DESIGN OF A MECHANICALLY OPERATED PHONE CHARGER

By

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Abstract

With the popularity and increased need of phones in today's world, it has become more apparent that cellular battery technology has fallen behind other aspects of phone technology, especially with the introduction of 5G. To create an alternative method of charging that could both charge a phone and provide a workout, my senior design team was tasked with designing a manually operated phone charger. In order to develop a design solution and a prototype to address this problem, the team went through the design process. Specifications, such as the design being portable, easy to operate, and capable of outputting 5 V and 1 A were established. Concept designs to address the problem and meet these specifications were generated and evaluated using a weighted trade study. A single-hand crank design was selected as the final solution. This design would consist of a handle, a gear transmission, a generator, and electrical conditioning units. The single-hand crank was then designed and modeled in more detail. An assumption was made that a user would only need to input a minimum of 2 lbs. and 30 rpm to the handle in order to charger a phone. Calculations were conducted to verify that the design should be able to charge a phone from this input. Additional stress analyses were conducted using SolidWorks Simulation on critical components to verify that the design would be safe. A physical prototype was then assembled based off of the modeled design solution. Testing revealed that the prototype was not able to properly charge a phone due to a lower voltage and current output than calculated. From the test results, it was determined that the selected generator used in the prototype was not as efficient as designed for, so the output voltage and current were lower than expected. The primary recommendation for future work on the prototype would be to select a new generator that would be able to output the necessary voltage and current to charge a phone.

Acknowledgements

I would like to thank my faculty mentor, Professor Campbell Dinsmore, and my senior design team, Manuel Aceves, Jessy Garcia and You Yu Ko, for their help on this project. I would also like to thank Matt McCormick and Steve Rightnar for their help in the machine shop and Marcos Ochoa and Manuel Robles for their help with 3D printing.

My contribution to this project as part of a team consisted primarily of the hand calculations, the assembly and testing of the prototype, and some assistance with modeling components. Additionally, everyone in the team was equally involved in the concept generation and selection phase of the project.

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Introduction

The purpose of this project is to design a manually operated phone charger that can charge a phone by converting mechanical energy into electrical energy. The design requires a user's manual input and should be capable of safely producing the 5 V needed to charge a phone.

The increased demand for portable battery chargers has revealed the weakness in the large power consumption of smart devices and the finite amount of energy that they can store. Portable battery chargers need to be charged ahead of time to be used; however, in certain situations individuals may not have access to electricity. The targeted customer for this project is an individual who does not have access to a power source for extended periods of time. In situations where individuals are outdoors, on the go, or in an emergency situation, the advantages of using a manually operated phone charger become more apparent.

The initial motivations for this project were based off the fact that many aspects of phone technology have been advancing, such as the introduction of 5G, but the battery technology for smart phones and similar devices have fallen behind. The method suggested to improve the appeal of battery technology was to design a device capable of charging a phone while simultaneously giving the user a workout. The team was tasked with designing a portable manually operated battery charging system that would be efficient, robust, and cost effective.

The finished prototype of the manually operated phone charger is robust, portable, and easy to operate. The prototype can produce the necessary voltage to charge a phone but requires a larger user input than desired. However, the generator selected is less efficient than expected and produces a smaller current. As a result, the prototype was able to meet the voltage requirements, but required a larger current to actually charge a phone.

This report will contain the goals of the project, the process of selecting and designing the final design solution, and the evaluation methods and results conducted on the prototype of the design. Additionally, any recommendations for future design of the phone charger will be made based off the results and observations made.

Problem Statement

The purpose of this project is to design a manually operated phone charger capable of charging a phone. A user's manual input should be able to comfortably convert mechanical energy into electrical energy. The charger also needs to be robust, efficient, and cost effective in a medium to large production scale.

The main requirement is that the charger needs to be able to produce a 5 V and 1 A output to charge a phone. The design should also be no larger than 12" x 6" x 6", weigh less than 10 lbs., and be able to fit inside of a backpack. The design should also be durable and reliable, and the user will be expected to intuitively and easily operate the charger.

Design Solution

The selected solution to our design problem is a single-hand crank phone charger. It is approximated that the user will only have to apply around 2 lbs. to the handle at 30 rotations per minute to be able to charge a phone. The single-hand crank should fit comfortably in one hand and the handle should fold into the casing for increased compactness. The single-hand crank consists of a handle set, a gear transmission, a generator, a voltage regulator and a female USB port.

The handle set consists of a handle which is connected to the handle base using a pin. This connection allows the handle to fold into the casing. The handle base is attached to the main gear shaft using a screw. When the handle rotates this allows the handle base and main shaft to rotate together. The drive gear is fixed onto the main shaft and drives the gear transmission when the handle is turned. The gear transmission consists of the drive gear, 2 compound gears, and a pinion gear which is attached to the generator shaft. The two compound gears sit on rods and spin freely. The generator is driven by the gear transmission and outputs power to a step up/step down voltage regulator. Due to the unstable user input, the function of the voltage regulator is to produce a consistent 5 V output. An AC to DC converter is not included since the selected generator outputs a DC voltage. The voltage regulator is then connected to a female USB port which sends power through a charging cable to charge a phone.

In figure 1, the exterior casing and the handle set can be seen. The design solution's dimensions are roughly 6" x 4" x 3" and the handle is 4.5" long. The casing is designed to be operated by a right-handed user and has grooves so that the charger can comfortably fit in one hand. The top casing also has a cavity for the handle to fold into when not being used.

