Playground Power Source

Final Report 2022-2023

A Major Qualifying Project Submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Bachelor of Science Degree in Mechanical Engineering (ME) by:

James Martin

ME

Erica Bonelli

ME

Submitted to:

Eben C. Cobb

Advisor

Abstract

Because of the growing demand for electricity and our desire to limit fossil fuel emissions, we seek to take advantage of alternative sources of energy. Children enjoy producing the motion of playground equipment such as merry-go-rounds. The goal of the project is to use the kinetic energy from a backyard merry-go-round to a hand crank generator that can charge a cordless drill battery. The drill battery can then be used to charge phones and other devices that run on small rechargeable batteries. Our device consists of a rubber wheel, to be installed in contact with the underside of a merry-go-round, mounted on a shaft connected to a gearbox with gears configured to increase the RPM, thereby multiplying the output voltage. A pin shaft connection is used to join the gearbox output shaft to the hand crank generator.

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I. Introduction

Electricity is used for everything in today's world, to build houses, make food, transport, lighting, and many more, but not everyone can access it. In 2020, 13% of the world's population didn't have access to electricity [4]. The majority of the electricity that is produced releases carbon dioxide into the air causing the world to slowly increase in temperature, contributing to global climate change [6]. If carbon dioxide levels in the atmosphere continue to rise it will affect our planet to a point where it is unfixable and endanger millions of people. Although the production of electricity can produce carbon dioxide there are sustainable ways to produce electricity using renewable sources.

Renewable energy is energy that is collected from a renewable resource that naturally replenishes such as wind, sunlight, and moving water. We use technology to harness natural energy through solar panels and turbines to capture both wind and water. These processes have been scaled up so that renewable energy can be produced at a large scale. Although these are beneficial, they tend to be limited to the weather around them. Harnessing mechanical energy eliminates the reliance on the weather as it uses the kinetic energy of a body to then produce electricity. The most common way kinetic energy is turned into electricity is by using the motion of the body to turn a generator. Generators work by having an electric motor and spinning backward; because the change of magnetic field in a wire induces a current which is electricity, as seen in Figure 1 [2].

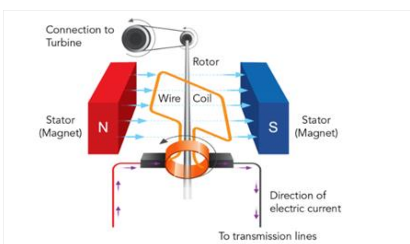

Figure 1: Schematic of the Inside of a Generator

Kids are well known for the amount of energy they have, being able to run around for hours at a time. Parents bring their kids to playgrounds so they can play with other kids on playground equipment. When a kid spins a merry-go-round or uses a seesaw, they are creating

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mechanical energy, but this energy is mostly lost to friction which generates heat. The goal of this project is to harness the energy spent in playgrounds to move the equipment and turn it into usable electricity for people in remote areas in New England.

II. Background

Recently people have created systems to produce electricity from playground equipment. Arevalo Godfrey and others developed a slide that converts the kinetic energy of kids going down a slide into electricity [3]. They accomplished this by replacing the seat of the slide with rollers so that the friction of the kids sliding would cause the rollers to turn. The rollers are then connected to a gear which is connected to a piezoelectric material, then use a charge controller to manage the power that goes to the battery. They were successful in their project and were able to produce electricity.

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A piezoelectric device is able to convert pressure into electricity as seen in figure 2. When a force is applied to the top of the material there is a shift of the positive and negative charge centers in the material causing an external electric field [5]. Pavegen is another company working towards sustainability by creating sidewalks out of triangular Piezoelectric platforms that generate electricity when walked over.

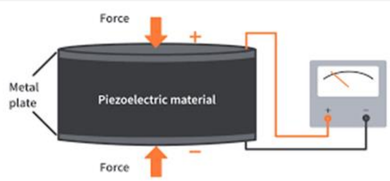

Figure 2: Piezoelectric Device

To turn the motion of the playground equipment into the generator we need to translate the motion of the equipment into circular motion to spin a generator that will produce the electricity. Gears can capture circular motion and can be used to increase or decrease the number of revolutions, while a 4-bar mechanism can be used to capture rocking motion and turn it into circular motion. To translate this motion a 4-bar linkage needs a flywheel to store rotational energy and allow the coupler continuous rotation about the crank. For these components to work they have to be close to the playground equipment, which can interfere with the use of the equipment. We wanted our components to not interfere with the use of the playground equipment so that the kids' fun is not impacted. Functional requirements, nice to haves, and constraints were developed before the design process began and are listed below.

Functional Requirements:

1. Moving playground equipment
    a. Generate rotational motion from it
    b. Grounded to the floor
    c. Weatherproof
2. Translate motion to generator
    a. Turning the motion into circular motion
    b. Connecting to the generator
3. Attract kids to it (if no kids no electricity)
4. Attach to an existing structure
5. Safe to use
6. Able to use playground equipment as normal.

Nice to Have:

1. Be able to utilize all the motion into the generator
2. Charge a battery
    a. Connecting the generator to the battery
    b. Make sure the voltage/current is enough to charge
3. Attach to an existing structure

Constraints:

1. Be under budget
2. Must be able to be assembled with standard tools and in 20 min.
3. Easily repairable

4. Standard parts
5. Maximum of three kids pushing the merry go round at once

III. Design Concepts

III.I Swing 1

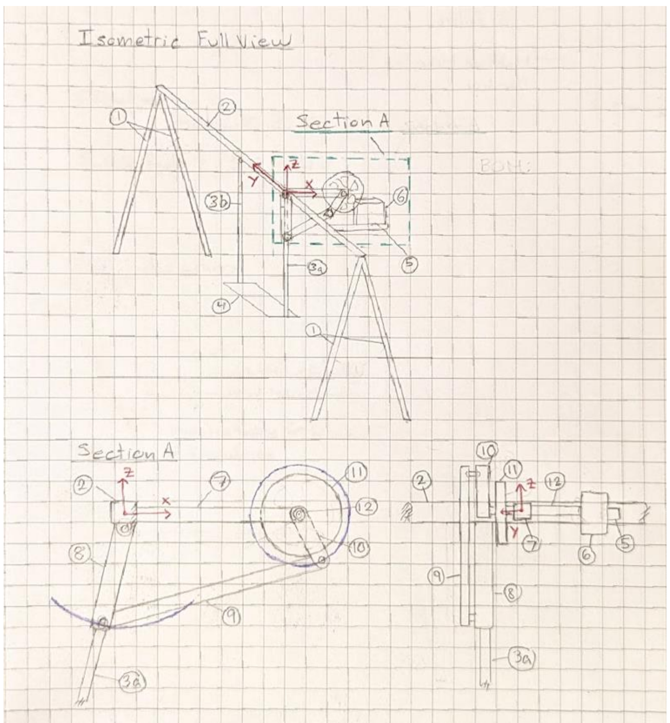

Figure 3: Sketch for Swing 1

One design incorporated a swing and a four-bar linkage, a 4-bar linkage is made up of 4 ridged bars called links. These links are the ground which statically supports the other links, the crank which goes in circles, the rocker which rocks back and forth, and lastly the coupler which connects the crank to the rocker. The motion of the swing is the exact same as the motion of the rocker, with the only problem being that chains would not be ridged enough to be the rocker. To

Commented [BE6]: changed, made 2 sentences and added ground link solve this the idea was to attach a bar to the outside of the chain to turn it into a ridged body. This would push the coupler and the crank. The crank would spin the generator. The problem with this is getting the crank in a full circle without it just rocking back and forth. To solve this a flywheel is attached to the crank to add extra weight to it so the flywheel's momentum drives the crank enough so that when the rocker returns it goes in a full circle.

III.II Seesaw 1

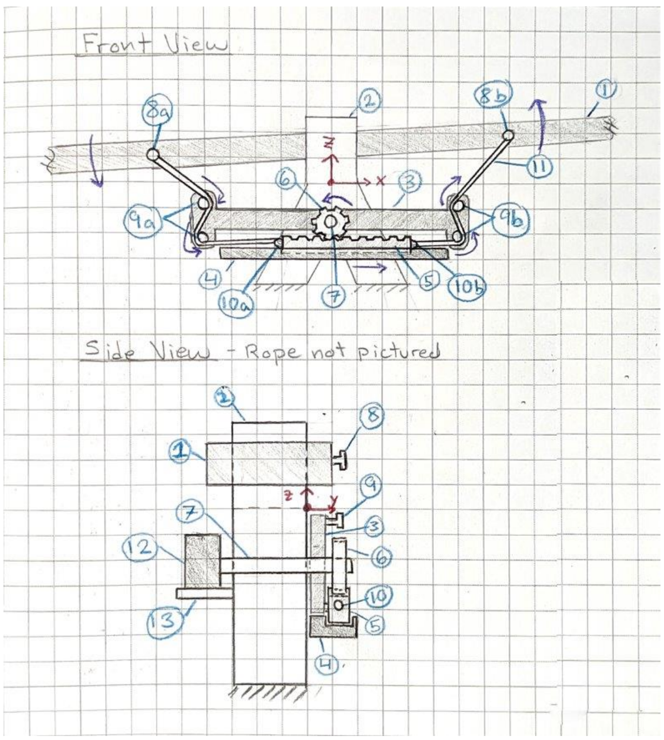

Figure 4: Sketch for Seesaw 1

The Seesaw 1 design uses the back-and-forth motion of a seesaw to operate a rack and pinion gear. The pinion gear would be fixed to a shaft in the center of the seesaw that also attaches the hand-crank generator. Ropes or cables fixed to either end of the seesaw beam would push and pull the rack gear along a track, driving the pinion. Because the pinion rotates both clockwise and counterclockwise while the seesaw is in use, this design will only harness ½ of the motion. In terms of safety for the children, there are a lot of moving parts in this design that would be difficult to fully cover and keep children out of.

