Second Generation Bicycle Charging Station

By
Jon Jerome, Michael Klinefelter, Connor Kroneberger,
Kori Molever, Robert Rosenberg
Team 22B

Final Project Proposal

Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design I – Fall 2013

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Table of Contents

Tables and Figures (in order of apperence)

Abstract

Marilla Lamb, a member of the first generation bicycle charging team, has sought out to have a second generation charging station made. After being a part of the design and build of the first generation station, it has come to her attention that there are quite a few components that need to be addressed so as to make the bicycle generator more accommodating for users and more educational for students of all backgrounds.

The second generation bicycle charging station must be more easily moved around campus and beyond for demonstrational purposes. The final design must include a display that will provide users with information about power generation both graphically and mathematically. Additionally, the station must include various small electronics chargers and a three-prong AC outlet. Finally, the build must fit within the budget, granted through the NAU Green Fund, of $1600.00.

The final design will implement an upright, three speed bicycle that will utilize a generator in contact with the rear wheel to harness the rotational energy and move it directly to the electronics in need of charge. The bicycle will be fully functional, thus providing human powered mobility, and use a front and rear wheel stand that will allow the user to engage for demonstration purposes and fold away for transportation purposes. A static analysis was performed on the stand to ensure that the stands would perform under extreme loads.

This project has been split into two teams. This report will detail the mechanical components of the second generation bicycle charging station. Please refer to the Electrical Team's reports for details regarding the display, power storage and generation, and programming components.

The anticipated cost for the mechanical components is $700.00. The project is on schedule for the requirements set forth in the Senior Design course and the final product is set to be ready by May 2014.

1.0 Introduction

1.1 Project Summary

In 2012, a team of engineers designed and built a bicycle generator intended to power small electronics and educate the public about electrical power generation. The purpose of this project is to design a second generation of the Bicycle Generator in the Engineering Building at Northern Arizona University. The current design, located on the second floor of the Engineering building, is limited in both its power output and ability to address user needs. The 2nd Generation Bicycle Charging Station project team aims to redesign the charging station in a way that improves the portability, efficiency, usability, and versatility of the assembly to better aid in the designs overall purpose.

1.2 Project Statement

Our team's goal for this project is to "Provide students with a way to understand and compare the amount of energy required to power and charge electronic devices with the amount of energy produced by pedaling a bicycle."

1.3 Recognizing the Need

The purpose of the bicycle charging station is to provide students with an avenue to understand and compare the amount of energy required to power and charge electronic electronic devices with the amount of energy produced by pedaling a bicycle in a controlled indoor setting. The first generation bike, however, does not meet all of the needs of the customer. The following are shortcomings identified within the first generation bike:

- The bike is not compatible with all major cell phones or laptops.
- The bike cannot readily be transported to different locations.
- The current display system is not user friendly and does not display adequate information.
- The bike is not comfortable or adjustable for the user.
- There is no consideration towards varying human power inputs (gearing and resistance).

1.4 Constraints

The second generation charging station will need to provide a more interactive display that includes power generation, carbon offset both for the duration of the user's ride and the total for the bike's history of use, both graphically and mathematically. In addition to the display, the bike must be easily portable allowing operators to move the station between demonstration sites. The second generation station will need to include a wide variety of electronic chargers and a three-prong AC outlet allowing users to charge higher wattage electronics. All parts and labor must fit within the allotted budget of the $1,600.00 granted through the Northern Arizona University Green Fund.

1.5 Operating Environment

The second generation charging station will be used as an educational tool to teach about power generation. The station will potentially be used in both indoor and outdoor settings by users varying in age and body type.

1.6 Project Background Research

Taking into consideration the constraints given by our client and developed by our team, there was quite a bit of research needed to narrow down various design concepts. These concepts fell under the topics of adjustability, portability, versatility and efficiency.

The adjustability of the charging station pertains to users being able to custom fit the bicycle to their individual body type easily and quickly. This is most prominent in the bicycle seat, which provides the primary adjustability users seek out. The handle bars also provide a basis for comfort as different types of handlebars allow for different positions of comfort during use.

