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Acknowledgments

We would like to begin by thanking the numerous individuals who helped us along the way with this project. First and foremost, we want to thank our primary advisor, Dr. Joseph Rosiczkowski. He helped to ensure we met our deadlines and helped to keep our project on track.

Secondly, we want to thank Jim Mighells. He helped us with much of the manufacturing process when we were unfamiliar and provided us with insight on how to do things when we sometimes were lost or confused.

Third, we would like to thank the help of the technicians at both EV West and Thunderstruck Motors. Our lack of knowledge in terms of these specific components added to our unique design which bypassed some systems. We would have never figured some of them out without their guidance.

We would also like to thank Dr. Tidrow, Dr. Dan Lu, and Fran Williams of Alfred University for their miscellaneous help. Whether it be simple questions about the system or how to measure certain things, or more complex issues like how to format and code components, they were invaluable assets to the project

Finally, we would like to thank Alfred University as a whole. Alfred has taught us many of the skills we needed for this project, and provided us with much of the funding, through APEX grants and Student Senate allocations. Without the support of any of these programs, we would not have been able to imagine much less build this project.

Abstract

As the demand for clean energy increases so does the demand for electric vehicles. There has been a large surge in electric cars but little in recreational vehicles. With rising concern about CO2 pollutants, we decided to take initiative. Our group saw this and wanted to extend the electric power to include such vehicles. An electric snowmobile was created by removing the internal combustion engine, gas tank, and other smaller equipment for an electric motor and batteries. The snowmobile motor is a 144 Volt electric motor being powered by five 25 Volt batteries. The torque is rated at 180 lb-ft and accelerates rapidly.

Introduction

A snowmobile was given to the Alfred University Clean Snowmobile team to be used for a full electric conversion. The sled is a 2010 model and was deemed unusable for the main SAE competition. The SAE Clean Snowmobile competition is an engineering design challenge for both undergraduate and graduate students. Engineers compete to re-design and alter a snowmobile to reduce the noise the vehicle produces and the pollutants from the emissions. The goal of these competitions is to implement the modified sleds into low emission and quiet vehicles that can be used by park rangers in national parks around the country and continue to perform as well or better than previous vehicles used. The clean snowmobile club has two snowmobiles and one of which is not to the regulations of the SAE Clean Snowmobile competition. This snowmobile also has a non-functioning engine. With a non-competing snowmobile and a broken motor, our team decided that we would create a new project and challenge ourselves. The team wanted to convert the sled by removing the internal combustion engine, running on gasoline, and replacing it with a fully electric motor. The sled is run by a motor selected through research and comparisons. This research led the group to select a 144V, 180 lb-ft, and 94% efficient motor by NetGain. The motor weighs around 100 lbs and is ideal for this application as it creates optimal torque to run the snowmobile. Electric Motors also pose the interesting characteristic, that they produce optimal torque through a large RPM range. The traditional engine in a snowmobile needs to rev to reach the peak point of its curve, which reduces efficiency and increases fuel use.

Research

To properly convert the snowmobile from running on a gasoline engine to an electric motor, research was required to find the necessary equipment, parts, and a proper motor. The motor to be selected needed to be as powerful as the engine and not be too big to leave room for the other internal components such as batteries and a controller. The motor's power curve was analyzed to ensure the motor will produce enough horsepower as well as torque for the snowmobile. The best option based on these criteria was the NetGain Hyper 9HV motor. Coming in at 100 pounds, and only nine inches in diameter, it is significantly smaller than the original internal combustion engine. The batteries needed to produce enough voltage to power the motor and stay within a certain size limit to fit as many batteries as needed. The LG Chem Lithium-Ion batteries fit this role, as they are only four inches across, and weigh a staggering twelve pounds apiece, adding less weight than other batteries would and still produce the power output the motor needs. These batteries each produce 25 volts making them a great choice to be used for the conversion. A controller needed to be selected that would be compatible with the motor that would be selected for the conversion. The motor chosen had the added advantage of coming with a controller. The charger was one of the most researched items on the sled. Due to supply chain issues, we had to get a charger that needed to be programmed rather than one that was preprogrammed. The final selection was for a Thunderstruck TSM2500, which has a max output charge voltage of 144 volts at 15 amps. Other necessary research was needed to determine proper skis for the snowmobile and a potential new track for the rear of the snowmobile if it was deemed a need for the project.

Initial Design

At the beginning of the design process, we knew that we wanted little to no alterations to the existing body style. For a simpler installment, we chose parts that would fit comfortably in the engine bay. The team determined that a motor that was similar in physical dimensions was the most important aspect and that if one similar in power could be found, that would be a bonus. The X144, dual shaft motor produced by NetGain is a compact design produced for electric vehicles. With the front face coming in at only 9 inches, and the total body length being 13.75 inches, it has an overall footprint being smaller than the original motor. The external heat sink would also aid with cooling the motor and reduce the risk of damage to internal components. Another challenge faced was room for the batteries. Due to the motor and controller taking up a significant amount of the engine bay, placement was strategic. The drive train was simplified down to a chain-driven 1-to-1 ratio system for simplistic purposes. We wanted to build a working system and leave room for optimization in the future.

Parts

The sled is run by an engine selected through research and comparisons, and the motor selected was a 144V, 180 lb-ft, and 94% efficient engine. This engine weighs around 100 lbs and is ideal for this application. The batteries selected for the sled were LG Chem batteries with a nominal voltage of 25 Volts, making five of them easy to apply to the motor. The engine will run off of 125 Volts but will still produce plenty of power to run the snowmobile. A controller came with the engine. It was mounted high above the motor to give it proper room to keep cool and allow for easy access for maintenance and encoding. New skis were needed to replace the old ones when it was given to the team. A sprocket and chain will be needed so the setup can be a direct drive system, making sure little to no power is lost from the motor to the track. A charger was also required to charge the batteries properly. The charger selected for this conversion was the Thunderstruck TSM 2500. Wires, small basic hand tools, paint, and an additional 12-volt battery were other necessities of the project. Most components were ordered on Amazon or at local hardware stores, with only the major custom components such as the batteries, motor and controller, and charger coming from a specific vendor. All together it means that anyone with some knowledge of how to build the system, and basic hand tools, would be able to do a conversion like this in their homes. Another part that has been added to the snowmobile is the Thunderstruck Motors, BMS Controller and two BMS Satellites. The BMS Controller consists of the BMS Processor and a measurement board while the two satellites contain one BMS measurement board each. The Controller is a standalone 42 cell BMS that can be expanded by satellites for up to 96 cells with three satellites. The BMS measurement board is optimized for measuring cells in large lithium packs and was designed to minimize power consumption, especially during long-term storage.

a. Batteries

The batteries ordered were LG Chem 25V batteries from the same supplier that we got the motor from. These batteries were selected because of their size and deliverable energy. With a snowmobile being as small as it is, there is a limited selection of batteries available. We could run twelve, 12V batteries to reach the 144V threshold but the system would weigh more than what we took out. The physical sizing would also require every open space on the system to be dedicated to the Pb acid batteries.