III.III Seesaw 2

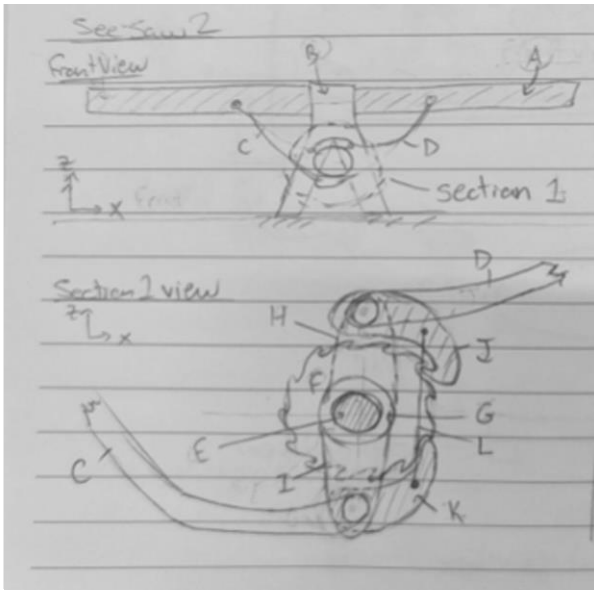

Figure 5: Sketch of Seesaw 2

Seesaw 2 converts the back-and-forth motion of a seesaw into continuous rotational motion with a ratchet and pawl mechanism. Two arms driven by the motion of the seesaw rotate the pawls, held in contact with the teeth of the ratchet by a spring, freely about the main shaft. When the seesaw changes direction, the pawl driving the ratchet switches due to the angled teeth, ensuring continuous rotational motion of the ratchet. Similar to the Seesaw 1 design's pinion gear, the ratchet is fixed to a shaft through the center of the seesaw's base and connected to the hand-crank generator. Since this mechanism is relatively small it can be easily covered to prevent small children from getting caught in it.

III.IV Merry-Go-Round 1

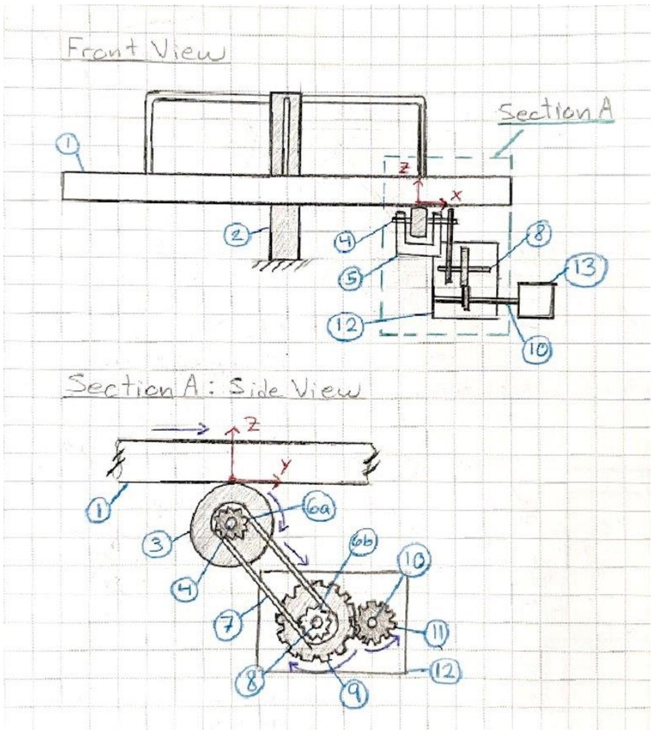

Figure 6: Sketch of Merry-Go-Round 1

This design used the rotational motion of the merry-go-round to spin a free-standing wheel similar to gears. It would sit underneath the merry-go-round with the wheel touching the underside, the wheel would be made of rubber to increase the friction. The wheel then spins an axle that goes to a gearbox that can alter the torque and revolutions per minute (RPM) for the generator. The gearbox will allow us to make sure that the generator will be able to spin with minimum input from the kids. Even if the kid is not strong enough to spin the merry-go-round because of the added torque from the generator, the gearbox will increase the output torque, allowing the child to spin it themselves.

III.V Merry-Go-Round 2

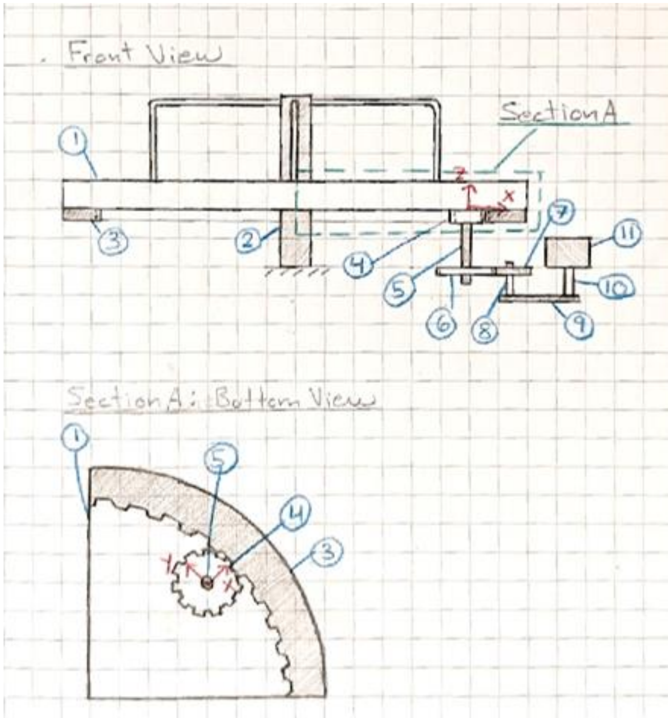

Figure 7: Sketch of Merry-Go-Round 2

This design captures the rotational motion of a merry-go-round using an internal gear system. A large internal gear is mounted to the underside of the merry-go-round platform and drives a smaller gear that is at a fixed point. A buried gear box that starts on the same shaft as the smaller gear further increases the RPM. The higher RPM is then delivered to the generator via a chain and sprockets, which allows the generator to be placed further away from the merry-go-round and prevents a tripping hazard for the children.

IV. Design Selection

To make sure we select the design that is best suited to our needs we evaluated the 5 different designs using a decision matrix. The decision matrix is shown in Table 1. The *Weight* depicts how important the evaluation criteria is on a scale from 1 to 5 with 5 being the most important. The *evaluation criteria* are all the different criteria we are comparing each of the different designs to. Depending on how well the design can accomplish the evaluation criteria they will receive a score 1 to 3, 3 being they are good at fulfilling the evaluation criteria and 1 meaning they are bad at fulfilling the evaluation criteria.

Weight (1-5)	Evaluation Criteria	Swing 1	Seesaw 1	Seesaw 2	Merry-Go-Round 1	Merry-Go-Round 2
4	cost for playground equipment	1	3	3	2	2
5	cost for mechanism	3	2	1	2	1
4	safety for children	2	1	2	1	2
3	simplicity	2	3	1	2	2
1	inclement weather usage	1	2	2	1	2
1	Maintainability	2	2	1	3	1
3	Manufacturability	3	2	1	3	1
5	Functionality (how likely it is to work)	1	2	3	3	2
3	efficiency (uses all input motion)	2	2	3	3	3
	total	56	61	58	65	52

Table 1: Decision Matrix

The table shows us which design best suits our needs with Merry-Go-Round 1 as the best and Seesaw 1 coming in a close second. We decided to make cost and functionality our top priority because we have a limited budget to create this and if we want our parts to be readily available, they cannot be expensive. Functionality was important because we wanted to create something that would fulfill the functional requirements.

V. Synthesis and Analysis

Based on the decision matrix we started to develop our top three designs. This allowed us to see problems that we had not thought of while we were making the design concepts. In the next section, we will talk about the process of the three different designs and why we decided to not pursue some and choose another.