Figure 1: Single-Handle Crank External View

In figure 2, the internal layout of the single-hand crank design can be seen. This figure shows how all the components fit relative to each other and the location of the supports and additional features added to the casing. A gear support was added to hold the second compound gear in place and two additional supports were added to hold the gear support in place. Two screw holes were also added to hold the two halves of the casing together. The voltage regulator and USB port sit on supports with a cavity feature to hold them in place.

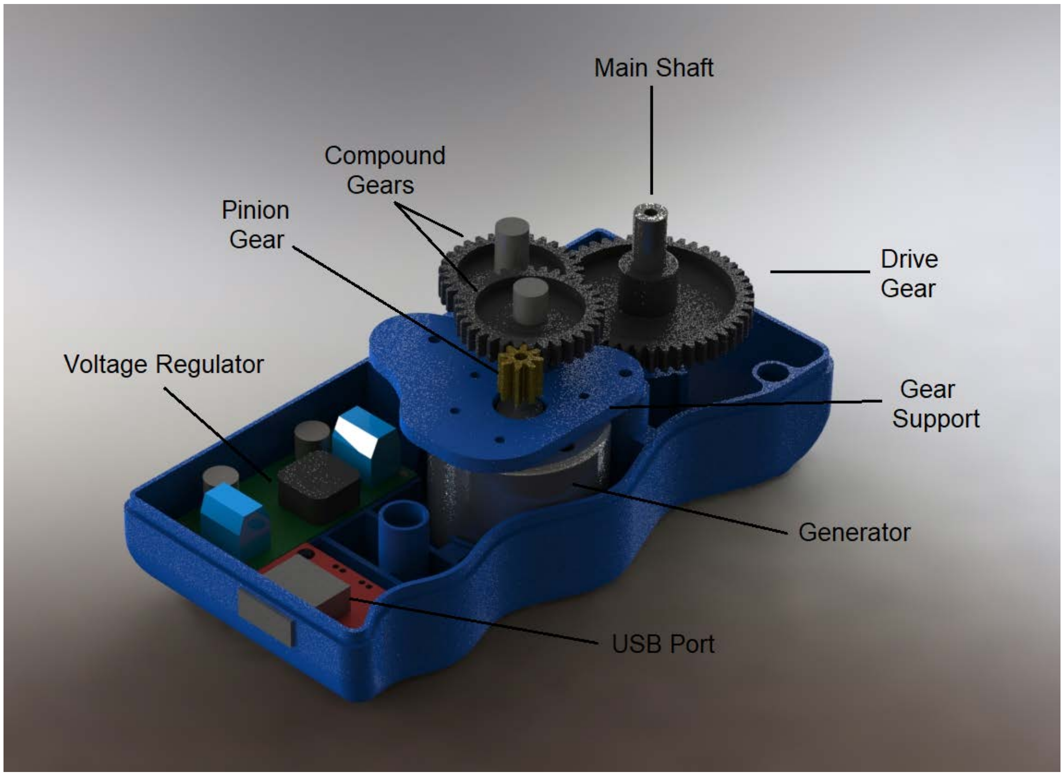

Figure 2: Single-Hand Crank Internal Isometric View

Modeling and Analysis

The purpose of this analysis is to verify the ability of the design solution to be able to produce 5 V from some user's applied force and rpm. It was initially assumed that a user would be able to charge a phone with a minimum applied force and rpm of 2 lbs. and 30 rpm. Selecting the size and number of teeth of each gear allowed the input force and rpm to be verified based off the gear ratio. The analysis primarily used the inversely proportional relationship between the speed ratio, torque ratio and gear ratio. To calculate the output voltage, a linear relationship was used to determine the output voltage by relating it to the output rpm.

Assumptions were made in the calculation that assumed there would be around a 50 % loss in efficiency to account for any losses in the system and to account for the physical motion of the user. The losses in the system were expected to be mainly due to friction or misalignment in the gear transmission. For the physical motion of the user, the applied torque is dependent on the angle that the force is applied to the handle, so it is assumed that the user only applies a force effectively for half of each rotation made.

The calculations, figure 5 in the appendix, assumed the user applied an input of 30 rpm to the handle. From this input and the specified gear ratio of the gear transmission the output rpm at the generator was calculated to be 4,320 rpm. Using a linear relationship, it was approximated that the generator would be able to produce 8.6 V. Next, using the torque at the generator and the gear ratio, the force applied to the handle was calculated to be roughly 0.73 lbs.

Based off the initial assumptions, the user should be able to produce a sufficient voltage to charge a phone from an input of 2 lbs. and 30 rpm. The actual values calculated resulted in an applied force of less than half of the initial assumption. Additionally, the output voltage of 8.6 V is higher than the 5 V needed to charge a phone, so it is assumed that even if there are losses through the electrical components this voltage should be high enough to charge a phone. This calculation was able to verify the compatibility of the assumed user input and selected gear transmission to be able to charge a phone.