The LG Chem batteries **(Figure 1)** are brand new to the EV market and had only been available for purchase for a few months when we discovered and bought them. Dimensionally they are 17 inches long by 5 inches wide by 4 inches tall. They individually weigh 12 lbs which is much less when compared to a traditional 12V car battery which is 40 lbs. These batteries fit the necessary criteria that we had established when starting the search for batteries.

Figure 1 - LG Chem 25 Volt Battery

The Largest downsize of these batteries being run in series, is that the maximum storage capacity is only 64 Ah. Considering the voltage, this puts the battery pack at just over 8 kWh. This limits our range, but we hope to see as the system initializes and wears itself in, it will eventually perform better.

b. Charger

The charger selected for this project was the Thunderstruck TSM 2500. The specifications for this charger include:

- Rated Input Voltage: 220VAC 50/60Hz.
- Power Factor: ≥ 0.99 @ 220VAC input, full power output
- Nominal output voltage: 144V
- Maximum output voltage: 180V
- Rated output current: 15A.
- Conversion efficiency: 95%
- Protection class: IP66
- Working Temperature: 25-55 degrees Celsius

The charger requires coding to properly charge the batteries for the snowmobile. With the proper instructions and setup, the batteries will not be overcharged, and the overall battery life will be extended. While this charger was not the primary choice for this application, it was still among the top candidates and was the best available item on the market.

c. Controller

The controller selected to be paired with our motor was the SME AC-X144 Controller. This was sent to us along with the 144V motor selected from NetGain. This is a 32-pin controller that can input up to 180V and output up to 500A at a peak power of 88kWs.

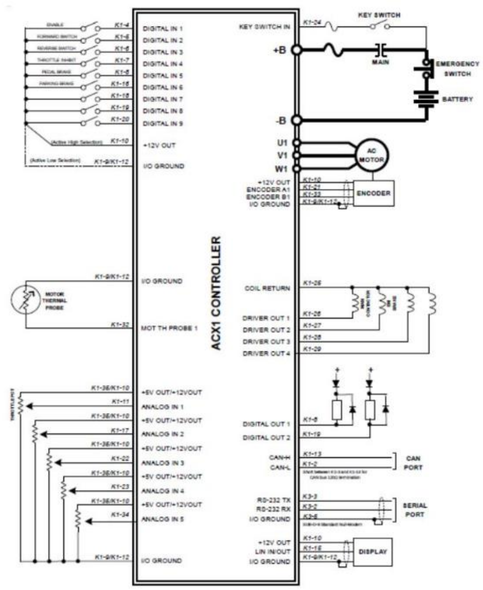


Figure 2a - AC-X1 with Asynchronous Motor Wiring Diagram

Figure 2 - Connection Diagram

Battery Monitoring System (BMS)

The addition of a Battery Monitoring System to the snowmobile offers many possibilities for the testing and safety of the vehicle. The BMS operates by connecting each individual cell in all five batteries to the main BMS controller and its satellite modules. Each satellite and the main control have two modules each and each module has the ability to connect 12 cells. In order to equip one battery to each module the system required two satellites in addition to the main. The installation of this system will monitor the charging levels in each cell to ensure that each cell is being charged evenly. It will also be able to shut the charger off when the batteries reach full capacity as well as when the batteries are diminished. In order to connect the BMSS and BMSC we had to use the port located on each side of the batteries. These ports connected to each cell including the ground to complete the circuit. When searching for the harness to fit the port we discovered that EV-West, the company we bought the batteries from, also sold a pre-assembled harness. This saved us a lot of time assembling the harnesses. The next step was tying the harnesses into the BMS wires. Along with the BMSC and its satellites we also ordered the EnGage II

Display which is made to work with the BMS and give us a digital display of the charge levels and the highest or lowest voltage cell in each battery. The BMS is also optimized to minimize power consumption, especially during long-term storage. During operation, the BMS collects pack and cell statistics. Statistics include high and low cell watermark data which can be used to track cell performance under load, and standard deviation which measures pack balance.