V.I Seesaw 2

Seesaw 2, as stated before, includes a ratchet and pawl mechanism that allows it to turn the up and down motion into circular motion. This seems ideal for a seesaw but after developing the CAD, as seen in Figure 8, we realized that when the seesaw moves up on one side and down on the other, it only spins the rachet a few degrees. Additionally, when the seesaw goes back to its original position no motion will be captured, as the arms on the pawl would also go back to their original position. This would make the system incredibly inefficient, and the children would have to go up and down a couple of times just for one revolution. After realizing this, the possibility of using the movement at the ends of the seesaw to move the mechanism was considered because they move more along the Y axis compared to the center. Since one of the constraints is making sure that the system is safe for kids, it was clear that adding moving parts close to the kids would be dangerous, so we started to work on other designs.

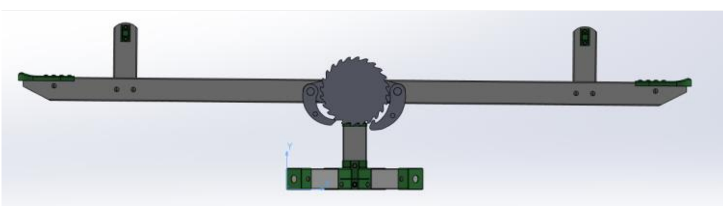

Figure 8: Seesaw 2 Initial CAD

V.II Seesaw 1

Seesaw 1 has a very basic idea on how to capture the motion, using the ends of a seesaw to pull a rack and pinion back and forth. Similar to the complication with Seesaw 2, it would have a lot of moving parts that would be in easy reach of kids. Not only this but a rack and pinion are easy for a kid to get their finger crushed in even with a safety box, so we decided not to develop this more.

V.III Merry-Go-Round 1

Merry-Go-Round 1 idea was a simple high friction wheel under the merry-go-round so that it would be able to capture the motion similar to a gear. We did not want the kids to trip on the system as they were running around the merry-go-round, but we wanted it to be stored under the merry-go-round. With this constraint in mind, we decided to use a chain to connect to a gearbox which would be stored underground with the generator. This then would have a cover that is flush with the ground so that the kids are still able to use the merry-go-round as intended. Considering the problems with the other designs and the decision matrix ranking, we decided to develop Merry-Go-Round 1 as our final design choice.

VI. Detailed Design Description

Merry-Go-Round 1 system can be broken up into 2 separate assemblies, motion capture and gear box as seen in Figure 9. The motion capture is stored under the merry-go-round and captures the motion of the merry-go-round and translates it to an axis. The gear box is underground and is used to increase the RPM so that the minimum output torque required to spin the generator is produced.

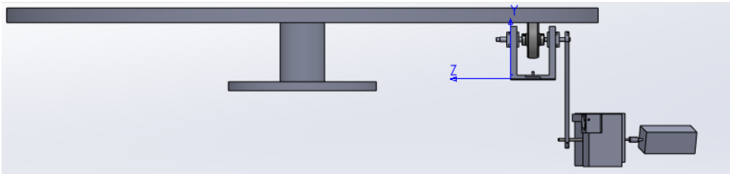

Figure 9: Assembly of Full Merry-Go-Round 1 System

VI.I Motion Capture Device

The motion capture device is made up of 24 different components as seen in Figure 10 and Figure 11. Moving in the negative Z direction, the axle is connected to a bushing at one end, and the wheel in the middle with shaft clamps on either side to translate the torque into the axle. We chose to use bushings instead of bearings because they are a lot cheaper. Next the axle is in another bushing and then the sprocket translates the rotational motion to the gearbox below. To make sure the wheel always has enough normal force on the bottom of the merry-go-round, springs were attached underneath the bushings. Putting them here allows the whole wheel and axle to move up and down, keeping in contact with the merry-go-round. The side of the axle where the chain and sprockets are attached has a lot more force in the negative Y direction, so two springs were used to compensate for the added force. To calculate the spring force needed, the forces on the axle had to be analyzed.

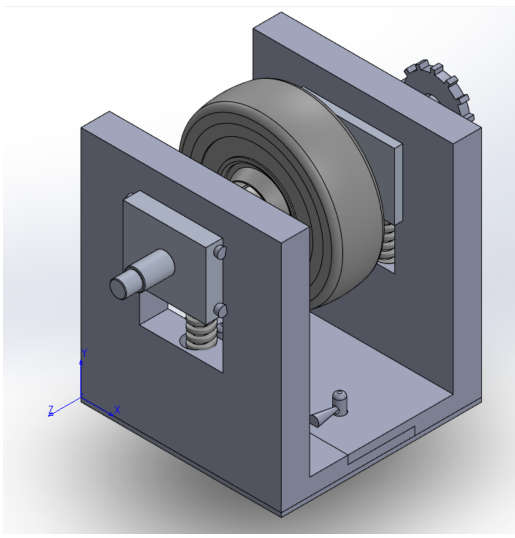

Figure 10: Assembly of Motion Capture Device

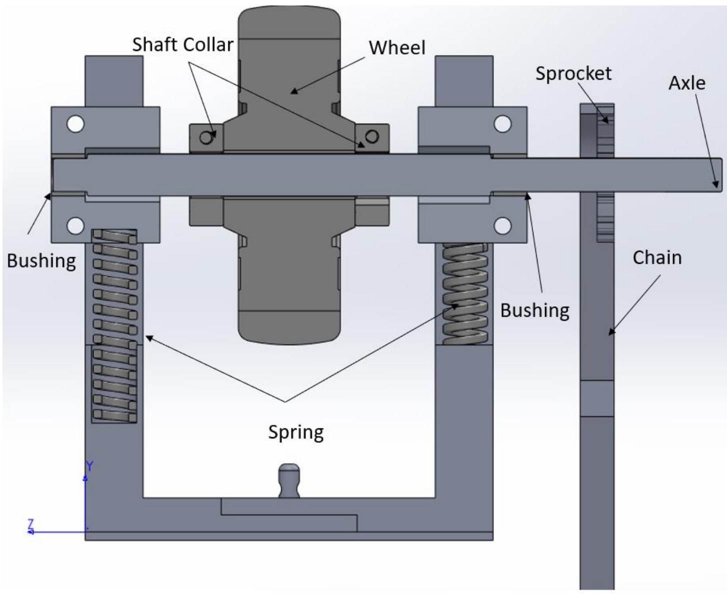

Figure 11: Cross Section of Motion Capture Device

VI.I.I Axle Calculations

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Knowing the forces on the axle is important to approximate the RPM and the torque being generated as well as calculate the necessary spring constants to hold up the wheel.

Assumptions:

- Wheel is 2 feet from center of merry-go-round
- One child could push a total of 130.36N based on average weight of American 8-year-old [7].
- 15% of the energy will be lost to friction

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Given these assumptions, the estimated torque was 24.83N and the output RPM of the wheel is 397. These are then used in the gearbox calculations to find the desired gear ratio to increase the RPM while still having enough torque to spin the generator. The forces in the axle can be seen in Figure 12, the majority of the force comes from the weight of the chain and spring from the chain tensioner.

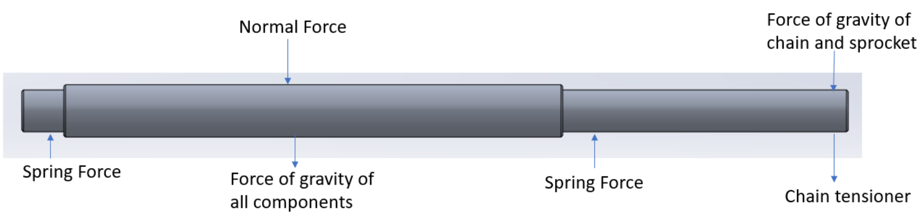

Figure 12: Description of all Forces on Wheel Axle

To calculate the forces for the springs a moment equation was created of the entire wheel axle, equation 1 and can be seen in Appendix X.V, the equation is equal to zero because as Newton's third law states, there is an equal and opposite reaction for every force. In Figure 12 the leftmost spring has a force of 57.868N and the right spring has a force of 698.84N. Due to the large difference in the spring forces the design was changed so that 2 springs can be used on the right, decreasing the force on each spring to 349.42N. Given this the springs were chosen to support 349.42N after being compressed slightly so that extra force from children would allow the springs to compress even more if needed.

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$$M = \Sigma(r \cdot F) = 0$$

Equation 1: Net moment equation for a point, r denote distance to force F

VI.II Gear Box

The gearbox, seen in Figure 13, decreases the torque so that the initially generated torque is enough to start spinning the generator. This allows us to increase the output RPM to generate the most electricity. To keep the gear and shaft in place, steps are machined in the shaft and a shaft collar is placed on the other side of the gear. The wheel produces a torque of 24.83Nm and the generator is estimated to require and torque of 0.0955Nm to spin so we are able to decrease the torque and increase the RPM. A minimum ratio of 0.1985 is required for the gears so this means the input gear is much larger than the output gear. To calculate the ratio, see equation 2, and for calculations see Appendix X.V.