Portability was one of the client's top priorities for our team. The current charging station has only been moved a few times due to weight and size restrictions. Our team has narrowed down the portable concepts to two designs; a collapsible bicycle and a bicycle with a custom build stand.

The versatility of the bicycle refers to its ability to provide users with multiple options for gearing. Implementing gears gives users the option to change resistance over the course of their ride and potentially provide more output to their electronics.

The efficiency of the bicycle generator takes into consideration the method for storing and releasing the power generated. Gears on the bicycle will add to the overall efficiency of the system as well as comfort for the user.

1.7 Quality Function Deployment

In preparation of concept generation and selection, a Quality Function Deployment (QFD) matrix was created to weigh the importance of the specifications to the objectives of the project defined by the clientele and problem needs. Within the QFD matrix, objectives and constraints are listed and weighted on a 1-10 scale of importance and then crossed with the specifications. The specification-objective scale relationship is a 1-3-9 scale with 9 being the most significant. The columns of specifications are then individually summed together to get a raw score and normalized against the highest raw score. The QFD, which can be seen below in figure 1, shows these relationships for the second generation bicycle charging station.

Obejctives	Weighted Importance	Specifications: Weight	Power Output	Cost	Required Mantainence	Accuracy
Adjustable	7	1		1	1	1
Interactive display	10		9	9		9
Sufficient AC Power	10	1	9	3		3
Collapsible	4			3	3	
Geared	8	3		3	9	
Geomerty	3	9		9		
Multiple Chargers	8		3	1		
AC plug for Laptop Charging	10		9	1		
Shows Power Generated	10		1			3
Shows Power Used	10		1			3
Shows Total Power Generated	9		1			3
Shows Total Number of Users	9		1			3
Carbon Offset	8		9			3
	Score	68	404	208	91	265
	Relative Weight	0.17	1.00	0.51	0.23	0.66
	Unit of Measure	lbs	Watt	$	Hours	*

* = relative error

Figure 1 - QFD Matrix

From the QFD, one can see that some of the more important factors are power output, accuracy in display and equipment cost. Weight and required maintenance were deemed to be less important, however they are not to be ignored altogether. The QFD matrix is vital to the decision making process and has a direct influence in the application of relative weights to criterion used to select concepts for the final design.

2.0 Overview of Concepts

2.1 Concept Selection

Working within the mechanical components of the second generation bicycle generator, our team has developed a table weighing the importance of project constraints and a matrix to help make a decision on which design option to implement. Design concepts included making the bike more adjustable for user comfort, more portable, and gearing of the bike.

The purpose of increasing the adjustability of the bike is to make it more comfortable. We will install an adjustable seat to provide a more comfortable charging experience for a variety of users.

Two concepts were generated in order to make the station more portable. The first was a collapsible frame that could fold up, or otherwise be disassembled and pack into cases for transport. The second concept involved making racks for the front and rear wheels that could pivot 180 degrees and lock to form stands which allow the bike to remain stationary while pedaling.

The gearing configuration of the bike was simple. We compared the benefits of gearing the bike with leaving it single speed.

The relative weights of importance of design constraints can be seen in Table 1.

Table 1 – Relative Weight of Constraints

Design Constraints	Assembly Time (sec)	Weight (lb)	Range of Adjustability (inches)	Cost ($)	RPM	Maintenance (hours)	Total
Assembly Time (sec)	-	0	0	1	0	0	1
Weight (lb)	1	-	0	1	0	1	3
Range of Adjustability (inches)	1	1	-	1	0	1	4
Cost ($)	0	0	0	-	0	1	1
RPM	1	1	1	1	-	1	5
Maintenance (hours)	1	0	0	0	0	-	1

Table 1 displays how the range of adjustability and RPM output are very important factors in determining which concept to select. The decision matrix can be seen below in Table 2.