In order to identify any safety hazards, a failure mode and effects analysis (FMEA) was conducted to identify the mode of failure on each component and its effect on the system for each potential failure, see table 1 in the appendix. FMEA is used to address, limit, and prioritize the failure modes of each of the critical components in the design. This allows for a better understanding of each components functions, the stresses acting on it, and how its failure will affect the design as a whole. The critical components identified were the handle tip, handle, handle base, handle pin, gear transmission, generator and electrical components. If the handle tip failed, it would make the charger harder to operate. If the handle or handle base failed due to unwanted torque, both would make the charger inoperable and could become potential safety hazards. The handle pin would also make the charger inoperable if it failed due to shear stresses. Deflections in the shaft, misalignment, or uneven wear on the gears could all potentially affect the gear transmission. Since the gear transmission is housed inside the casing it would be harder to detect and any failures could either make the charger less efficient or inoperable. The generator failing would mean the charger would not be able to operate, but this is less likely to occur because of the increased quality control that manufacturers have in producing small generators. Similarly, electrical components would mean there would be no way to condition the power generated by the current and make the charger not operate properly, but this is less likely to happen since these parts are also produced by manufacturers.

Approach to Solution

First, the problem was decomposed into four main parts: the human interface, the power transmission, the generator, and the power conditioning units. The team used the 6-3-5 style, actually the 4-3-5, to generate a list of concepts. This list was narrowed down based on which designs were unique and repeated the most. A total of seven concepts were selected to be focused on and drawn in more detail.

These seven concepts consisted of a single and dual hand crank, a linear and spiral pump, a wind turbine, a string pulley, and a squeeze-grip design. The single-hand crank concept consisted of a crank handle, a gear system, and an axial generator. The dual-hand crank concept was similar except that it had another handle and the handles could be interchanged with pedals. The linear pump concept relied on a linear generator and a magnet fixed to the handle that would use the pumping motion to oscillate between copper coils. The spiral pump used a worm gear to rotate on a ratchet gear which led to an axial generator. The wind turbine concept consisted of a controlled system and moving diaphragm to push air through a turbine to generate electricity. The string pulley concept used a return spring system attached to a transmission system to power a generator. Finally, the squeeze-grip concept used a ratchet gear and gear system and connected to a generator.

These seven concepts were then evaluated using a weighted trade study, see figure 6 in the appendix. First, a list of design requirements was generated and weighed based off the requirement specified in the problem definition. The ability for the concept to produce 5 V was determined to be the most important requirement. This was checked by doing a basic analysis for each concept and making some assumptions to simplify each analysis. Ease of operation was also weighed as one of the more important requirements. It was important for the user to be able to not have to put too much effort to charge a phone. The simplicity of the design, or how intuitive it was, was weighed higher because it was determined that a simpler motion would be easier to do for longer periods of time. The size requirement was split into how compact it was while in use and while not in use. Together with the weight of the concept, these requirements were also weighed more heavily. The reliability and durability of the concepts were also deemed important but were not weighed as heavily as requirements pertaining to the main function of the charger. The safety and cost of the concepts were not considered as important because they also did not pertain to the functionality of the charger and all the design were safe. The manufacturability of the concepts was not weighed as highly, again, because the function was prioritized over how easy it was to build. Finally, the aesthetics of the concepts was the least important requirement because the appearance of each concept was not considered as important as the size or function of the charger.

With all the design requirements weighed based off their importance, each of the concepts were evaluated on how well they met each requirement on a scale of 1-10. Summing the weighed scores for each concept, the design with the highest weighted score was the selected design solution. The advantage of using this method is that each design is evaluated independently based on how well they meet each requirement.

The single-hand crank was the concept with the highest weighted score and the selected design solution. This concept had the highest score for size, weight, and ease of operation. Additionally, it scored on the higher end for the rest of the requirements and also had a much higher sum than the second highest scoring concept. While the sting-pulley concept, the second highest scoring concept, was the favored design by the team, it was a more complicated design that may not have performed as well as the single-hand crank design and this decision was reflected in the weighted trade study. The simplicity of the single-hand crank and the more reliable transmission system made the single-hand crank concept more reliable and less likely to have unexpected problems occur. Overall, given how the single-hand crank would be relatively smaller in size and weight, and how it would be intuitive and easy to operate, it was determined to be the best design.

The single-hand crank design was evaluated to have been above average when meeting all the specifications relative to the other designs. It was determined able to produce the 5 V output. It was determined to be made small and light enough and it was also considered to be both easy to operate and manufacture. Based on how it would be made it would also be durable and more reliable than most of the other designs.

Discussion of Results

The physical prototype developed is similar to the design solution, see figure 3 and figure 4. The overall dimensions of the prototype are 4.96” x 2.5” x 2” and it weighs 0.456 lbs. The casing, handle set, and gear support were initially printed using ABS plastic, but finalized using PLA. Supports and component fixtures were also added to the interior of the casing to better support and hold the internal components in place. The handle set consists of a screw holding the handle tip to the handle and a steel pin to hold the handle to the handle base. Both the handle tip and handle can rotate. The handle base is screwed into the main shaft which has the drive gear fixed to it. Two similar stainless-steel shafts hold the compound gears. The second compound gear meshes with the brass pinion gear which sits on the generator shaft. The generator is then connected to a voltage regulator which outputs a fixed 5 V to a USB port. Screws are also used to mount the gear support and to keep the top and bottom casing held together.

