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Capstone Systems Design ENGR 4951U/ Winter 2022/ Group 12-5-5 Design and Development of an Electrical Power Conversion and Storage Unit

Prof. REMON POP-ILIEV,
Dr. Brendan MacDonald

Team Members

	First Name	Last Name	Student ID
	Bryce	Elvin	100696601
	Daniel	Kuiumdjian	100541688
	Cameron	Slade	100703005
	Lucas	Sprung	100699915
	Christian	Toso	100702768

Executive Summary

The main purpose of this project is to produce a device that is capable of generating usable power as efficiently as possible from a rotational input of varying speed. The main components of the device are a continuously variable transmission (CVT) and an induction machine taken from a Champion generator. Operation of the device begins with the input rotation which then spins the CVT and a series of pulleys which all transfer the rotational energy to the induction machine which then generates power and brings the speed of the rotation to approximately 3600 rpm which is needed to generate 120V AC which is standard for a North American wall plugs. The CVT is in place such that if the system starts to go outside the desired speed of 3600 rpm, the pulley ratios change to maintain a constant speed even with a varying input speed.

The process of designing and building the device starts with concept generation which was done mainly for the means of how the system could accept a variable input while still maintaining efficient power generation. After evaluation of different concepts, it was decided to use a pulley that adjusts its pulley ratio which would maintain speed without user input, and being a fully mechanical solution, it would not require additional power to operate. After the concept evaluation was complete, the necessary parts were obtained to begin assembly of the prototype which included a CVT that functioned using similar principles to what was required for the project. Once the CVT was obtained, testing was done to better understand how it functioned and how it could be adjusted to work within the required speed ranges. It was determined the springs within each side of the CVT were what determined the range of speed the CVT operated. Testing was then conducted with a series of different springs of varying strength on both sides of the CVT to tune the system to the range that was required. After all the components were obtained, the unit was then built and prepped for testing.

Upon testing the unit the input device used for testing did not have a high enough torque to rotate the pulleys which is likely a result of the pulley ratios used to obtain the desired speed of 3600 rpm for the unit to function properly off of a lower speed input. An assisted start was used in testing which allowed the system to function however, the system was not able to move fast enough in testing for the CVT to adjust and maintain constant speed on the entire unit but separate testing showed that the CVT will change pulley ratios when a certain threshold is achieved. Changes to different parts of the unit would be required in order to address the issues found through testing. Once these changes are implemented, the system should be able to achieve the desired requirements set out at the beginning of the project.

Table of Contents

Section 1: Design Problem and Objectives

Problem Definition

When it comes to power generation, specifically portable generators, many brands and models supply power for appliances. However, these devices usually operate using gas-powered engines, which operate at fixed speeds and produce harmful chemicals. Most portable generators also do not store the energy they create. There is no current method to achieve useful electrical power on a portable scale by allowing multiple methods of mechanical input energy. That is to say, the only convenient way to produce electrical power from a portable generator is with fuel like gasoline and an internal combustion engine.

This project aims to create a device capable of electrical power generation from mechanical input on a portable scale while allowing the user to provide their own method of mechanical power. The prime purpose of this project is to be used in a demonstration with a newly developed Stirling engine, where the engine's speed depends on the heat source and is therefore not constant. This purpose creates a need for an electrical power generation system capable of accepting multiple mechanical input speeds, as the electrical output of current generators is heavily dependent on how fast the generator turns. The goal is to get the device to create a steady output given variable input. In addition, this device should also demonstrate the ability to work with everyday items that people may already have in their homes, specifically electrical power storage, like a rechargeable battery.

As defined by the customer, the list of requirements is as follows:

- The device must be capable of converting mechanical to electrical energy.
- It must be able to accept multiple rotational speeds on the mechanical side.
- It must be able to store the electrical energy converted.
- It must be able to provide useful electricity from the power storage.

Finally, the device needs to communicate to the user the current charge level of the battery.

Specific problems will need to be addressed for this project. For example, the easiest way to convert mechanical to electrical energy is with an induction machine, but multiple kinds of induction generators could be considered, especially when designing for multiple rotational speeds. Multiple rotational speeds are one of the primary problems that will need to be solved, as an induction generator's output depends on the rotational speed.

In terms of power storage, most electrical power storage methods are batteries. Batteries use DC power, whereas a generator outputs AC power. Therefore, there will need to be an interface to convert the AC generator output to DC to be safely stored. There will also need to be a way to "cap" the power going to the battery so as not to overcharge it. Overcharging a battery can be dangerous, especially for batteries like lithium-ion cells, which are very energy-dense. Finally, there may need to be a cooling method within the device to prevent overheating the battery, generator, and other electronics.

Another of the more significant problems that will need attention is the format of useful electricity on the device's output side. What constitutes "useful electricity" as defined by the customer is similar to what one would find in their home. Since appliances can run on different power needs, there will likely have to be some form of conversion from the battery power to the output. For example, if the battery was 24V, a phone only needs 5V, but a blender might need 120V.

Another area where problems may come up is the heating of the electronics. Without a proper cooling system, the unit may get very hot internally. If the power electronics heat up too much, it could cause issues with the battery, as batteries do not react well to extreme temperatures.

Noise could also be an issue. Some induction machines can be very loud depending on how they are built and mounted to an assembly. So making sure the unit is not too loud will need to be a consideration when designing the unit.

The customer has outlined the importance of displaying the battery's charge to the user. This goal will require a good amount of thought into a sensor to keep track of the charge and what kind of display should be used. Simple LEDs might do the trick, but an LCD would be more user-friendly.

Literature Survey

This project utilizes a lot of technology that uses the concepts of electromagnetism. This includes induction machines and induction generators. Another important concept is power inversion, converting DC electrical power into AC. This section will give a brief overview of these technologies, as well as the existing technologies that utilize these concepts.

Induction Machines

An induction machine consists of two parts: a rotor, and a stator. Each part consists of a magnetic material, and a coil of wire with an integer value, n, of windings. When the stator windings are supplied with an AC source, typically 3-phase, it produces a rotating magnetic field in the stator. The speed at which the magnetic field rotates is called the synchronous speed. If the rotor is a permanent magnet, it will want to align with this magnetic field, and will rotate within the stator attempting to resist changes in the magnetic field. This is how an induction machine operates as a motor. The Rotor will not quite be able to achieve the synchronous speed, and will lag behind slightly. The percent difference between the rotor and synchronous speed is called slip, and is given by the equation below.

$$s = (N_s - N)/N_s$$

Where s is the slip, N_s is the synchronous speed, and N is the rotor speed. The synchronous speed of the machine is a factor of the number of poles in the machine, and the frequency. As the rotor speed increases, we can observe how the torque responds according to the following graph

In order to produce the maximum torque from a motor, the rotor spins close to the synchronous speed, normally within about 5% of the synchronous speed. As the rotor speed increases past the synchronous speed, and the slip becomes negative, the torque starts to move into the region on the right side of the graph. Here, the induction machine acts as a generator, as the rotor speed acts as a magnetic force driving the electric circuit.

Induction Generators

An induction generator functions in the opposite (though similar) way to an induction motor. If one can turn the rotor above the synchronous speed (produce a negative slip), one can induce a voltage into the stator windings and send an output out of the stator to whatever power grid is connected; this is because an induction system is inherently bi-directional. Inducing a force (be it electrical or mechanical) will produce an equal force in the other direction, with some loss due to friction/heat dissipation. The rotor will not naturally turn itself above the synchronous speed in a generator. One needs to attach the rotor to a mechanical device to spin it fast enough to induce a voltage in the stator. Spinning the rotor inside the stator, however, is not enough. It is necessary to supply the rotor windings with current, called excitation current or excitation power. With this supply current going through the rotor, the rotor will create a magnetic field as it spins. This magnetic field will push against the stator windings and induce a voltage in the stator, reversing the system.

Excitation Power

There are a couple of ways to supply the excitation power to the induction machine. The first is by using a capacitor. Capacitors use stored energy to provide the excitation current in the rotor and help stabilize the voltage in the output. Capacitors are typically seen on brushless induction machines. The other way to provide excitation current is by supplying the rotor directly with a DC source; this method requires a brushed induction machine, where the excitation current is provided to the rotor by brushes that connect to slip rings on the rotor in order to maintain the contact with the rotor and the source as the rotor spins. The amount of current supplied to the rotor will also play a role in the induced voltage output from the generator.

Regulators

A prevalent way that generators operate is by using combustion engines. As mentioned before, the rotor needs to be turned mechanically to get the right speed, and they are a reliable way to get the rotor to turn at a speed that will replicate the power of a wall outlet at the cost of being very loud and requiring gas power. In theory, one can connect the rotor to any mechanical device to produce power, like a windmill, a watermill, a stationary bike, or even another motor, which are less common because the induced voltage will be affected by the rotor speed. The faster the rotation, the greater the induced voltage. Without regulating the output, to replicate the AC signal from a wall outlet, one would need to turn the rotor just above 3600 rpm for a two-pole generator. Is it possible to use gears and pulleys to speed up what is required? Yes, but then one will run into the issue that without regulating the output, the speed needs to be kept consistent with keeping the voltage consistent, and the nature of these sources is unpredictable and continuous. In order to make sure one has a consistent voltage on the output, one can use a regulator. A regulator will monitor the generator's output and adjust the supply current to the rotor based on a specified, desired voltage. As mentioned before, the induced voltage will be a product of the rotor speed and the excitation current. If the speed is too low and is not producing the desired output anymore, the regulator will increase the current being fed to the rotor, increasing the strength of the magnetic field that the rotor creates and increasing the induced voltage maintaining the desired output. This method works if the speed is too high; lowering the current will bring the output back into the desired range. It becomes much more difficult to regulate a brushless generator.

Output

The output of an induction generator is in AC, and depending on the stator wiring, is usually 3-phase or single phase. If a DC source is required for an application, diodes can be used to create a rectifier that will convert the AC signal to DC. There are some instances where one may want to keep the AC source. Some generators are capable of producing the same AC signal that comes out of a wall outlet, and would not need to be modified. The output of the generator will depend on the application for using them, and the appliances that need to be powered. To charge a battery, like the one in a cell phone, a DC source is needed. However, to power something like a kitchen appliance that plugs into a wall, an AC signal is necessary.

Power Inversion

Most inverters utilize a circuit called an H-Bridge. An H-bridge is a configuration of transistor switches and diodes to push a source voltage across a load in a certain direction. The direction that the voltage goes across the load is dependent on which transistors are active. Using just an H-bridge, it's very easy to produce a simple square wave from a DC source. Find the desired frequency, then simply flip the direction at that interval; the DC voltage will flip from positive to negative across the load.

Transistor switches are also used in another important part of inverting signals: Pulse Width Modulation (PWM). PWM is a way of controlling, or limiting an output voltage according to the input signal. This is very commonly used in DC/DC step down conversions. The way this works is by flipping the voltage source on and off very fast, to limit the time that the voltage is connected to the load. The percent time that the switch is turned on is called the duty cycle. For example, if there were a 10V DC source, and a switch was used at a 50% duty cycle, that means that the switch is only turned on for 50% of the time. Therefore, the source is only connected to the load for 50% of the time that it is being operated. This means the load will only experience 50% of the source voltage, so, this example would output 5V DC. This is a particularly useful subject in the digital electronics world, as nearly all modern computers operate exclusively in a DC, digital environment.

PWMs can also be used by modulating two separate AC signals. For example, a sine wave and a triangle wave can be compared to each other, and a controller would then look for when the triangle wave is greater than the sine wave. It uses that to form the PWM that will be sent to the transistor switches to modulate the output voltage. When the sine wave is in its negative half cycle, the comparison functions the same, it's just now sending the PWM to the other two transistors. In this case, the carrier signal is the triangle wave, and the modulating signal is the sine wave.

Current Technology

The most similar technologies this project is looking to produce are portable power stations. These power stations vary in size and storage capacity and usually offer a variety of appliances that they can charge and multiple methods of charging, often with solar power.

These power stations take in power from a source and use multiple lithium-ion cells to store power. Some models may have lead-acid batteries instead, but most newer models use more energy-dense lithium-ion cells. On the lower end of the market, power stations batteries are around 200W but can go up to around 2000W. The battery's power storage limit contributes to cost, as it allows for more appliances to be plugged into the device at once.

Power stations include some form of power inversion circuit to offer an outlet that replicates a standard wall outlet and has a few direct DC/USB outputs for charging things like cell phones. However, it is also possible to find power inverters made separate from power stations. These power stations are usually made to interface with a vehicle's lead-acid battery to allow people to power one or two appliances from their vehicle. The cost of this kind of power inverter depends on how clean the output is; the closer it gets to a pure sine wave, the more expensive it becomes.

Current power stations use external methods of charging the battery. Often, the power stations offer multiple charging methods, most commonly being able to plug into a wall outlet or the 12V port on a car. Like the GoalZero Yeti models or Jackery models, some power stations allow interfacing with solar panels as an alternative method to charge the power station. Some of the Yeti power stations also offer a way to wire the power station directly to the alternator of a vehicle, mainly targeting people who use these in vans, RVs, and trailers.

Most generators operating in the desired power range for this project are either found in vehicles or gas generators. In vehicles, the alternator acts as a generator to charge the battery and power the electronics in the vehicle. Alternators produce AC power but are rectified and regulated to DC to suitably power the vehicle's battery and electronics.

Gas generators are usually made to replicate the power found in a residential wall outlet. Some may offer some DC output ports, but they are generally aimed at people for camping or construction sites, where one might need to power appliances or equipment in a remote location. These generators usually operate by using a single cylinder gas-powered engine that rotates the generator's rotor to induce power to the output. These engines are made to rotate the generator at the specific speed needed to produce 120V AC. Alternators also require an excitation power to the rotor to produce power. When a car battery is drained completely, the car no longer starts. Instead, the car battery provides the excitation power required to start the engine cycle.

The generator is wired directly to the output on simpler models like some Champion generators, with only a circuit breaker. This connection means that the engine needs to spin at a constant speed to produce the desired output. These generators are built without the requirement of an excitation system. Some more expensive gas-powered generators, like ones made by Yardworks, offer more options for output. One example is a DC output for small devices like phones. These require more internal components and have much more complicated wiring diagrams. Yardworks also offers a remote start feature and uses a wireless receiver and motors powered by a reserve battery to trigger the engine's starter. Honda creates slightly more complicated gas generators that use a 3-phase winding, separating the output of the windings to differentiate the AC and DC output.

There are multiple other common brands of gas-powered generators, but they all operate on the same principle, using a small, ordinarily single-cylinder engine to drive the rotor of an induction machine to provide power to output. The variation between the brands exists in the intermediate steps that they put into the system, providing different features depending on the brand purchased.

