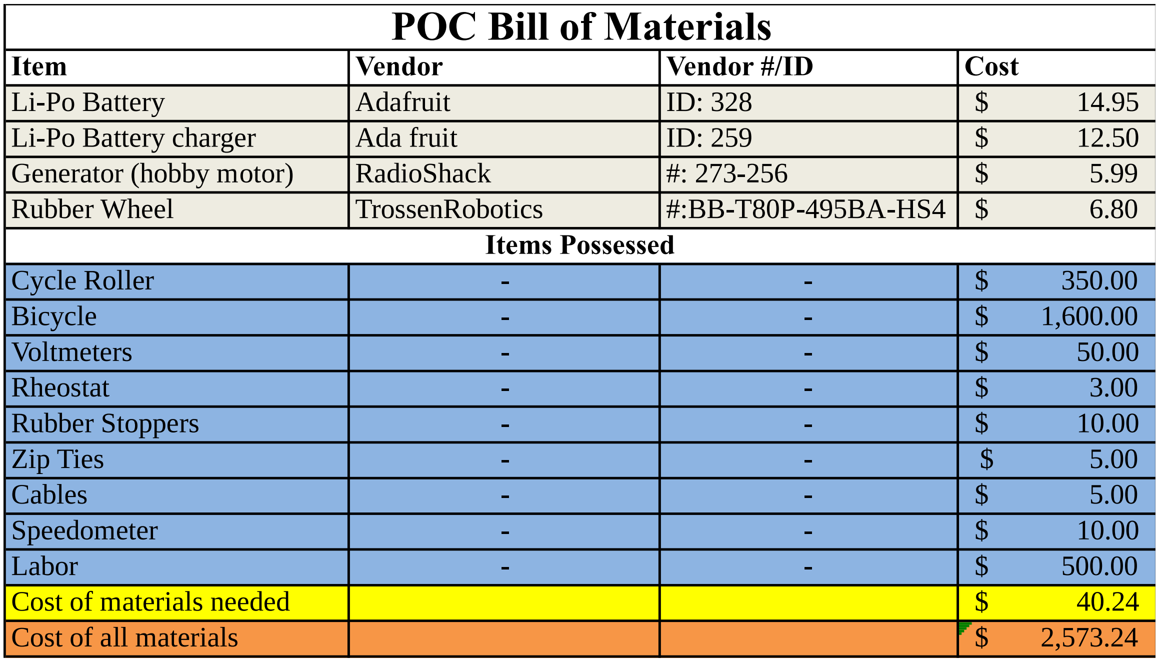
Complete Bill of Materials for POC, Prototype, and Mass Production

Table 1: Compete Bill of Materials.

Prototype and Mass Production Bill of Materials

Item	Vendor	Vendor #/ID	Prototype Cost	Mass Production Cost (10,000 Units)
Li-Po Battery	Adafruit	ID: 328	$ 14.95	$ 7.00
Li-Po Battery charger	Adafruit	ID: 259	$ 12.50	$ 5.00
Generator (hobby motor)	RadioShack	#: 273-256	$ 5.99	$ 2.00
Polyurethane Rod	McMaster-Carr	8784K19	$ 15.17	$ 3.00
Universal Clamp	Ace Hardware	-	$ 2.99	$ 2.00
Generator Latch Plate	Palmer Mfg. Lab	-	Donated	$ 6.00
Generator Power Cord	Amazon	B00FTH6WNS	$ 6.95	$ 3.00
Water Bottle Bracket	Palmer Mfg. Lab	-	Donated	$ 5.00
Electronics Pack	Palmer Mfg. Lab	-	Donated	$ 10.00
Generator Housing	Palmer Mfg. Lab	-	Donated	$ 4.00
USB Connector	Fry's Electronics	-	$ 10.00	$ 0.50
DAP Silicone Sealant	Ace Hardware	1012228 | 070798006881	$ 6.99	$ 0.50
Fasteners	Ace Hardware	-	$ 5.00	$ 1.50
Mounting Hinge with Spring	Hardware Source	658081	$ 9.99	$ 3.00
1 uF Capacitor	RadioShack	-	$ 0.50	$ 0.10
JB Weld	Ace Hardware	88089 | 043425828002	Donated	$ 0.50
Solder	RadioShack	64-013	$ 7.50	$ 0.40
Foam Padding	Ace Hardware	-	$ 2.99	$ 0.50
GoPro Mounts	Walmart	-	$ 19.99	$ 1.00
Aluminum Stock	McMaster-Carr	8975K315	$ 32.57	$ 5.00
Items Possessed				
Cycle Roller	-	-	$ 350.00	-
Bicycle	-	-	$ 1,600.00	-
Voltmeters	-	-	$ 50.00	-
Rheostat	-	-	$ 3.00	-
Speedometer	-	-	$ 10.00	-
Digital Oscilliscope	-	-	$ 350.00	-
Labor	-	-	$ 3,000.00	$ 5.00
Cost of materials needed			$ 154.08	**$ 65.00**
Cost of all materials			$ 5,517.08	

Table 2: Complete Proof of Concept Bill of Materials.



POC Bill of Materials			
Item	**Vendor**	**Vendor #/ID**	**Cost**
Li-Po Battery	Adafruit	ID: 328	$ 14.95
Li-Po Battery charger	Ada fruit	ID: 259	$ 12.50
Generator (hobby motor)	RadioShack	#: 273-256	$ 5.99
Rubber Wheel	TrossenRobotics	#:BB-T80P-495BA-HS4	$ 6.80
Items Possessed			
Cycle Roller	-	-	$ 350.00
Bicycle	-	-	$ 1,600.00
Voltmeters	-	-	$ 50.00
Rheostat	-	-	$ 3.00
Rubber Stoppers	-	-	$ 10.00
Zip Ties	-	-	$ 5.00
Cables	-	-	$ 5.00
Speedometer	-	-	$ 10.00
Labor	-	-	$ 500.00
Cost of materials needed			$ 40.24
Cost of all materials			$ 2,573.24

Appendix F

Testing Apparatus Assembly and Instructions

Testing Assembly

1. Place bicycle onto cycling stand and lock in place.
2. Attach generator to rear triangle and tire sidewall.
3. Connect speedometer to rear tire. Check manufacturing instructions for proper placement and calibration.
4. Using a breadboard, connect the generator to the positive and negative rails.
5. Connect multi-meter positive lead to the breadboard positive rail and the negative lead to the negative rail.
6. Connect multi-meter in series between generator and charging circuit. The positive lead of the multi-meter connects to the positive rail of the breadboard. The negative lead of the multi-meter connects to the positive lead of the charging circuit.
7. Complete the circuit by connecting the negative lead from the charging circuit to the negative rail of the breadboard.

Testing Instructions

1. After proper assembly, a team member will mount the bicycle. Begin pedaling once observers are ready to record data.
2. Have the cyclist begin pedaling and increasing to a speed of 11 MPH. Record voltages, amperage and speed.
3. Increase the speed of rotation by 1 MPH every 15 seconds. Do not increase speed past 20 MPH.
4. Record the speed of the bicycle, the voltage, and amperage.
5. Steadily reduce speed to a stop after voltage, amperage, and speed has been recorded at 20 MPH.
6. Repeat steps 2-5 three times.
7. Compare different data sets, determining average voltage and amperage output at each speed from 11-20 MPH.

Appendix G

Complete POC Testing Data and Calculations

Table 1: Test 1 Data.

Proof of Concept Testing Results - Test 1		
Speed (mph)	Voltage (volts)	Amperage (amps)
11	4.93	0.17
12	5.18	0.23
13	5.59	0.32
14	5.63	0.33
15	5.85	0.36
16	5.91	0.39
17	6.23	0.43
18	6.63	0.48
19	7.12	0.54
20	7.91	0.61

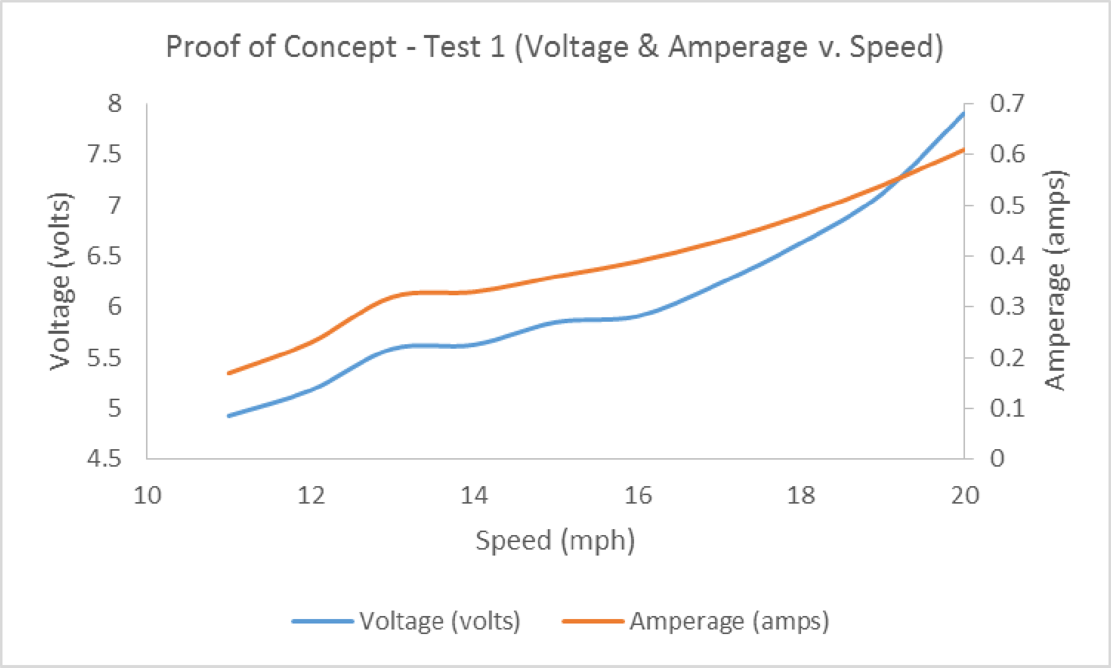


Fig. 1: Voltage & Amperage vs. Speed for Test 1.

Table 2: Test 2 Data.