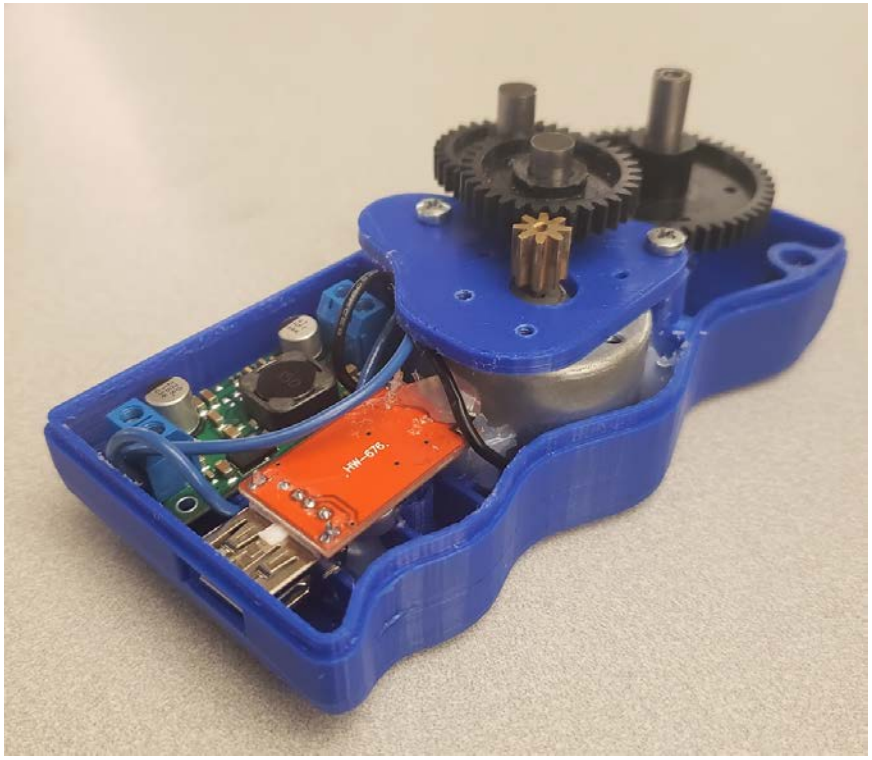

Figure 3: Internal view of physical prototype

Figure 4: External view of physical prototype

To evaluate the prototype, a series of simulation and physical tests were conducted. The design of the prototype was evaluated using SolidWorks Simulation in order to determine the stress acting at critical parts of the design. A stress analysis was conducted for both the handle and the hand pin. The simulation was tested for an applied force of 3 lbs. which was larger than expected, and a hand calculation was conducted in order to verify the accuracy of the simulation results.

The simulation produced a max von Mises stress of 10,000 psi on the pin and 5,600 psi on the handle, see figure 7 and figure 8 in the appendix. The pin has a yield strength of 25,000 psi and the handle has a yield strength of 5,660 psi. This resulted in a factor of safety of 2.5 on the pin and 1.01 on the handle. These calculations were done under a worst-case scenario and the results indicated that the design should be safe.

The hand calculation resulted in a max von Mises stress of 32,594 psi on the pin and 2,106 psi on the handle, see figure 9 and figure 10 in the appendix. Comparing this with the results of the simulation, there was a percent error of 225% for the pin and 62.45 for the handle. When doing the calculations, the analysis was assumed to have been simplified too much and the results from the calculations were not accurate.

The physical components used in the prototype were also tested first individually and then as a whole. A power supply and multimeter were primarily used in order to conduct these tests. First, the voltage regulator was tested for a variable input voltage. A multimeter measured its output to verify that it produced a fixed 5 V, see table 2 in the appendix. The USB was also tested to determine if there were any significant losses by measuring its output voltage from an input of 5 V. The measurements showed that the losses were minimal.

The generator was initially tested with a drill in order to verify that it was producing some voltage and current. Once it was confirmed that it worked properly, it was tested together with the gear transmission to measure the voltage output for different input rpms. The generator produced around 1.6 V at 30 rpm, 2.9 V at 60 rpm, and 5.3 V at 120 rpm, see table 3 in the appendix. The voltage regulator was then connected to the generator and the output voltage and current was then measured for the different input rpms. The voltage regulator produced around 1.4 V and 0.002 mA at 30 rpm, 4.9 V and 75 mA at 60 rpm, and 4.9 V and 0.2-0.25 A at 120 rpm, see table 4 in the appendix.

The prototype was then tested as a whole to determine whether it could charge a phone or not. At the three different rpms, a few different kinds of phones were connected to the prototype using a phone cable, but none were able to be charged.

The prototype was able to meet the requirement of producing 5 V; however, it was not able to do so at 30 rpm. Additionally, because the current produced by the generator was lower than expected, the prototype was not able to charge a phone. The prototype was easily able to meet both the size and weight requirements specified in the problem statement. And it was also intuitive and relatively easy to operate. While the assumed input of 30 rpm was not able to be met, the prototype did not require much force to operate. Additionally, the groves in the side of the casing helped the user with gripping the casing more easily. Because the main focus of the prototype testing was spent verifying its ability to charge a phone, there was not enough time to conduct durability, reliability, or cost effectiveness tests. Ideally, the charger would be able to survive drops; however, the 3D printed material has different structural properties than a production made part. As a result, any testing on the prototype's durability would not be useful information about the actual design durability. For the reliability, the prototype would first have to be capable of charging a phone properly, then it could be tested over a period of time to determine the effects of wear over time. For cost effectiveness, the bill of materials used to build the prototype would be different than the cost to produce the design. As a result, the cost analysis would have to be conducted after determining the cost to manufacture the parts using the finalized components and materials.

