Second Generation Bicycle Charging Station

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Engineering Analysis

Document

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Project Summary

In 2011, a grant was proposed to the NAU Green Fund to build a bicycle generator that students could use to charge small electronics, while simultaneously demonstrating how much physical effort is required to generate small amounts of electricity. In 2012, the Green Fund approved the grant request. The 1st generation bicycle charging station was designed and built shortly after. 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 can not 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).

Concept Overview

The concepts that will be compared are different frames and gearing setups.

Structural analysis of a frame with horizontal dropouts usually seen on single speed bicycles will be compared with analysis of a vertical dropout frame. The front and rear stands will also be evaluated. Expected nominal range of rpm will be compared for single speed and three speed gearing setups.

Design Assumptions

In order to make the analysis of the system straight forward there were a number of assumptions made regarding the overall design. For the analysis of this bicycle station we are looking to take the input power of a user that will be sent through a number of gear to the final stage where it attaches to the generator. While many would argue that the crank arm length should be taken into consideration when determining the final usable power output, our team has found written support suggesting that this variable can be neglected. As a simple justifying logic check, the crank arm length is approximately the length of the radius of the chain ring for this specific design. That translate to an approximate gear ratio the remains the same when power is finally transferred to the generator.

The next design assumption that was made was to neglect the load applied to the bearings within the unit. Typical loads on bearings are the result of the user riding the bicycle over a surface and transferring forces from the ground to the bearings. However, the usage of this design removes this transfer of forces and redirects it into a lower applied force of the roller which is attached to the generator shaft being pressed into the rubber of the bicycle tire. The ground force is therefore transferred directly to the axle.

RPM Analysis

The building of the generator requires knowledge of the input RPM in order to calculate the turns of coil needed to produce certain power outputs and not fry the capacitors that will regulate voltage to the display and user's device. A few assumptions need to be made in order to calculate an approximate RPM output to the generator. Experimentation at NAU's Health and Learning Center provided 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 paces were collected from 15 users and the averages can be seen in the User Input column of Table 1 below. Because a donated bike will be used, the gear teeth ratios and tire size are currently unknown. Typical single speed bikes contain a ratio of approximately 42/17, while a typical 3-speed bike contain ranges from 42/16 to 42/32. A rear wheel diameter (including the tire) commonly found on bicycles is 26.6 inches. At the moment we plan on using a 3 inch diameter roller to supply input to the generator. Table 1 shows these assumptions along with the expected rotational speed of the generator input shaft and the typical average bike speed. The average bike speeds are what will be submitted to the electrical team for generator consideration. The higher end range will need to be taken into consideration for capacitor set-up and selection.

Table 1 - 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]
Single Speed	40-132 [71]	42	17	26.6	3	876-2891 [1555]
3-Gear	40-132 [68]	42	16-32	26.6	3	1536-3072 [1653]

Structural Analysis

For the structural analysis of the bicycle frames and stand, many different iterations were run to find variations in results. Each CAD model had various mesh sizes applied to determine the accuracy of the model itself. Our team first started off with a medium density mesh and went on either end to determine the accuracy of our models and whether they needed to be restructured. The results in the following sections are those which contained the most consistent results. Both the bike frames and stand were analyzed with the material property being AISI 4130 steel as this is very common in frames and structural work.

Single Speed

The first concept is to have an upright frame with a single speed. The single speed concept increases simplicity of design and operation. A single speed bike can be acquired at a significantly smaller cost than a geared bike. However, it may be uncomfortable to maintain higher rpm with a single speed bike due to decreased resistance while pedaling quickly. The first generation bicycle is a single speed design.

Single speed bicycles have a specific frame geometry that allows them to be more fitting to the simplicity of no gear set. The defining feature of a single speed frame is the dropout configuration. The dropouts are where the wheel sits in the frame. In a single speed frame, the dropouts are designed to be horizontal. Given the option of a single speed bicycle, it was determined that a static analysis should be done on the frame to `determine a difference, if any, between a single speed frame and a frame designed for gears. As seen in figure 1 the analysis showed a significantly higher stresses in and around the dropouts.