Proof of Concept Testing Results - Test 2		
Speed (mph)	Voltage (volts)	Amperage (amps)
11	4.89	0.15
12	5.21	0.24
13	5.6	0.32
14	5.63	0.33
15	5.83	0.36
16	5.92	0.4
17	6.25	0.44
18	6.61	0.47
19	7.15	0.55
20	7.86	0.6

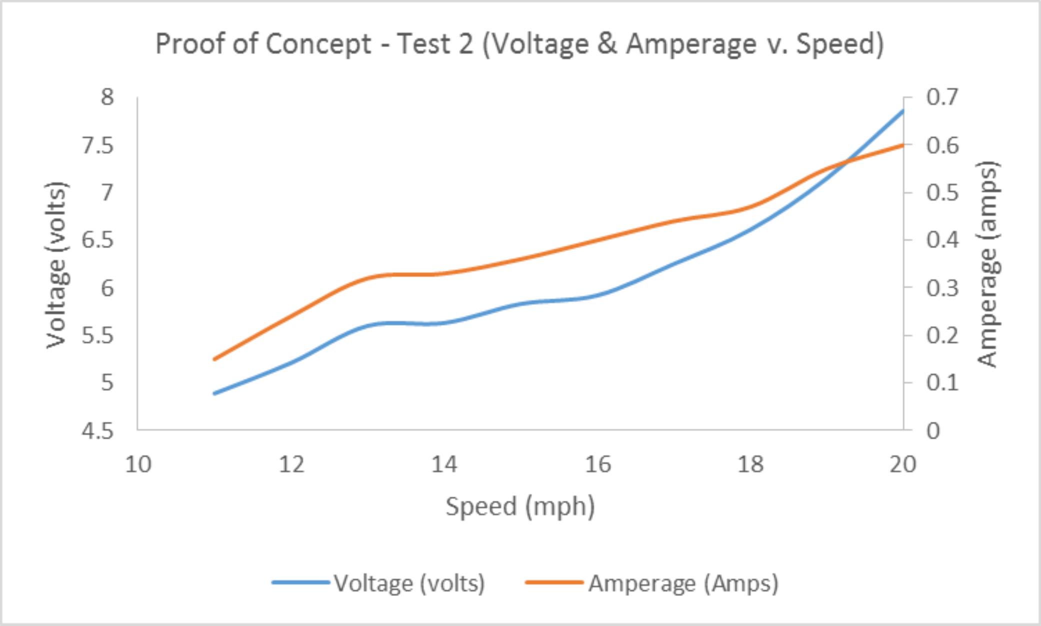


Fig. 2: Voltage & Amperage vs. Speed for Test 2.

Table 3: Test 3 Data.

Proof of Concept Testing Results - Test 3		
Speed (mph)	Voltage (volts)	Amperage (amps)
11	4.91	0.16
12	5.2	0.24
13	5.57	0.31
14	5.65	0.33
15	5.8	0.35
16	5.89	0.39
17	6.23	0.43
18	6.6	0.47
19	7.1	0.53
20	7.9	0.61

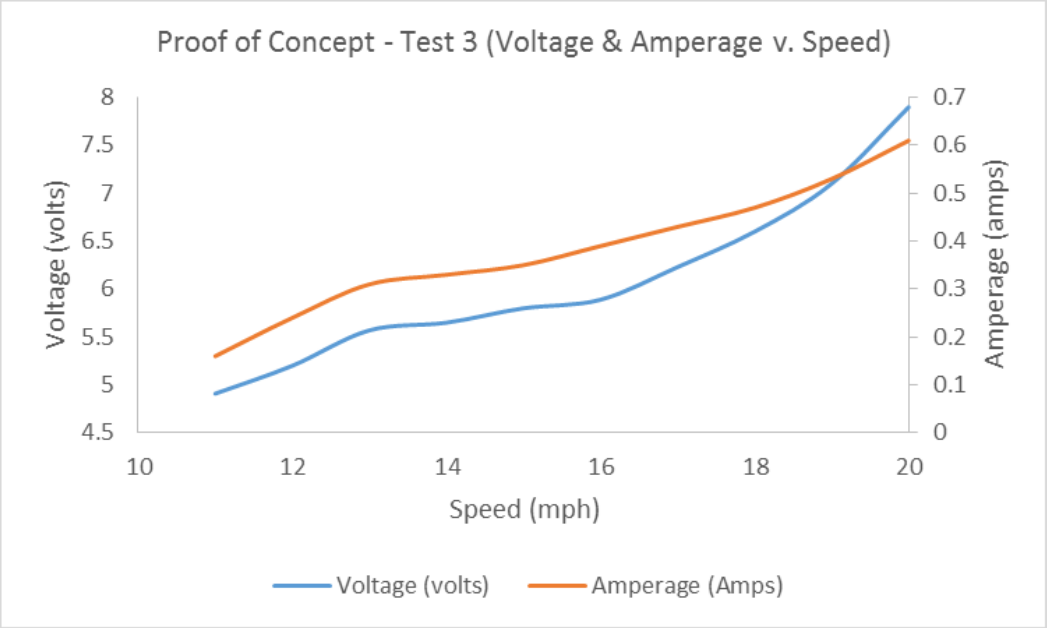


Fig. 3: Voltage & Amperage vs. Speed for Test 3.

Table 4: Average Speed and Power Output.

Average Power	
Speed (mph)	Power (watts)
11	0.7856
12	1.229877778
13	1.769111111
14	1.8601
15	2.078177778
16	2.323288889
17	2.702555556
18	3.130311111
19	3.8466
20	4.7866

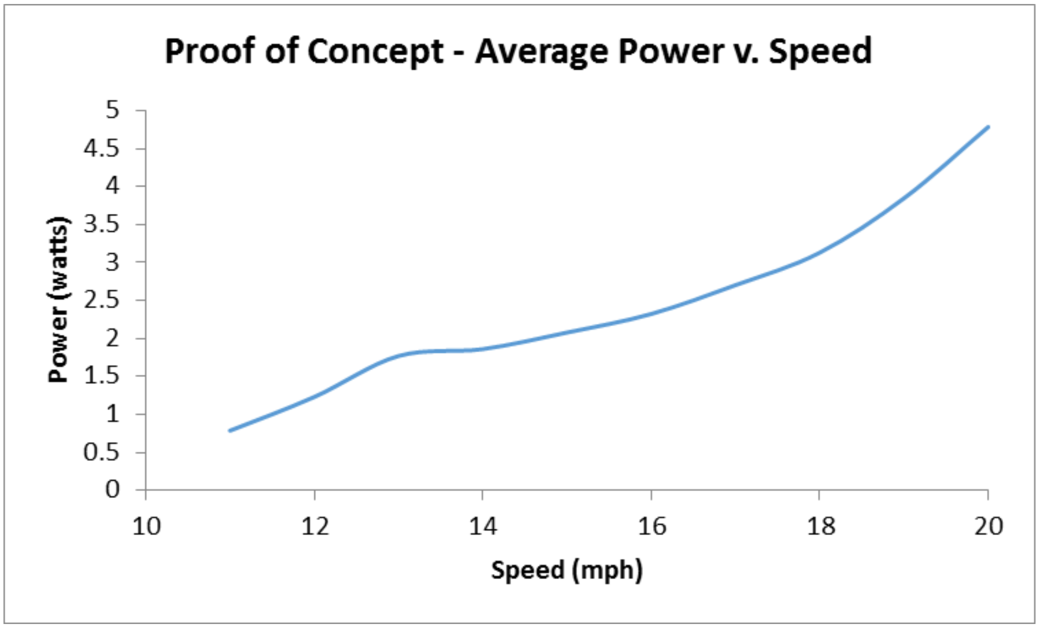


Fig. 4: Average Power vs. Speed.

Testing Calculations:

Equations 1-2 are used to determine the RPMs of a 700c wheel (622mm nominal diameter) given a bicycle velocity of 12 mph (19,312.1 meters per hour).

$$Eq. 1 \qquad D \times \pi = \frac{meters}{rev} = 0.622m \times \pi = 1.95407\frac{m}{rev}$$

$$Eq. 2 \qquad V \times \frac{1\ hr}{60\ min} \times \frac{rev}{meter} = 19312.1\frac{m}{hr} \times \frac{1\ hr}{60\ min} \times \frac{1\ rev}{1.95407m} = 164.717\ RPM$$

Equation 3 shows the ratio conversion for wheel radius r_1 at wheel RPM ω_1 to generator wheel radius r_2 at generator wheel RPM ω_2 to find the RPM of the generator shaft.

$$Eq. 3 \qquad \frac{\omega_1 \times r_1}{r_2} = \omega_2 = \frac{164.717RPM\ \times 0.311m}{0.00476m} = 10762\ RPM$$

Appendix H

Manufacturer's Data Sheets

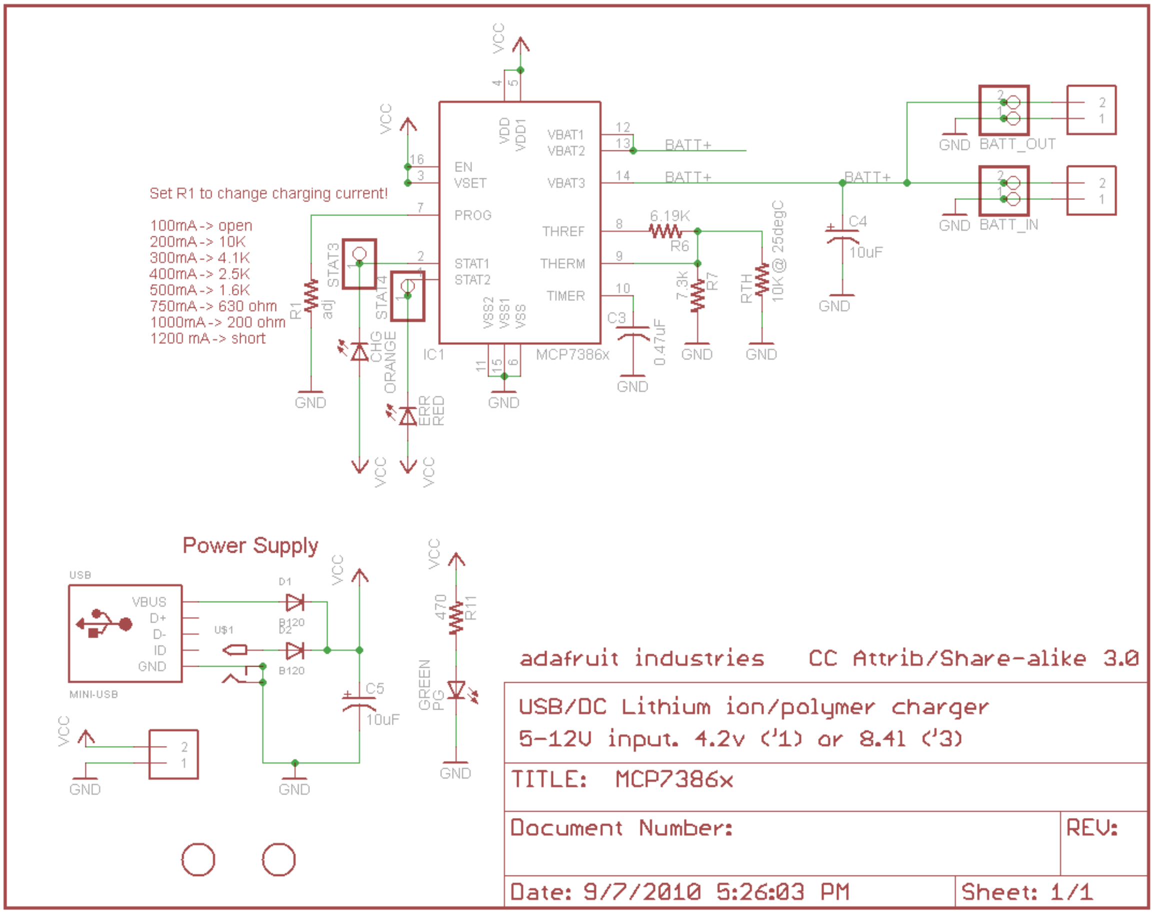
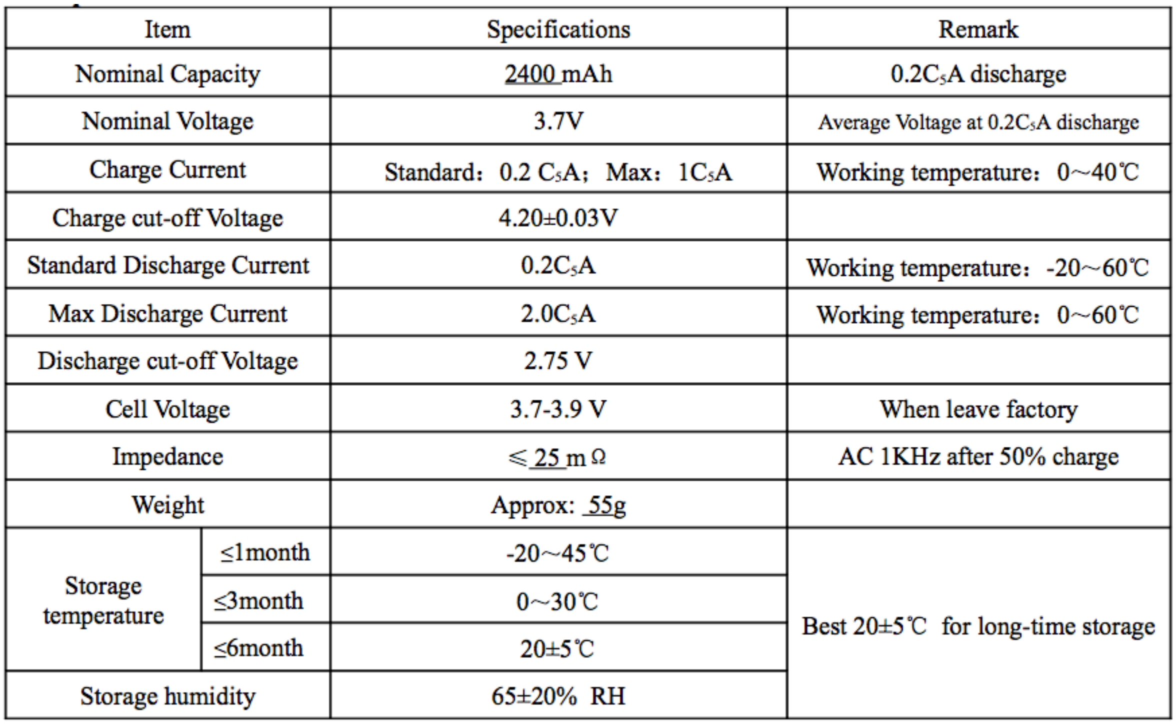