Table 2 - Concept Decision Matrix

Scale: 1-unfavorable 5-favorable	Assembly time (sec)	Weight (lb)	Range of Adjustability (inches)	Cost ($)	RPM	Maintenance (hours)	Total
Collapsible	5	2	1	1	1	2	23
Wheel Stands	5	2	1	3	1	2	25
Upright Frame	5	1	5	4	3	1	48
Recumbent Frame	2	2	5	2	1	2	37
Geared	1	1	3	4	5	3	48
Single Speed	1	1	2	1	5	1	39
Relative Weight	1	3	4	1	5	1	

Table 2 suggests that the wheel stand concept would allow for greater ease of portability. It can also be seen that an upright frame is favorable due to its potential to be less expensive. Gearing the bike allows for greater RPM output and user comfort.

2.2 Final Design Selection

The final design will utilize an upright geared bicycle frame. The frame will be combined with a 3 x 1 gear configuration, allowing for multiple speeds and levels of resistance while riding. The station will utilize two stands, one for the front wheel, and one for the rear. The stands will serve to stabilize the bike and make it stationary while in use as well as provide housing for the generator and roller components, as shown in Figure 2. The stands will be locked into the stationary position by tightening the fasteners at each junction. When the bike is to be transported, the stands can be repositioned and locked into place to above the wheels, allowing the bike to be easily ridden to a new location (Figure 3). The generator will utilize the rotational energy of the rear wheel. Rather than store energy in a battery, the second generation charging station will instead utilize a series of capacitors to immediately release the power generated to the electronics plugged into the system.

Figure 2 - Charging station (stationary position)

Figure 3 - Charging station (transport position)

3.0 Engineering Analysis

3.1 Structural Analysis

Bicycle frames come standard in two styles. Single speed bicycle frames utilize horizontal dropouts (figure 5) that allow the user to easily adjust the tension in the chain. Geared bicycle frames utilize vertical dropouts (figure 4) which provide the user more room to adjust the chain given a variety of gears. Given the dynamic environment that bicycles are constantly put through, the dropouts are subject to extreme loads. After performing various structural analyses on both frames, it was found that a geared bicycle had both a higher factor of safety and lower stress in the dropouts; This coincides with the decision to utilize a three-speed gearing system.