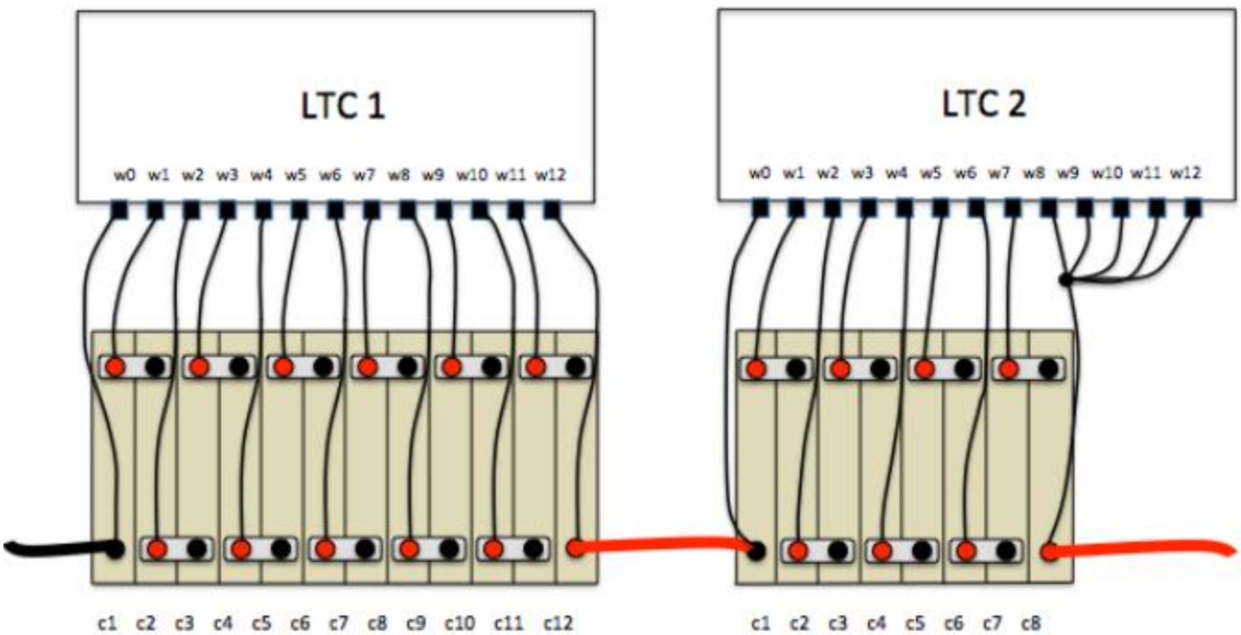


Figure 3: BMSC Wire Diagram

Figure 4: BMSC

Figure 5: Engage II Display

Final Design and Fabrication

The installation of new electrical components into the existing snowmobile chassis required the creation of several custom brackets and mounts. This would ensure all parts fit within the provided space. To ensure proper fitment of these parts, precise measurements were taken from the existing snowmobile frame, as well as the selected replacement powertrain. These measurements allowed the team to determine where the batteries, motor, and controller would fit, and let the designer begin work on mounting them. The locations that were identified as being sufficient in terms of both space and stability then came under more careful observation, as the designer took several more measurements of nearby mounting points. Accounting for both the selected mounting points and component geometry, the designer then used SolidWorks to model each bracket that would be later fabricated. This allowed the fabricator to create all the necessary custom mounts that would locate the new powertrain components within the snowmobile.

A. CAD Modeling

Before fabricating any mounts that would be necessary for locating the new electronics in the snowmobile, it was important to decide on appropriate designs that would allow the fitment of components while being strong enough to handle the forces on them. This process was completed in SolidWorks. Considering the parts that needed to be installed, the designer recognized that there would need to be mounts for five 25v batteries (two sets of two and an individual), controller mounting tabs, a box for the 12v battery, and a motor mount. The 25-volt batteries, taking up the most room at around 4”x5”x16.75” each had desired locations selected first. The first set of two was to be located in the front of the snowmobile, over the front suspension. The next set of two was meant to sink back into a hole in the front of the fuel tank, which was no longer needed for any purpose other than keeping the body intact. The third mount for an individual battery would sit on top of the motor mount, as the new electric motor is shorter than the gas engine whose place it took. Each battery tray was measured against the battery base dimensions and a frame with raised edges was drawn, with a support for the battery centers running the long way down the middle. This created part of a box that would support batteries and prevent movement. This was repeated for each of the three designs, while the third battery box was half as wide without the center support, as it only needed one battery. The front battery mount, which was over the control arms, had to be held off-center of the sled to clear the steering components. To accomplish this, a small off-center tab was drawn under the front edge of the tray that connected a front brace for the body panels. The rear tabs were drawn at the angle of an aluminum cross-member that acted as support for suspension so that the rear of the tray could be mounted. The tray in the fuel tank needed to mount to bracing for the snowmobile frame, which took the form of steel tubes under the plastic of the fuel tank. Small, angled pads were drawn under the back edges to keep the batteries closer to level while providing a flat surface inside the tank over the tubes that would be mounted off. The front end of this mount had two support legs drawn to meet the top of the tunnel for the track. The last, single battery tray was mounted off the motor mount. This design needed to clock the battery between 15 and 30 degrees off the top of the motor towards the back of the sled to clear the steering components. It also created a mount that was level with the chain side of the motor mount to avoid contact between the tray and the chain. The design used four angled legs that would bolt to the top and bottom of the motor mount. The two larger battery trays are visible in the figures below (Figure 4 and Figure 5).

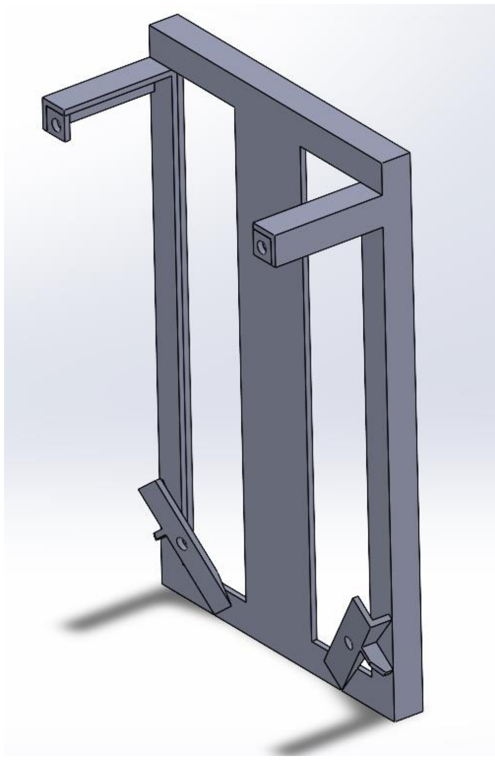


Figure 6

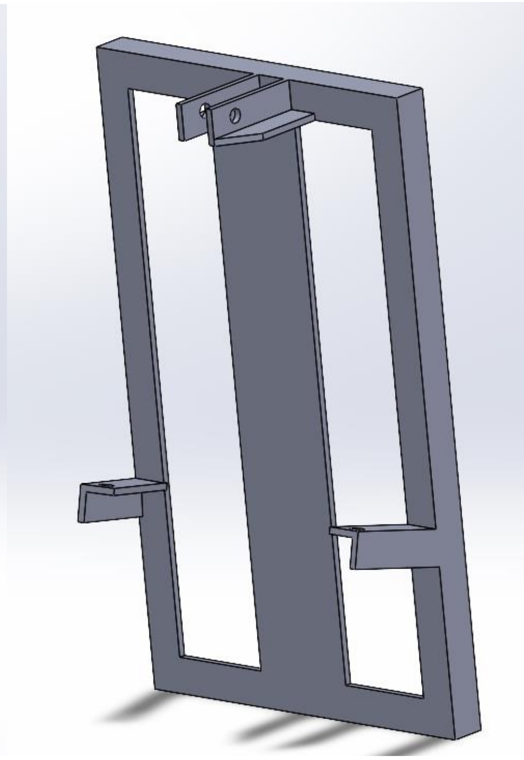


Figure 7

The controller mount design was simple, as the device has four bolt holes arranged in a rectangular pattern. This controller needed to attach to the carbon fiber supports on the front of the snowmobile, so two upper tabs and a lower bracket were designed. The upper tabs utilized a bolt near the top of these supports and had a stud about an inch away to attach to the controller. The bottom end of the controller was narrower than the supports at that point, so a wider bracket that clamped to the supports at either end had bolt holes in the middle that lined up with those on the lower end of the controller.