Fig. 1: Adafruit Charging Circuit Schematic.

RadioShack Hi-Speed Motor 273-256 Specifications:

- No load: 9VDC 380mA current max., 11000± 15% speed, 150g.cm min. torque
- No load: 12VDC 400mA current max., 15200± 15% speed, 190g.cm min. torque
- No load: 18VDC 430mA current max., 24000± 15% speed, 290g.cm min. torque
- With load: 9VDC 1.1A current max., 9300± 15% speed
- With load: 12VDC 1.5A current max., 11500± 15% speed
- With load: 18VDC 2.4A current max., 18000± 15% speed

Table 1: Li-polymer Battery Specifications.



Item		Specifications	Remark
Nominal Capacity		2400 mAh	0.2C$_5$A discharge
Nominal Voltage		3.7V	Average Voltage at 0.2C$_5$A discharge
Charge Current		Standard：0.2 C$_5$A；Max：1C$_5$A	Working temperature：0～40℃
Charge cut-off Voltage		4.20±0.03V	
Standard Discharge Current		0.2C$_5$A	Working temperature：-20～60℃
Max Discharge Current		2.0C$_5$A	Working temperature：0～60℃
Discharge cut-off Voltage		2.75 V	
Cell Voltage		3.7-3.9 V	When leave factory
Impedance		≤25 mΩ	AC 1KHz after 50% charge
Weight		Approx: 55g	
Storage temperature	≤1month	-20～45℃	Best 20±5℃ for long-time storage
	≤3month	0～30℃	
	≤6month	20±5℃	
Storage humidity		65±20% RH	

Appendix I

Complete Design Drawings, Models, and Photos

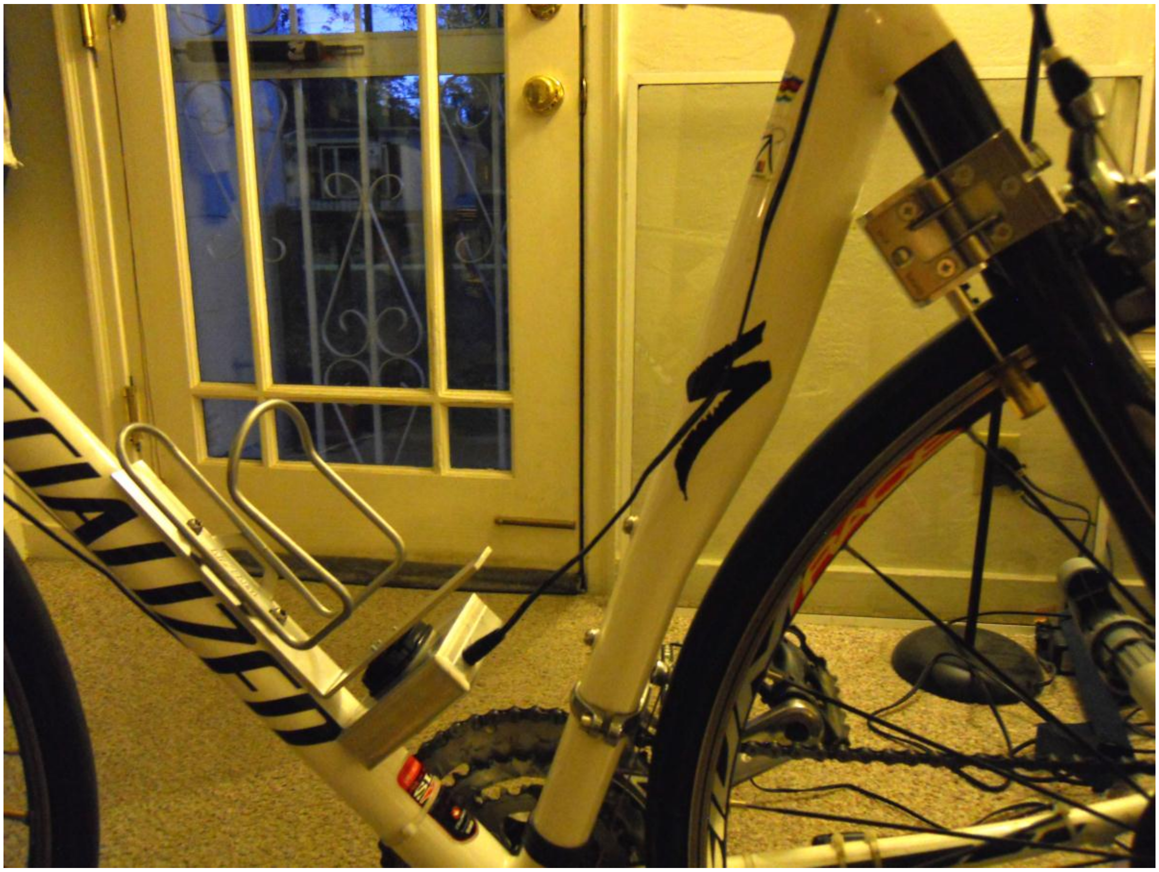


Fig. 1: Complete Pedal Power prototype mounted on bicycle.

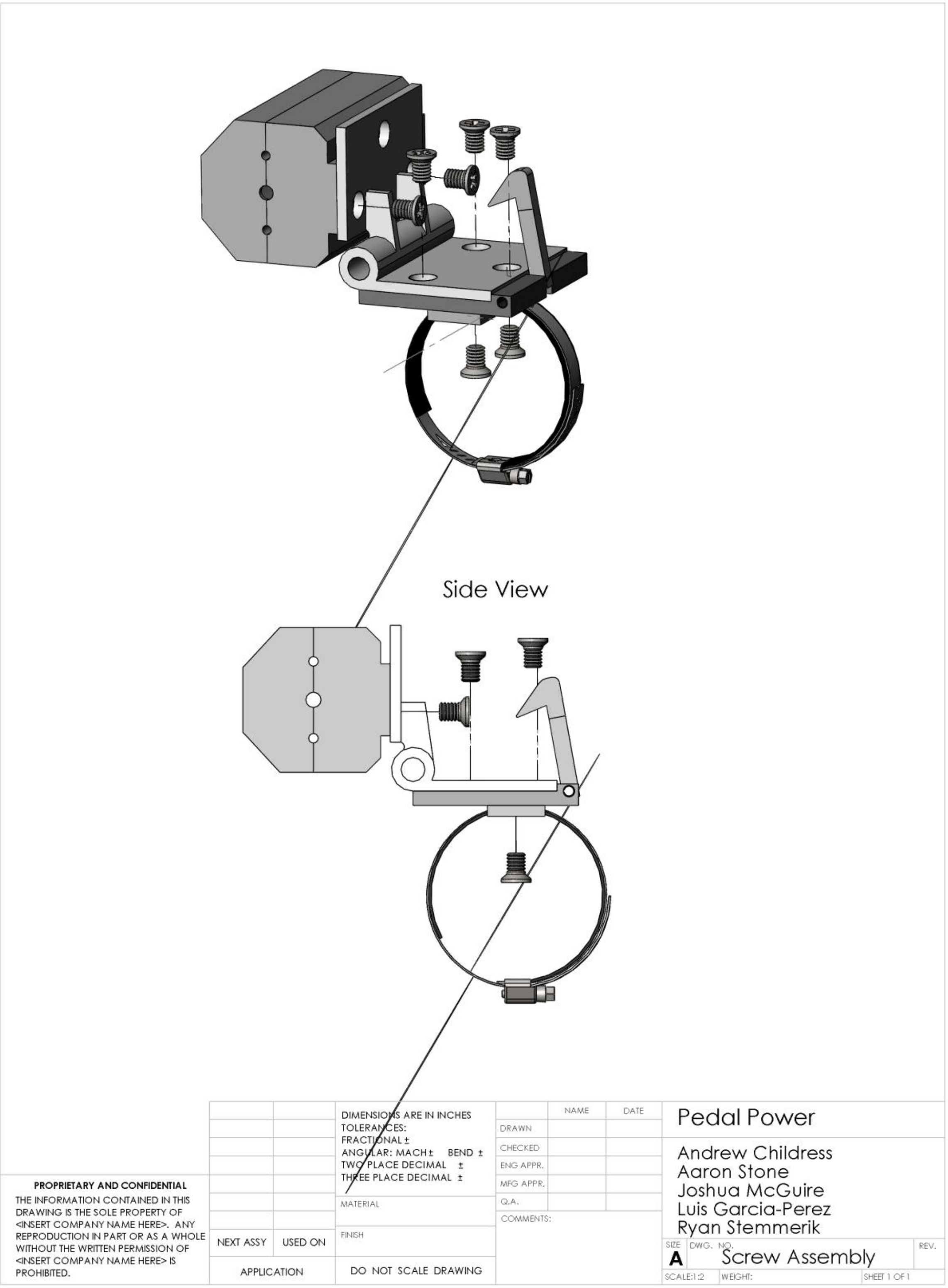


Fig. 2: Complete generator enclosure and mounting bracket assembly.