Conclusion and Recommendations

The testing of the prototype revealed that a higher input rpm of around 120 rpm would be required to generate a higher voltage and current. The efficiency of the selected generator was lower than calculated for, so the generator was not able to produce 5 V from a user input of 30 rpm. At a higher rpm, it was determined that due to the specific configurations of the USB data pins, a USB controller was needed. The various iterations of the 3D printed casing revealed differences in design such as thickness and alignment when producing a 3D printed prototype versus a production made part. The differences between printing with different types of material was also observed. ABS resulted in prints that were slightly smaller than the initial model, while PLA tended to maintain similar dimensions to the model.

There were also many recommendations made for future work on the project. A different generator would be recommended for the prototype since the generator was not able to produce the necessary voltage and current at 30 rpm. The gear transmission would also need to be adjusted based off the specifications of the new generator. Ideally, it would be preferred to manufacture specialized gears for the prototype. Due to the limitations of the size, number of teeth, and price of off the shelf gears, making our own gears would allow for a more compatible gear transmission with the prototype and the gears could also be selected to reduce the wear on the teeth. Since the configuration of the data pins on the USB required specific configurations depending on the phone, the addition of a USB controller would improve compatibility with a larger range of phones. ABS was initially used to print the casing, handle set and supports, because of its improved ductility over PLA. While both ABS and PLA have similar yield strengths, we switched to PLA because it was easier to work with for rapid prototyping and testing purposes. While testing the prototype it was determined that a shorter handle would be more comfortable to use. The length of the initial handle meant a larger circular motion was needed to turn the handle and it was difficult to turn at higher rpms with this longer length. The generator output an inconsistent voltage and current due to the nature of the variations in the user's input. A filter could be used to help with smoothing the output. Likely, we would use a low pass filter to help attenuate higher frequencies since the ideal input frequency is lower. Other things to add would be an indicator light to show charging status, a battery to store excess energy, and fast charging capabilities

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Appendix

Single-Hand Crank: 30 rpm input assumed

S = velocity, N = # of teeth, T = torque

Velocity & Teeth:

Equations: $\frac{S_A}{S_F} = \frac{N_B}{N_A} \times \frac{N_D}{N_C} \times \frac{N_E}{N_F}$; $S = \pi \times PD \times rpm$

Calculations:

$S_A = \pi \times 1.5" \times 30\ rpm = 45\pi = 141.37\ in/min$

$\frac{141.37}{S_F} = \frac{N_B}{N_A} \times \frac{N_D}{N_C} \times \frac{N_E}{N_F} = \frac{16}{48} \times \frac{16}{32} \times \frac{8}{32} = 0.0416$

$S_F = \pi \times 0.25" \times rpm\ F = 3392.92\ in/min$

$rpm\ F = 4320\ rpm$

Torque & Teeth:

Equations: $\frac{T_F}{T_A} = \frac{N_B}{N_A} \times \frac{N_D}{N_C} \times \frac{N_E}{N_F}$; $T = F\ x\ L$

Given: $T_F = 35\ g-cm = 2.53\ x\ 10^{-3}\ lb-ft$

Calculations:

$\frac{2.53\ x\ 10^{-3}}{T_A} = \frac{N_B}{N_A} \times \frac{N_D}{N_C} \times \frac{N_E}{N_F} = \frac{16}{48} \times \frac{16}{32} \times \frac{8}{32} = 0.0416$

$T_A = 0.0672\ lb-ft$

$T_A = 0.0672 \cdot 2 = 0.1214\ lb-ft = 1.4572\ lb-in\ (accounting\ for\ losses)$

$F_{in} = \frac{T_A}{L} = \frac{1.4572}{4} = 0.3643\ lb$

$F_{in} = 0.3643 \cdot 2 = 0.7286\ lb\ (accounting\ for\ users\ motion)$

Voltage Output:

Equation: $\frac{v_{max}}{rpm_{max}} = \frac{V_{out}}{rpm_{out}}$

Given: $V_{max} = 12\ V$, $rpm_{max} = 6,000\ rpm$

$\frac{12\ V}{6,000\ rpm} = \frac{V_{out}}{4,320\ rpm}$

$V_{out} = 8.64\ V$

Figure 5: Calculations for input force and rpm

Components:	Severity	Occurence	Detection	RPN
Handle tip	5	3	2	30
Handle	6	4	2	48
Connecting Rod	6	2	5	60
Handle Base	6	3	4	72
Gear Transmission	6	3	5	90
Generator	7	2	6	84
Electrical Components	7	2	6	84