Problem Definition Statement

The goal of this project is to create a demo model power generation/conversion device compatible with a new stirling engine design, by taking its rotational mechanical energy and converting it into useable electrical energy.The design of this device is not limited to the customer requirements listed earlier, and will have additional factors that need to be addressed when creating design concepts. These are as follows:

- The design should be visually appealing;
- The design should be presentable;
- The design should be highly efficient;
- The design should limit noise disturbance;
- The design should limit the need for human interaction;

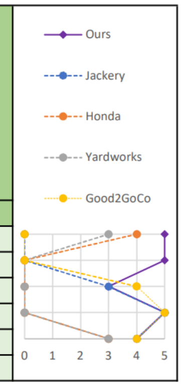
- The design should be as safe as possible;
- The design should be cost effective.

Criteria For Success

Table 1: House of Quality

Legend	
Strong Relationship	●
Medium Relationship	△
Weak Relationship	□
Strong Positive Correlation	++
Positive Correlation	+
Negative Correlation	-
Strong Negative Correlation	--

Maximize or Minimize		↑	X	↑	↓	X					
House of Quality Power Conversion and Storage Unit	**Engineering Specifications**	Generator Efficiency	Target Speed	Power Storage	Indicated Power Level Error	Electricity Output	**Comparative Assessment**				
Customer Specifications/Importance		**1**	**2**	**3**	**4**	**5**	**Jackery**	**Honda**	**Yardworks**	**Good2GoCo**	**Ours**
Convert Mechanical to Electrical Energy	4	●	△			●	0	4	3	0	5
Accept Variable Input Speed	5	□	●			△	0	0	0	0	5
Store Energy	3	□		●	□	●	3	0	0	4	3
Display Power Level	2			△	●		5	0	0	5	5
Output Useful Electricity	5					●	4	3	3	4	4
							12	**7**	**6**	**13**	**22**
		90%	3600rpm	200 W	<5%	120 V AC					
Difficulty		1	4	2	1	3	11				
Weight		9%	36%	18%	9%	27%	100%				



Compared to competitors, the proposed design is the only one capable of meeting all of the requirements set out by the customer. While some of the other generators are capable of generating power, they can't store it. The power stations capable of storing power are incapable of producing it. Finally, none of the competitors offer a variable speed input, as this would result in a different voltage. In the case of this design, 120V AC is necessary, meaning that none of the generator options can meet this requirement reliably.

Project Objectives

The objective of this project is to create a power unit that is capable of accepting a variable speed input, producing electricity, and storing it. The unit should also be able to output useful electricity to power devices, and store the current battery storage level. The specific requirements set by the engineering specifications are as follows: >90% generator efficiency, target generator rotor speed of 3600 rpm, power storage capacity of at least 200 W, indicated power level error of less than 5%, and electricity output near 120 V AC.

Section 2: Design Process

Concept Generation

The variation in concepts for this project can be broken into a few categories. First is the method of converting mechanical power to electrical power. The easiest way to do this is with an induction machine, but there are a couple common models that can be considered. Larger induction machines seen on gas generators would be built robust to survive in outdoor conditions and should provide suitable power. The alternative would be something smaller, like the alternator on a car. These alternators are usually internally regulated, which means that we would not need to build a rectifier for the battery, but we would be limited to whatever the regulator is outputting. Alternators normally run at a lower voltage, and are therefore less efficient for a number of reasons. The base design will look very similar through each concept, and their rough layout can be seen in figure 1. It consists of a case that contains the generator and the battery. A pulley attachment to interface with the prime mover is extruded from the outside of the wall adjacent to the generator. The front wall of the case contains the electricity ports and the battery display. The variation in design will focus on the generator and the battery.

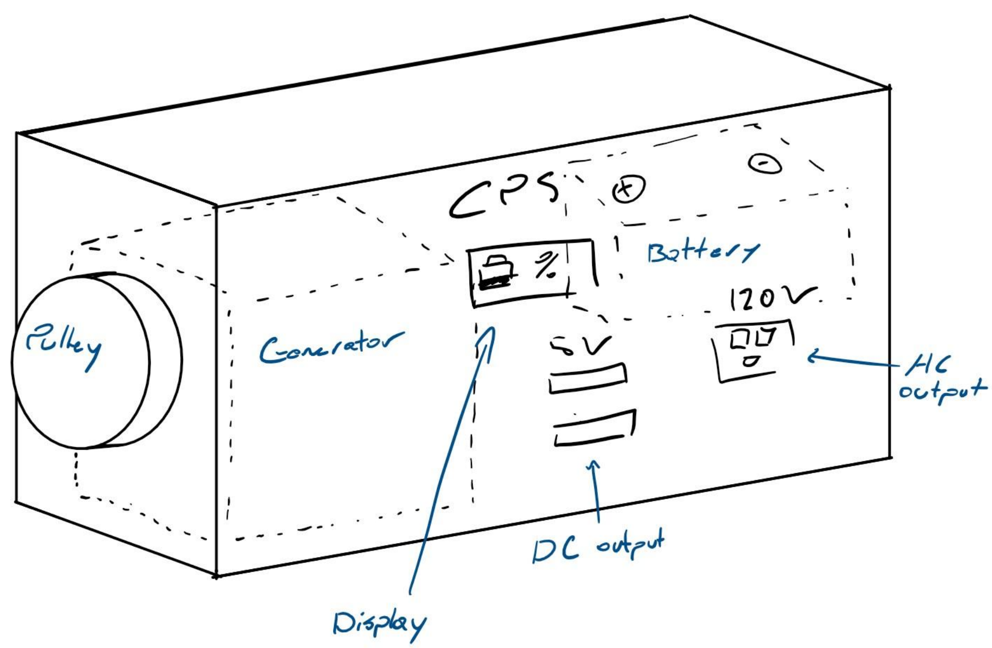


Figure 1

There are multiple ways that the machine can be built to account for different rotational speeds. These can be on either the mechanical, or the electrical side. The mechanical side would be in the form of some kind of transmission. A manual transmission would be able to allow for a change in gear ratio between the prime mover and the rotor of the induction machine. Something like a bicycle gear system seen in figure 2 would be on the scale we are looking for. This would consist of multiple sizes of gears connected to a chain. By the use of a tensioner, the chain can be moved between gear sizes. One set of gears would attach to the rotor shaft of the generator, and the other would attach to the prime mover.

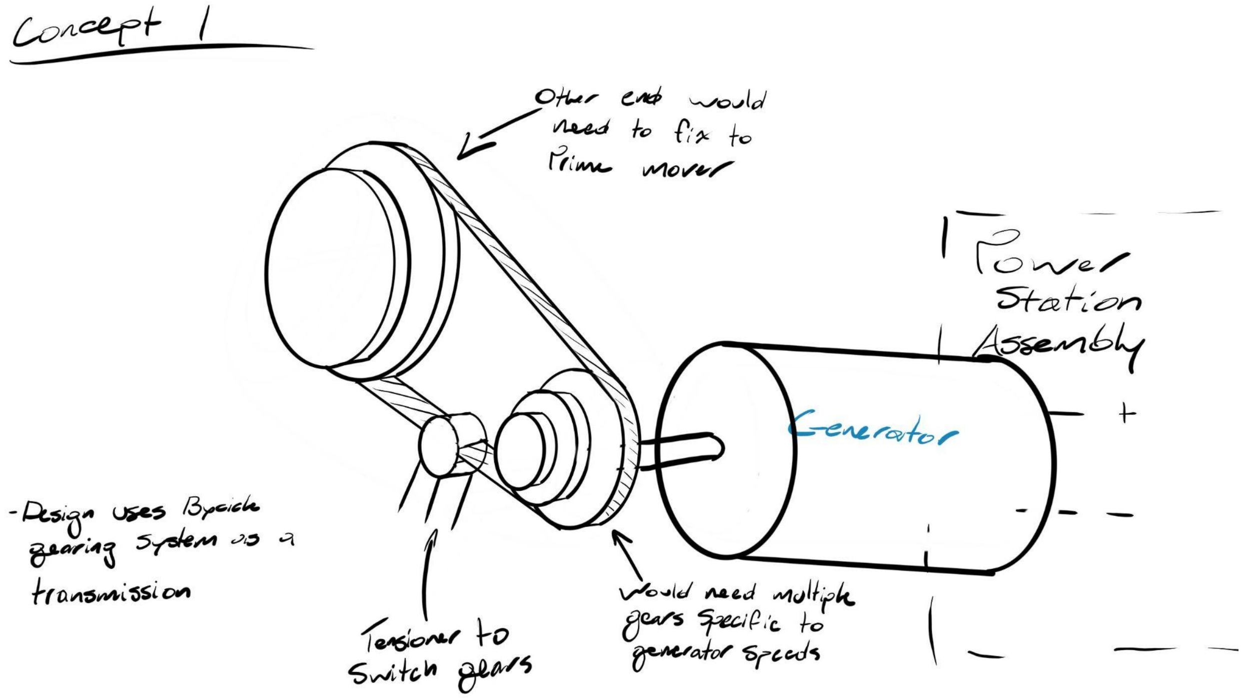


Figure 2 - Proposed concept for transmission system.

This could possibly be converted to an automatic transmission as well using a similar system with some extra steps. If we wanted to go a slightly more complicated route, a continuously variable transmission (CVT) as seen in figure 3 could be used to ensure a smooth gear ratio conversion between the prime mover and the rotor. The CVT would adjust the gear ratio based on the rotational speed of the rotor by moving the sheaves of a pulley closer together or further apart, and could be tuned to the specific speeds of the generator by modifying the spring that causes the pulleys to move back and forth.

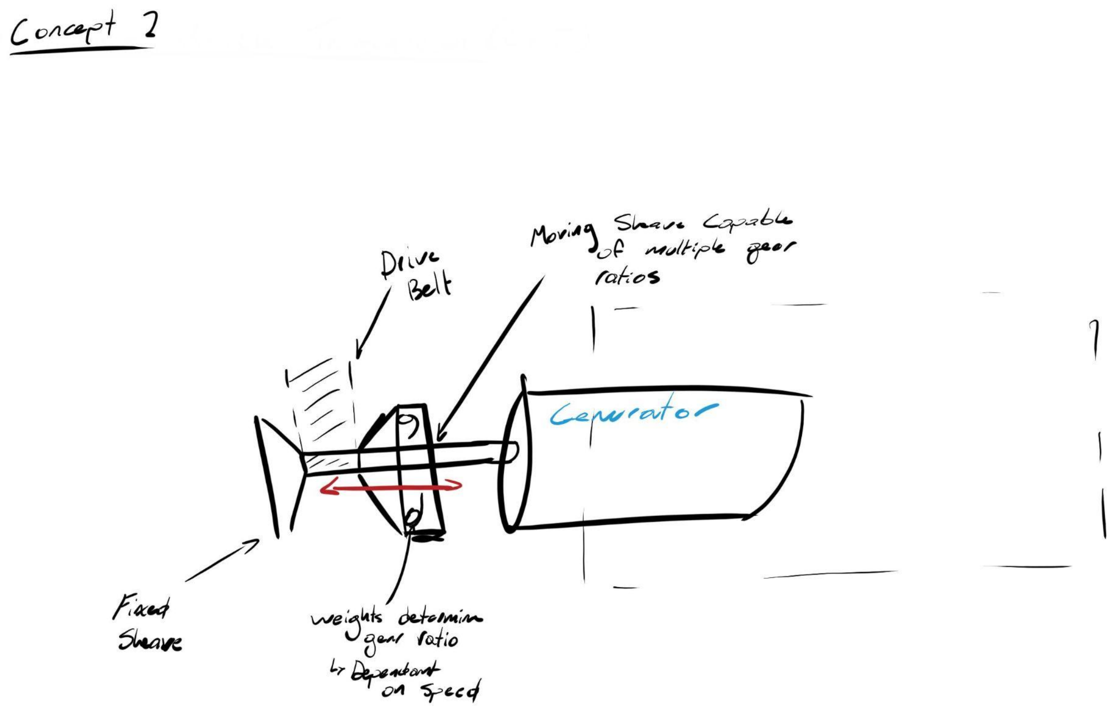


Figure 3 - Proposed concept for Continuously Variable Transmission.

Using elements from both the design of modern bicycle chains combined with a stick shift of a vehicle's manual transmission, a new design was theorized that could regulate the mechanical input. By using pulleys of varying sizes that are fixed together as seen in figure 4, we can create the gear system we need for regulating the generator speed. A stick shift can be used to push the belt from one pulley to another. Similar to the bike chain, the stick shift would likely need an idler on it to help force the belt into place.

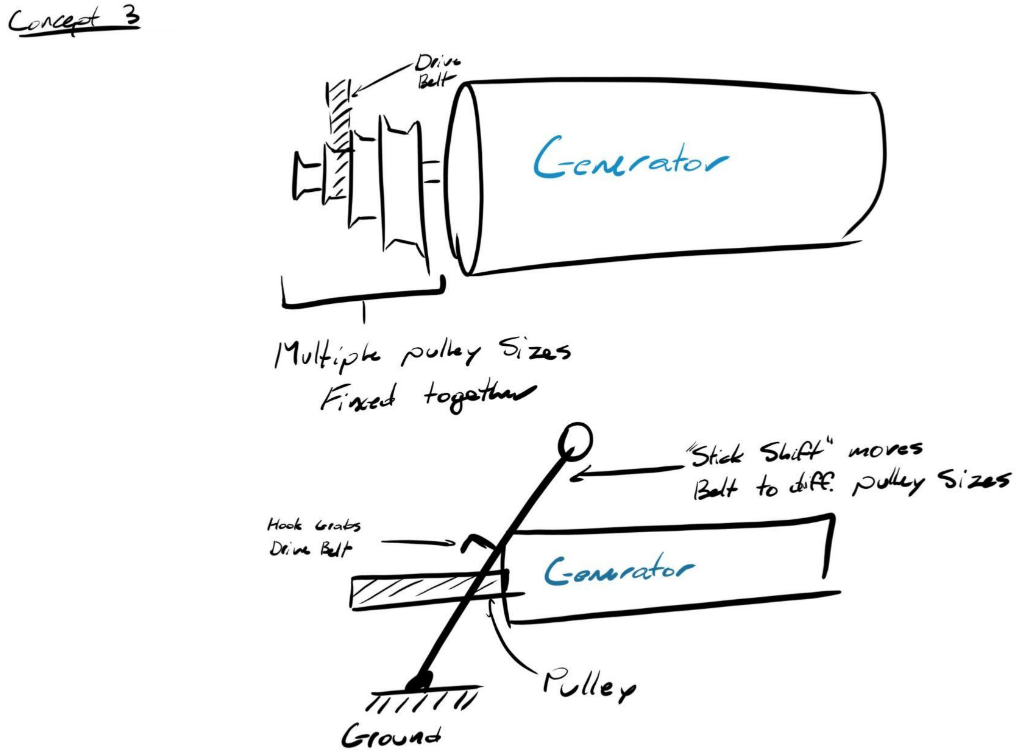


Figure 4 - Proposed concept for manual transmission.