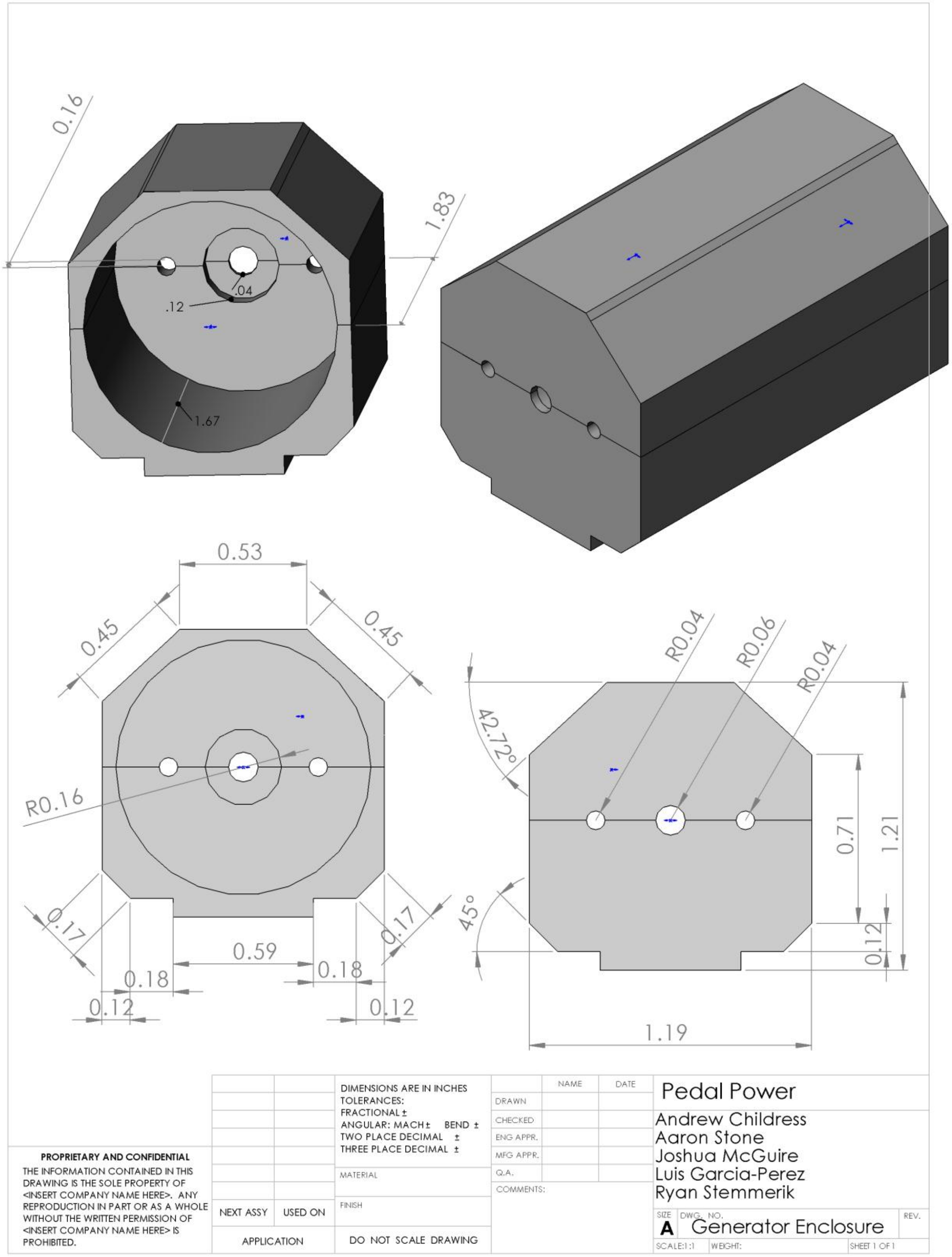


Fig. 3: Generator enclosure drawing.

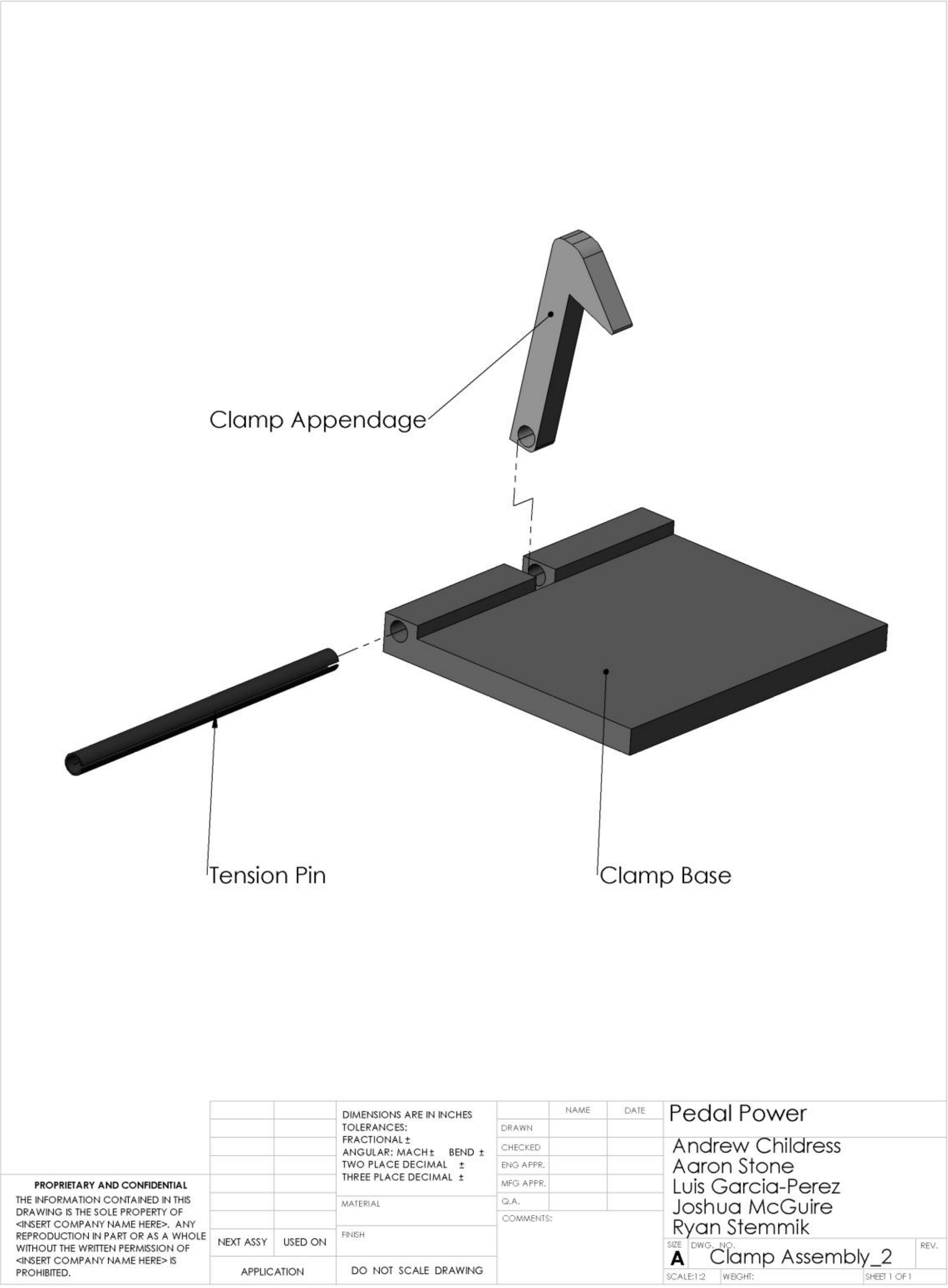


Fig. 4: Clamp base assembly.