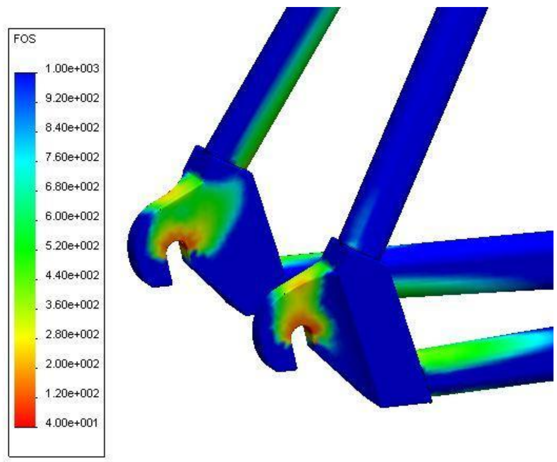

Figure 4 - Factor of Safety for Vertical Dropouts

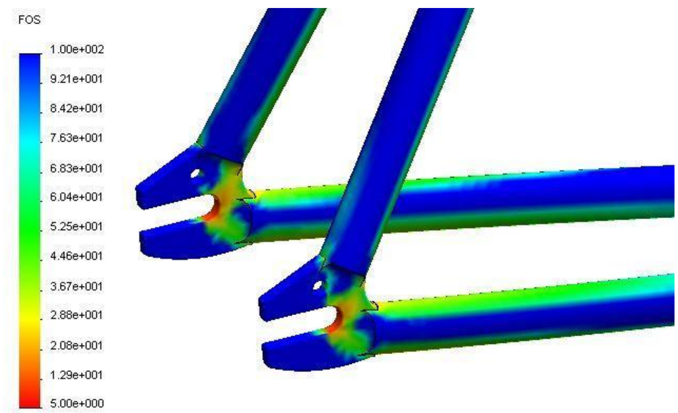

Figure 5 - Factor of Safety for Horizontal Dropouts

The bicycle stand will be custom built from 4130 tubular steel. The stand must support the weight of the bicycle and user while also minimizing the overall weight it will add to the bicycle. A static analysis was performed on the frame to ensure that the geometry would not fail under load conditions. The axle on which the 1200N distributed load was applied represents the center axle for the wheel's hub on which this stand will be mounted. The results of the analysis (figure 6) show that each stand can handle much more than the anticipated loads and that given two stands to distribute the weight, the design will be appropriate for this application.

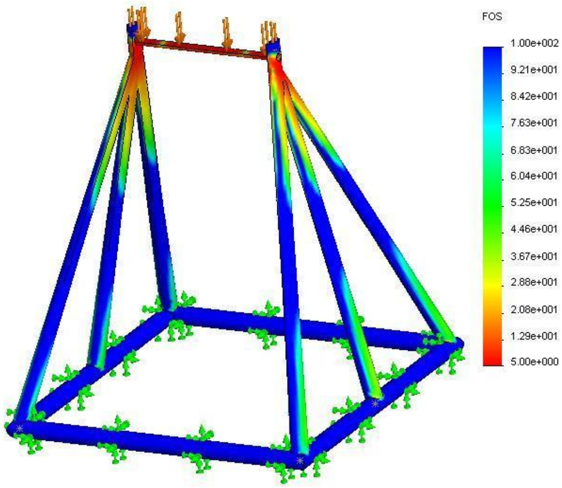

Figure 6 - Factor of Safety for Stand

3.2 RPM Analysis

An estimated RPM analysis needed to be completed in order to aid in generator selection. If the system were not properly tuned, the generator could overheat or provide too much power and melt important electrical components. This analysis is provided for the electrical team in order to mitigate risk.

From concept selection, a geared bike was chosen as the final design and only this design will be reported. Previous design analysis has been provided and can be found in the paper titled Engineering Analysis. Experimentation was done at NAU's Health and Learning Center to provide averages of various users' revolutions per minute of a bike chain ring for a single speed and geared bike. Individuals were asked to pedal at three paces: relaxed, typical average, and full exertion speeds for one minute. These speeds were collected from 10 users and the averages can be seen in the User Input column of Table 3 seen below.

Because a donated bike will be used, a few assumptions will need to be made about the bike specifications. Specifically, the gear teeth ratios and tire size are currently unknown as is the input shaft of the generator. Typical 3-speed bikes contain gear ratios from 42/16 to 42/32, and a common rear wheel diameter (including the tire) found on bicycles can be assumed to be 26.6 inches. Currently, the team has assumed we will use a 3 inch diameter roller to supply input to the generator. This assumption was necessary in order to complete the calculations, shown below in Table 3.

Table 3 shows these assumptions along with the expected RPM input into the generator. The average bike speeds and expected generator input range were submitted to the electrical team for generator consideration. The higher end range will need to be taken into consideration for capacitor and generator set-up and selection.

Table 3 - User Inputs, Assumed Gear Specifications, and Expected Generator Input RPM

	User Input (RPM) [Average]	Front Gear (teeth)	Rear Gears (teeth)	Rear Tire Diameter (in.)	Generator Track Diameter (in.)	Expected Range (RPM) [Average]
3-Gear	40-132 [68]	42	16-32	26.6	3	1536-3072 [1653]

As can be seen from the table, a typical user of this bike will provide approximately 1653 RPM to the generator without exerting too much effort. However, it may not be uncommon for users to reach well into the 2000-3000 RPM range, especially when potential users are exerting maximum effort.

4.0 Cost Analysis

The second generation bicycle charging station was given a budget of $1600 by a grant from the NAU Green Fund. This budget will largely go towards covering the cost of various materials needed to build the charging station. Table 4 shows an expected breakdown of the mechanical aspect of project, which totals to $750. This, along with expected electrical budget of $800 leaves $50 of the overall budget left over.