Regulating the electrical side of the energy conversion would include a voltage regulator like the sketch in figure 5, and likely some kind of controller to monitor the output of the generator. The output signal is rectified to DC for the battery. It would be possible to monitor this voltage, and if it gets above what the battery can safely handle, step the voltage down. It is worth noting that the rectifier will be needed regardless of whether or not this method is used, as the battery will require a DC voltage to charge safely and properly.

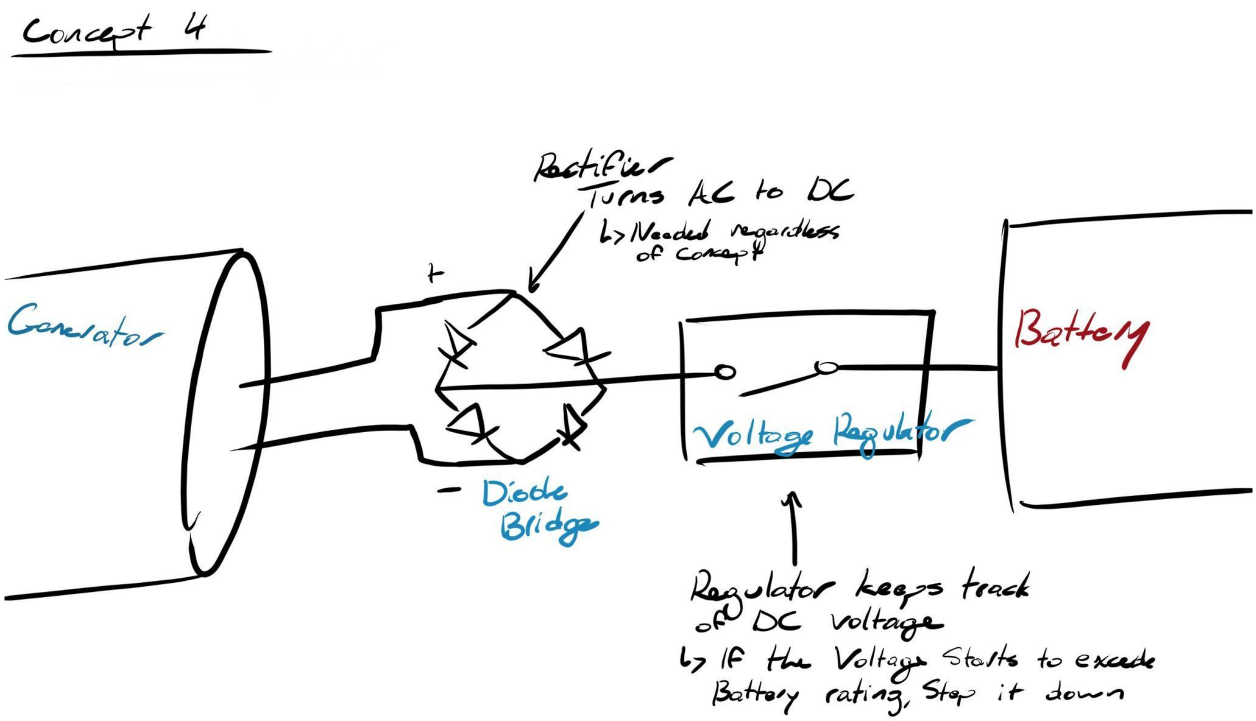


Figure 5 - Proposed concept for electrical power regulation.

The battery can have a few variations mostly differing in what type of cells are used. The two most common types would be lithium ion and lead acid. Lithium ions would be more energy dense, but lead acid would be safer in more extreme conditions. It's worth noting that changes in the battery itself does not warrant changes in the connections between components. Each version of a battery will still require a battery management system, and will still need to take in a DC voltage from the generator's output.

Concept Selection

Concepts for the generator all serve the same purpose, making sure the speed of the rotor falls into the same speed range. Concepts 1 and 3 however require the operator to constantly monitor the device to see when the speed needs to be changed. This would also require the device to have a method of monitoring the speed and conveying that speed to the user, adding additional components that are unnecessary in an automatic transmission system. To this end, the CVT in concept 2 is capable of regulating itself based on the speed of the rotor and/or the prime mover, and is therefore a more desirable design than the other methods of mechanical regulation. When considering concept 4, the method of electrical regulation, this would still require sensors capable of monitoring the output, whereas concept 2 monitors itself. Therefore concept 2 is still the more desirable design concept when it comes to regulating the generator. The CVT would also produce considerably less noise without the belt/chain sliding between gears.

When choosing the best battery system, there are some factors to consider. Our battery needs to have a relatively long capacity to hold a charge for a long time. Regardless of the type of battery, the higher the ampere hour, the better. Out of the many types of batteries available on the market, there are two types that stand out more than the others: lithium ion and lead-acid. Obviously there are other types of batteries out there with technologies like nickel–cadmium, or nickel-metal hydride. However, Li-ion and lead-acid are chosen because of their availability, popularity, low(er) cost, and ease of integration. Ultimately, the perks of having a lithium battery over a lead-acid, is the high specific energy, which means they can produce more energy at a lower mass. A system with Li-ion batteries will be much lighter and smaller than a system with lead-acid batteries, which for application is important since portability is a factor. The drawback is the price - lithium batteries are significantly more expensive than lead-acid batteries. Regardless of the type of battery, a battery management system must be integrated to ensure the batteries are not over-charged; this can lead to damaging the battery and more importantly safety risks.

As discussed previously, Concepts 2 and 4 require no human interaction to run the device. Concepts 1 and 2 would require the user to operate the gear shift, meaning that the efficiency of the device can only be as good as the user. If the user isn't closely monitoring the device speed, and is letting the generator run above or below the recommended speed range, then the user will not be getting the full power out of the device that they could be.

The difference between using an alternator vs a larger induction machine has to do with efficiency. Alternators would be easy to implement for this design as a purchased part, however they are not made to be efficient. In short, alternators are not efficient because they don't need to be. Losses in the alternator are dwarfed by the total power that the engine uses, therefore these losses are seen as acceptable for an automobile system. Because this project prioritizes efficiency, these losses are a much bigger deal. The components that contribute to these losses are the internal electronics to regulate and rectify the signal from the machine. By using a larger induction machine that does not include other internal electronics, the efficiency can be greatly increased, therefore a larger induction generator is more favourable for the design. Lithium Ion Batteries are chosen over lead acid for similar reasons surrounding efficiency.

Concepts 1 and 2 involve taking pre-existing parts and integrating them together. Concepts 3 and 4 however would need to be designed and manufactured. Given the limited budget and time constraints of the project, it is more desirable to use the pre existing parts rather than ones we would need to design and manufacture.

The device is to be made with all surfaces closed off, as seen in figure 1. The customer would like to have some of the mechanical parts visible, therefore a transparent material can be used for that side of the device to protect the user from getting their hands caught in anything. Unfortunately it is impossible to enclose all of the mechanical parts of the designs, given the customer requirement that the device be able to change out the prime mover. At least one drive belt will be exposed in all concepts.

Design Process

When evaluating the different designs, it was determined that design concept 2 was going to be the successor to the evaluation process. However, there was much consideration in all of the design concepts. An in-depth decision matrix can be seen below.

Table 2: Decision Matrix

Decision Matrix	Technical Requirements			
Designs	**Doesn't Need Human**	**Easy to Implement**	**Doesn't Need Extra Power**	**Continuous Constant Vout**
Concept 1	✘	✘	✔	✘
Concept 2	✔	✔	✔	✔
Concept 3	✘	✔	✔	✘
Concept 4	✔	✘	✘	✔

From the above matrix, only concept 2 meets all of the most important technical requirements. It is relatively easy to implement, it doesn't require a human to operate, and it does not require extra power (electricity) to operate. Concepts 1 and 3 were discarded because they aren't capable of reliably maintaining a voltage for output from the generator. Concept 4 was also considered as an alternative to concept 2, but it was disregarded mainly because of the difficulty of implementing an entirely electrical system that maintains a high efficiency, without access to a high quality electronics design lab. In the end, concept 2 was decided to be the most beneficial for the needs of this design.

Section 3: Detailed Design Documentation

Assumptions Made

An assumption made about this system is that it is to be used mainly in conjunction with a stirling engine. Although it can be used with various other rotational inputs, the main purpose of this system and why it was introduced is to be the device that converts the efficient energy generated from a stirling engine into useful electricity.

System Function

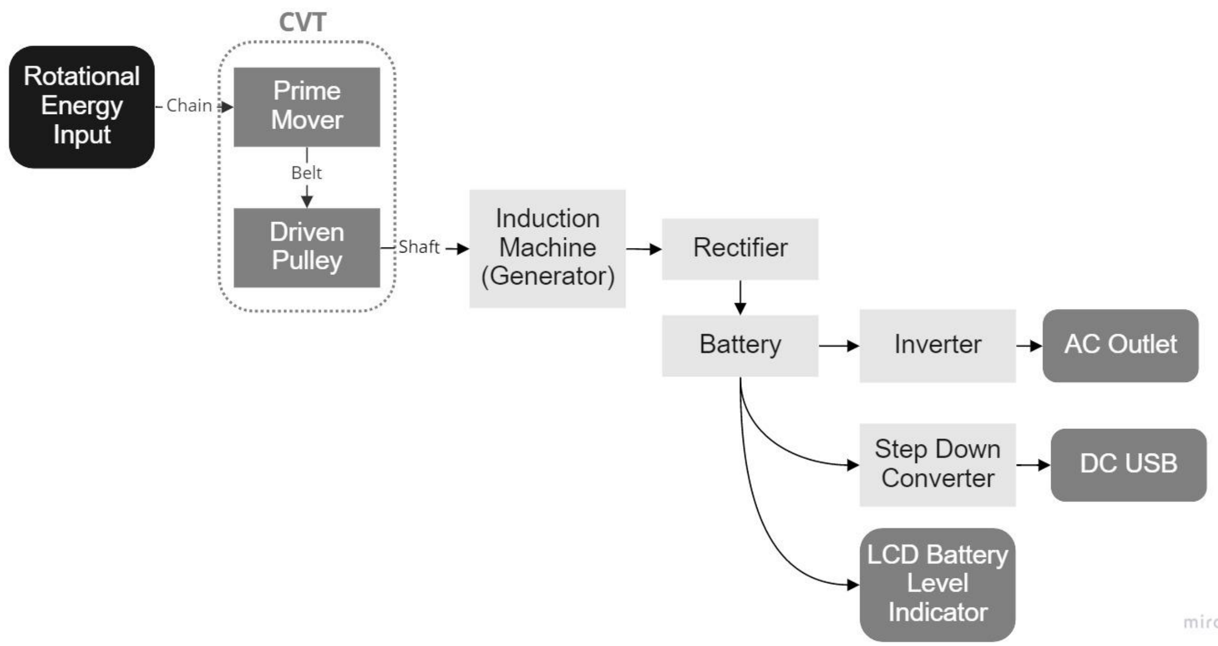


Figure 6 - System Functionality Flow Chart

The functionality of the system is best described through a process flow from input to output as seen in the flowchart figure above. The direction of the energy also follows this flow. The system starts with a rotational input energy which would rotate at a certain revolution per minute (rpm) rate ranging from 500 to 3600. This rotational input is connected to the prime mover pulley of the continuous variable transmission (CVT) via chain and sprocket. The prime mover then rotates the driven pulley via belt. The CVT functionality is described below. The drive pulley is connected to the induction machine (generator) with a shaft. The rotational energy is then transferred to the rotor of the generator. The rotational kinetic energy then gets converted to electrical energy as there is an induced current generated in the stator. The electricity generated by the induction machine then flows through a rectifier which converts the current to DC. This DC current is then stored in the batteries. The second half of the process handles the conversion of the stored energy into useful electricity. For 120 V AC power, the electricity from the batteries is converted to AC by the use of an inverter. For 5 V DC power, the battery voltage gets stepped down to 5V to have the ability to supply power to USB devices. The total battery level is indicated to the user with an LCD screen.

The CVT is used to keep the rotational input speed at a constant 3600 rpm. This is done by continuously varying the gear ratio by adjusting the two pulley's diameters. In order to make sure that the pulleys will actuate at the desired rpm range, the springs inside the off the shelf part will need to be replaced. Calculations done on the desired speed of the prime mover to find the force that acts on the weights within the pulley. This force was then used to find the approximate spring constant value the replacement springs would need to have. The rotational speed used is around 500 rpm, which is the lowest speed desired for before the system starts to move.

Pulley force sample calculations:

$$F = m\omega^2 \cdot r = 0.5kg \cdot (52\, rad/s)^2 \cdot (0.06m) = 81N$$

Spring constant sample calculations:

$$k = F/x = \frac{81N}{0.16m} = 507\ N/m$$

These values shown above are of course approximate values used to get a starting point to search for new springs for the system, however during the testing, tuning of the springs may be needed. Further tuning may also be needed once the intended prime mover of the system, the stirling engine, is able to be connected to the assembly.

Meeting Engineering Specifications

The engineering specifications for this system were met by implementing and interfacing specific components, calculating and analyzing certain methods of approach, and determining the best elements for our application. To accept various rotational input devices ranging from 500-3600rpm, a CVT with a sprocket attached to the prime mover was outfitted to the side of the system. This CVT is also responsible for regulating the input speed to be a constant 3600 rpm rotation, which was another specification. The requirement to convert mechanical to electrical energy was met by outfitting the system with an induction machine that generates a single phase AC power source. Another engineering specification was to store this power with a capacity of 240 Wh and this was done by the use of a rectifier and then the energy is stored in a Li-ion battery pack. To ensure the user can identify the battery level, a LCD screen is fixed to the side of the system displaying the battery life. To utilize this stored energy, a 5V DC and 120 V AC source are pulled from the battery with the use of a DC to DC step down converter and an AC inverter respectively. This system is also compact to be portable as specified by the engineering requirements.

Virtual Prototype

The CAD model is designed to be modular and to integrate all the relative components addressed in the customer and engineering specifications. The prototype render can be seen in the appendix labeled figure N. It is a wooden enclosure reinforced with an aluminum frame. It has a CVT protruding from the side which is enclosed with acyclic sheets. The wooden panels have cutouts for various items such as the shaft on the right side, and the user interface (LCD screen and power connections) on the front side. The prototype has a total dimension of 520 x 445 x 324 mm. The enclosure has rubber feet at the bottom which dampen the system when it is in use which in turn will reduce the noise and vibrations. An exploded view of the assembly can be seen in the figure below.