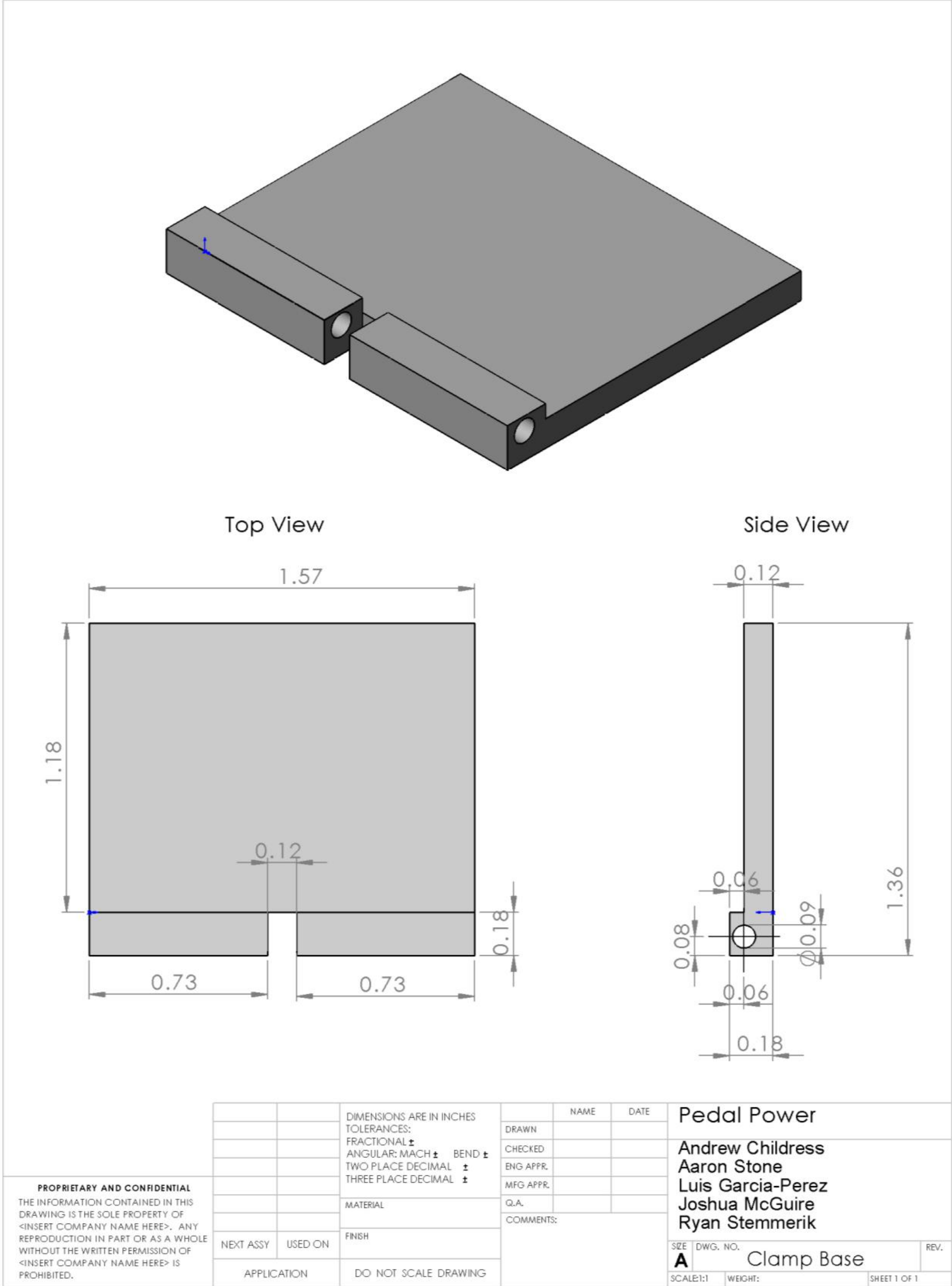
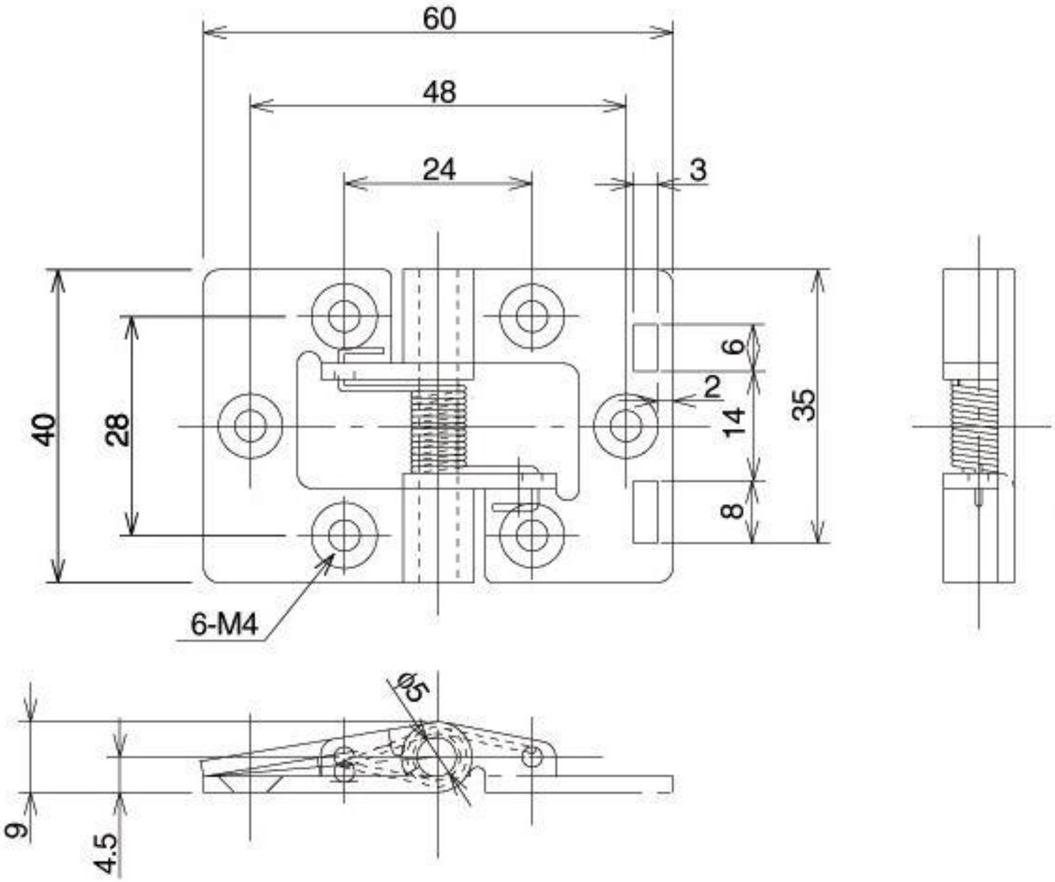
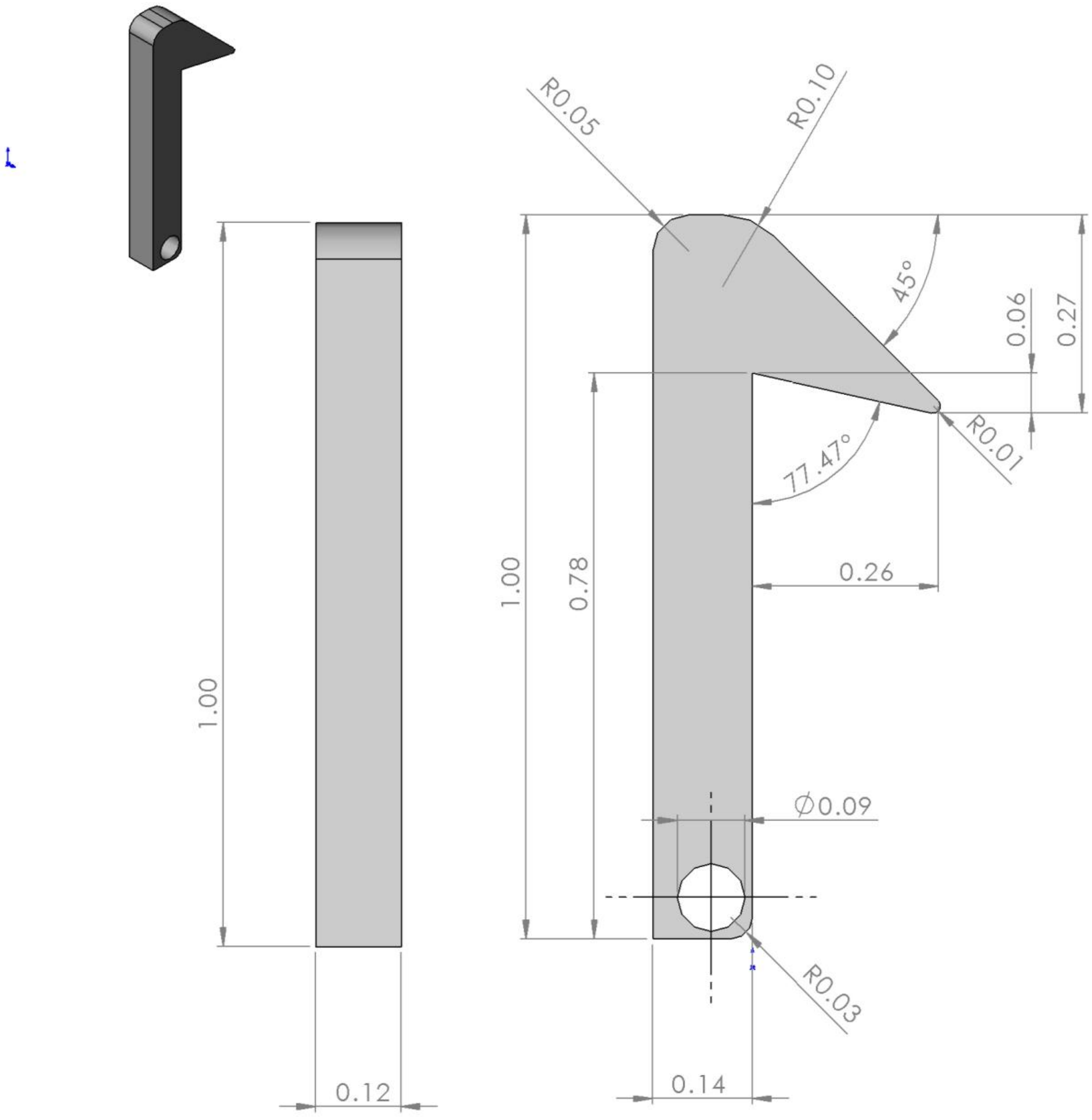


Fig. 5: Clamp base plate drawing.



Dimensional Diagram for HardwareSource SKU Numbers 658082 and 658081. All dimensions are in millimeters.

Fig. 6: Prefrabricated spring hinge dimensions.



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

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NEXT ASSY | USED ON

APPLICATION

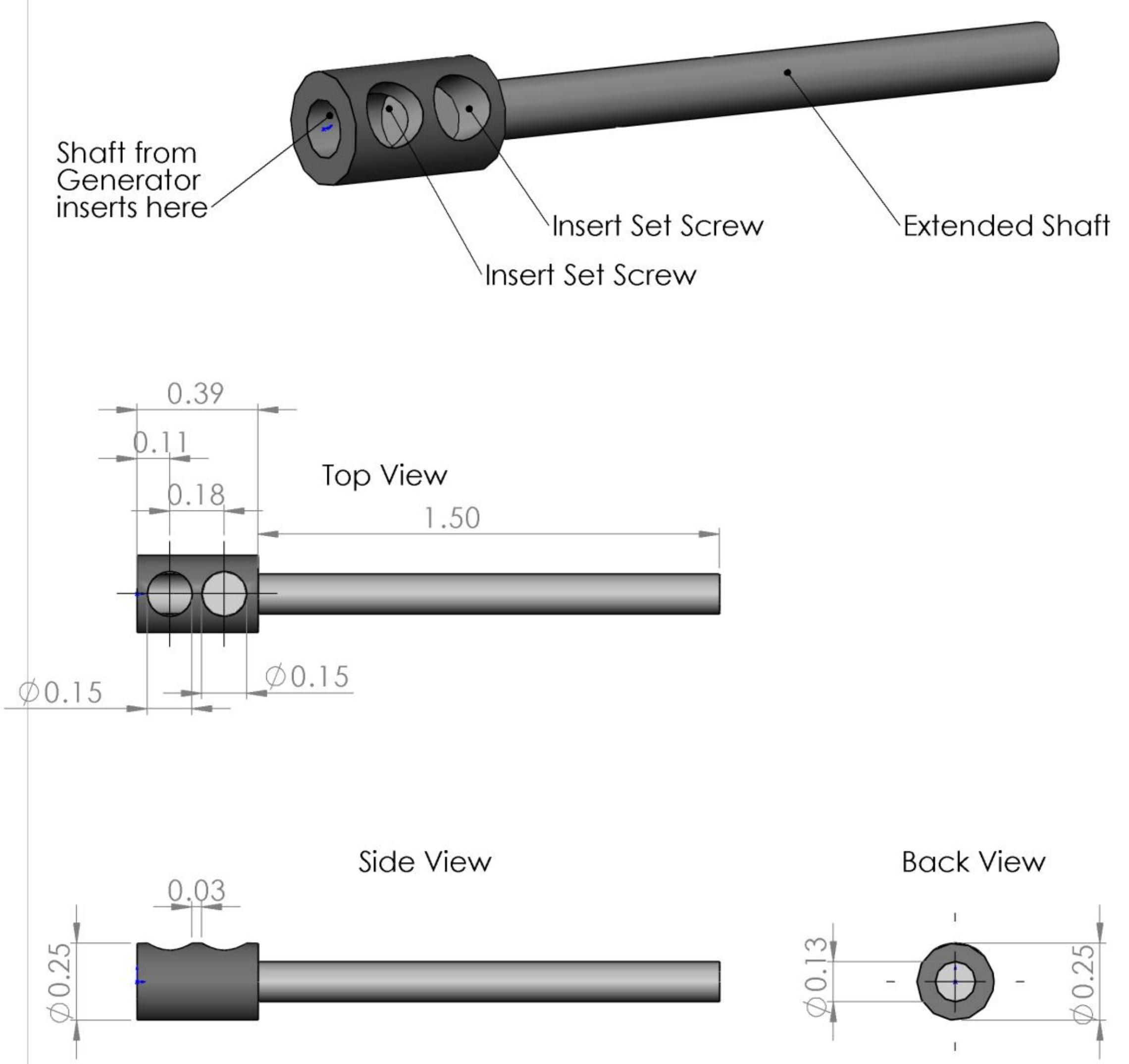
Pedal Power

Andrew Childress
Aaron Stone
Joshua McGuire
Luis Garcia-Perez
Ryan Stemmerik

SIZE A DWG. NO. Clamp Appendage REV.