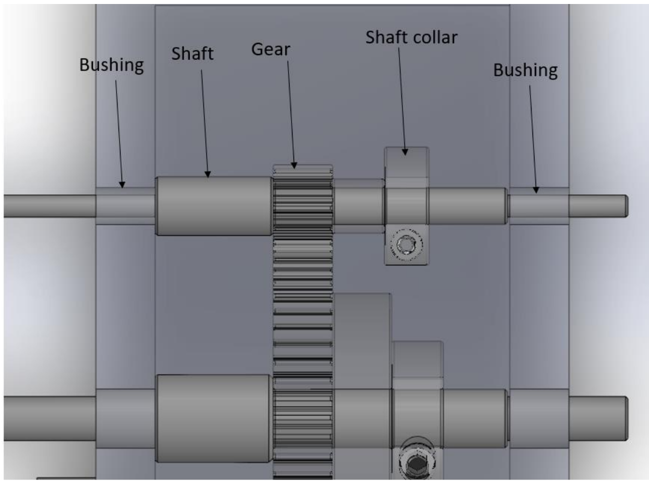

Figure 13: Gearbox Components

$$\lambda = \frac{RPM_W}{RPM_M} = \frac{D_{G2}}{D_{G1}} = \frac{t_{G2}}{t_{G1}}$$

Equation 2: Ratio equation for gears, RPM of the wheel (RPMw) over RPM of the motor (RPMm) is equal to diameter of the output gear (DG2) over the input gear (DG1) which is also equal to the teeth ratio (t)

VI.II.I Fatigue Calculations

When the gears are spinning, they exert a force on each other. This force is translated into the shaft and causes the shaft to bend back and forth as it spins. Fatigue analysis of the shaft was completed to calculate the safety factor of the shaft to see if it would have an infinite life. To calculate this, the Von Mises equation for stress was used. The safety factor came out to 0.5113 which is less than 1 so the shaft won't have an infinite life. Instead, the number of cycles of the shaft was calculated using the fatigue strength equation, Equation 3 with calculations in Appendix X.V, and a total of 1.587 e+51 cycles were estimated for the smaller of the two shafts.

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$$S(N) = aN^b$$

Equation 3: Stress level, S(N), is equal to constant, a, times the number of cycles, N, to the power of constant, b.

VI.III Bill of Materials

The bill of materials to recreate the systems as described above are listed in Table 2. This bill of materials only includes the exact number of materials in the final design of the project and not any of the reorders or bulk orders. A small merry-go-round was constructed to test the system, which is also not included as it is not part of the system design. Within Table 2 some of the unit price is free, this means these parts were given to us and therefore free.

System	Part Name	Quantity	Unit Price in American Dollars	Total Price in American Dollars
Motion capture	Rubber Wheel	1	10.9	10.9
	Bushing for wheel	2	5.08	10.16
	Springs	3	2.95	8.85
	Shaft Collar	2	11.17	22.34
	Wheel Axle	1	Free	0
	Bushing holder, 1 spring (3D printed)	1	1.95	1.95
	Bushing holder, 2 springs (3D printed)	1	2.03	2.03
	Wheel housing, 1 spring (3D printed)	1	13.57	13.57
	Wheel housing, 2 springs, (3D printed)	1	11.14	11.14
	Wheel housing base (3D printed)	1	2.79	2.79
	Pins (3D printed)	10	0.02	0.20
	Sprocket	1	12.77	12.77

Gear Box	Sprocket	1	12.21	12.21
	Chain tensioner	1	Free	0
	Gear 1	1	68.43	68.43
	gear 2	1	26.55	26.55
	Bushing 1	2	1.40	2.80
	Bushing 2	2	1.14	2.28
	Shaft 1	1	26.67	26.67
	Shaft 2	1	10.5	10.5
	Shaft collar 1	1	10.18	10.18
	Shaft collar 2	1	9.98	9.98
	Gearbox main (3D printed)	1	13.24	13.24
	Gearbox face (3D printed)	1	11.46	11.46
	Chain tensioner holder (3D printed)	1	8.52	8.52
	Connection to generator (3D printed)	1	0.29	0.29
Generator and connection	Heat set inserts (for connection)	1	0.25	0.25
	Set screws (for connection)	1	0.14	0.14
	Generator	1	44.92	44.92
Total				345.04

Table 2: Bill of Materials

VII. Manufacturing

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The Manufacturing process began with 3D printing the wheel housing sides, the bushing holders, and the gearbox main and face parts. Simultaneously, the shafts for the wheel and 2 gears were machined on a CNC Lathe with a tailstock to prevent deflection of the bars during tooling. Shaft 2 was started first. Due to the minimum diameter of the Lathe with a tailstock, a steel rod with a larger diameter than the specified largest OD was machined down to all three diameters on the gear side of the shaft. The bushing diameter was too thin and broke off at the end of the operation, seen in Figure 15. A new shaft of the bushing's ID was ordered, and a bore hole was machined on each end of the partial Shaft 2 to insert the new shaft.

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Figure 14: Shaft 2 in the Lathe Prior to Breaking

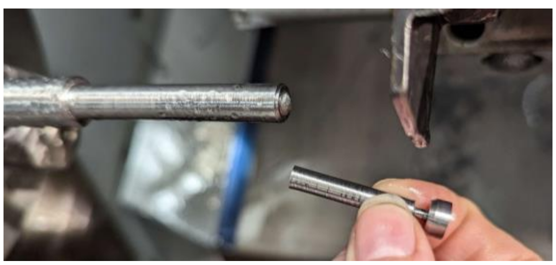


Figure 15: Broken Shaft 2 in the Lathe

Shaft 1 was machined from a shaft with a pre-made step for Gear 1's diameter. After machining the step for the bushing's diameter on the gear side, it was discovered that the large OD section needed to be 2in long instead of the original 1in. This allows the shaft to be properly secured in the chucks with enough clearance from the end of the planned cut and the chucks to prevent any tools from ramming into the chucks. To accommodate the new Shaft 1 length, the Gearbox Face was redesigned and reprinted. The wheel shaft was machined on the Lathe without issue.

Next, an initial assembly test was made for the wheel housing system and the gear box, which revealed several issues. First, the CAD for 3D printed parts had accounted for the fit tolerances of each part but had not accounted for the 3D printer's printing tolerances. To fix this, we used files and a Dremel tool to remove the excess material. Second, the springs we ordered could not be sufficiently compressed by hand to be inserted into the wheel housing assembly. To fix this, we selected and ordered 2 new types of springs that would require approximately 1/3 and 1/8 of the force to compress them into the assembly compared to the original springs. Once they arrived, we tested both springs and found the spring requiring 1/8 of the force was the best fit for the system. Third, there was nothing to hold the gear box together and nowhere to attach the chain tensioner. A new part, the Chain Tensioner Holder, was designed and 3D printed to mount the chain tensioner when slid over the 2 gear box parts, holding them together. Fourth, the initial plan to use bolts to keep the 2 sides of the Wheel Housing together was not viable. Our solution was the 3D printed Wheel Housing Base with 2 pegs that keep the wheel housing aligned.

To translate torque from the gears to the shafts we planned to use a broaching kit to add keyways to the gears and their respective shafts. However, the previous fix for Shaft 2 meant the gear side had an OD of 5/16" and an ID of 3/16", so we were concerned the 1/16" of remaining steel would be compromised if a keyway was machined out. This material concern extended to how we would translate the torque from the main part of Shaft 2 to the inserted smaller diameter shafts. To solve this, we consulted the machine shop staff and decided to have Gear 2 and the smaller shafts welded to the base of Shaft 2. For consistency, Gear 1 was also welded to Shaft 1. We then removed the excess metal splatter from the shafts to ensure the bushings still had a good slip fit. The gear box was assembled, revealing Shaft 2 had been distorted in the welding process, which prevented Gears 1 and 2 from meshing properly and Shaft 2 from rotating smoothly. To fix this, Shaft 2 was clamped at Gear 2 in a manual lathe and gradually bent into alignment. Unfortunately, Gear 2 seems to be slightly misaligned on Shaft 2, meaning we are unable to properly align Gears 1 and 2, resulting in a section of greater resistance on Gear 2.

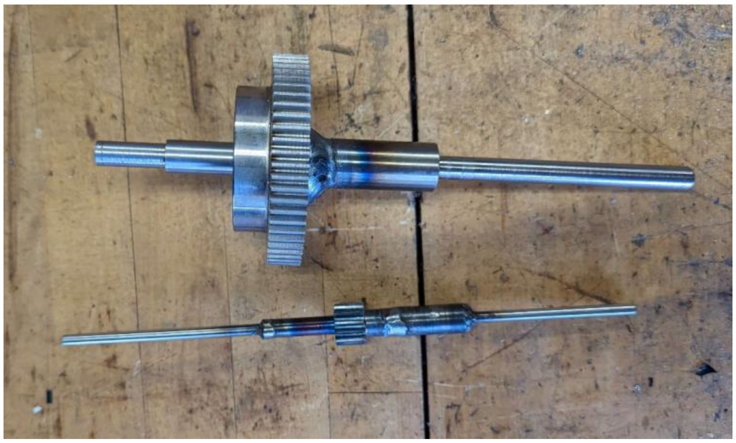


Figure 16: Welded Shaft 1 (top) and Shaft 2 (bottom)

To translate torque between the sprockets and Shaft 1 and the wheel shaft, we initially planned to add keyways. However, the metal key stock would've torn through the plastic bike sprockets we had. To solve this, we purchased metal sprockets with set screws. These new sprockets were too thick for the bike chain to engage properly. The excess material was removed on a CNC Mini Mill until the sprockets could properly engage the chain.