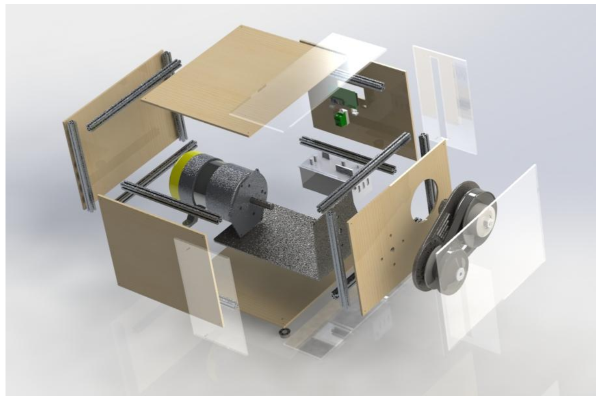


Figure 9 - System Prototype Exploded View

Cost Analysis

Table 3: Cost Analysis

Item	Cost per item (CAD)	Quantity	Total Cost (CAD)
CVT	$130.00	1	$130.00
Generator	$480.00	1	$480.00
Shaft	$40.00	1	$40.00
Bearing	$13.00	2	$26.00
Generator mount	$40.00	1	$40.00
20mm Aluminum T-Slot 30cm	$2.36	4	$9.44
20mm Aluminum T-Slot 34cm	$2.68	4	$10.72
20mm Aluminum T-Slot 38cm	$3.00	4	$12.00
4'x8'x1/4" inch plywood	$44.75	1	$44.75
Acrylic sheet	$26.23	2	$52.46
Jackery Power Station	$250.00	1	$250.00
Hardware	$60.00	1	$60.00
Acrylic bonding agent	$40.00		$0.00
		Total	**$1,155.37**

The cost analysis table shown above depicts the cost and quantity of each item that is to be purchased for our system. All of the electrical components are from the jackey power station. These items include the battery, inverter, rectifier, USB interfaces, AC outlet, and LCD display along with all the wiring required.

There are a few components that had specific calculations performed and cut plans designed to guarantee accurate costs. These components are the Aluminum T-slot bars used to build the frame, the ¼” plywood which encloses the inside of the system, and the acrylic sheets that enclose the CVT. The aluminum slots are 20mm by 20mm in width and height. There are three different lengths, 300mm, 340mm, and 380mm. Priced from an online distributor, the cost for aluminum extrusions is $0.20 per inch. As for the acrylic and wood, the price for those are determined by the amount of sheets needed. The cutting plans for those materials are found in the *Manufacturing Process* subsection below.

Manufacturing Process

The manufacturing process is broken down to the specific materials and components used to construct the system. The frame is made from Aluminum extrusion T-slot rails. The rails have 1x1 inch square cross sections. The rails are cut to size and joined together using 90 degree angle brackets along with mounting fasteners meant for the aluminum rails. The walls are plywood panels that are bolted into the T-slot bars. The plywood is ¼” thick and all the panels are cut from a 4’ by 8’ plywood sheet. The cutting plan can be seen below. Also there is a lot of extra wood after all the cuts are made, this plywood at its specific dimensions is the least expensive option when sourced from online distributors. The acrylic, much like the wood, is also sourced from online distributors and will be laser cut to allow the panels to be mounted to the frame. The acrylic is cut out of two 12” by 24” by 1/4” sheets of clear acrylic. The panels are cut to size and using similar fasteners to the angle brackets, mounted to the frame. The acrylic panels are also bonded together with an acrylic bonding agent. The generator mounting plate will be constructed using similar aluminum rails and brackets to allow the tension in the belt to be adjusted. This will be connected to the bottom side of the aluminum frame. The cutting plans account for a 1/8th inch blade thickness for manufacturing. The pulleys used for connecting the transmission to the generator are made as 3D printed parts. These pulleys are designed to fit their respectives shafts, and the nature of their rapid prototyping method of manufacturing allows the pulley ratios to be adjusted as needed during testing. The final assembly of the prototype can be seen in figure.

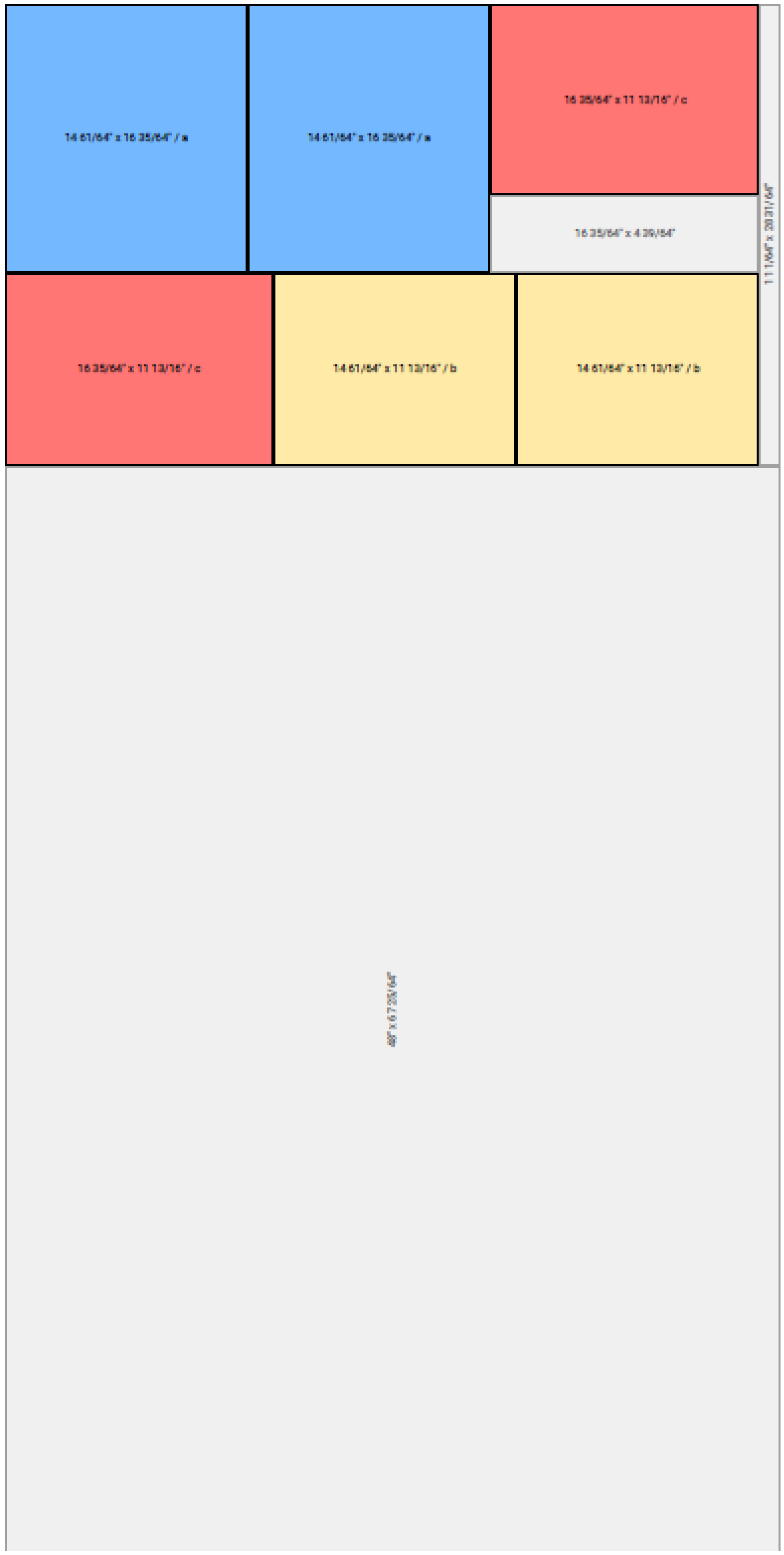
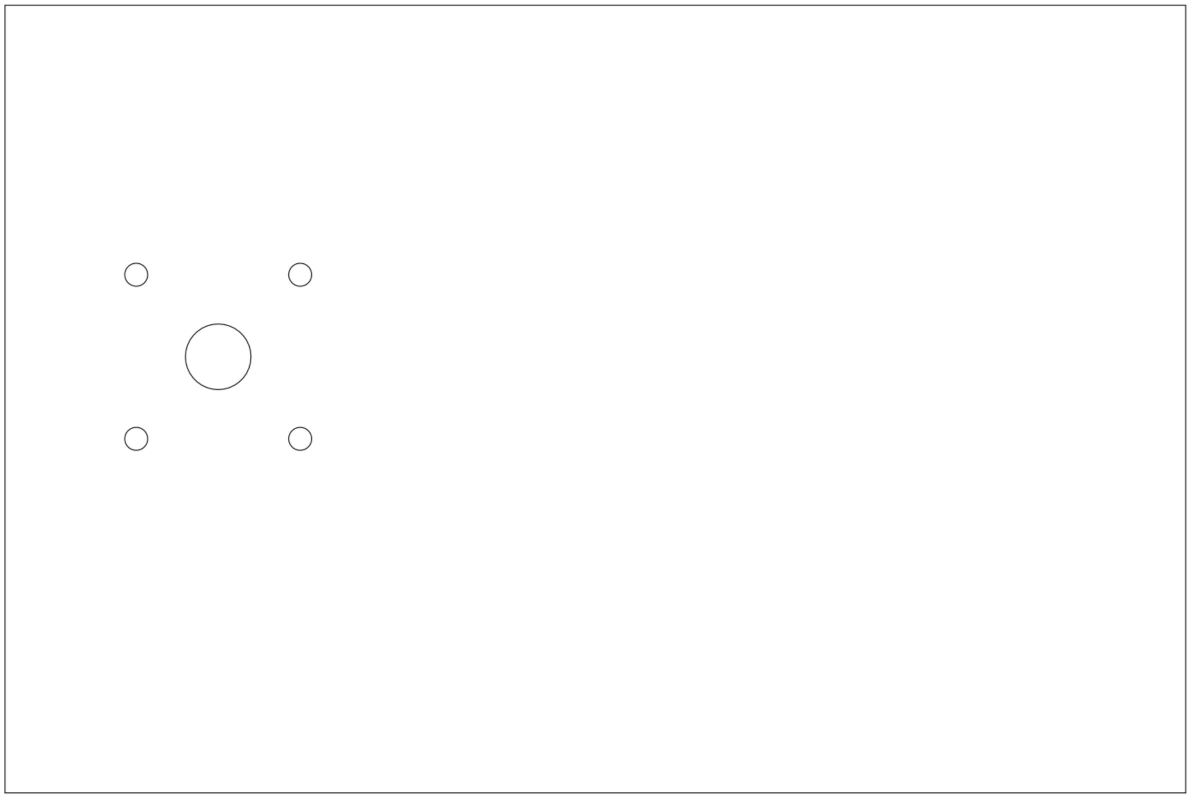
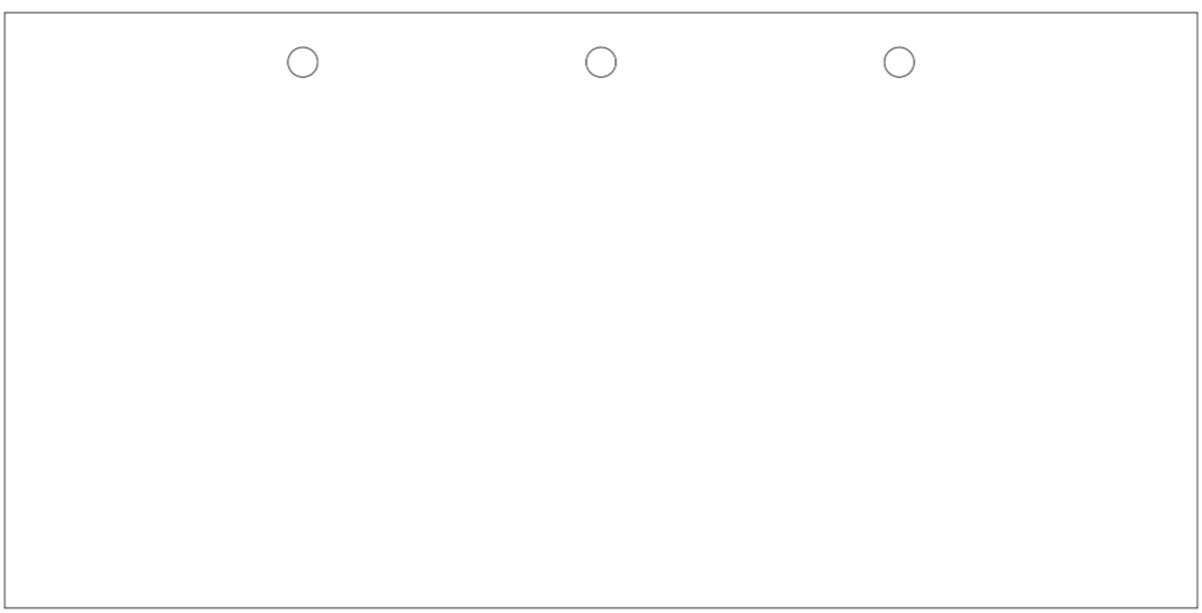


Figure 10 - Plywood Cutting Plan





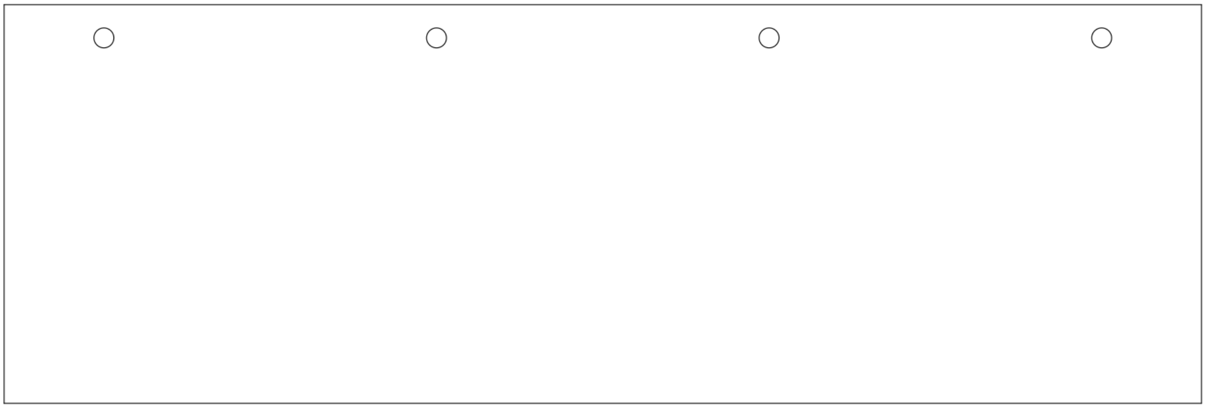
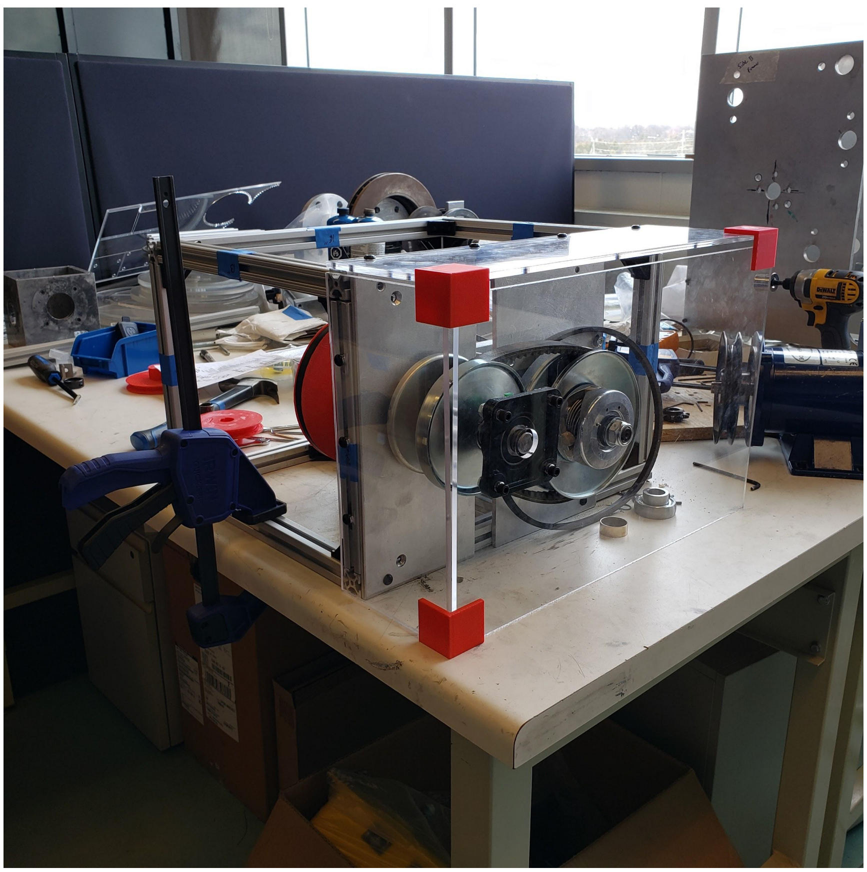