Table 1: Failure Mode and Effect Analysis

Final Weighted Trade Study		Concept 1		Concept 2		Concept 3		Concept 4		Concept 5		Concept 6		Concept 7	
Design Requirements:	**Weight (1-10)**	Pump: Linear	PL (weighted)	Pump: spiral	PS (weighted)	Dual hand Crank	DHC (weighted)	Single Crank	SHC (weighted)	Pull String	P-S (weighted)	Turbine	T (weighted)	Grip	G (weighted)
Ease of Operation	8	4	32	6	48	6	48	8	64	6	48	5	40	5	40
Simple Design	8	8	64	8	64	8	64	9	72	8	64	8	64	8	64
Compact (in use)	5	4	20	4	20	5	25	7	35	7	35	4	20	8	40
Compact (travel)	9	5	45	5	45	6	54	8	72	8	72	4	36	8	72
Light	7	5	35	6	42	6	42	8	56	7	49	7	49	8	56
Safety	6	9	54	9	54	8	48	9	54	8	48	8	48	8	48
Cost	5	4	20	4	20	6	30	8	40	6	30	5	25	7	35
Manufacturability	6	5	30	5	30	6	36	8	48	6	36	5	30	6	36
Reliability	8	7	56	7	56	8	64	9	72	7	56	6	48	6	48
Durability	7	7	49	7	49	8	56	8	56	7	49	6	42	6	42
Produce 5V	9	2	18	4	36	7	63	6	54	5	45	6	54	6	54
Aesthetics	3	5	15	5	15	6	18	7	21	7	21	8	24	6	18
Total:			438		479		548		644		553		480		553

Design Requirement Explanations:
Ease of Operation - How easy the physical motion is.
Simple Design - How intuitive the design is.
Compact - Size of design
Light - Weight of design
Safety - How safe the design is
Cost - How much it costs to produce design
Manufacturability - How easy it is to make/produce design
Reliability - How reliable the design is
Durability - How durable the design is
Produce 5V - Can it output 5V
Aesthetics - How the design looks