A 12v battery that is needed to boot up the electronic system needed a mount in the front end that kept it over the larger batteries and out of the way of steering. A cross-member between the upper ends of the shock towers on either side was designed, which was attached to a small box that was the size of the battery footprint and wrapped about halfway up it. This bracket, like the other battery trays, had tabs that could be used for attaching a battery tie down.

The motor mount held the central component, the electric motor, in place within the center of the front end of the sled. This had to keep the motor shaft in line with the input shaft. This design could only mount to the motor on its ends. The design used two round plates with the appropriate bolt patterns cut in. These plates had slots down the center, allowing for the motor ends and shafts to drop down between them. This design used a rolled cylindrical piece to wrap around the bottom of the motor and attach to the ends, adding rigidity to the structure. To meet the four existing motor mounts, two plates were attached perpendicular to the rolled bottom piece and used gussets that would provide strength. These plates were big enough that each one contacted both the front and rear mounts on its respective side, while they had to be shaped to fit into the available space. The cradle without the legs, which was the one utilized for fabrication purposes, can be seen in the figure below (Figure 6).

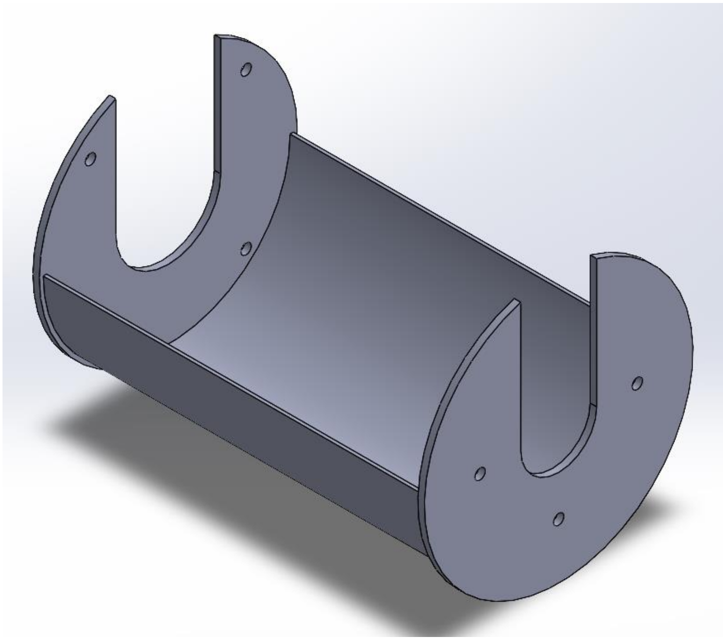


Figure 8

B. Fabrication

Fabrication of the modeled components utilized different stock material to create the shapes made in SolidWorks. The selected materials were ⅛" steel, ¼" steel, and 1"x1"x3/16" angle iron. These were selected as they were strong enough to withstand the forces on the components, as were easy to work with from a fabricator's point of view. Tools used were those in standard metalworking. Grinders with soft wheels, grinding wheels, and cut-off wheels were needed. Other cuts were made using a reciprocating saw, band saw, chop saw, and a plasma cutter. Holes were drilled most often with a drill press; however, a hand drill was needed to create mounting points on the snowmobile. Mig welding was utilized in the attachment of all metal components. Additional tools used included a metal brake and a shear.

Battery trays were the first component to be fabricated. The mentioned frames used angle iron, as this material already had the desired lip to locate batteries. Tabs that mounted to the snowmobile were also made of angle iron. After the appropriate angles were transcribed onto the small lengths of the material, they were cut or ground down to meet these angles. After the metal was cleaned and prepared, the tabs could then be welded on in the appropriate locations. Most of the tabs and legs for battery mounts are attached on one end of the angle iron, with the 90-degree bend providing proficient strength. This was not the case for the pads in the rear on the tank-mounted tray. These were long and required a larger base that ran along the plastic in the appropriate locations. This meant that the needed angle was cut down the length of the angle iron, which was welded with the flat side down. This smaller contact area required that the fabricator add gussets for strength on these mounts. Battery trays can be seen in the figures below during various stages in their construction (Figures 7 - 9).

Figure 9

Figure 10

Figure 11

The controller mounts, which were simple in design, took little effort in fabrication. The upper tabs and the lower bracket were cut from ¼” plate steel using a plasma cutter. Two holes on the tabs were drilled around an inch away from each other. One was left empty, as it would attach to the supports via an existing bolt. The second hole on both then accepted a stud that was welded in. The stud was simply a grade 8 bolt with the head cut off, as this one was already confirmed to work in the controller holes. The lower bracket, which just had two holes cut in without studs for the use of through-bolts, were then given ½” long slots running perpendicular to the length of the bracket. These slots were around 1” from either end and allowed a hose clamp to hold the bracket and controller in place on the carbon fiber supports. The attached controller with its brackets can be seen in the figure below (Figure 10).