SCALE:2:1 WEIGHT: SHEET 1 OF 1

Fig. 7: Clamp appendage drawing.



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

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MFG APPR.		
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MATERIAL

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NEXT ASSY | USED ON

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Pedal Power

Andrew Childress
Aaron Stone
Joshua McGuire
Luis Garcia-Perez
Ryan Stemmerik

SIZE A DWG. NO. Generator Shaft Extension REV.

SCALE:2:1 WEIGHT: SHEET 1 OF 1

Fig. 8: Generator extension shaft.

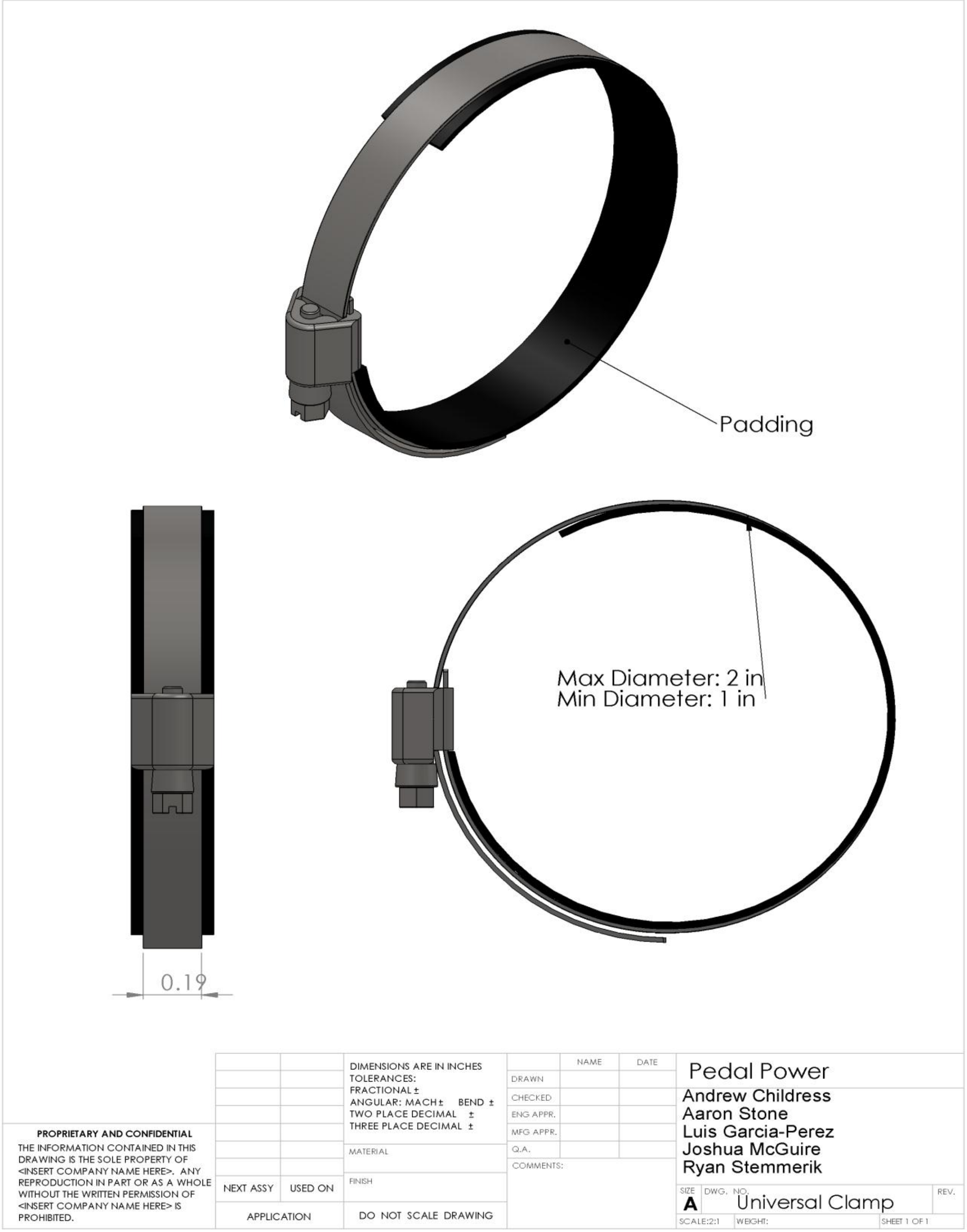

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Fig. 9: Universal worm screw clamp with foam padding.

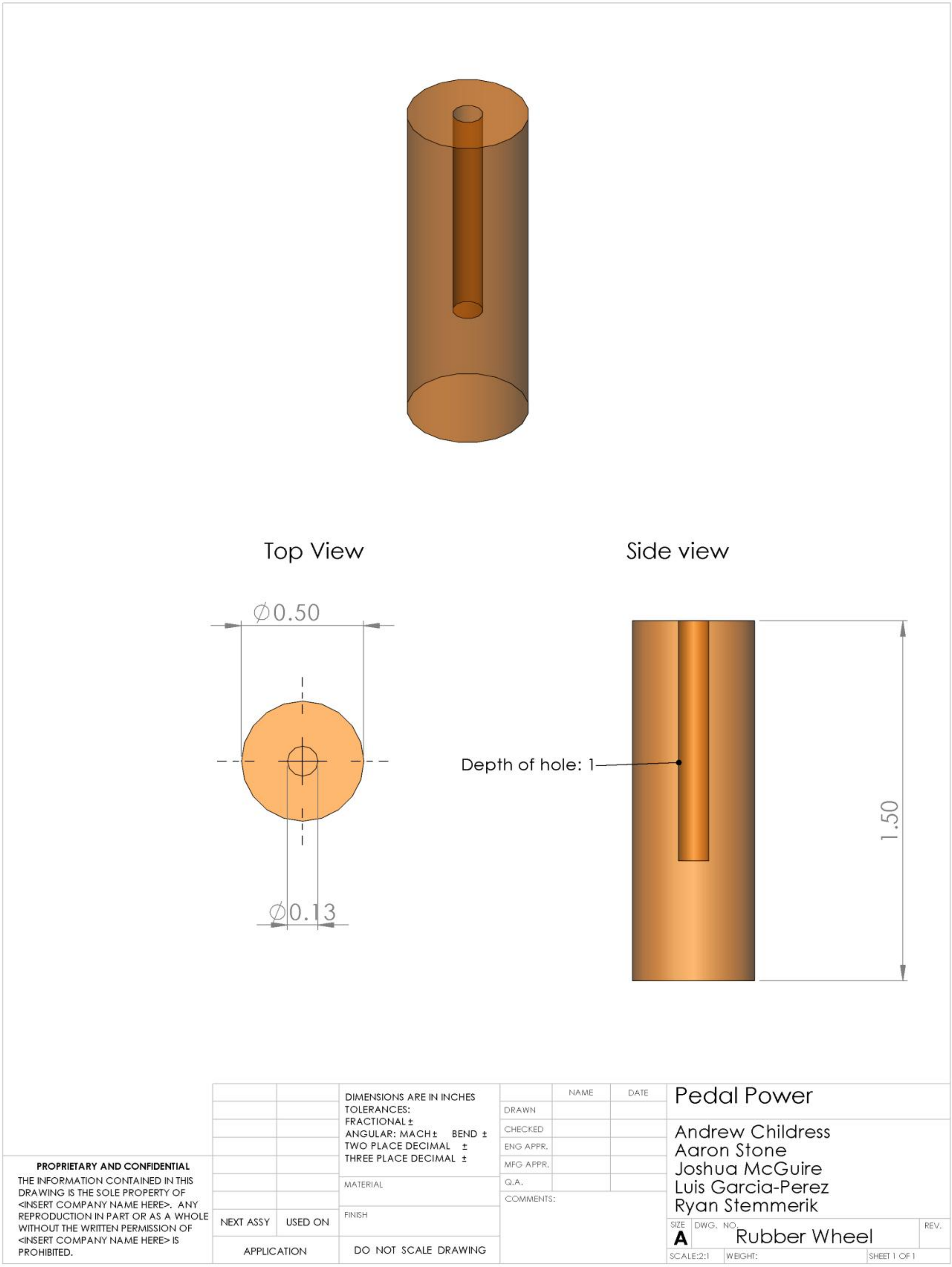


Fig. 10: Polyurethane roller wheel.

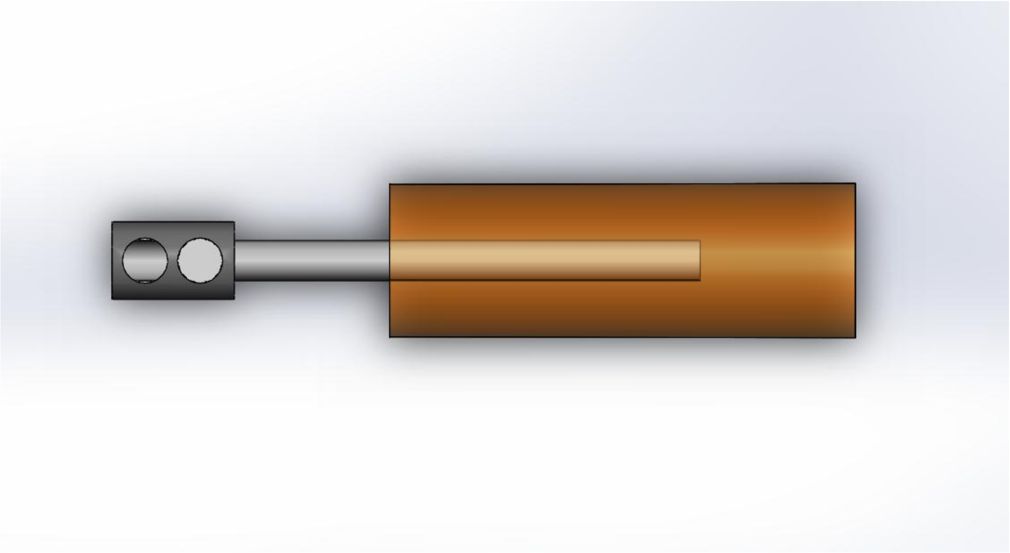


Fig. 11: Polyurethane roller press fit onto extension shaft.