Figure 11 - Acrylic Cutting Patterns



Figure

Section 4: Lab Tests

The conversion for electrical to mechanical energy is done by removing the induction machine from the champion generator. The manufacturers specify that the rotor needs to turn at a speed of 3600 rpm in order to produce the rated 120V AC. Since the power station is meant to be charged with 120V AC from a wall outlet, the generator needs to be held close to this speed in order to charge the battery.

On the low end, the prime mover will produce around 500 rpm as described by the customer. In order to get into the speed range we want, we need about a 1:7 gear ratio to bring the generator speed up to the targeted 3600 rpm. The CVT will likely not achieve this ratio on its own, and a secondary gear ratio will likely be needed as a primary ratio with the CVT used to regulate speeds that would exede what is safe for the battery

A test rig was created to confirm that the generator output was still the same when the engine was removed from the induction machine. A DC motor was used with a drive belt to turn the rotor, and a sensor was used to measure the rotational speed of the rotor in the generator, and a multimeter was used to measure the output voltage. The results can be seen in table 4 below.

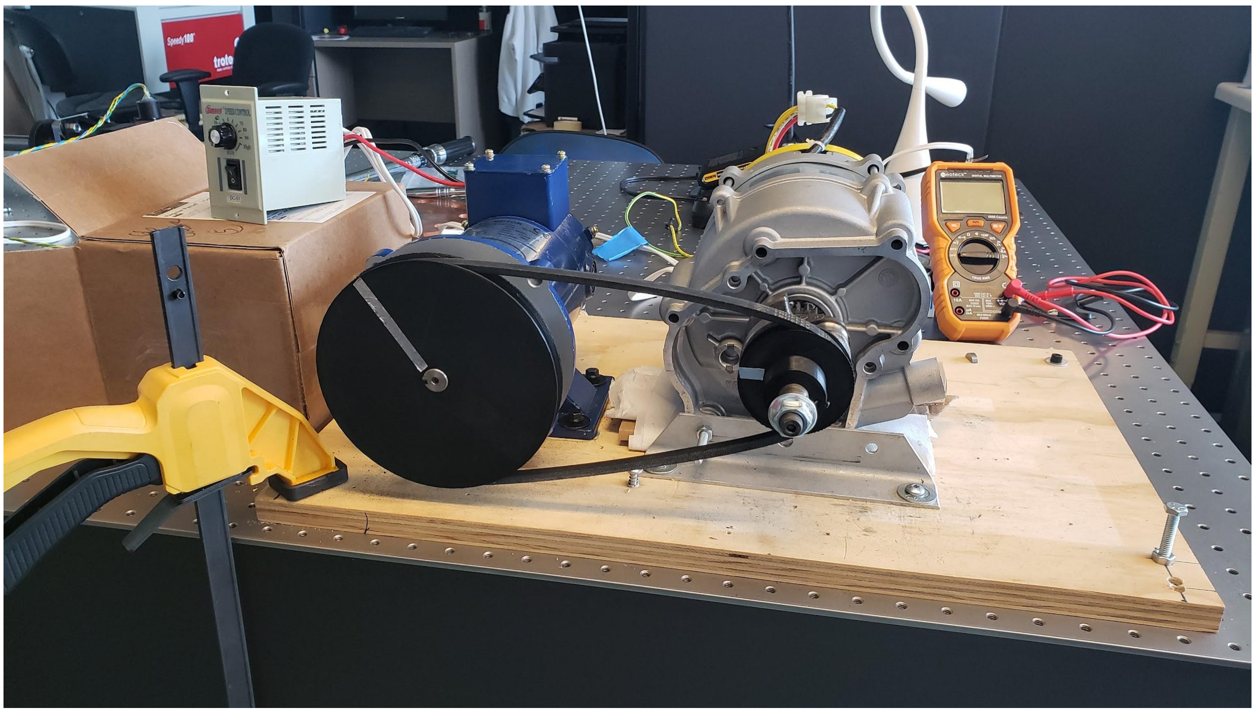


Table 4

Generator Speed (rpm)	Output Voltage (V AC)
1324	2
1625	2.4
1971	3.6
2297	5.3
2592	12
2640	15
2846	30.8
3003	50

3108	67
3238	83

The table was plotted on a graph seen in figure 12.

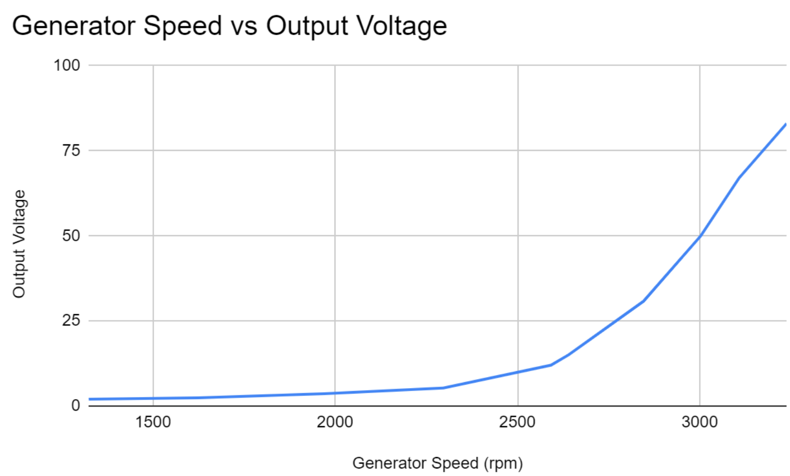


Figure 12 - Output Voltage vs Generator Speed Graph

Figure 12 shows an exponential relationship between the rotor speed and its output voltage. While the experiment didn't get us quite up to 3600rpm, there is enough data to create a general equation for the relationship between the speed and the voltage.

$$y = a(b)^x$$
$$15 = a(b)^{2640}$$
$$a = \frac{15}{b^{2640}}$$

$$83 = a(b)^{3238}$$
$$83 = \frac{15}{b^{2640}}(b)^{3238}$$
$$83 = 15(b)^{598}$$
$$b = 1.00286495$$

$$15 = a(1.00286495)^{2640}$$
$$a = 7.87(10^{-3})$$

$$y = (7.87 \cdot 10^{-3})(1.00286495)^{x}$$

Then using the equation extrapolated from the experiment, it was estimated that the speed required to create 120V AC from the generator was approximately 3367rpm. This is lower than the expected 3600rpm, however it's an approximation. It is safe to say that the induction machine will still need to turn at or close to 3600rpm in order to produce sufficient power to charge the battery. With more accurate methods of obtaining the data, it's likely the approximation would be much closer to the expected value.

While the power inversion portion of the project will be purchased, an analysis was still done on a basic inverter circuit to further understand how it works. Most inverters utilize a circuit called an H-Bridge. An H-bridge is a configuration of transistor switches and diodes to push a source voltage across a load in a certain direction. The direction that the voltage goes across the load is dependent on which transistors are active. Using just an H-bridge, it's very easy to produce a simple square wave from a DC source. Find the frequency you want, then just flip the direction at that interval, and the DC voltage will flip from positive to negative across the load.

Transistor switches are also used in another important part of inverting signals: Pulse Width Modulation. PWM is a way of controlling, or limiting an output voltage according to the input signal. This is very commonly used in DC/DC step down conversions. The way this works is by flipping the switch on and off very fast, to limit the time that the voltage is connected to the load. The percent time that the switch is turned on is called the duty cycle. For example, if you had a 10V DC source, and you used a switch at a 50% duty cycle, that means that the switch is only turned on for 50% of the time, and the source is only connected to the load for 50% of the time as well. This means the load will only experience 50% of the source voltage, so this example would output 5V DC.

The main problem to solve with replicating a sine wave using PWM is getting the output signal to gradually rise and fall. This cannot be done with a constant duty cycle, as then it would produce a constant voltage output. This problem is solved by using a carrier and reference signal to tell the switches in the H-bridge when to turn on or off.

A sine wave and a triangle wave are compared to each other, and a controller looks for the when the triangle wave is greater than the sine wave, and uses that to form the pwm that will be sent to the transistor switches to modulate the output voltage. When the sine wave is in its negative half cycle, the comparison functions the same, it is now sending the pwm to the other 2 transistors.

Simulink was used to create and simulate a full sine wave inverter using an H-bridge and pulse width modulation to create a timing signal. The results of this simulation can be seen in figure 13.

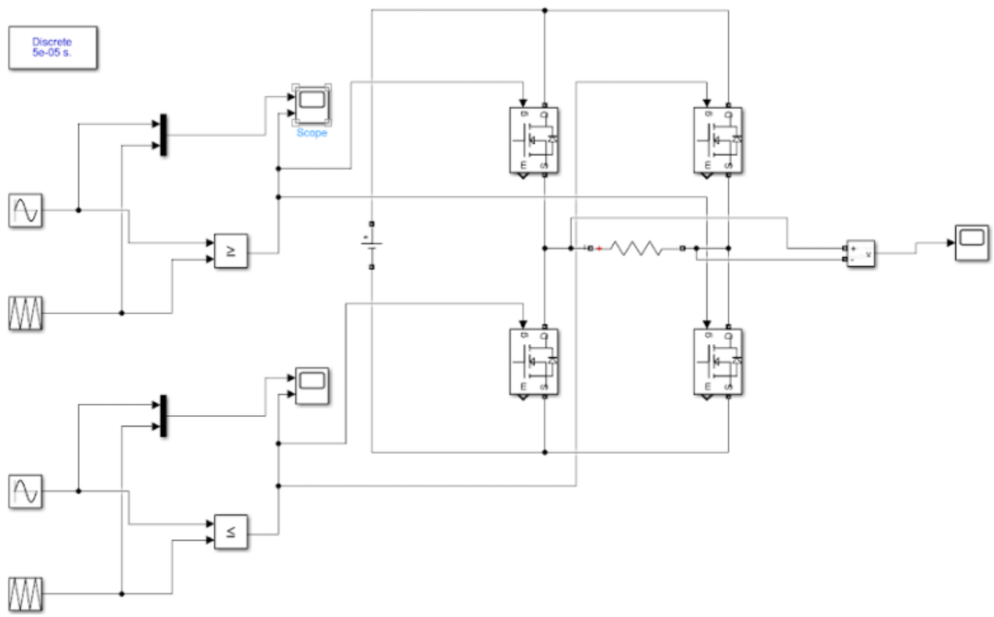


Figure 13 - Full sine wave simulation

The timing signals when used with the H-bridge produce a simulated sine wave shown below. The blue sine wave is only there to show the accuracy of the signal.