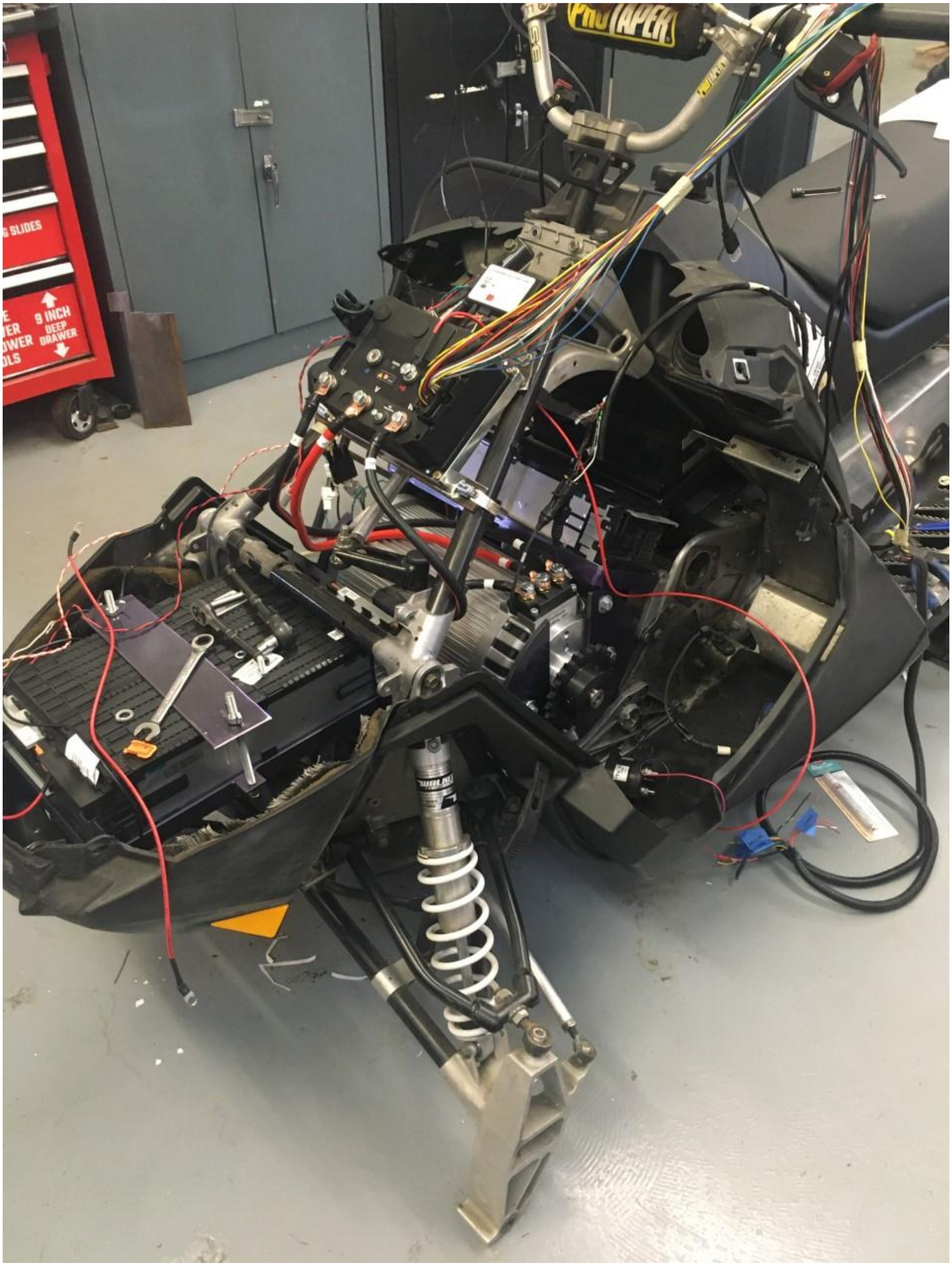


Figure 12

The smaller, 12v battery cross member was made of angle iron with end caps welded in, allowing existing bolt holes on the snowmobile to be used. Tabs welded onto the ends prevented rotation of the bracket. The battery box that attached to this was made from ⅛” plate steel, which included a plate welded on for the base and a strip that ran around to surround the sides of the battery. This was bent according to the size of the battery with a metal brake and welded to the plate. The whole box was then welded to the cross member. This component is visible in the below figure (Figure 11).

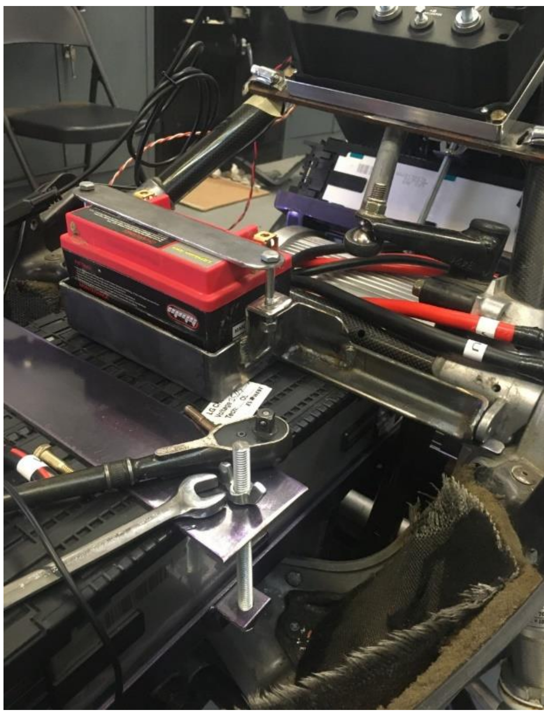


Figure 13

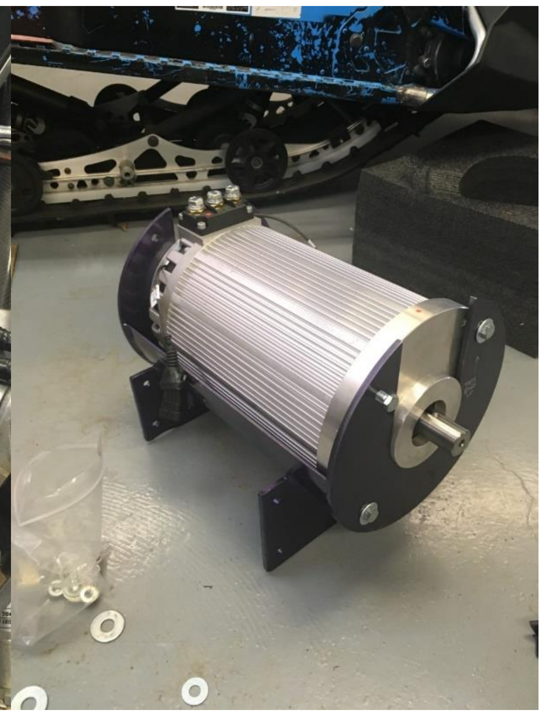


Figure 14

The motor mount, which was central to the design, used both ¼” plate and ⅛” plate, as the goal was to save weight when possible. The end cap SolidWorks files were sent to a local fabrication shop where they were cut from ¼” steel with a 3kW laser, as accuracy was very important for these parts. A piece of ⅛” steel was rolled to make up the cradle. The plates were bolted to the ends of the motor before the rolled steel was welded in place, ensuring proper fitment.