Figure 6: Weighted Trade Study

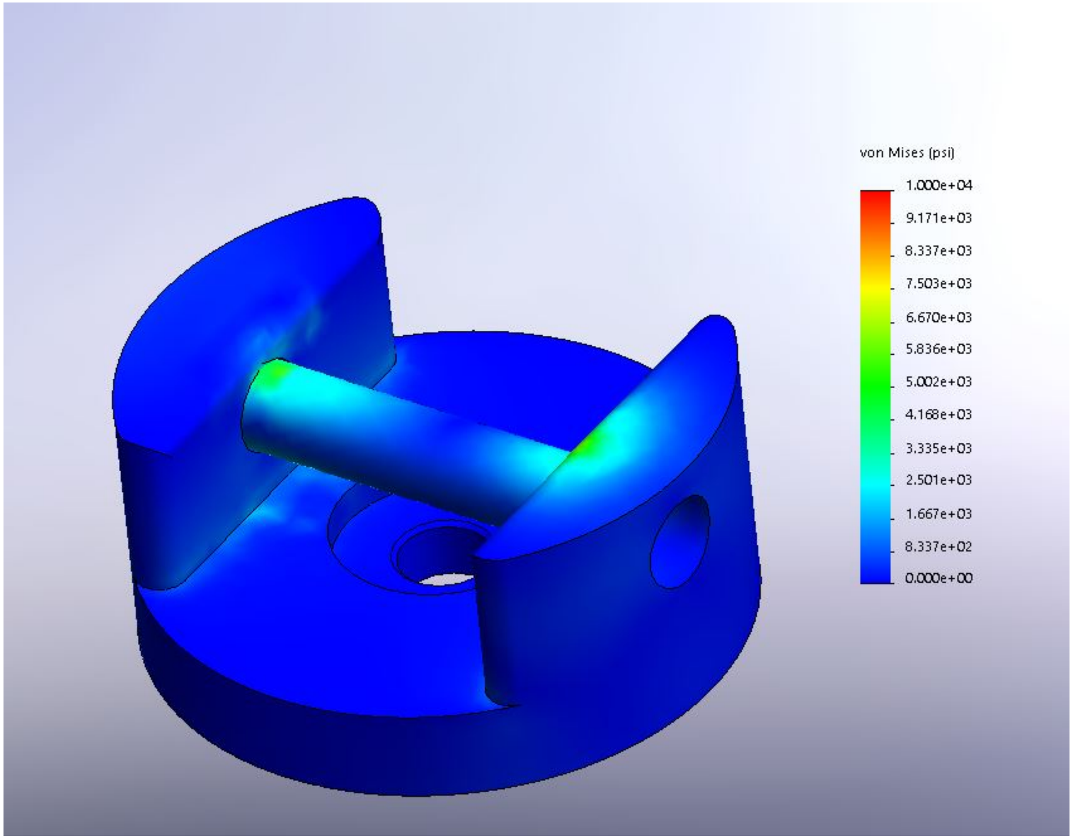


Figure 7: SolidWorks Simulation on pin

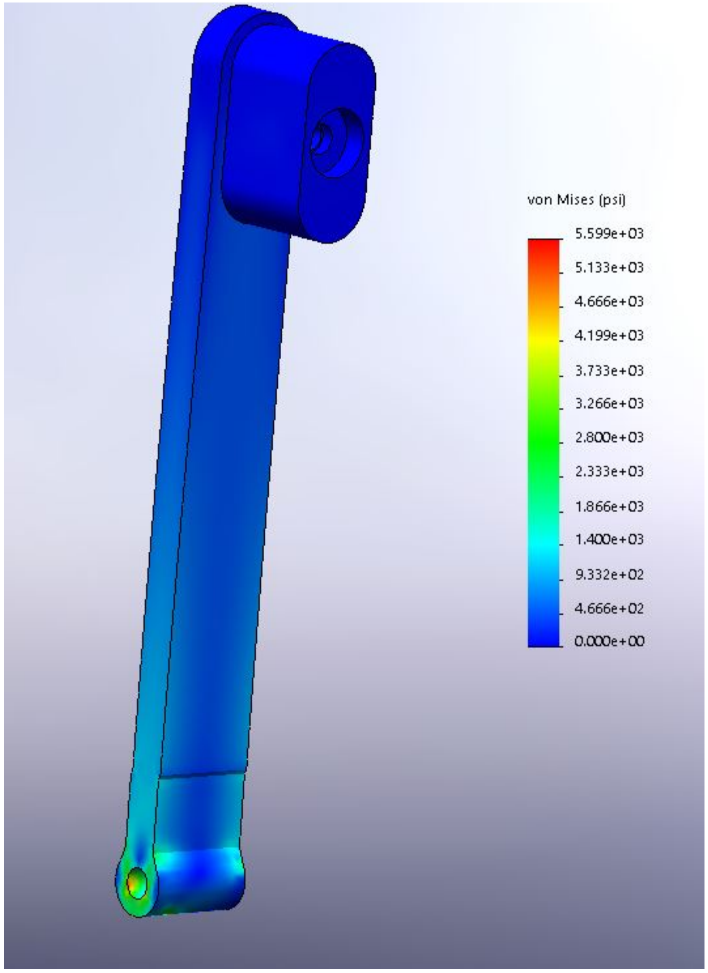


Figure 8: SolidWorks Simulation on handle

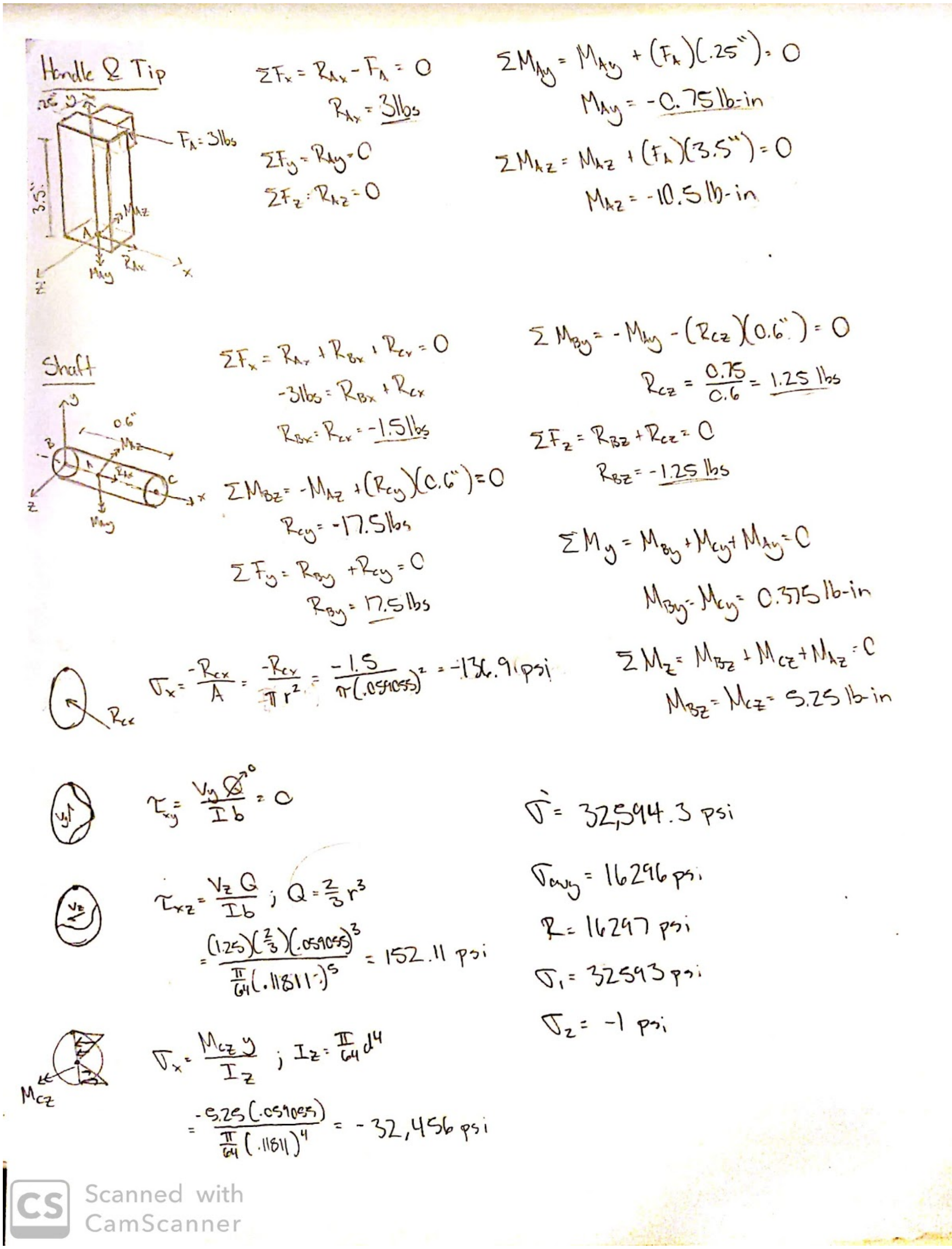
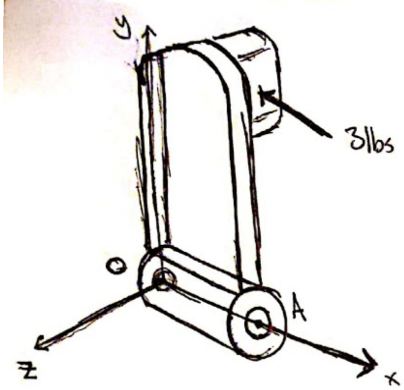