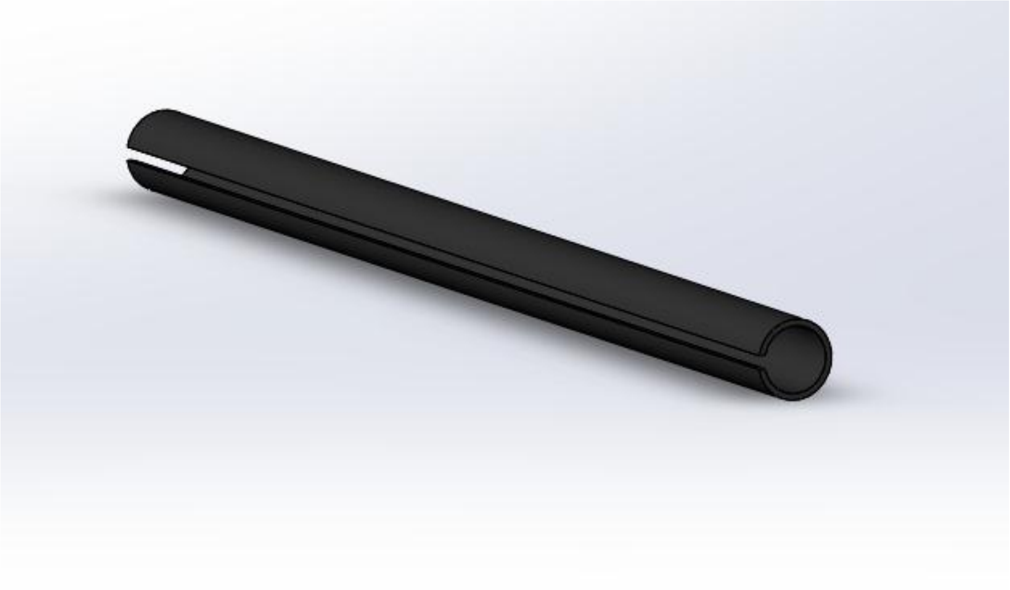


Fig. 12: Tension pin.

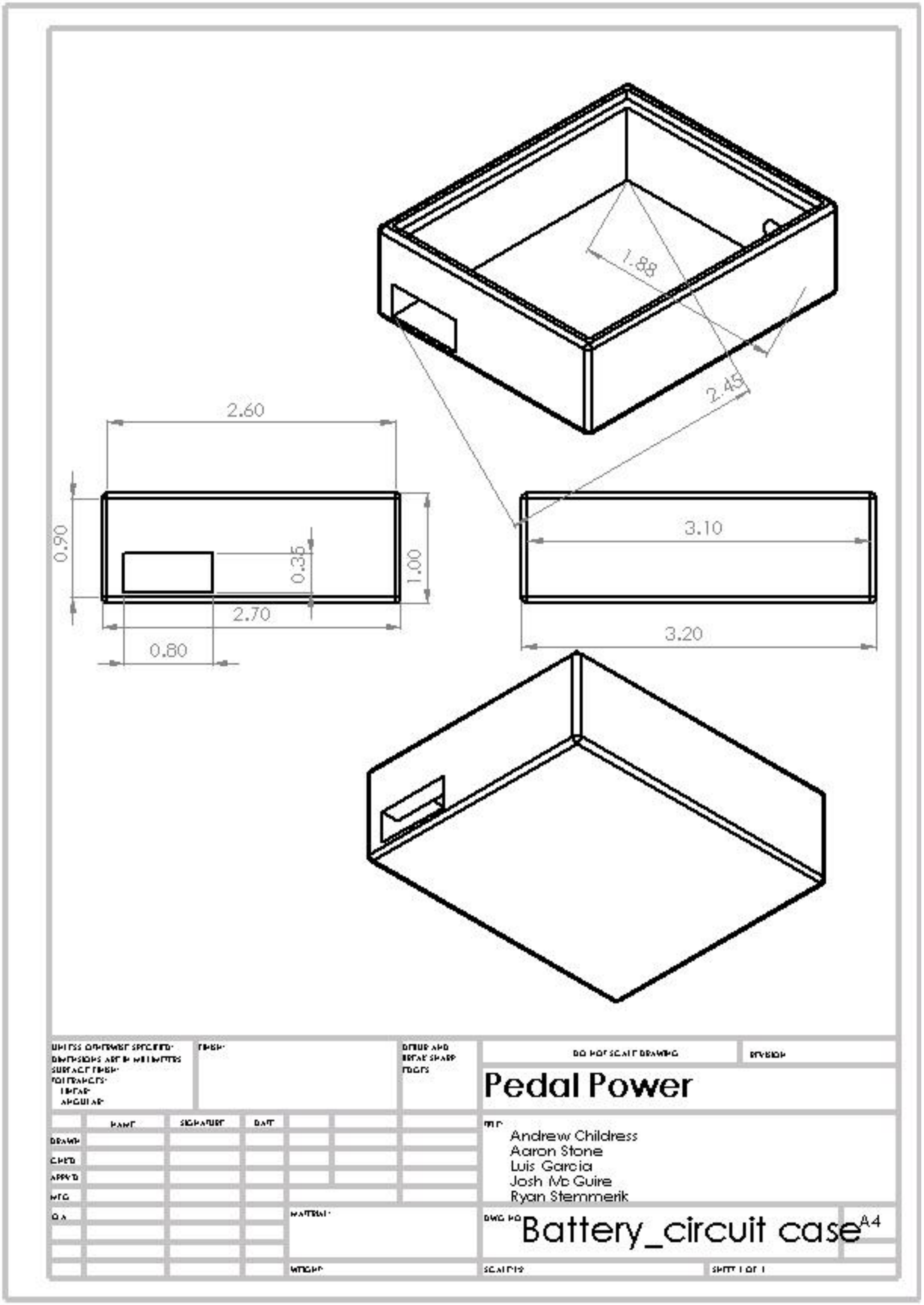


Fig. 13: Electronics pack drawing.

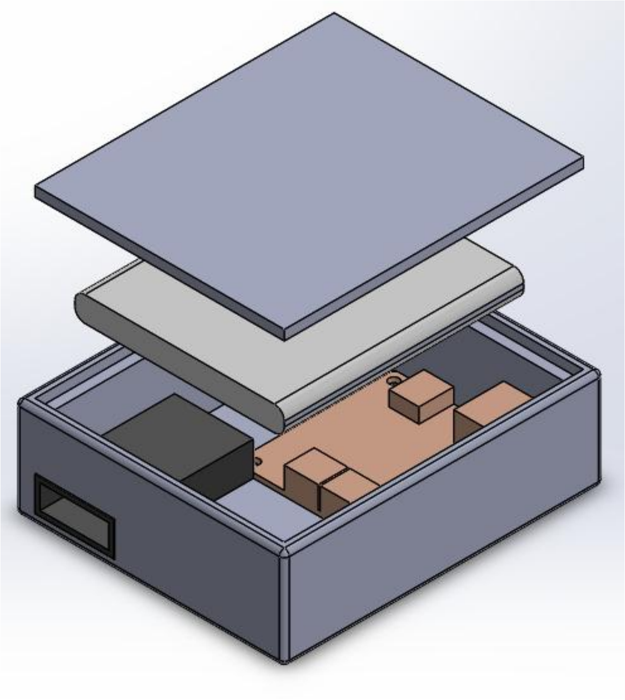


Fig. 14: Electronics pack enclosure, circuit boad, USB connector, and power connector.

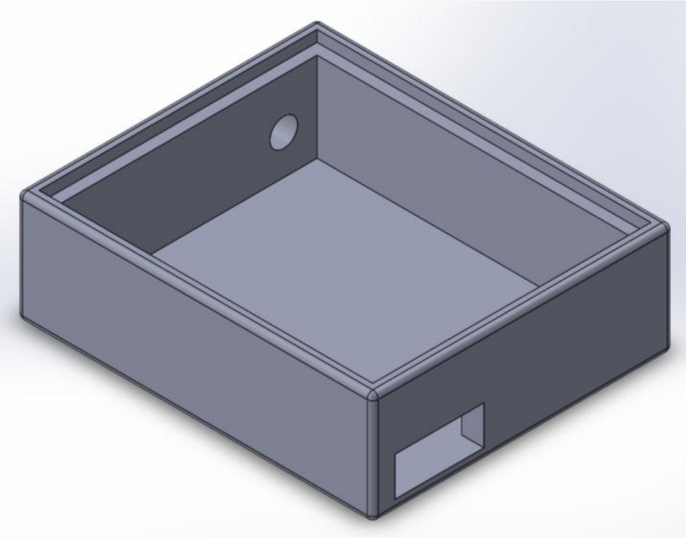


Fig. 15: Electronics pack case.

Fig. 16: Generator and mounting bracket assembly mounted onto rear triangle.

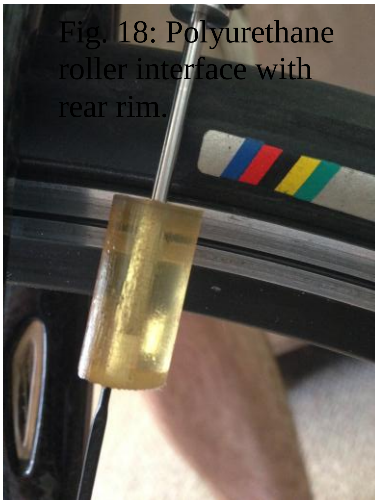


Fig. 18: Polyurethane roller interface with rear rim.

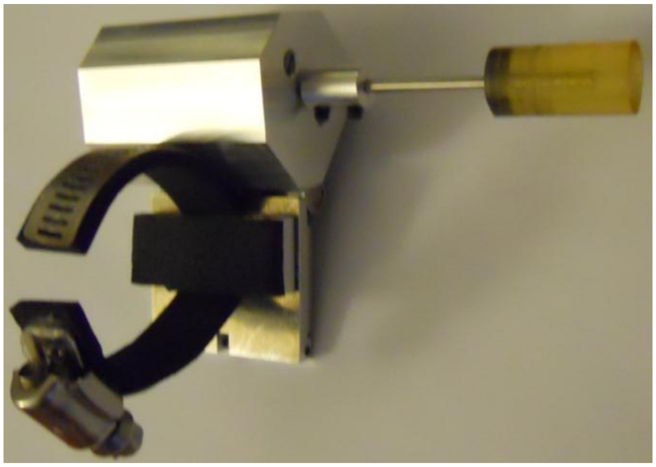


Fig. 17: Generator mounting bracket, enclosure, and extension shaft with roller.