The legs that would attach to the motor mounts were cut with a plasma cutter, and then had holes drilled in the necessary locations. After taking final measurements, these plates, made of the ¼” steel, were welded on, using centerlines and a framing square to ensure proper alignment. 2 triangular gussets made of ⅛” steel was welded into place on the inside of each leg for improved rigidity. The finished mount can be seen above (Figure 12).

The input shaft for the track, though already an appropriate size, required additional machine work. Since the new design relied on a chain drive system with keyed sprockets instead of the CVT, the splines on the input shaft to the track were no longer appropriate. This shaft was removed and a ¼” keyway was cut using an overhead mill with an endmill. The shaft was reinstalled.

While most mounts were made from a combination of the different sized plate steel along with the mentioned angle iron, a chain guard that did not was also necessary for the safety of the operator and the components. To save weight, 16-gauge aluminum was used for this design, which covered the top of the chain as well as wrapping down the motor side of it. Connections between this material used 3/16” rivets, as are common in sheet metal work. A handheld pair of snips were used for smaller cuts, while longer ones could be completed with a shear. The finished guard installed over the chain is seen in the below figure (Figure 13).

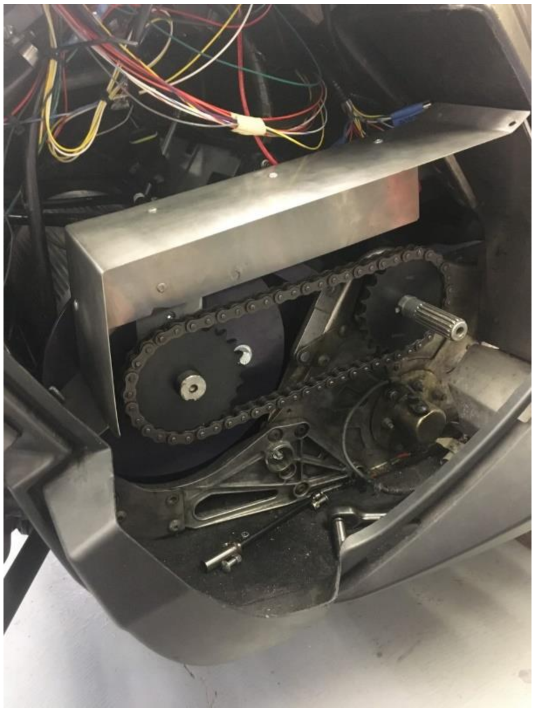


Figure 15

Another aluminum component required was a longer drag link for the steering system. By crossing over the steering and relocating the ball joint that was attached to the top end of the tie rod onto the bottom of its mount, more needed space for the controller was created. This was created on a lathe, where threads for the old heim joints were also cut in. This required that one end-use right-hand threads while requiring left-hand threads on the other.

Figure 16

Software:

There are a few different types of software required to make this electric snowmobile operate. These range from testing forces to telling components what they need to do. The software that was chosen include Solidworks, SmartView, Multisim, and a Putty.exe to run the charger. Solidworks has been the main system for designing and testing physical pieces for the snowmobile. This is a program that aids in the designing of parts and testing their functionality before actually manufacturing them. This was especially useful in recreating the frame of the snowmobile. From mounting the motor to deciding which sprocket size to use, this program has been used to help aid the decision process. This resulted in better financial situations as simulations cost much less than their physical counterpart.

SmartView is the software that NetGain has given to talk to their controller. This is their software that poses a challenge to learn and add to. An obstacle that was not initially thought of as it was assumed to be a plug-and-play system. Many options are hidden in menus, and the software was prone to crashing or exiting to the main menu, regardless of the computer running it. However once these issues could be avoided, the software does offer a large amount of versatility. Almost every behavior of the motor is customizable including, throttle mapping, draw rates, and other power and torque limiting factors. The program is very nice in that the controller begins to learn the system and can create a power density curve. This means that a State of Charge (SoC) percentage can be displayed, along with an estimate of how long it expects the batteries to last between charges.

Overall, the software was fairly straightforward to use, and when issues were encountered, its uniformity allowed for easy diagnostics over the phone. For instance, the easy command interface with the Thunderstruck Charger allowed for the easy tracing of CAN BUS messages and output commands to test the functionality of the charger and controller. This is how we were able to diagnose the charger being incorrectly paired to the system.

Unforeseen Issues:

Unfortunately, we began to undertake this project at a time when the world was still coming out of COVID-19 lockdowns. This meant that many places were still returning to the workplaces. This also meant that working with our primary electronics company, EV West, a company based in California, several issues were encountered. The motor and its accompanying controller were ordered in Mid-October, once all account issues were resolved and the money required was accessible. The items did not reach our hands until just before Thanksgiving break. This resulted in a much adjusted and tighter timeline than initially aimed for. Other parts took extended periods to arrive as well, continuously delaying progress on the snowmobile. With the number of delays the project encountered, the project could not be completed by the February deadline that was originally put in place. The project is now being completed at the tail end of the semester, in late April. This means that very little time was spent debugging, fine-tuning, and testing the sled before it was presented during the Undergraduate Research Forum.

Other issues encountered include an outdated wiring diagram, with numerous mislabeled or mispenned wires which led to near impossible diagnostics. It took people who knew that it was misprinted and outdated, and who acknowledged the need for an updated version, to guide how to properly wire some of the secondary items such as the throttle.

The charging system was another one of the problematic components. Due to our charger being wired for 110 Volts instead of 220 Volts, or J1772 compatibility, it led to several error messages. Many of them were minor, such as it is looking for a loop signal indicating the J1772 plug being connected and locked. This was bypassed by simply grounding the signal.

As with all prototypes, issues are bound to occur, and this project was no exception. One of the first to present itself was the lack of space for components. While we knew the motor would be smaller than the gasoline one that was removed, more than 400 square inches of space had to be dedicated to holding the five batteries used to power the system. Two fit very easily in the nose of the sled, however, the last three proved troublesome. Stacking in the nose posed a balancing issue, as well as making the entire power source being housed in the area most likely to face an impact. Instead, two batteries were placed on the opposite side of the motor. This was accomplished by cutting the face of the gas tank out and making a mount that held them firmly. The final battery was ultimately housed in its mount bolted onto the motor mount. This keeps all the batteries separated for balance, and hopefully should help keep them cooler.