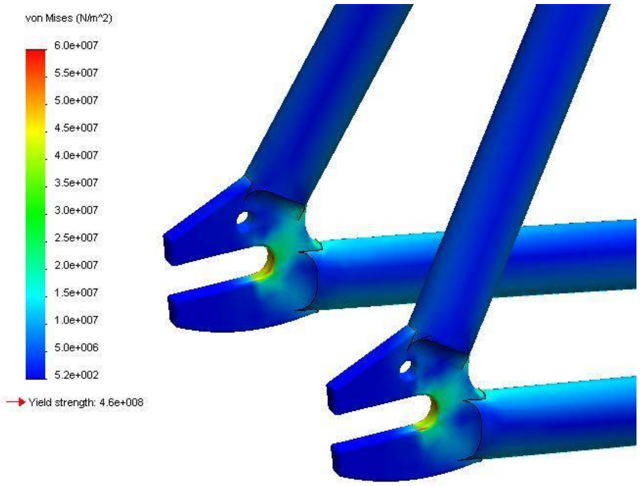

Figure 1: Von Mises stress figure for single speed frame with horizontal dropouts

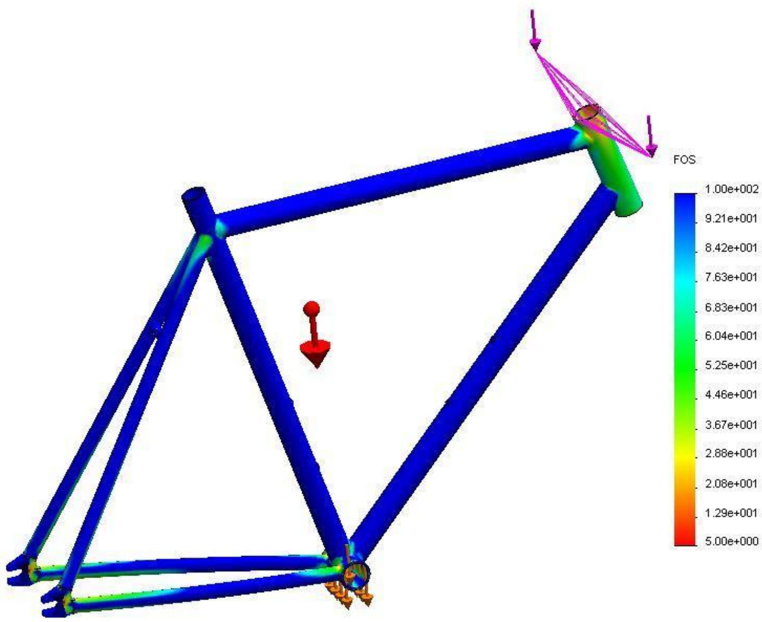

Figure 2: Factor of safety for single speed frame

In addition to the analysis on the dropouts, our team ran a static analysis on the entire bicycle frame seen in figure 2 to determine whether additional stresses would affect the frame integrity and impact the overall factor of safety. When compared to the tests ran on the geared bicycle frame, the single speed proved to have significantly higher stresses and a lower range (between 5, the lowest, and 100, the highest) for the factor of safety when tested with identical loading.

Geared

The second concept is a geared upright frame. While it may be more expensive, a geared bicycle will allow the user to comfortably maintain higher RPMs for longer durations, effectively increasing the user's ability to generate power.

After performing Finite Element Analysis on the dropouts and overall frame for the single speed option, a comparison was needed for a frame designed to accommodate a gear set. The analysis on the dropouts, which are vertical for a geared bike as seen in figure 3, showed considerably lower stresses. This makes more sense, given that there is more contact area with the axle.