The merry-go-round was assembled from a bike wheel, plywood cut into a circle, and some 2x4 wood. To construct the merry-go-round a bike wheel was procured, and a bike frame was used as the axle for the merry-go-round. The two front forks on the bike were cut off the frame and flattened so that they could be stacked on top of each other to hold the wheel in place. This was done instead of the traditional bike, with a fork on either side of the wheel, to allow the wheel to hold a large piece of plywood to increase the diameter of the wheel and add a material similar to a normal merry-go-round. To make the height three 2'x4' wood planks were used. One had a fork screwed on it, another as a spacer and the last had a hole to insert the other fork so that it could be disassembled easily, seen in Figure 17. Lastly, a base was added to support the whole wheel system.

Commented [BE15]: @Martin, James Add how the merry-go-round was made

Commented [MJ16R15]: i added it

Figure 17: Mini Merry-go-round Axle

A wooden stand was made to align the hand crank generator's input shaft with the output of Shaft 2. The collar connecting Shaft 2 to the motor's input shaft was 3D printed. To accommodate the 3/16" diameter of Shaft 2 at this connection, a heat-set insert was set into the connecting collar and a set screw was used to secure the collar to the end of Shaft 2. The bolt and nut that came with the original handle for the generator was used to secure the collar to its input shaft.

Figure 18: Initial Assembled System

The full system was assembled once again to identify any remaining fixes or additions needed. First, the chain tensioner interfered with the side of its holder when pulled to tension, causing it to eventually pop out. A groove was filed out of the side of the holder to remove the interference. Additionally, the tensioner holder's cavity was filled with epoxy and the tensioner was set inside, creating a snug mold to more effectively hold the chain tensioner in place. Second, the wheel housing and gear box needed to be held apart and kept aligned when the tensioner is engaged. Using more 2x4s, a frame was made to keep each box aligned without twisting. Additionally, we made a wooden wedge to bring the chain to tension after the chain is looped onto each of the sprockets. Lastly, we reduced the friction in the system by adding bike lubricant in the bushings and between the gears.

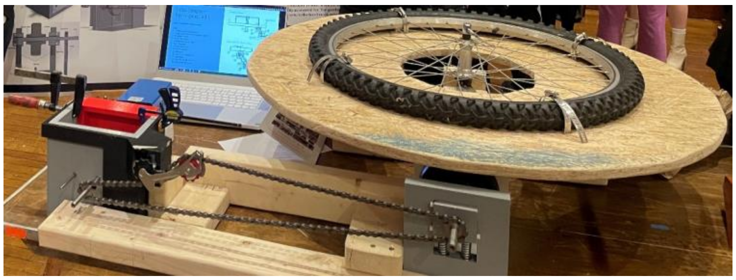


Figure 19: Final Assembled System

VIII. Testing

The first test we conducted was to measure the actual power output of the hand-crank generator. This was done to ensure the generator worked and to establish a baseline of what to expect. We made a circuit of 1.2Ω of parallel power resistors with the generator's regulated voltage output connectors and two multimeters measuring the current and voltage, shown below.

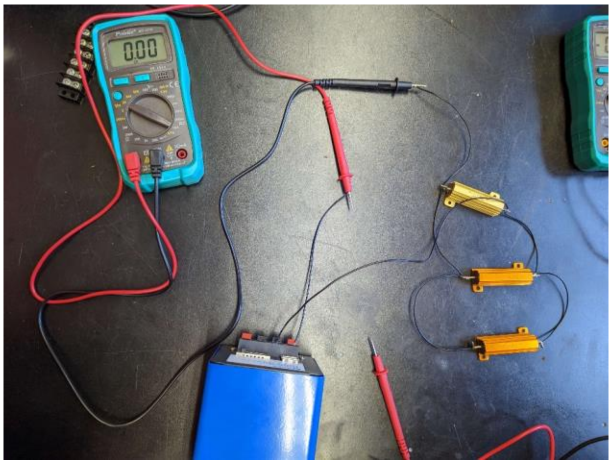


Figure 20: Test Set Up

Turning the handle at a relaxed speed as consistently as we were able resulted in a low, sporadic power output. We attempted to spin the generator's hand crank as fast as we could to determine the highest output we could achieve. During this test, the two highest outputs recorded were 3.05A and 5.01V with a power output of 15.28W, followed by 2.65A and 9.89V with a power output of 26.21W. Unfortunately, immediately after the generator reached 9.89V, the generator's handle broke off where it was welded to the shaft collar, pictured below. Due to time constraints, we were unable to make a new handle to conduct additional testing of the hand crank generator itself.

Commented [BE17]: remember to calculate/ put in what the power for both of these cases are

Figure 21: Broken Hand Crank Generator Handle

The second test we conducted was to check that the full mechanical assembly worked properly. This was done to verify our hypothesis that the system we designed would increase the RPM from a merry-go-round input to the output of Shaft 2, thereby increasing the input RPM and electrical output of a hand crack generator. We also needed to identify any remaining failures in the mechanical system that needed to be fixed. The initial run, prior to attaching the hand crank generator, found there was too much friction in the system, so it did not run consistently. Additionally, the Chain Tensioner was not properly secured and interfered with its holder. As mentioned in Section VII, the first issue was addressed by adding bike lubricant to the bushings and between Gears 1 and 2. The second issue was addressed by making a silicone mold and cutting a groove in the Chain tensioner holder to properly secure the Chain Tensioner. Running the test again revealed the fixes made the mechanical system consistent and run smoothly, but Gear 2 was still slightly offset and had one section of greater resistance when it was closer to Gear 1. At this stage in the process, this issue could not be addressed.

Lastly, we connected the output of Shaft 2 to the input shaft of the hand crank generator and ran the system to test that it would generate electricity. This test found that the mechanical system did not produce output enough torque to turn the hand crank generator's input shaft.