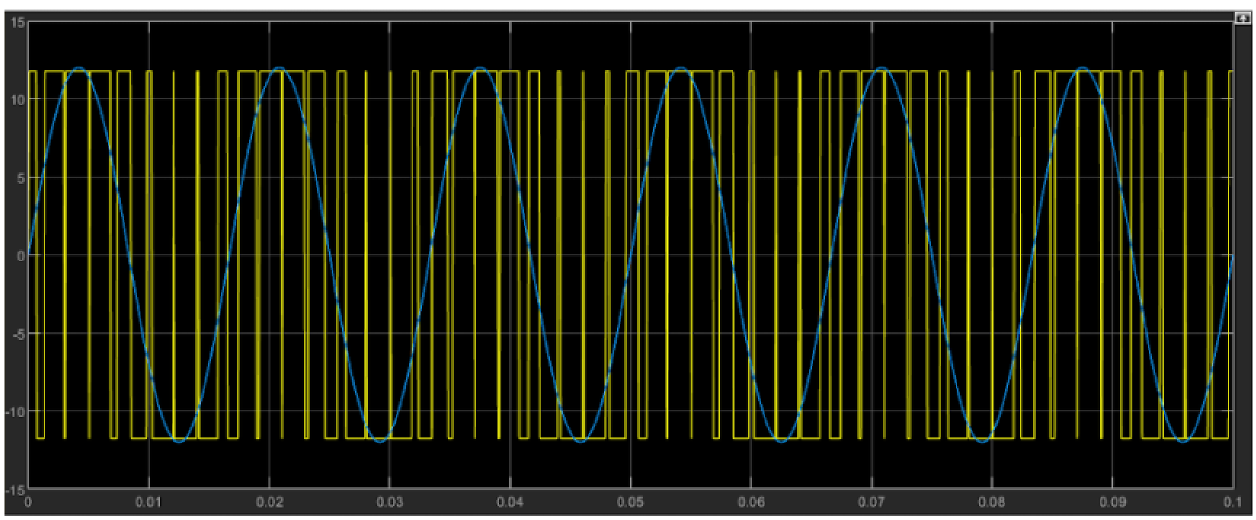
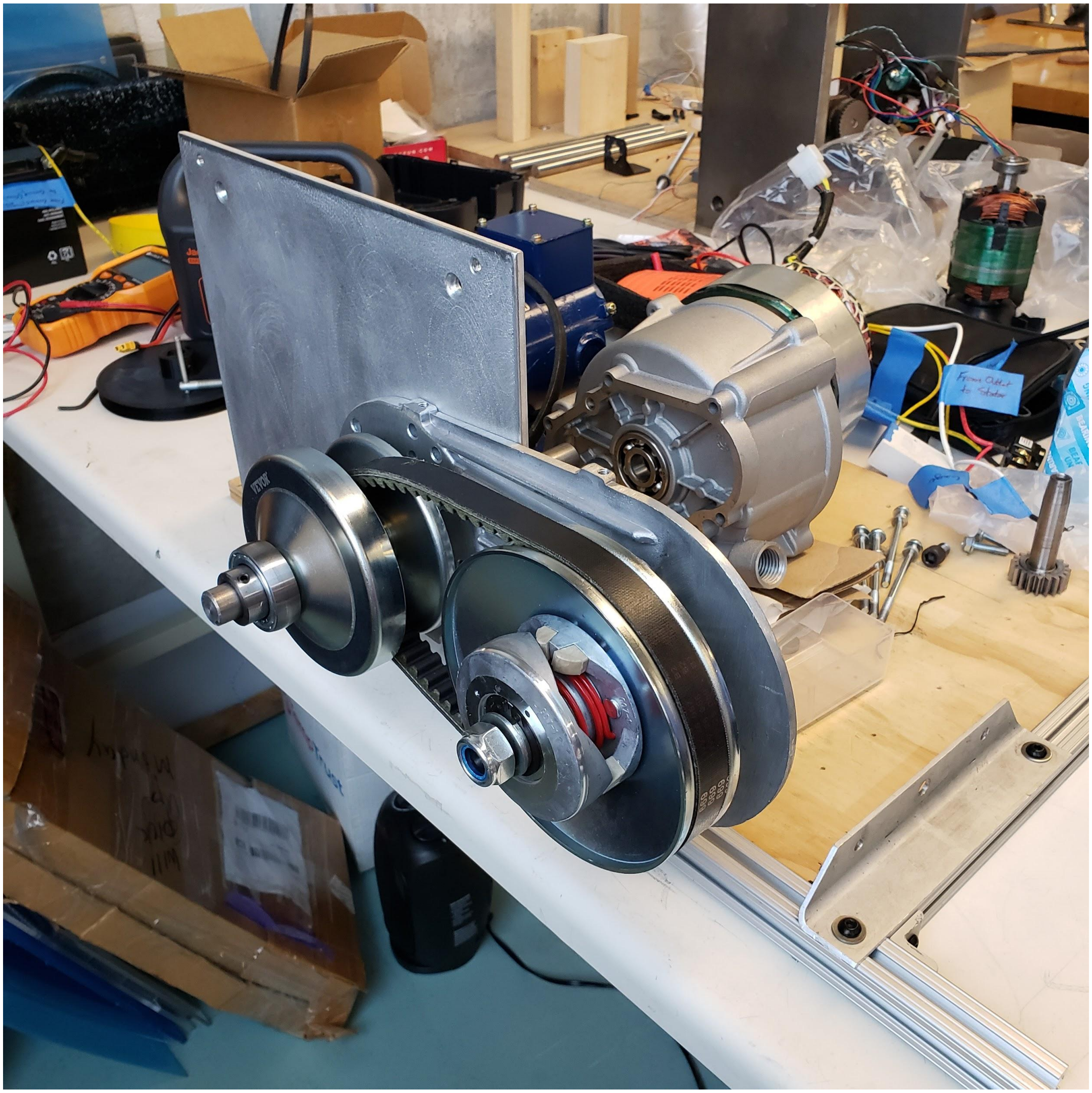


Figure 14 - Simulated sine wave

The continuously variable transmission (CVT) is designed and assembled in such a way that it has an idle speed, where the belt does not catch the pulley, a speed where the belt does start to catch, and then a speed where the pulleys start to move. A test rig was created for the CVT to find out whether it would suit the project as an off the shelf part, or if it would need to be modified in any way. This test rig includes using the same DC motor used to run initial tests on the induction machine mentioned prior connected to the driver pulley of the CVT. The CVT itself was bolted to an aluminum plate, which in turn was connected to the wooden mounting panel that the DC motor was on via 1 inch square cross section aluminum rails.

During these tests, it was found that off the shelf the CVT was unable to perform as needed for the project. Despite the gear ratio used from the motor and the driver pulley, the CVT was not able to generate enough rotational force to move. Since the CVT was being tested towards the upper limits and beyond our desired rpm range, changes would need to be made. There are 2 sets of springs in the CVT that can be altered, the driver springs, and the follower springs. The driver springs are wrapped around the centrifugal weights housed inside the driver pulley of the CVT. as the pulley spins, the rotational force acting on the weights pushes outward. Once this force is high enough that it can overcome the tension on the springs wrapped around them, they start to separate, which pushes the sheave of the pulley closer to its other half. The follower spring is housed inside of a cage on the follower pulley. As the driver pulley moves, the tension on the belt forces the two sides of the pulley apart, compressing the spring. When the CVT is returned to its default position, the spring pushes on the pulley and returns it to its default state. Both of these springs would need to be swapped out for springs with a lower spring constant value than what came off the shelf.

The process of determining the correct springs was done through trial and error. Both of these springs ended up being changed for ones with lower spring constants. The CVT was now able to actuate somewhere in the range of 1200-1600 rpm, which is on the higher end of the desired rpm range, but until the full assembly is completed for final tests, this was considered a good rpm range to show the function of the device. It was also found that in order to eliminate the idle effect of the transmission, where the belt does not catch until a certain speed, the off the shelf mounting plate of the CVT would need to be replaced. This was done by using 2 plates of aluminum that each pulley could be mounted to, so that the distance between them could be adjusted until the belt was tight enough that the pulleys would catch the belt at lower speeds.



The full prototype assembly was then assembled to be tested. The side panels were not attached for testing in case things needed to be modified or changed during the high level tests of the full assembly system. The tests of the full assembly were done using the same DC motor from the other subsystem tests, as it allows the system to be tested with its simulated variable speed load. This was connected via a drive belt to the transmission of the system. During these tests, it was found that there was a much higher amount of torque needed for the system to move, and the motor used for testing was not powerful enough to move the system at higher speeds. During testing, this could be corrected using an assisted start to help the initial drive belt catch. Another issue arose due to the fact that the CVT is attempting to run in reverse. With the driver and follower pulleys switched, the pulley that normally drives the CVT could not get up to its idle speed to catch the belt. Initially it was thought that tensioning the belt would cause the pulley to catch, but this was not the case. Tests of the system could be done with an assisted start using a hand drill, however the speeds necessary to actuate the CVT could not be reached.

Maintenance

The induction machine and transmission are mounted to the frame in such a way that they can be adjusted by loosening the fasteners and sliding them across the rails that make up the frame. This can be done to adjust the tension in the dive belts, or to remove the belts if needed. Tuning of the transmission can be done by removing the acrylic shield that covers the CVT, as well as the bearing flange attached to the front panel. From there, the driven pulley should be accessible. Once the cover of the driven pulley has been removed, the weights and springs can be taken out of the pulley. The springs can be removed by unhooking the ends from each other. Depending on how stiff the springs are, this may need to be done with pliers. There should be two springs wrapped around the weights. To put them back on, the springs should be placed around the weights first, then place them back into the pulley. The weights have their own little rails on them to prevent them from moving around during motion.

To adjust the spring in the driver pulley of the system, the acrylic shield will still need to be removed. Remove the bolt and washer that keep the pulley from being disconnected from the shaft. Unlike the follower pulley, the drive belt will need to be removed in order to take the pulley off of the shaft. Once the pulley has been taken off of the shaft, take a pair of ring clamp pliers and remove the retainer ring found on the side of the pulley that has the spring visible. Be very careful when you do this, as depending on the spring inside the cage, the cap that is held on by the retainer ring will be spring loaded to some degree. From here, the spring can be changed out if needed.

It is possible that the pulley ratio between the transmission and the induction machine may need to be adjusted. To do this, a new set of pulleys will need to be manufactured. To do this, edit the file of the pulley by adjusting the radius of the disc, and reprint. The generator pulley should just slide onto the gear at the end of the rotor shaft, and the transmission side pulley connects using a key and set screws.

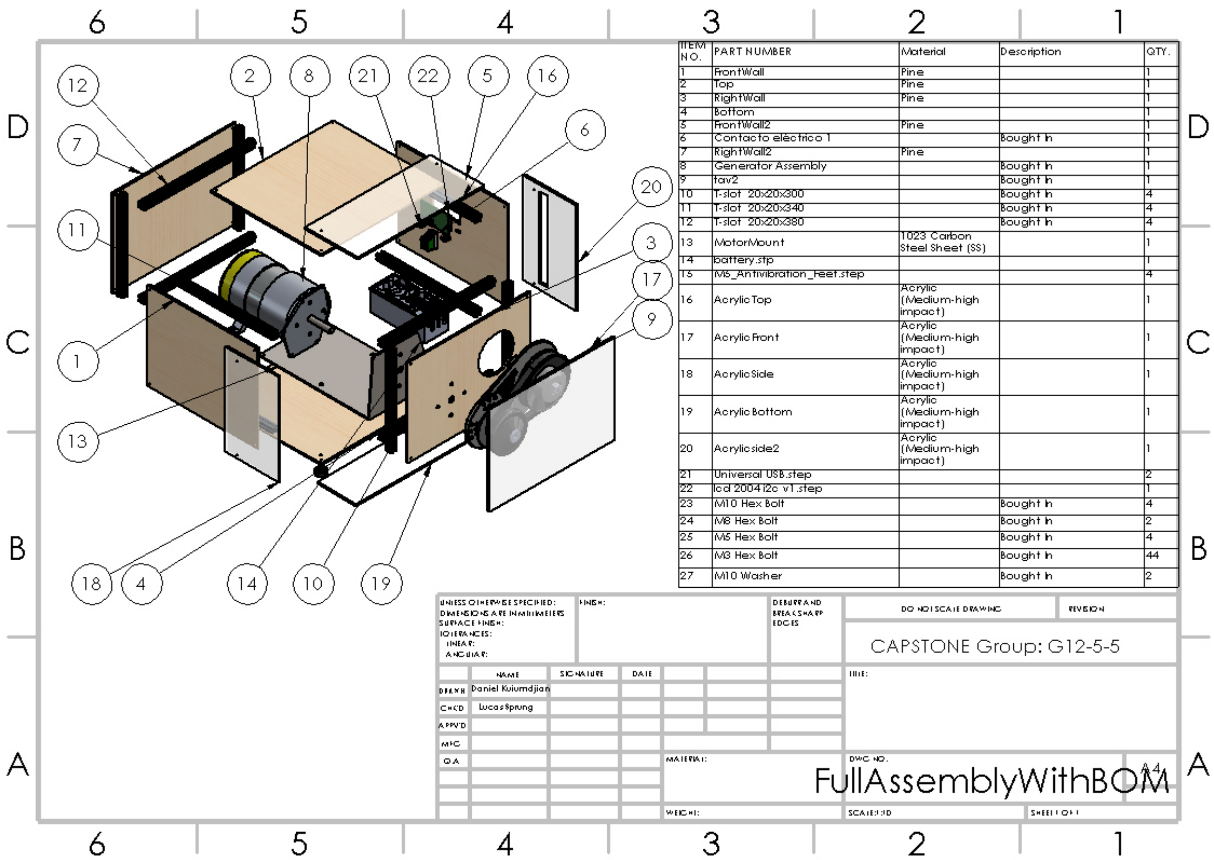
In the event that the induction machine needs to be taken apart for any reason, special care needs to be taken when removing the rotor from the housing. Remove the yellow cap from the back end of the induction machine. Take a thin rod and place it in the hole at the center of the rotor. The rod should enter the rotor fully with room still in the tube. There is a thread at the end of the rotor. Take a bolt that fits the thread, and screw it into the rotor by hand. The bolt should not screw in all the way, and should press up against the rod you inserted earlier. Take a hand drill, and carefully screw the bolt into the rotor. The bolt will press up against the rod, which will in turn press up against the crankshaft, which is only press fit into the rotor. After a few short bursts from the drill, the shaft should disconnect from the rotor, allowing the shaft to be removed. The stator coils will have to be removed first before the rotor can be removed from the housing.

Considerations for Future Prototypes

Considerations were made to try and address the shortcomings of the current design. These involve trying to correct the torque issue, and the issue with the CVT pulley not catching the belt. Drive belts were used on the system to try and keep the efficiency high while keeping the noise low. The belts could be swapped out for chains, which would reduce the slip on the pulleys when the system is in motion. The only drive belt that cannot be replaced is the belt that connects the two pulleys on the CVT, as it is needed to operate the transmission properly. The other option would be to use meshed gears, removing the belt/chain altogether. This would again help with the slip that occurs during operation, while still maintaining the ability to have the necessary gear ratio to spin the induction machine at its desired speed.

With regards to the CVT belt not catching, it was thought that washers could be used inside the pulley that houses the weights to force them to separate such that the pulley is pushed forward just enough to catch the belt. This way the CVT may still function as intended, while removing the idling feature at lower speeds.

Section 5: Bill of Materials



ITEM NO.	PART NUMBER	Material	Description	QTY.
1	FrontWall	Pine		1
2	Top	Pine		1
3	RightWall	Pine		1
4	Bottom			1
5	FrontWall2	Pine		1
6	Contacto eléctrico 1		Bought In	1
7	RightWall2	Pine		1
8	Generator Assembly		Bought In	1
9	tav2		Bought In	1
10	T-slot 20x20x300		Bought In	4
11	T-slot 20x20x340		Bought In	4
12	T-slot 20x20x380		Bought In	4
13	MotorMount	1023 Carbon Steel Sheet (SS)		1
14	battery.stp			1
15	M5_Antivibration_Feet.step			4
16	Acrylic Top	Acrylic (Medium-high impact)		1
17	Acrylic Front	Acrylic (Medium-high impact)		1
18	Acrylic Side	Acrylic (Medium-high impact)		1
19	Acrylic Bottom	Acrylic (Medium-high impact)		1
20	Acrylicside2	Acrylic (Medium-high impact)		1
21	Universal USB.step			2
22	lcd 2004 i2c v1.step			1
23	M10 Hex Bolt		Bought In	4
24	M8 Hex Bolt		Bought In	2
25	M5 Hex Bolt		Bought In	4
26	M3 Hex Bolt		Bought In	44
27	M10 Washer		Bought In	2

Figure 15 - Bill of Materials

The motor mount is meant to hold the gas generator in place during operation, and to minimize the amount of noise in the assembly. The aluminum rails form a frame which the panels can be mounted to for presentability. The acrylic sheets for an "aquarium" style box around the CVT so that it can be viewed during operation. The electrical components are taken from the jackery power station and the generator from the champion gas generator.

Section 6: Project Plan

In order to plan out the timeline of the proof of concept and the desired deadlines, the major tasks associated with completing the proof of concept first needed to be outlined. To help visualize the tasks and their association to each other, a design structure matrix was created based on what were considered the biggest accomplishments for the project this semester.