Figure 9: Hand Calculations on pin



Forces

$\Sigma F_x = 0 = O_x + A_x - 3 \Rightarrow O_x = A_x = 1.5\text{ lbs}$

$\Sigma F_y = 0 = O_y + A_y \Rightarrow O_y = A_y = 0$

$\Sigma F_z = 0 = O_z + A_z \Rightarrow O_z = A_z = 0$

Moments about O

$$\Sigma M_o = M_{ox}\hat{i} + M_{oy}\hat{j} + M_{oz}\hat{k} + M_{Ax}\hat{i} + M_{Ay}\hat{j} + M_{Az}\hat{k} + \vec{r}_{OA} \times \vec{F}_A$$

$\vec{r}_{OA} = .25\hat{i} + 3.5\hat{j} - 0.25\hat{k}$

$\vec{F}_A = -3\hat{i}$

$$0 = (M_{ox} + M_{Ax})\hat{i} + (M_{oy} + M_{Ay})\hat{j} + (M_{oz} + M_{Az})\hat{k} + \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ .25 & 3.5 & -.25 \\ -3 & 0 & 0 \end{vmatrix}$$

$$= 0\hat{i} + .75\hat{j} + 10.5\hat{k}$$

$\hat{i}$

$M_{ox} + M_{Ax} = 0 \Rightarrow M_{ox} = M_{Ax} = 0$

$\hat{j}$

$M_{oy} + M_{Ay} + .75 = 0 \Rightarrow M_{oy} = M_{Ay} = -0.375\text{ lbs-in}$

$\hat{k}$

$M_{oz} + M_{Az} + 10.5 = 0 \Rightarrow M_{oz} = M_{Az} = -5.25\text{ lbs-in}$

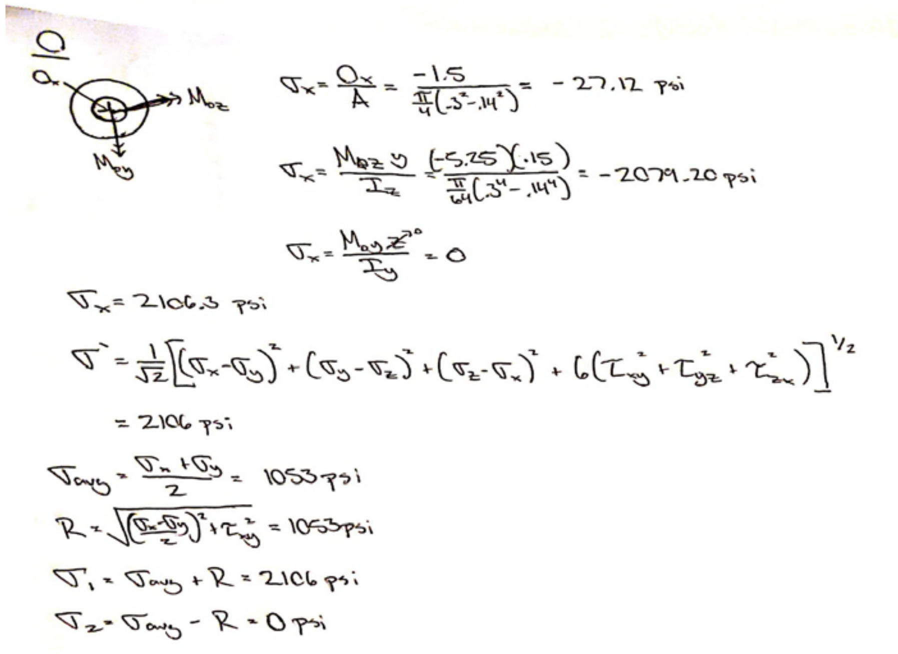


Figure 10: Hand Calculations on handle

Power Source Voltage [V]	Multimeter Measurement [V]
2.97	4.99
4.08	4.99
5.99	4.99
6.96	4.99
10.10	4.99
15.94	4.99

Table 2: Voltage Regulator measurements

Generator @~30 rpm		Generator @~60 rpm		Generator @~120 rpm	
Test	VDC	Test	VDC	Test	VDC
1	1.9234	1	2.8295	1	5.1256
2	1.3736	2	3.2254	2	6.0125
3	1.6443	3	2.9409	3	4.5555
4	1.5492	4	2.9227	4	5.5075
5	1.7725	5	2.8142	5	5.3339
Average	1.6526	Average	2.94654	Average	5.307

Table 3: Generator testing

Regulator @~30 rpm		Regulator @~60rpm		Regulator @~120 rpm	
Test	VDC	Test	VDC	Test	VDC
1	1.764	1	4.9841	1	4.9918
2	1.5198	2	4.9658	2	4.9108
3	1.3643	3	4.8643	3	4.9925
4	1.186	4	4.9658	4	4.9917
5	1.0802	5	4.7843	5	4.9953
Average	1.38286	Average	4.91286	Average	4.97642

Table 4: Regulator testing