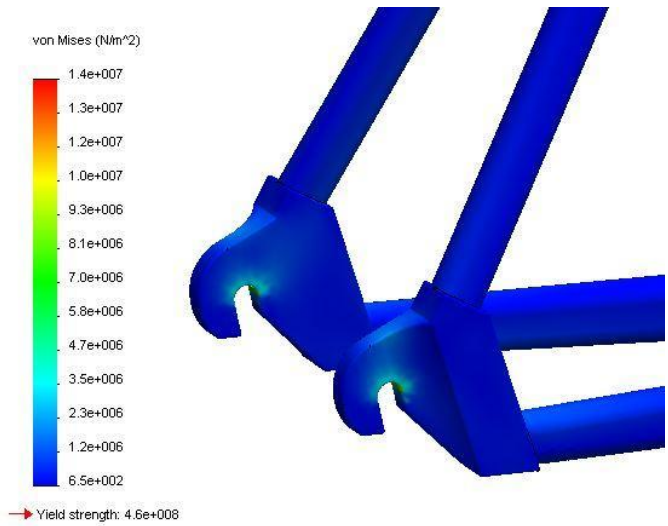

Figure 3: Von Mises stress analysis for geared frame with horizontal dropouts

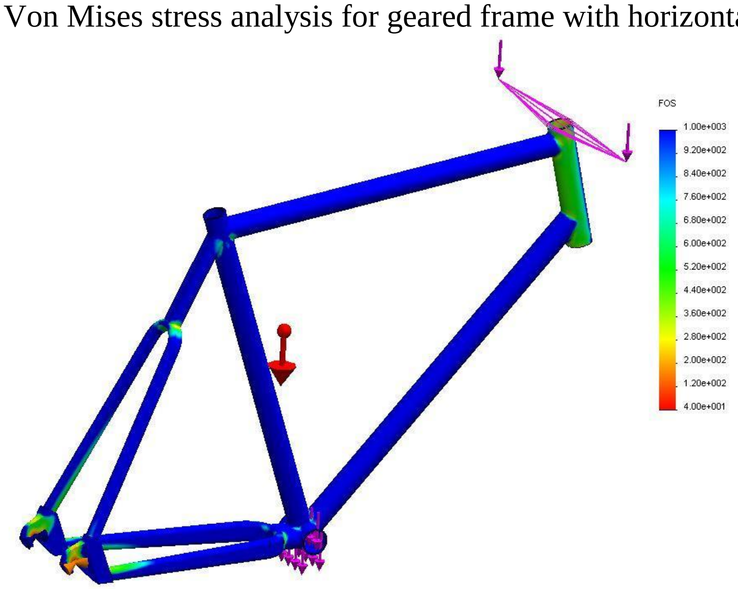

Figure 4: Factor of Safety for geared frame

In the analysis of the whole bicycle frame, we saw significantly lower stresses on each of the components susceptible to failure. This was especially evident when we ran a factor of safety analysis on the entire frame seen in Figure 4. The factor of safety analysis shows a much higher range (between 40, the lowest and 1000, the highest). With both frames made of the same material and having the same forces applied, the geared bicycle frame proves to be considerably stronger and safer for our applications.

Bicycle Stand

Our client has requested that the second generation bicycle generator be more easily portable than the current model. During our concept generation, our team had narrowed down the portability aspect to two ideas, a collapsible bicycle and a built in stand. Running a series of decision matrices resulted in the consensus to pursue an integrated stand.

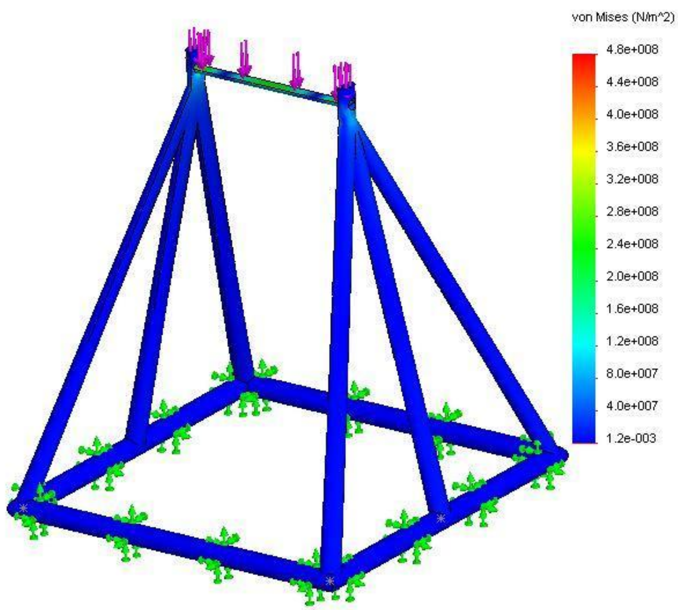

Figure 5: Von Mises stress analysis for bike stand

Once a design had been agreed upon, our team drafted up a CAD modeling and subjected the stand to varying forces. In order to ensure the safety of our riders, as well as the integrity and longevity of our model, the frame was tested under a 1200 N distributed load displayed in Figure 5. With the bicycle Two of these stands would be able to support upwards of 2400 N (540 lbs). The average weight of a bicycle and other components is approximately 40 lbs. By accounting for a variety of user body types and weights, it can be assumed our stand has been safely designed for the anticipated load and more.

During a factor of safety analysis, the stand showed FOS values ranging from 5-100, as shown in Figure 6. This assured that our design would be over engineered for the application thus ensuring safety to the users.