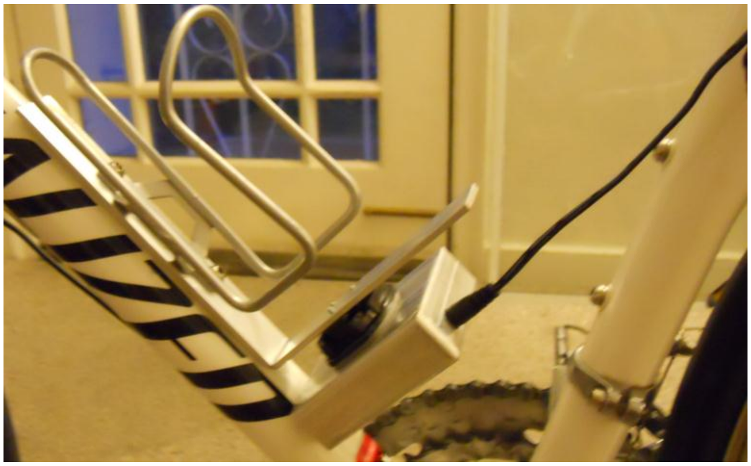


Fig. 19: Water bottle post mounting bracket and electronics pack.

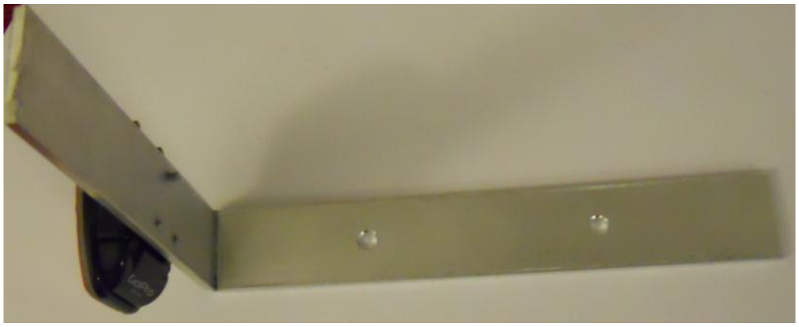


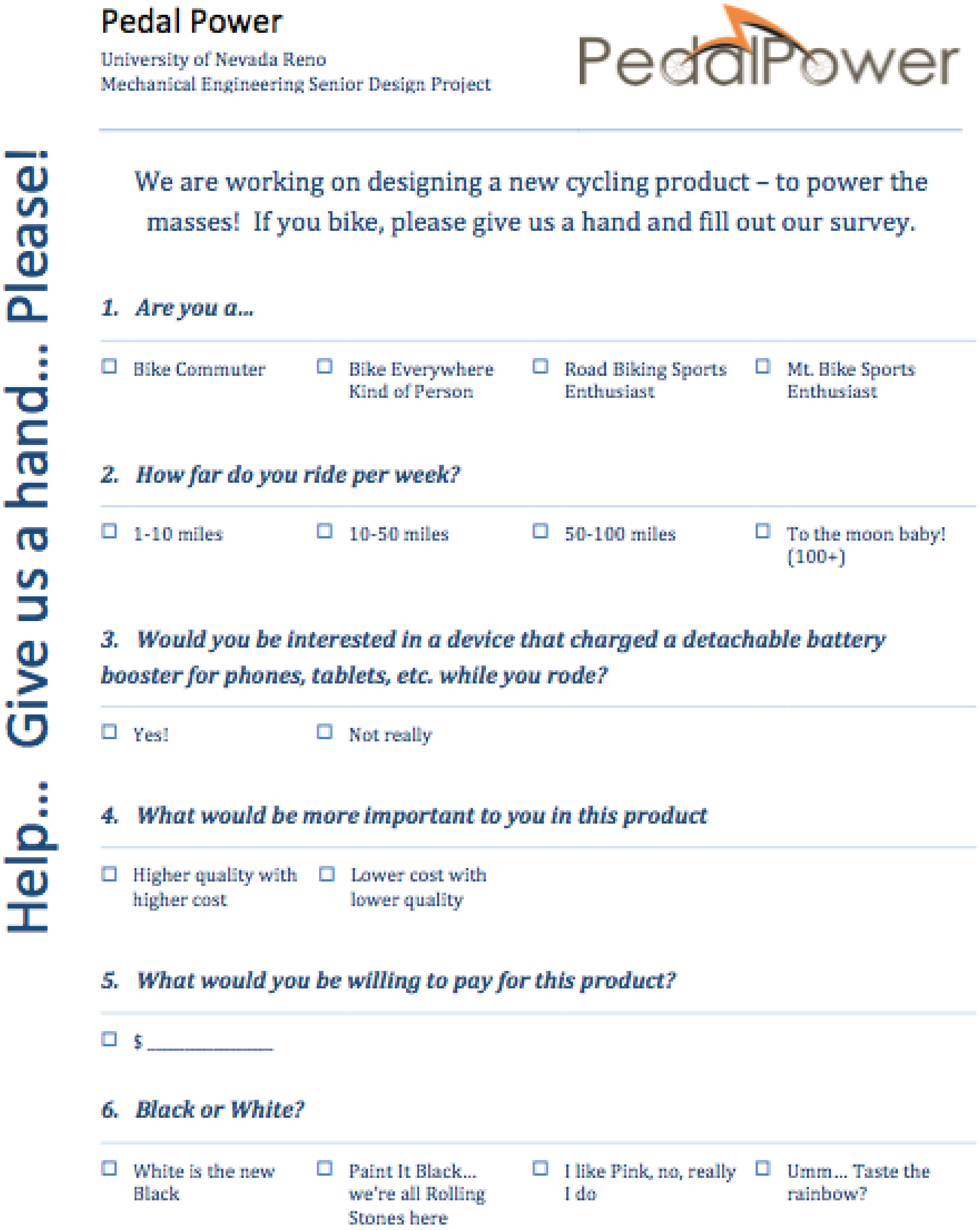
Fig. 20: Water bottle post mounting bracket with quick-release mechanism.

Fig. 21: Electronics pack internal view.

Fig. 22: Electronics pack external view.

Appendix J

Product Interest Survey



Pedal Power

University of Nevada Reno
Mechanical Engineering Senior Design Project

Help… Give us a hand… Please!

We are working on designing a new cycling product – to power the masses! If you bike, please give us a hand and fill out our survey.

1. Are you a…

☐ Bike Commuter
☐ Bike Everywhere Kind of Person
☐ Road Biking Sports Enthusiast
☐ Mt. Bike Sports Enthusiast

2. How far do you ride per week?

☐ 1-10 miles
☐ 10-50 miles
☐ 50-100 miles
☐ To the moon baby! (100+)

3. Would you be interested in a device that charged a detachable battery booster for phones, tablets, etc. while you rode?

☐ Yes!
☐ Not really

4. What would be more important to you in this product

☐ Higher quality with higher cost
☐ Lower cost with lower quality

5. What would you be willing to pay for this product?

☐ $ ____________

6. Black or White?

☐ White is the new Black
☐ Paint It Black… we're all Rolling Stones here
☐ I like Pink, no, really I do
☐ Umm… Taste the rainbow?

Fig. 1: Product interest survey.

Appendix K

Project Timeline

All finalized assignments and reports will be completed by the designated date outlined on the class Google calendar. Report rough drafts were to be compiled and edited three days before the final draft was to be turned in to Dr. Geiger. The major assignments for the spring semester included Project Presentations 1 through 6, website assignment, the Intermediate Design Report, Business Plan, Poster Design and Presentation, and the Final Design Report. The culmination of these projects and reports is the presentation of the finished project at Innovation Day. Specific due dates regarding each report and assignment are outlined below in Fig. 1.

Moving into March, the Business Plan and its accompanying presentation was the primary focus of our classwork. Indirect testing and assembly work, including fitment testing, product machining and assembly occurred concurrently. Product testing and finalization took in early April, with buffer room at the end of the month for any unseen challenges. The course presentations and reports helped to create the final presentation for Innovation Day in May and the Final Design Report. Preliminary due dates concerning each report and presentation are shown below in Fig. 1.

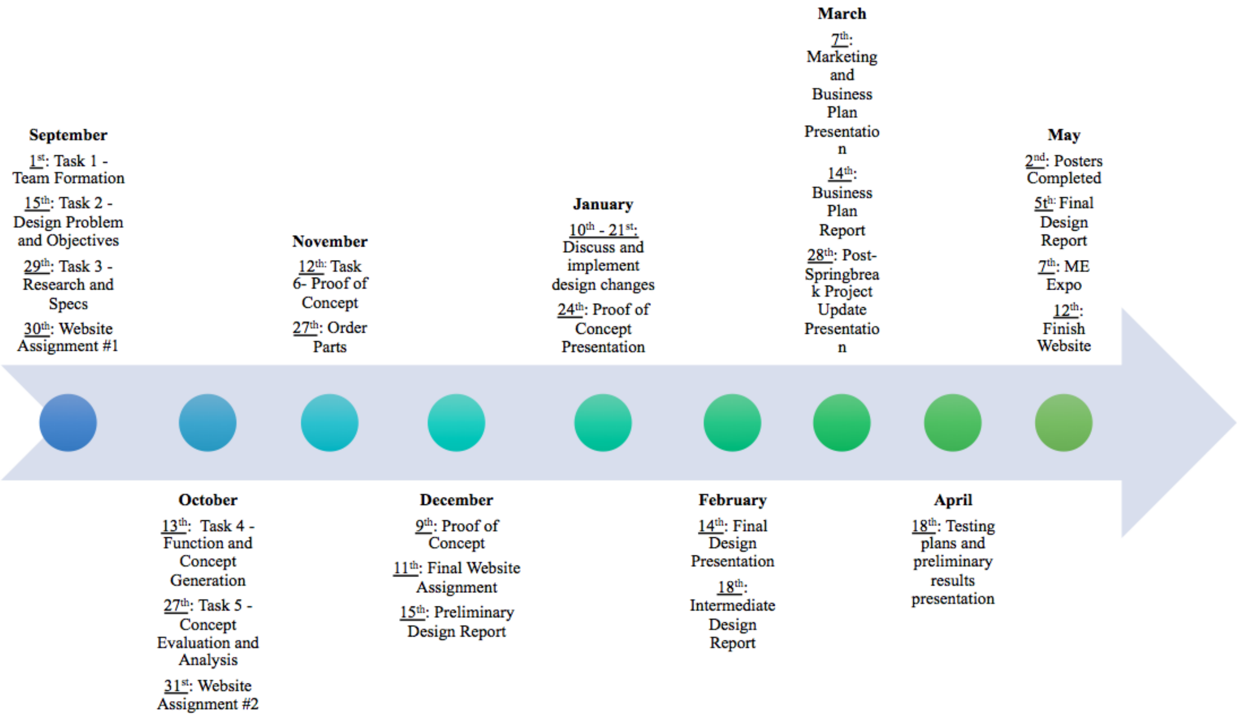


Fig. 1: Course and project timeline.