Task	Building Test Rig	Assemble the Battery	Design System to Monitor Battery	Test Charging the Battery	Test Monitoring the Battery	Design Useful Output Power	Test Useful Output Power
Building Test Rig for Mechanical to Electrical Conversion				X			
Assemble the Battery				X	X		X
Design System to Monitor Battery				X	X		
Test Charging the Battery					X		
Test Monitoring the Battery							
Design System for Useful Output Power							X
Test System for Useful Output Power							

Figure 16 - Design Structure Matrix

From this matrix it is clear that testing charging the battery would require the most prerequisite tasks. The monitoring of the battery also requires the battery to be assembled and to be able to charge it. Testing of the output power will require the battery and the system for output power to be designed. Once these tasks were outlined and their connections to each other had been determined, a timeline could be created for the project in the form of a Gantt chart.

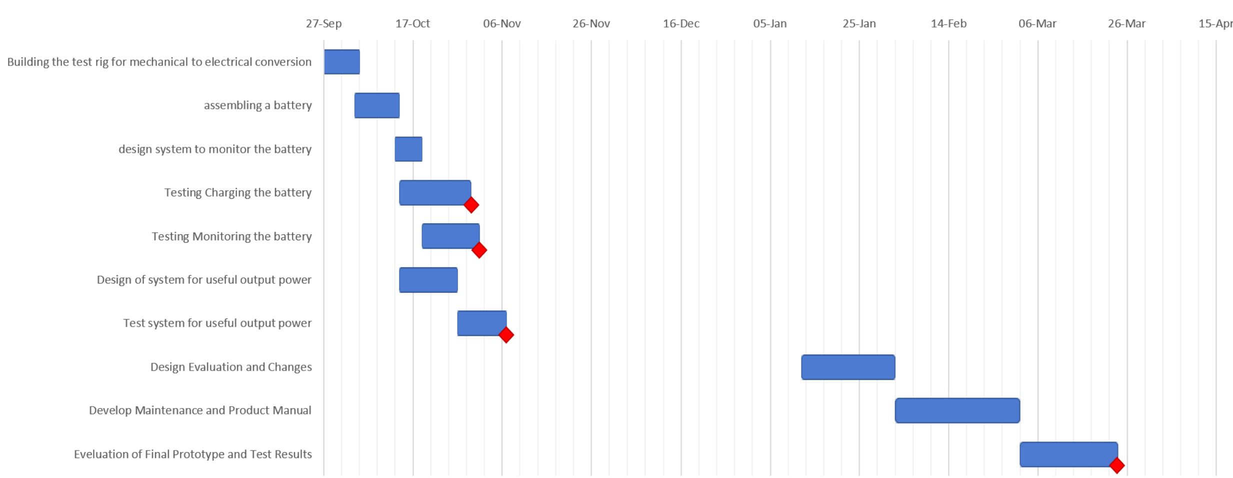


Figure 17 - Gantt Chart

Each task was given a start date, and a number of days to complete. Tasks that can happen concurrently can have similar starting dates. Construction of a test rig starts on September 27, and testing of the project subsystems can be done once the test rig has been completed by October 4. By looking at both the design structure matrix and the Gantt chart, we can see there are potential bottlenecks in the project, specifically with building the battery. Multiple tasks require a battery in order to properly test and complete the task. The task of assembling a battery is given slightly more time to try and give a bigger window in case of any problems during that stage. This timeline will ensure that the proof of concept for the project will be complete by the deadline on November 9th with a small grace period to allow for editing and review of the report before submission.

The second phase of the project has to do with proof of product. The Gantt chart displays a chunk of time between some of the tasks, which represents the break over the holidays. Testing can still be conducted during this time, but there are no obligated tasks to complete over this period. After this break, there are three major tasks that need to be accomplished coming out of the new year, with the focus now shifting to evaluating the results from the proof of concept and making any necessary design changes. The last third of the term is dedicated to finalizing the proof of product and getting ready for the capstone design exhibition on March 23.

There were major milestones for the project that can be identified on the Gantt chart by the red diamonds. Completion of the testing phase for each part of the project marks a major milestone within the project for this term. Charging the battery with a method of mechanical to electrical conversion, monitoring the battery charge level, and the method for output power are all crucial parts of the project. These 3 major categories of the proof of concept were then further examined, and members of the project team were chosen to focus their efforts on one of these categories. This way, tasks that can be worked on concurrently can progress at the desired times, and team members can be in close communication about the status of each major project task for this phase of development. A task-person list was constructed to help organize which tasks fall into which categories, and which people would work on specific parts of the project.

Category	Task	Team members
Charging the Battery	Building Mechanical to Electrical Test Rig	Lucas Sprung
	Testing Charging the Battery	
Manitoring Battery Charge	Assemble the Battery	Daniel Kuiumdjian
	Design System to Monitor Battery Charge	Bryce Elvin
	Test Monitoring the Battery Charge Level	
Controlling Output Power	Design System for Useful Output Power	Christian Toso
	Test System for Useful Output Power	Cameron Slade

Figure 18 - Task-Person List

This list should help to minimize any confusion between team members and what parts of the project they should be focusing on. Team members were chosen to focus on specific tasks based on interest and previous experience with the technology. This should improve project efficiency and help mitigate any potential bottlenecks.

Section 7: Ethical Considerations

This project is meant to interface with a new Stirling engine design. The device itself does not produce any harmful emissions. The only component that would produce harmful emissions is the generator, however the single cylinder gas engine, the part that would produce emissions, has been removed from the induction machine that produces power. The primary purpose of the device is to interface with a new design of stirling engine, which produces next to no waste material. This device could also be connected to other types of renewable energy sources, such as wind turbines, water mills, or a human operated machine such as a stationary bike.

This device is developed as part of a larger project meant to create a new way to generate energy that does not consume fossil fuels or produce large amounts of harmful waste materials.

Section 8: Safety Considerations

This project deals with high voltages and a considerable amount of moving parts. Any moving parts that can be covered up are done so to avoid any injury to users or observers. Unfortunately the belt that connects the prime mover to the rest of the assembly must be exposed in order to be able to swap out the prime mover. There isn't really a way to cover up the entire prime mover from access. The device is designed so that there are no exposed wires on the exterior, and that the power generator is properly grounded and insulated.

Acknowledgements

Dr. Brendan MacDonald
Brayden York
Cole Lamothe

References

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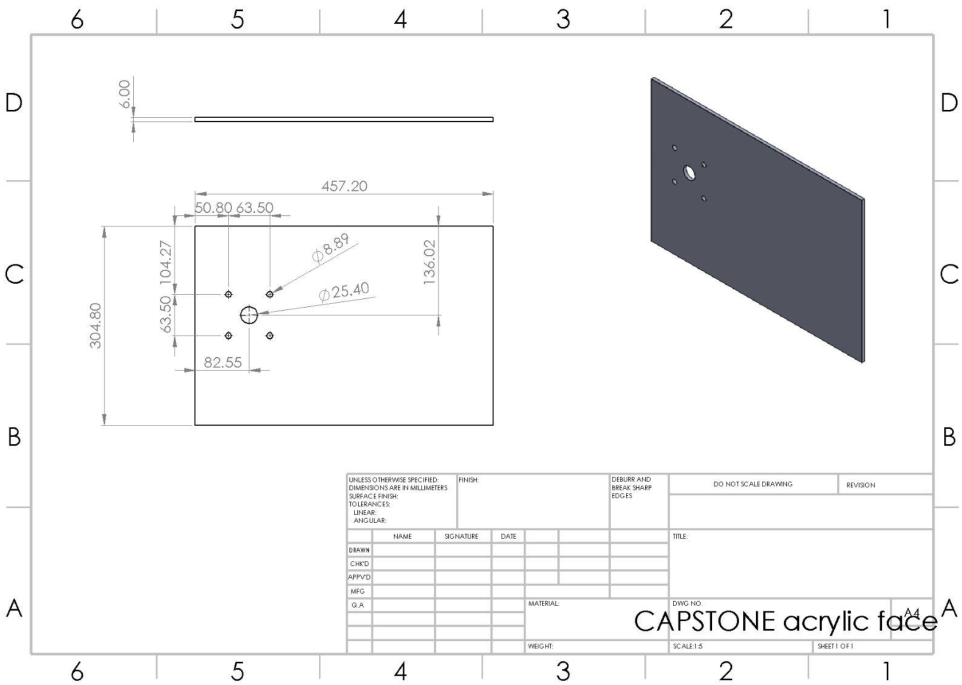
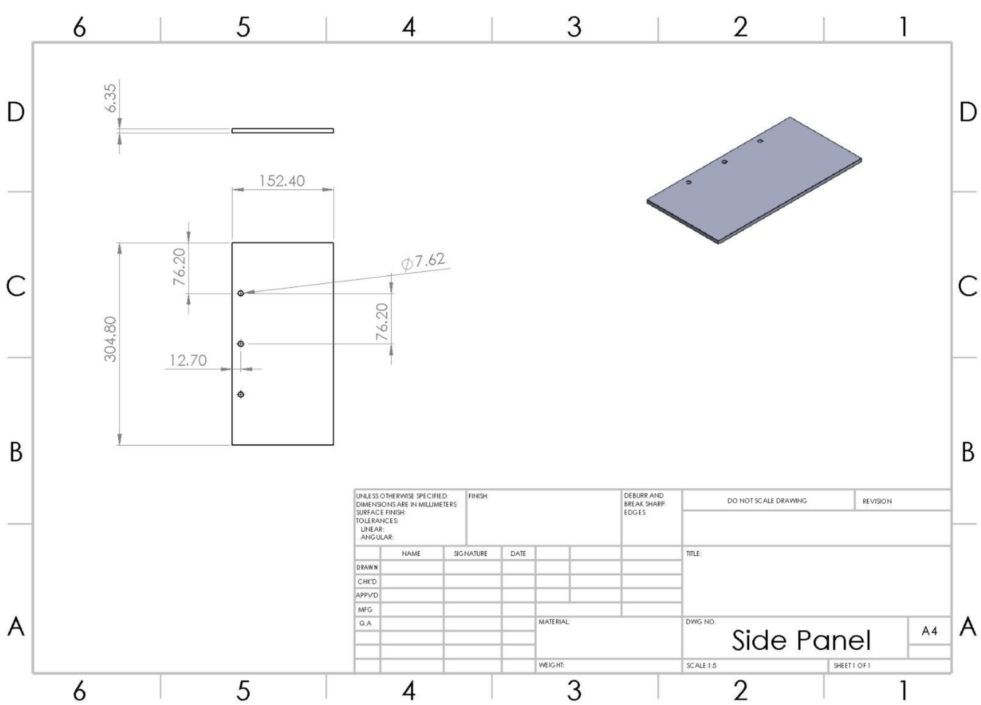
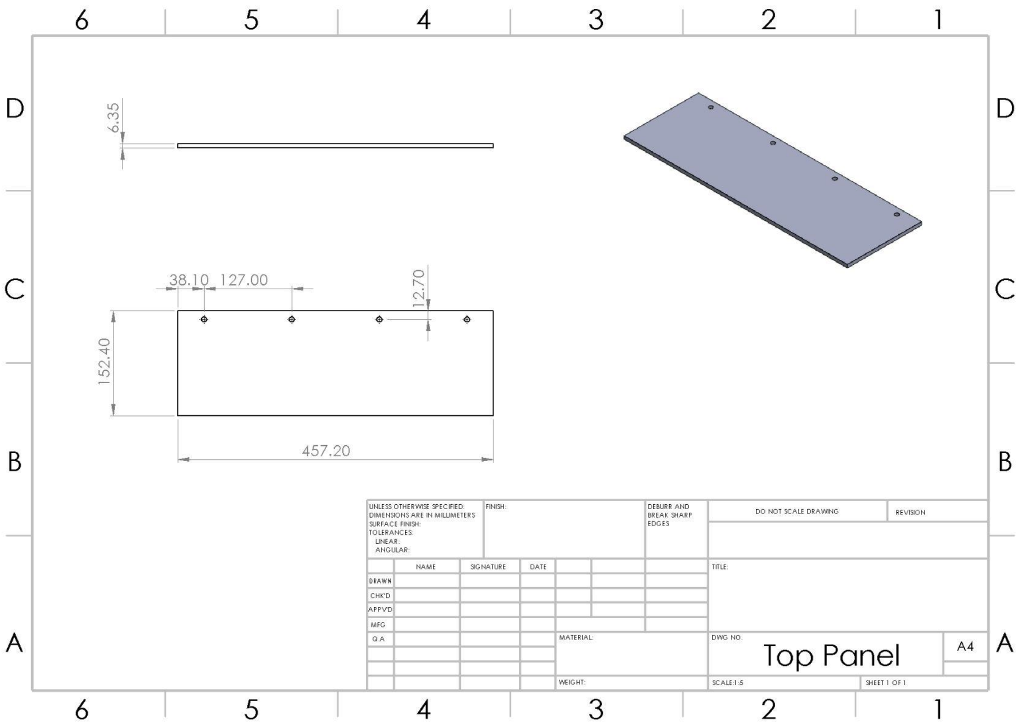
Appendix