IX. Conclusions and Recommendations

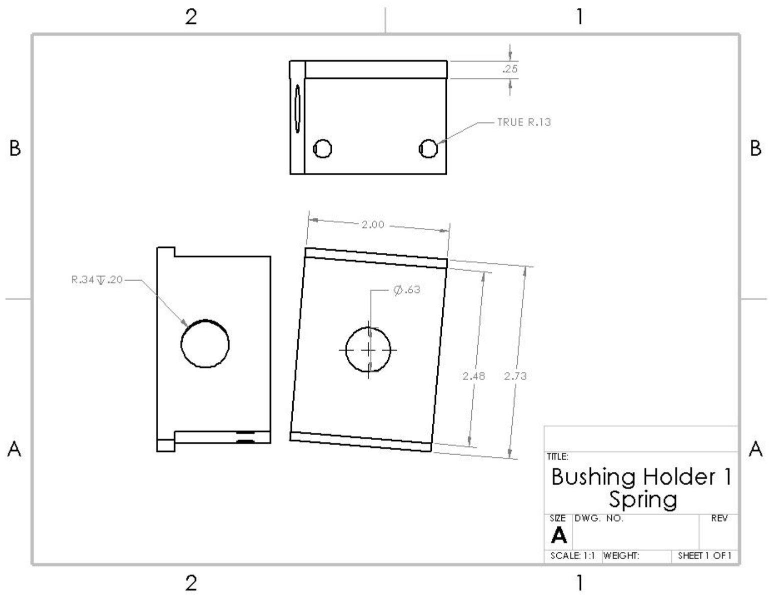
Commented [BE18]: Already Checked

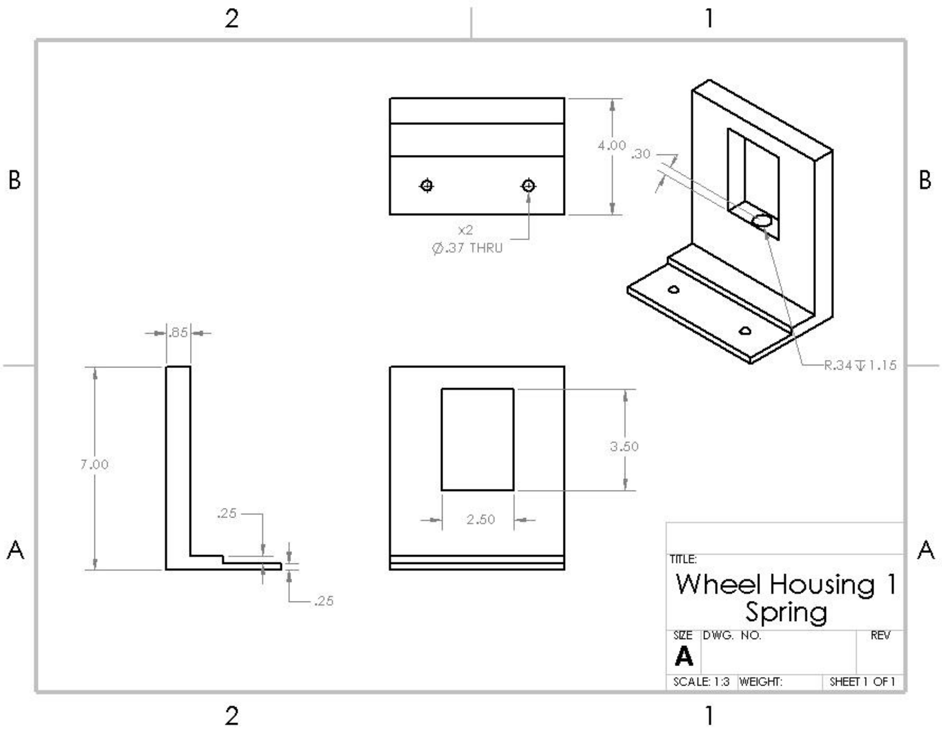
Although our system is not able to generate electricity, it is able to satisfy the majority of the functional requirements. The system can work with any existing merry-go-round, as it is built out of mostly easily replicable parts aside from the shafts for the gearbox, and it is safe for kids as most of the components are underground. Each system can disassemble within 5 minutes, so it follows this functional requirement as well. As explained before, a large amount of friction and larger than expected torque for the generator means we can't generate electricity, so it fails the functional requirement to generate electricity and charge a cordless drill battery.

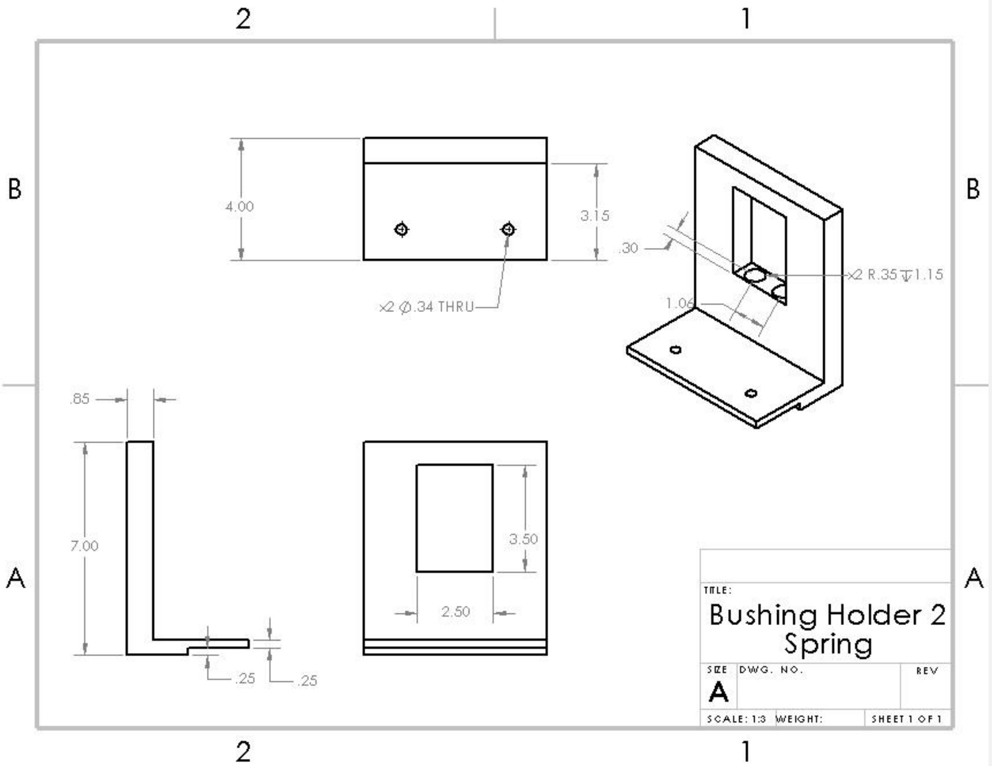
For future projects to build on we have a few recommendations based on some of the problems we ran into while building and with our test results. The largest problem as stated in the manufacturing section was machining Shaft 2, the smallest of the gearbox shafts. Some problems that arose due to the small size of the shaft were it breaking while being machined, difficulties adding a keyway, and not being straight after welding the end of the shaft. To fix these problems we recommend using a much larger diameter shaft or a stronger material such as 440c stainless steel. The other problem as described before is that there isn’t enough torque to spin the generator, we believe this is due to a significant amount going to friction within the system and the gear ratio is too big, so all the torque is being lost to increase the RPM. To fix this problem we recommend using bearings instead of bushings to decrease the friction. We chose to use bushings due to budget constraints, but they have caused more friction than we anticipated. Another recommendation to decrease friction is to ensure the shafts are straight. This will help with the rotation in the bushings as one side won't be pushing into the bushing causing more friction. Another option instead of increasing the torque is to decrease the amount of electrical friction in the generator. This can be achieved by using a brushless motor instead of a brushed motor. We recommend using a better generator than the one we acquired because it has bad wiring and is untrustworthy with the amount of voltage it outputs.

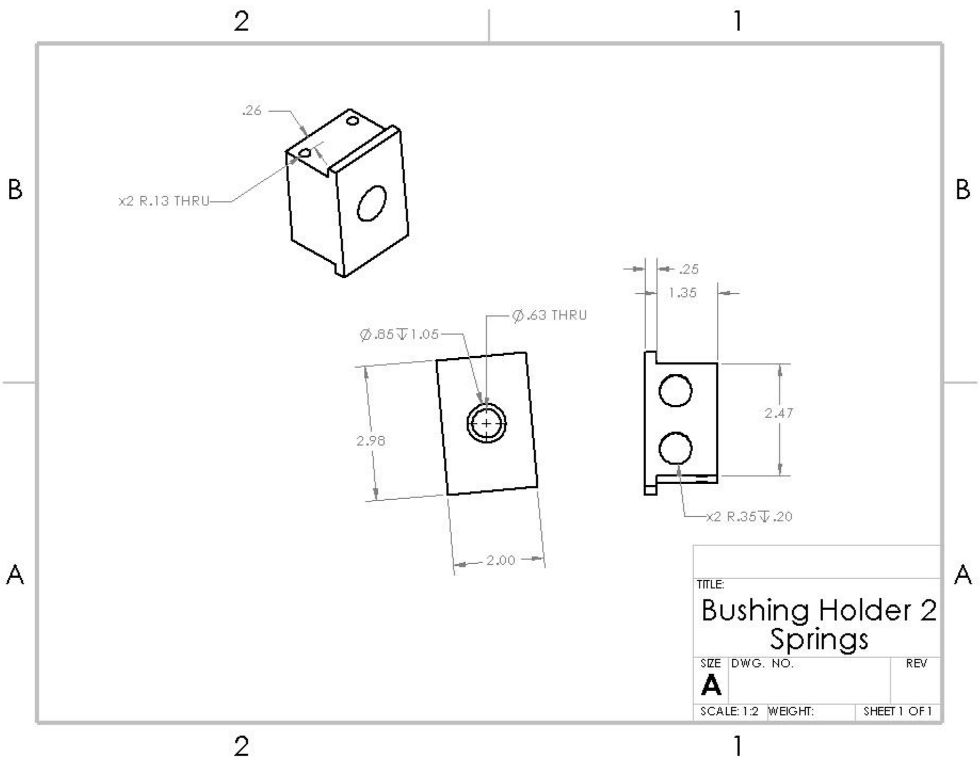
X. Appendices:

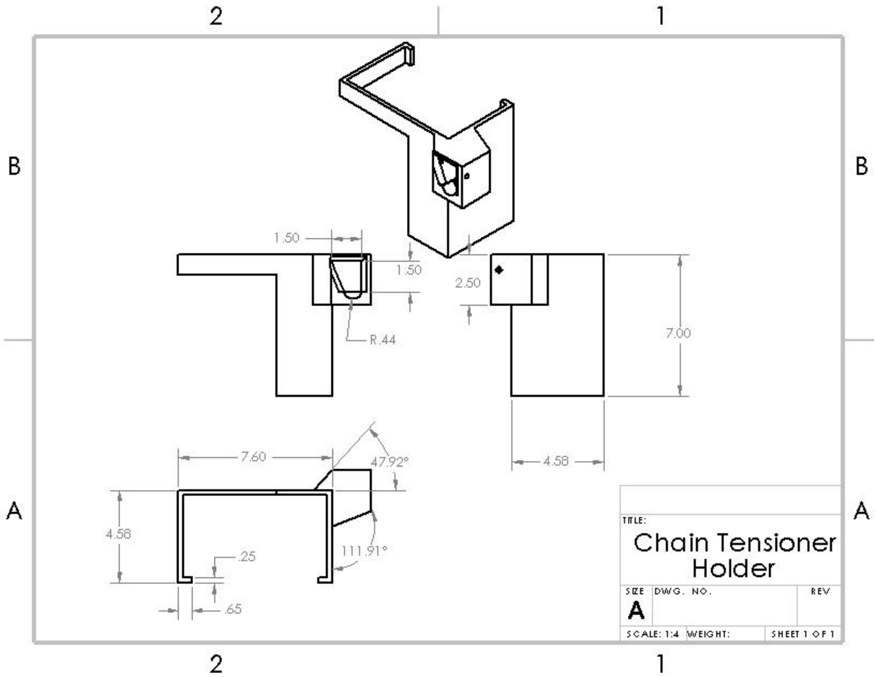
X.I Part Drawings

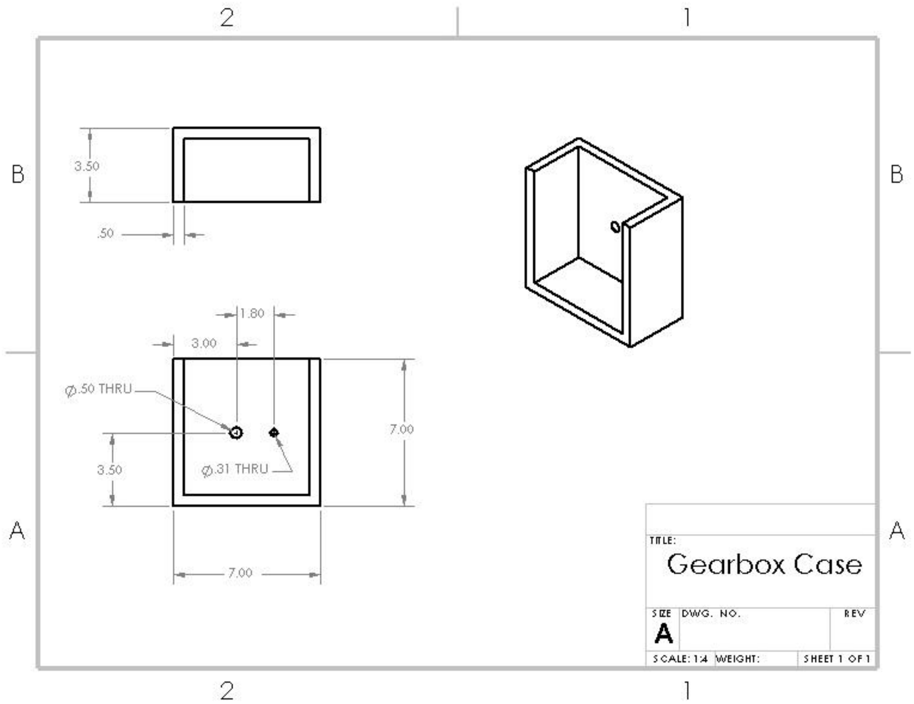


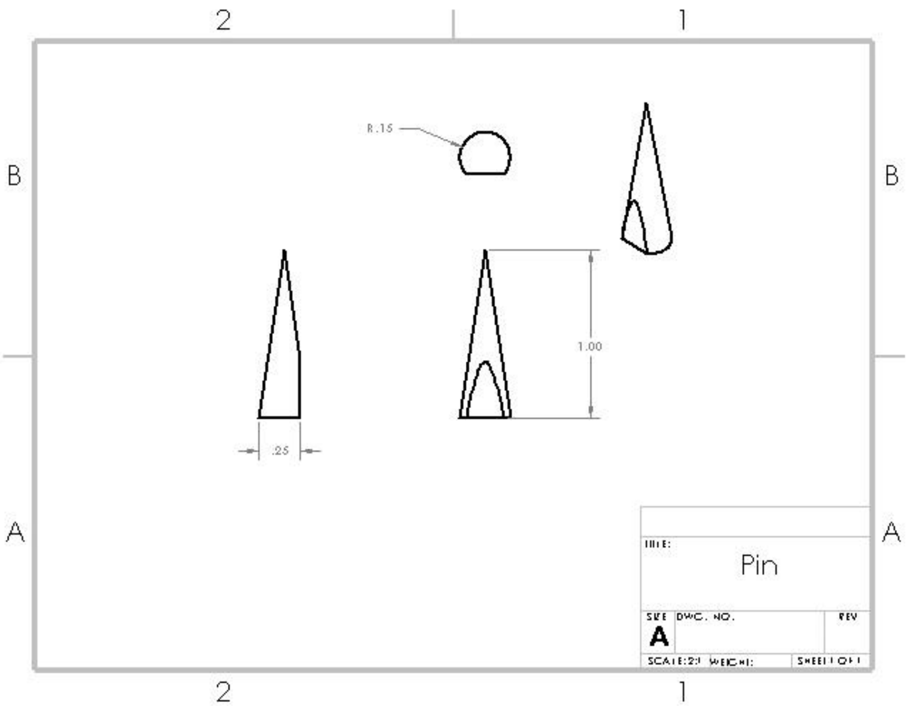

2
1
B
A
4.00
.30
x2
Ø.37 THRU
R.34 ↧ 1.15
.85
7.00
.25
.25
3.50
2.50
TITLE:
Wheel Housing 1
Spring
SIZE
A
DWG. NO.
REV
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1


2
1
B
A
4.00
3.15
x2 Ø.34 THRU
.30
x2 R.35 ↧1.15
1.06
.85
7.00
.25
.25
3.50
2.50
TITLE:
Bushing Holder 2
Spring
SIZE
A
DWG. NO.
REV
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1

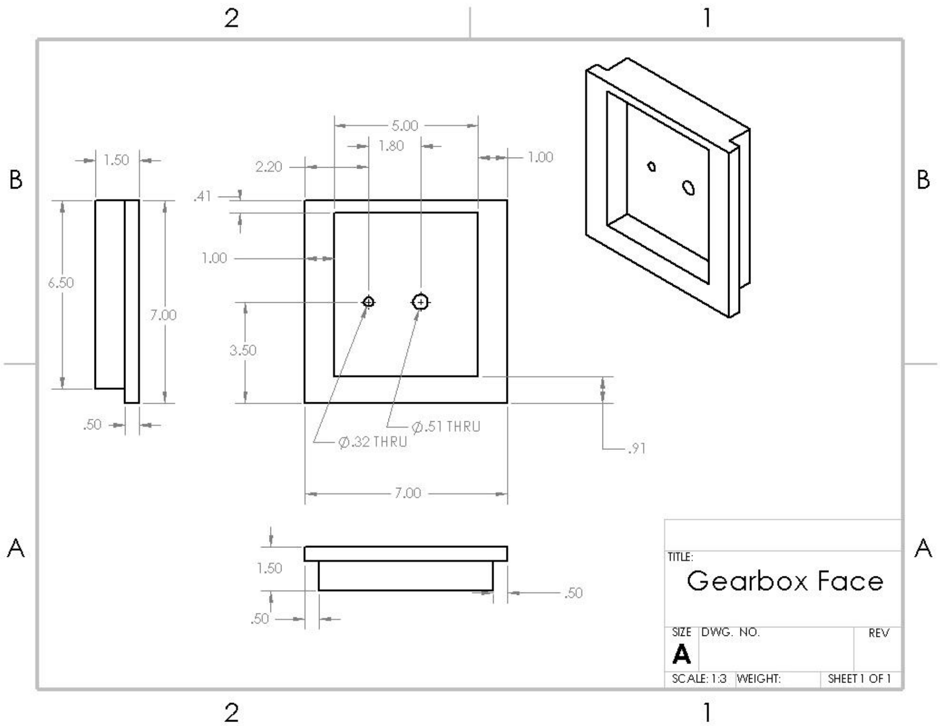

2
1
B
A
.26
x2 R.13 THRU
.25
1.35
Ø.63 THRU
Ø.85 ↧1.05
2.98
2.47
x2 R.35 ↧.20
2.00
TITLE:
Bushing Holder 2 Springs
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


2
1
B
A
1.50
1.50
2.50
R.44
7.00
7.60
47.92°
4.58
4.58
.25
.65
111.91°
TITLE:
Chain Tensioner Holder
SIZE
A
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1


2
1
B
A
3.50
.50
1.80
3.00
∅.50 THRU
∅.31 THRU
3.50
7.00
7.00
TITLE:
Gearbox Case
SIZE
A
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1