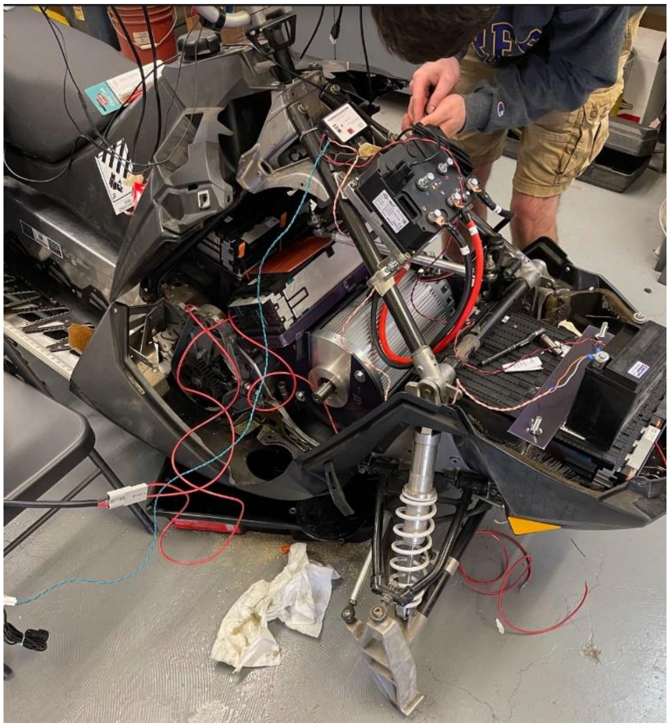


Figure 17

Shortly after all the wiring for the batteries was completed, we discovered that we forgot to order a fuse for the system. Not knowing what size to get, a call was made to the manufacturer. While we were told previously that the system "Had low input amperage", we quickly discovered that this meant low in comparison to the 500-amp output. Low, in this case, meant approximately 250 amps, with surges as high as 400 amps. This was far too high of a current for the 10-gauge wire used and required us to swap it all for 2/0-gauge wire. This is a difference of one-half-inch diameter (0.51 inches) versus one-tenth inch (0.161 inches) diameter wire. This was a very time-consuming setback that required small modifications to the batteries. The batteries ordered were recommended to us for use in this project by a conversion company. They're incredibly small and lightweight but feature high voltage and power storage. Despite all of this, and them being advertised for their ease of wiring in series or parallel, they only have ¼ inch studs for terminals. Additionally, these studs are mounted in plastic which makes them prone to becoming loose. This proved to cause difficulty with the much bigger wires being used however the system was completed and made safe with the addition of rubber covers to cover the copper lugs of the wires, and a spray-on material to prevent touching the other metallic battery components.

The final wiring issue faced before programming was the master disconnect and fuse. Ultimately a decision was made to order from across the country and pay for overnight shipping. Due to the unusually high voltage in combination with the high amperage, the only options were large industrial panels and disconnects. Besides being large and difficult to mount, with some being larger than the motor itself, we again turned to our supplier. A solution was found in a 1000 Volt, 800 Amp disconnect in addition to a 300-volt, 400 amp fuse to protect the system. With our research, the disconnect offered is one of the only ones on the market with as high of a rating as it has. Often, we would find one with the correct current maximum, with the compromise of only being rated for 48 or 60 volts maximum. The only component not permanently mounted now is the charger due to its large size. Places where it initially might have gone, have since been dedicated to other items. Two remaining locations would be where the brake light formerly was behind the rider's seat (Blue) or sticking out of the hood near other large items (Green) seen in Figure 16 below. The charger we originally intended to use with the system is physically much smaller but has been backordered for months. When purchasing the charger in early January, a projected delivery date of early June was offered to us.

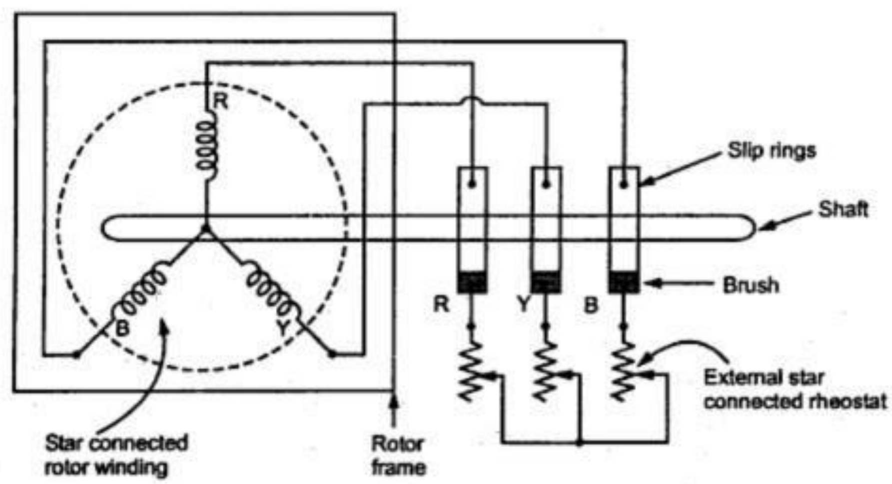
This semester brought new challenges to face. With the goals for the Fall 2022 semester laid out the first step in starting to reach these goals was to acquire the funds to buy all of the parts needed. This proved to be the pivotal part of this project and is the reason for not reaching our goals. The method for gaining funds that we have used in the past was to make an individual funds request to the senate for Clean Snowmobile instead of going through the Saxon Racing board because we have our own separate business account. This method was forced to change this semester due to a change in the senate advisor position. After submitting and getting approved by the senate board three weeks in a row the advisor to the board denied my requests. After finally coming to a conclusion on what needed to be done, I was instructed to start from scratch and make a brand-new club to submit funds requests. This was another three-week process due to approvals and holiday breaks. In total the time it took to receive the funds was a painstakingly long six weeks. Once finally approved, the needed parts were ordered with three weeks left in the fall semester. Prior to ordering these parts, we did order supplemental parts to work on something while waiting for the rest of them. We were able to figure out a lot of the wiring and placement of the parts on the snowmobile but could go further until the rest of the parts arrived. By the end of the fall semester little was accomplished but much was done in terms of starting the new club, successfully obtaining funds, and planning for the next semester.