Table 4 - Material Cost Breakdown

Material	**Cost ($)**
Bicycle	$200
Handlebars	$50
Stands- Materials and Labor	$350
Gear cassette/ derailleur	$50
Seatpost Clamp	$25
Tools to be included	$10
Fasteners	$15
Display box	$50
Grand Total	$750

In order to make the bike more affordable and work on less of a budget, the mechanical team will be working with local businesses to work on reducing the costs of materials. A donated bike, for instance, would reduce the mechanical expected budget by $200, and a donated 3-gear cassette, another $50. Other parts of the bike can be salvaged or donated, further reducing the cost. The $350 allocated towards the bike stands is a conservative quote from a local fabrication shop, which includes needed steel materials and construction labor. The NAU machine shop provides reduced construction and material costs to senior design students and will allow for further reduction of expenditures. To further iterate, the $750 budget shown in Table 4 is the expected worst case.

5.0 Conclusion

Our client, Marilla Lamb, has requested that the second generation bicycle generator be more portable, contain visually stimulating and educational information about power generation, and provide users the ability to charge a variety of small electronics with the option of utilizing a three-prong AC outlet. Several concepts were designed over the duration of this semester that considered both the client's constraints and those brought determined by the capstone team. After a series of decision matrices and consultations, it has been decided that utilizing a three-speed, upright bicycle with versatile stands will be the most effective design for this project.

Static analysis on the stands found that they are sufficient in strength and very applicable for this project. The stands will be built at Northern Arizona University's machine shop from 4130 tubular steel. Our current design cannot be considered the final design, however, due to the possibility of it being incompatible with the generator that is yet to be chosen. The stands provide our team with a buffer to accommodate for the generator once it has been chosen.

The final design combines a three-speed upright frame with an adjustable seat, and pivoting wheel stands. The pivoting wheel stands will allow for the greatest portability by giving the user the ability to ride the bicycle around to various destinations and immediately engage the stand to put the bicycle into a suspended freewheel state in order to charge small electronic devices.

Work Cited

[1] "Background of the Invention." *Bike Handle Securing Device for a Collapsible Bike Frame*. N.p., n.d. Web. 30 Oct. 2013.

[2] "Bicycle Forest Wanderer." Www.bikecad.ca. N.p., n.d. Web. 30 Oct. 2013.

[3] Budynas, R.G., Nisbett, J.K., "Shigley's Mechanical Engineering Design" 9th Edition. McGraw Hill, New York, NY. 2011

[4] Lamb, M., First Generation Bicycle Generator Design & Build Team. Personal Communication. 2013

[5] Lamb, M., The NAU Green Fund Addendum Application for Second Generation Charging Station. Feb. 2013.

[6] Lamb, M., First Generation Bicycle Generator Design & Build Team. Personal Communication. 2013

[7]"Mccreavy." Mccreavy. N.p., n.d. Web. 30 Oct. 2013. <http://mccreavy.com/1837/how-does-a-capacitor-work>

[8] Sheldon Brown, . Frame Analysis.. Web. 17 Nov 2013. <http://sheldonbrown.com/rinard/fea.htm>.

[9] "Shimano 9-Speed Bike Gear Cassette." | Meijer.com. N.p., n.d. Web. 30 Oct. 2013.

[10] "So You Want to Design a MBB : The French Expertise - BentRider Online Forums." *So You Want to Design a MBB : The French Expertise - BentRider Online Forums*. N.p., n.d. Web. 30 Oct. 2013.

[11] "SPI LCD Module (Arduino Compatible)." - Emmeshop Electronics. N.p., n.d. Web. 30 Oct. 2013.

[12] Whitt, F.R., Wilson, D.G., “Bicycling Science” 2nd edition. MIT Press, Cambridge, MA. 1982

[13] "12 Volt 20 Ah Sealed Lead Acid Rechargeable Battery with Insert Terminal."BatteryMart.com. N.p., n.d. Web. 30 Oct. 2013.