2
1
B
A
R.15
1.00
.25
Pin
SIZE DWG. NO.
REV
A
SCALE:2:1 WEIGHT:
SHEET 1 OF 1



X.II Bibliography

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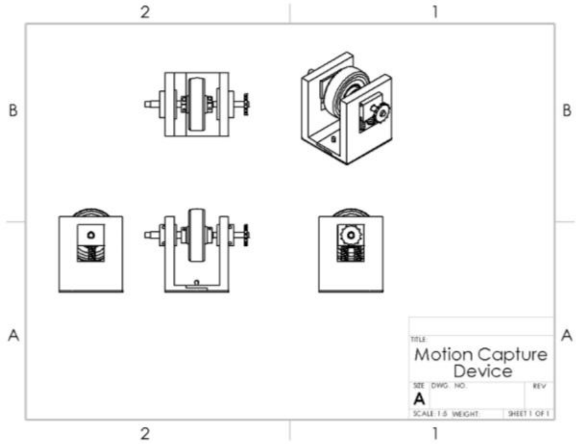
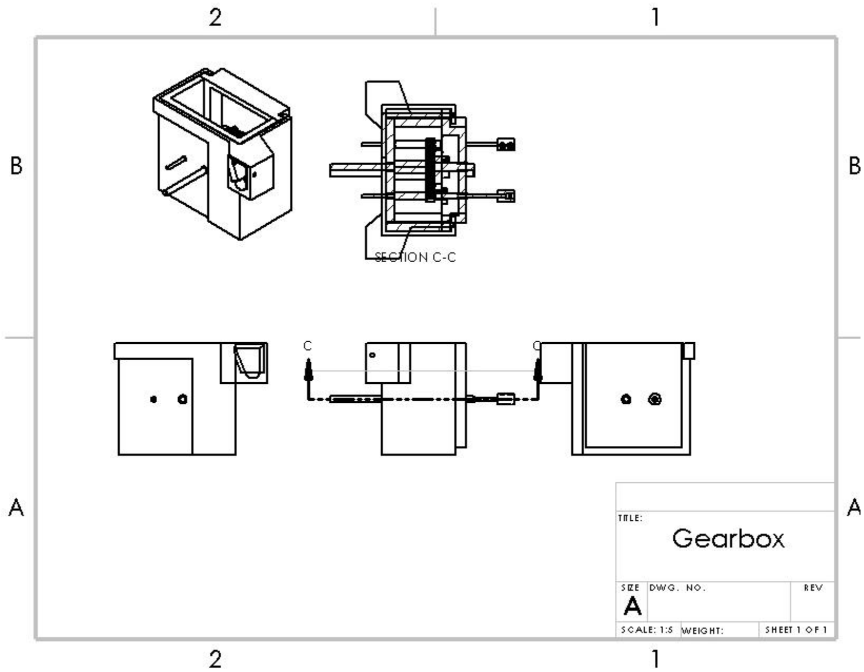
X.III Assembly Drawings





X.IV Authorship

Section	Author(s)	Reviewer
Abstract	James	Erica
I. Introduction	Erica and James	Erica and James
II. Background	Erica and James	Erica and James
III. Design Concepts	Erica and James	Erica and James
IV. Design Selection	Erica	Erica and James
V. Synthesis and Analysis	James	Erica
VI. Detailed Design Description	James	Erica
VII. Manufacturing	Erica	Erica and James
VIII. Testing	Erica	
IX. Conclusions and Recommendations	James	Erica

X. Appendices	James	Erica

X.V Calculations

```
%Force of all components on wheel shaft
Frw=21.4448;%rubber wheel (N)
Fc=0.4893;%clamp (N)
Fbh=2.89;%Bushing holder (N)
Fs=0.845; %Sprocket (N)
Fch=117.655; %Chain (N)
Fb=0.444; %Bushing (N)
Fa=1.28; %Axle (N)
Ft=1739; %Max tention of chain (N)

Fg=Frw+Fa+Fb+Fch+Fs+Fbh+Fc;%Combined force of gravity

Tchild=130.36; %Torque min, one child pushing (N)
Tchildmax=3*Tchild;%Torque max, 3 children pushing (N)
rmg=0.609;%radius of merry-go-round at wheel (m)
rw=0.0635; %radius of wheel (m)
us=0.95 %Friction coefficent
```

```
us = 0.9500
```

```
FchT=200; %Chain tension, based of spring in tensioner (N)
Fg=FchT+Fg; %Force in the vertical direction (N)
Fsmin=((Tchildmax+(Fg*us))/(2*us)); %minimum force of one spring
Fnmin=(2*Fsmin)-Fg;%minimum normal force on bottom of merry go round

Tw=Tchildmax*rw;%torque of wheel (NM)
disp(Tw);
```

```
24.8336
```

```
Tw2=Tw* 8.851;%torque in (lb in)
disp(Tw2);
```

```
219.8020
```

```
%equations for fatigue
r=1/8;%radius of tool (in)
D=0.5; %diameter of large step (in)
d=0.31;%diameter of medium step (in)
q=0.78; %q of material

%Bending moment factor

A=0.93836;%from page 1048 in machine design textbook 6th edition
b=-0.25759; %From page 1048 in machine design textbook 6th edition

Kt=A*((r/d)^b);%Bending moment equation
Kf=1+q*(Kt-1);%fatigue concentration factor in bending

%Torsional moment factor

AT=0.84897;%from page 1049 in machine design textbook 6th edition
bT=-0.23161;%from page 1049 in machine design textbook 6th edition

Kt2=AT*((r/d)^bT);%torsional moment equation
Kf2=1+q*(Kt2-1);%fatigue concentration factor in torsional

%bending stress

a=3;%distance from end to gear location (in)
l=12;%total length (in)
F=53.324681;%force on shaft (lbf)
R=0.31/2;%radius of shaft (in)
MaxM=F*a*(1-(a/l)); %max moment equation

Ib=(pi*d^4)/64;%area moment of inertia

BS=((MaxM*R)/Ib)*Kf;%Bending stress equation with fatigue concentration factor
disp(BS);
```

```
4.6965e+04
```

```
%Toursional stress

T=Tw2;%torque (lb in)
J=(pi*0.31^4)/32; %polar area second moment

TS=(T*R/J)*Kf2;%torsional stress with fatigue concentration factor
disp(TS);
```

```
3.8976e+04
```

```
%Von Mises equation

VM=sqrt(BS^2+3*(TS^2));%equation for von mises
disp(VM);
```

```
8.2237e+04
```

```
%endurance limit equations

Csurf=0.7;%Figure6-26 p368 in machine design textbook 6th edition
Csize=0.869*(0.31^-0.097);%size effect equation 6.7 page 267 in machine design textbook 6th edition
Cload=1; %Equation 6.7, page 366 in machine design textbook 6th edition
Ctemp=1; %equation 6.7f page 371 in machine design textbook 6th edition
Creliab=0.868; %Conservative number, page 371 in machine design textbook 6th edition

TS=142137; %Tensile strength in PSI
Seu=0.5*TS;%unmodified endurance limit

Se=Creliab*Ctemp*Cload*Csize*Csurf*Seu;%endurance limit (PSI)
disp(Se);
```

```
4.2039e+04
```

```
Sm=0.9*TS;%Estimated strength, equation 6.9

b=-(1/3)*log(Sm/Se);%equation 6.10
disp(b);
```

```
-0.3709
```

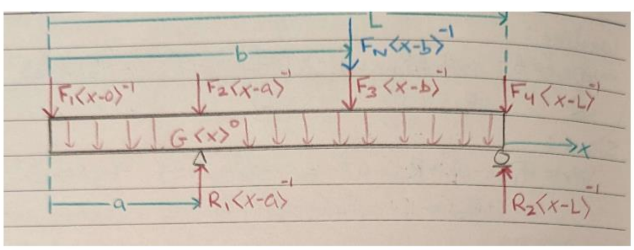
```
a=10^(log(Sm)-(3*b));%equation 6.10
disp(a);
```

```
7.4476e+12
```

```
N=10^((log(Se)-log(a))/b);%Equation for number of cycles, example 6-1-I
disp(N);
```

```
1.5871e+51
```

```
%Beam Loading
I=imread('beampic.PNG');
imshow(I);
```



```
a2=0.0762;% a in pic above (m)
b2=0.1524;% b in pic above (m)
L2=0.2286; % L in pic above (m)
G=5.599;%uniformly distributed (N/M)
F1=Fch+Fs+FchT;%N
F2=Fb+Fbh;
F3=Frw+Fc;
FN=Fnmin;
%boundary condidtions
%X=L, V=0, M=0, c1=C2=0

%M=-F1*(L2)+R1*(L2-a2)-F2*(L2-a2)-F3*(L2-b2)-FN*(L2-b2)-(G/2)*(L2^2)+R2(L2-L2)==0;
%%Moment equaiton for wheel axle
R1=((F1*L2)+F2*(L2-a2)+F3*(L2-b2)+FN*(L2-b2)+(G/2)*(L2^2))/(L2-a2); %rearanged moment equation to solve for R1 (N)
disp(R1);
```

```
698.8426
```

```
%V= -F1+R1-F2-F3-FN-(G*L2)+R2==0; %Shear equation for wheel axle
R2=F1-R1+F2+F3+FN+(G*L2);%rearange and solve for R2 (N)

disp(R2);
```

```
57.8686
```

```
%R1 is going to be 2 springs instead of 1 (N)
R12=R1/2;
disp(R12);
```

```
349.4213
```

```
% Gear Calculations
Tw; %torque of wheel
RPMw=397; %RPM of wheel
Tm=0.0955; %Motor torque, Nm
RPMm=2000; %RPM of motor

RPMratio= RPMw/RPMm; %gear ratio of RPM
Tratio=Tm/Tw;%Ratio for torque
disp([RPMratio, Tratio]);
```

```
0.1985    0.0038
```

```
%Use gear ratio instead of torque ratio when finding gears this will output
%a reqired RPM and a higher torque.
```