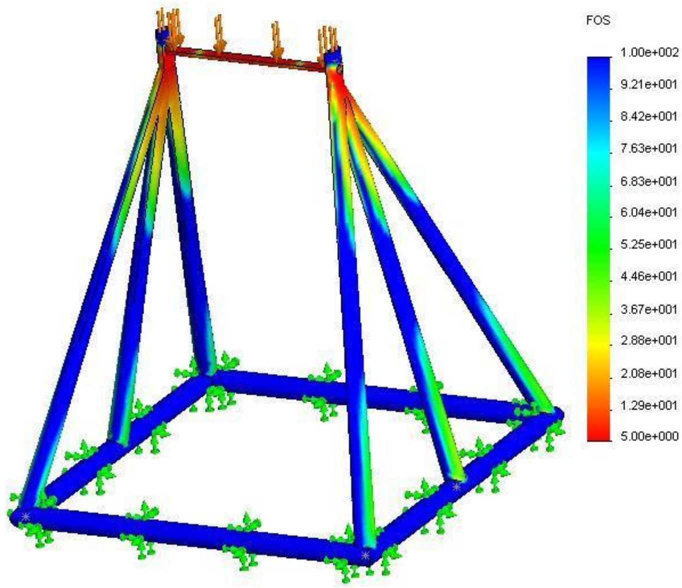

Figure 6: Factor of Safety analysis for bike stand

Project Update

Conclusion of a comprehensive engineering analysis leaves the project proposal as the final remaining task for the Fall 2013 semester. The project proposal will contain a detailed breakdown of materials, needs, and estimated costs, as well as an outline and designs needed for successful building and implementation of the project. The project proposal will conclude with the expected outcomes and an explanation of how they will meet the constraints and requirements of the client. The Gantt chart, as seen in Figure 7, is shown below. Additional work this semester will be done in conjunction with the electrical team this semester to ensure cooperation of the mechanical aspects of the bike and electrical needs of the generator. An extension of the Gantt chart will be provided with the project proposal showing a detailed breakdown of planning, building, testing and final presentation for the following (Spring 2014) semester.

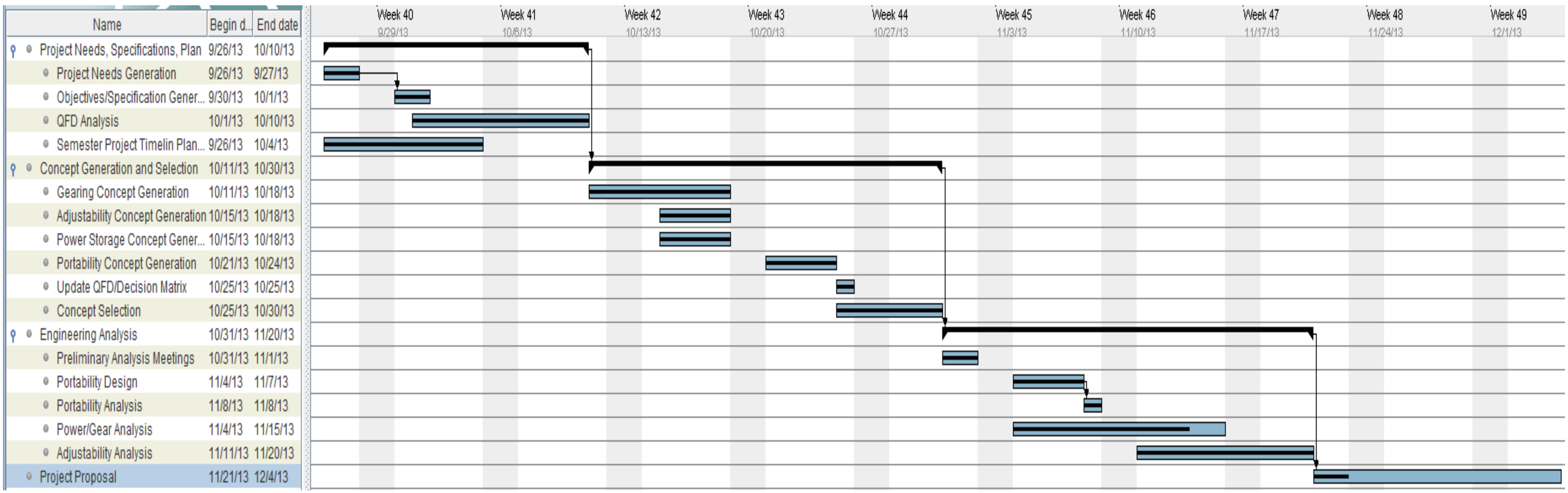

Figure 7: - Gantt Chart Fall 2013

Conclusion

Completion of the engineering analysis enabled our team to decide to gear the bicycle, select a frame design, guarantee stand stability, and determine a nominal rpm for power calculations.

After structural analysis of both frames, the geared frame with vertical dropouts was found to be significantly superior to single-speed frame. The geometry of the geared frame allows for more contact with the axle, which distributes the stress better, allowing for a greater factor of safety.

Additionally, with the concept of adding gears having a high score in our concept generation, using a geared frame agrees with the overall design concept.

FEA analysis of the front and rear stands with a 1200 N distributed load on each axle results in a minimum factor of safety of 5.

The nominal output to the generator with the geared configuration is roughly 1653 rpm. Choosing the geared configuration also promotes user comfortability.

References

[1] Budynas, R.G., Nisbett, J.K., “Shigley’s Mechanical Engineering Design” 9th Edition. McGraw Hill, New York, NY. 2011

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

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