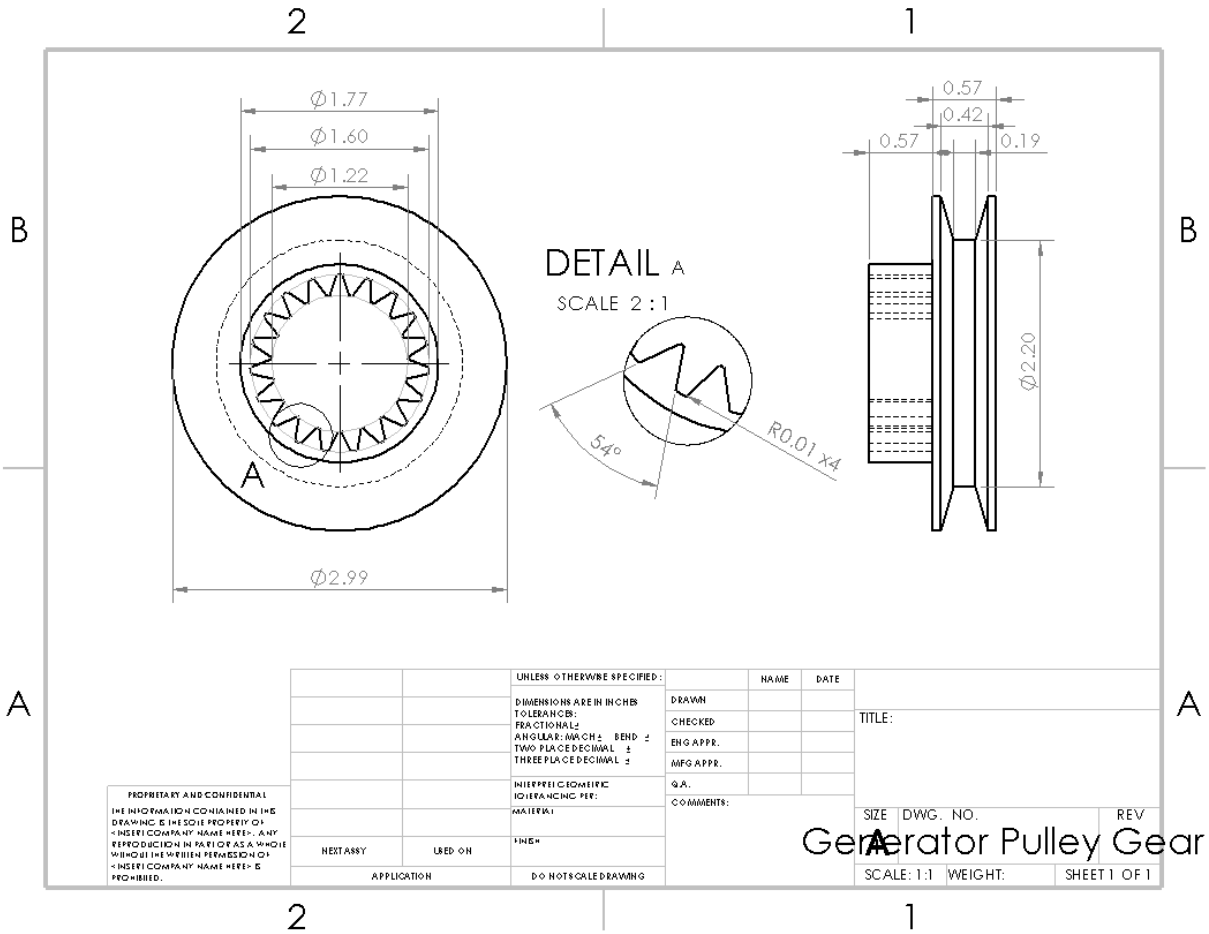
Drawings for manufactured parts



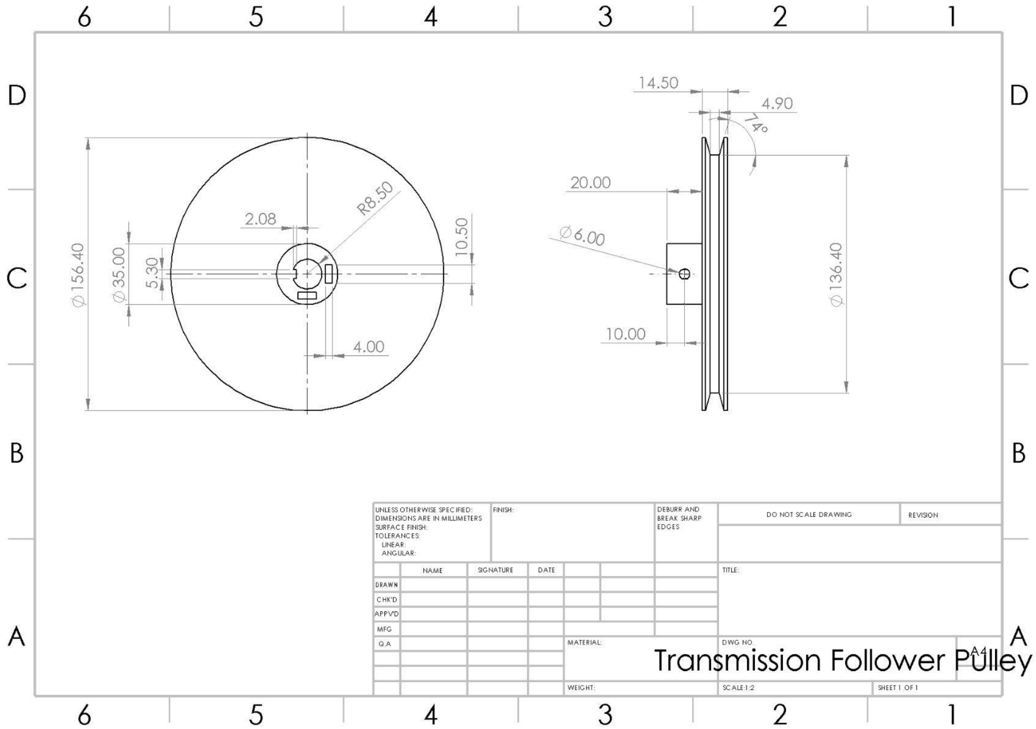


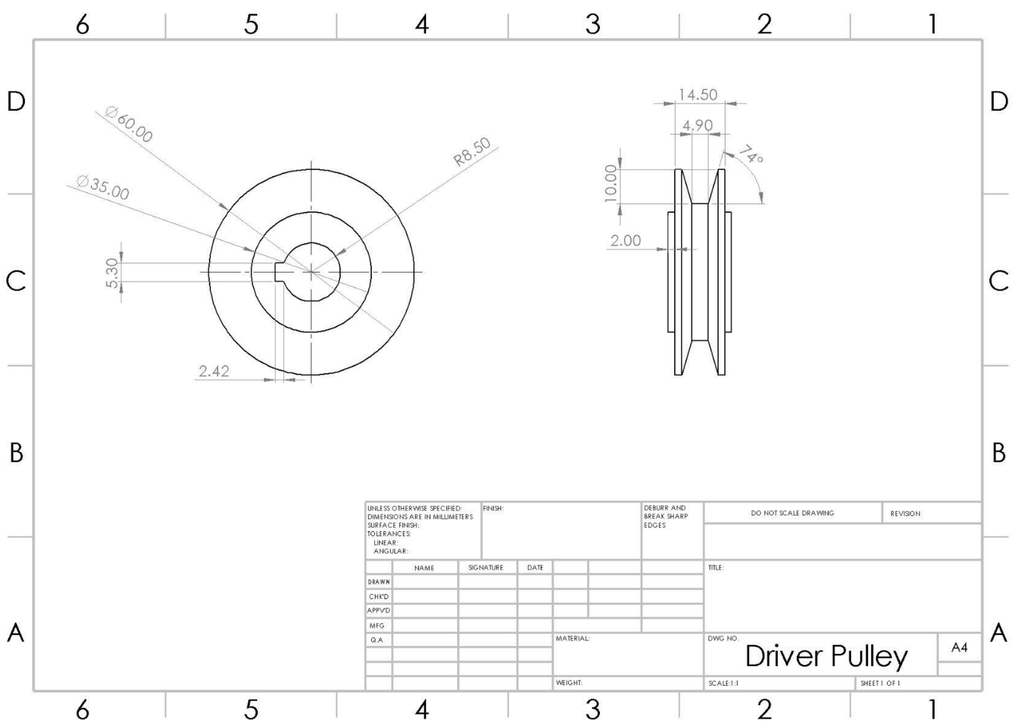


6.35
38.10
127.00
12.70
152.40
457.20
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
DWG NO.
Top Panel
A4
SCALE:1:5
SHEET 1 OF 1

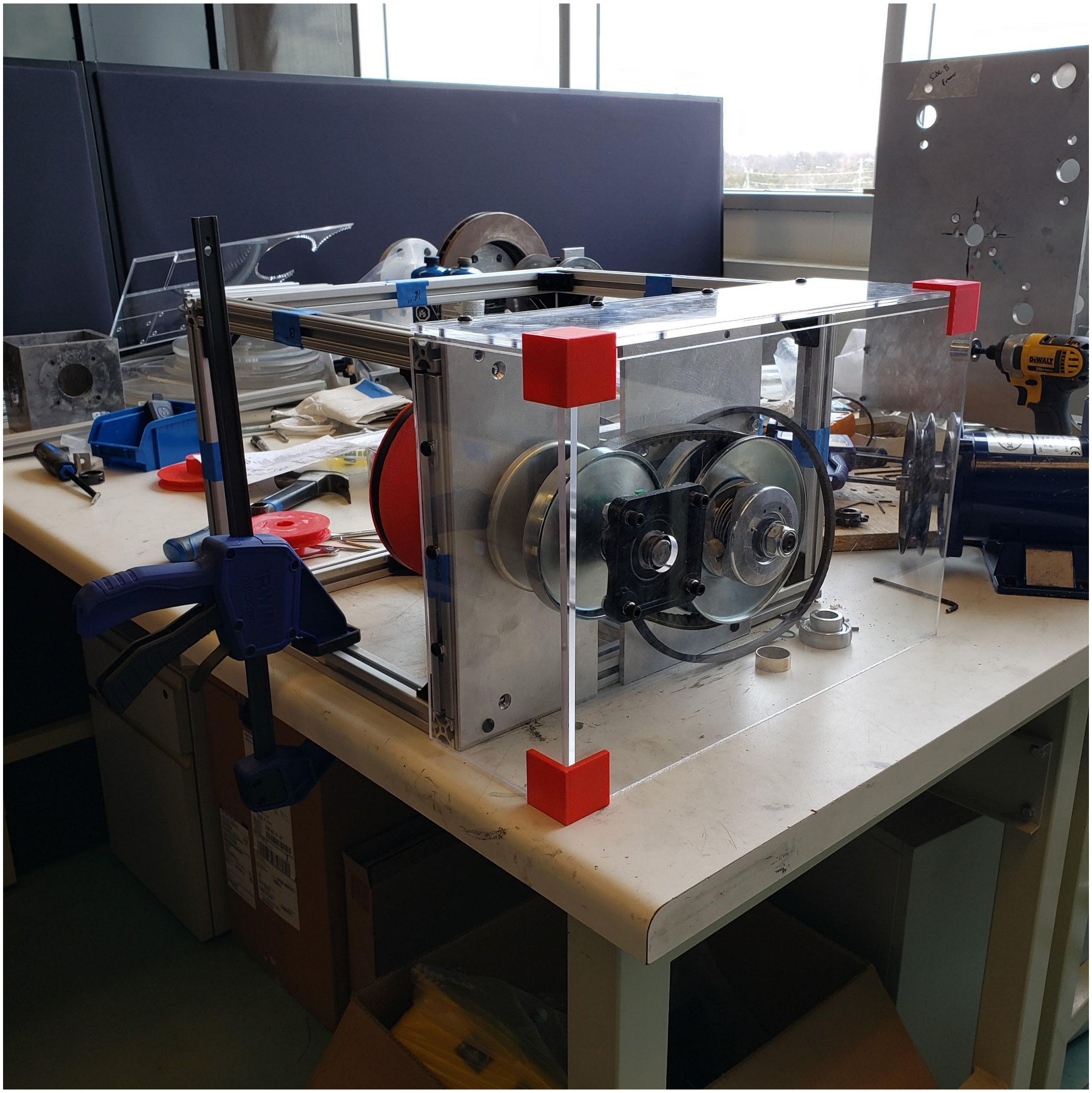


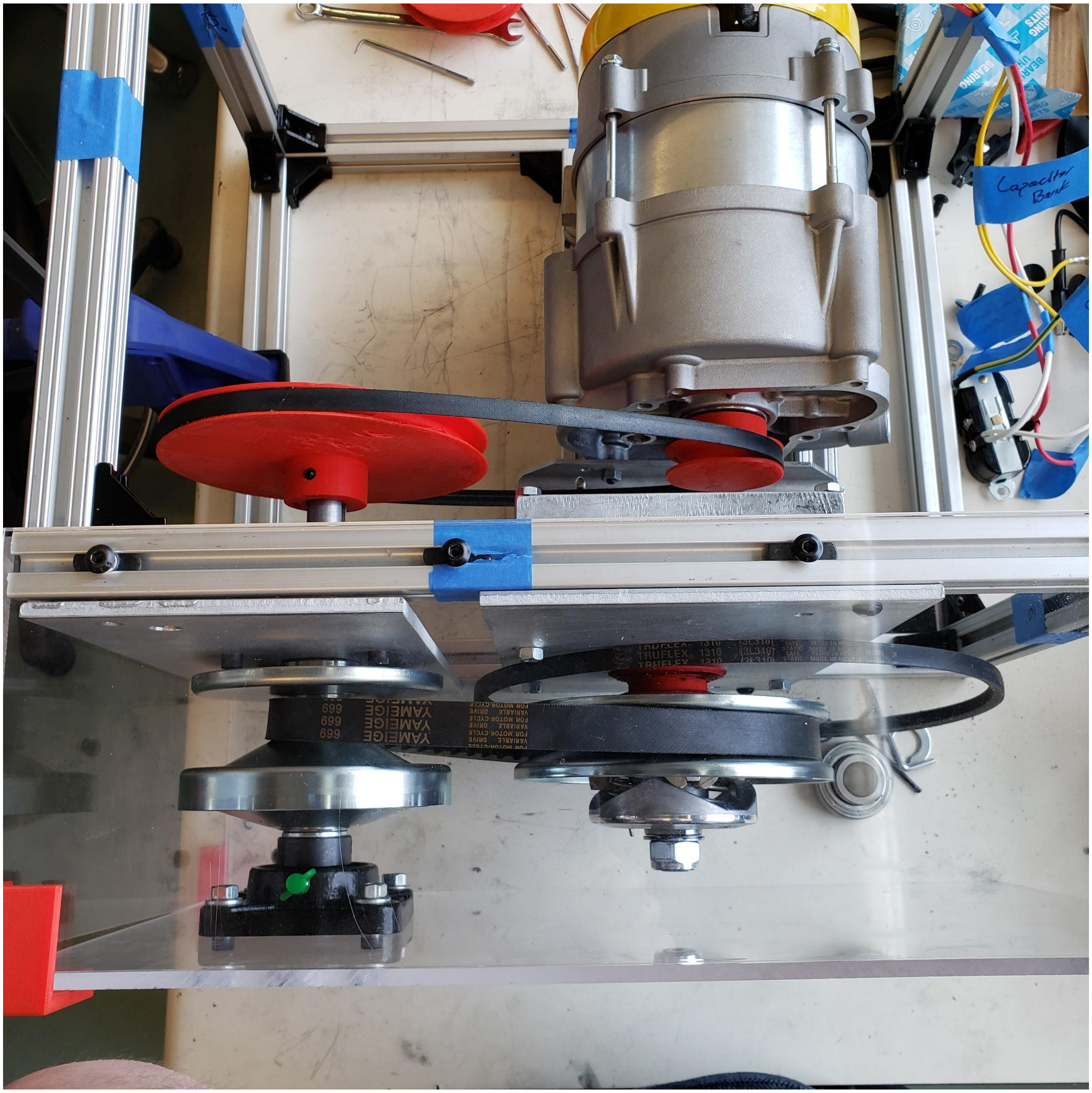
Ø1.77
Ø1.60
Ø1.22
Ø2.99
A
DETAIL A
SCALE 2 : 1
54°
R0.01 x4
0.57
0.42
0.57
0.19
Ø2.20
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A
Generator Pulley Gear
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL





Assembly Images


DEWALT


Capacitor Bank
YAMEIGE
699
TRUFLEX 1310 (3L310)