Advantages:

“Why would the group want to make an electric snowmobile?” This question can be answered through a series of advantages that come along with having an electric motor over a combustion engine. Generally, electric motors are easier to maintain. Internal combustion engines are highly complex and rely on thermodynamic chain reactions to function properly and at the highest efficiency allowed by the motor. Removing a lot of internal parts and functions opens the stage for easier physical maintenance. Talking specifically about the snowmobile itself, a rider may be in more unfriendly conditions during a breakdown than they would find themselves in while operating other vehicles, like an electric car. Simply stating, it is easier to perform maintenance on a road than it would be on a snowy trail in the woods. Therefore, by diminishing some of the complexity of the engine it would be a safer and easier alternative to swap an internal combustion motor for an electric one. Secondly, it is widely known among enthusiasts that electric motors are vastly superior in terms of efficiency. For snowmobiles, this is a huge consideration to consider. On average, snowmobiles tend to have 10-20 MPG of fuel consumption. While tolerable, this could be drastically improved upon by stored battery energy. Practically, this is also again preferably more manageable. A longer-range provides a greater tolerance to work with while riding on trails. Longer trips can also be taken; however, it is worth noting measures need to be taken to prevent excess battery drain due to cold ambient temperatures. This increase in efficiency is also environmentally friendly, although snowmobiles are not a major contributor to carbon emission damages. However, that can be a major selling point regarding modern climate concerns. Another advantage of an electric motor would be a substantial increase in output torque. Electric motors can produce instant torque, which is the act of reaching the maximum torque of a motor at a standstill. Normal gas-powered engines cannot achieve this mainly because the engine is heavier than an electric motor which adds resistance to the vehicle's ability to accelerate. With this in mind, and in moderation, instant torque would prove to be useful for multi-terrain conditions that a snowmobile may encounter. Getting out of deep snow or an emergency would be a lot easier using an electric motor. It is important to keep in mind the weight of the vehicle, however, as too much torque could make it undrivable. Like a drag car, too much torque could send the snowmobile upwards and could result in a hazardous situation. And since a snowmobile is not a very heavy vehicle, this is a consideration to consider. Other than practical purposes, an electric sled can offer many recreational pleasures that can be more appealing than traditional sleds. For example, there is virtually no noise being produced by the sled. Approaching this from a recreational standpoint, this can be great for someone more concerned about nature while riding trails. Along with this, there may be more areas to ride in the future due to lack of noise pollution, trails can be more involved with populated areas while respecting laws regarding noise restrictions. These trails may also be limited to electric sleds only, meaning there will be less traffic restricting riding pleasure. Circling back to instant torque, while useful for getting out of emergencies, can also be enjoyed by consumers looking for quick acceleration. There is already a large demographic of people interested in performance sleds and an electric sled can meet that standard. With 0-60 times easily overwhelming gas-powered sleds, an electric sled can be increasingly appealing.

Electric Motors:

Induction motors tend to be three-phase machines that can act as a motor as well as a generator for the vehicle. They work by having a coil of wire run through a magnetic field. From there a current must be run through that coil for a phenomenon to happen called electromotive force (EMF). This is the basis of induction



motors.

Figure 19

The stronger the magnetic field and input of current determines how much force is outputted. These motors do not have a flywheel like combustion engines because they don't have to build up to a specific rpm range. The instant torque is a big reason for the choice of an induction motor. Due to the split in-between conductive strips, there is a backward EMF that is created. This is why there is a lack of top-end speed produced by the motor. This is where the permanent magnet motor makes up for those losses while retaining all the bottom-end torque. The permanent magnet motor is all that induction motors are and more. They are different in that they have four magnets overlaying an iron core. This makes up a more efficient magnetic field. These magnets are aligned every 45 degrees to give maximum output torque. This makes it able to run at synchronous speeds. But just like with the induction motor there is still a back EMF formed at high speeds. The other issue with this type of motor is the eddy currents they create. These currents add to the heat generated by the motor as well.

Competition and Design Influence:

When the sled was first being designed by our group, there did not exist a product on the market that was doing what we set out to do. However, only a few more months after we began to undertake the project, Taiga Motors came into the news. With recent bans and the increase in incentives and interest, more companies have been popping up with electric or hybrid vehicles and options. One of these is Taiga Motors out of Canada. They offer a limited range of electric snowmobiles, ranging from utility mountain sleds to high-speed performance versions like what we built. When looking at the spec sheet, their standard, and our design are nearly identical by numbers. Their motor produces 120 Hp, with 185 Lb-Ft of torque. All this is powered by a 15-kWh battery pack. Compared to our system, we feature 110 Hp, with 175 Lb-Ft, powered by an approximately 8 kWh battery pack. If their numbers can be understood to be like what we should expect during testing, then we should be easily capable of hosting a 4-second 0-60 mph acceleration time, as well as an approximately 50-mile range on a charge. The range is underwhelming but when considerations are made, our batteries are much smaller than theirs and ultimately far less expensive, it proves to be enticing. Taiga Motors can be looked to for some interesting technology to be seen.

Figure 20 **Figure 21**

Their motor is not often advertised but has some interesting details which should be made known. Firstly, Taiga Motors has opted to follow the same route as us in choosing to go for direct drive. Secondly, the motor they are using is incredibly small. Coming in at 8.7 inches in length, that makes the motor shorter than ours is wide. With the saved space, an assumption would have to be made that they filled the remaining space with battery packs to expand storage capacity. Unfortunately, since only pre-production models are available for testing, none of them have been opened to offer a glimpse into what is going on under the body panels. Once these are made public, future students will have blueprints to improve our existing design.

Testing Program:

We are looking to take as many measurements as possible and tests to see exactly how well our snowmobile will perform after our conversion, compared to before the conversion. There are several tests performed by Snowmobile Manufacturers that we will try to replicate in our real-world testing program.

These tests will consist of:

- Acceleration Test- This test will measure the time it takes for the snowmobile to go from 0mph to 60mph. This will be a good performance baseline to compare to factory sleds. We will use a zero to sixty timer app that will accurately determine the exact time that the snowmobile reaches 60 mph.
- Deceleration Test- This test will measure the distance that it takes for the snowmobile to go from 60 mph to 0 mph. This test is a good measurable to determine the overall preventative accident safety of our snowmobile compared to factory sleds.
- G-Force Test- This test will measure how hard the snowmobile will accelerate and decelerate; we can perform this test at multiple different starting speeds to see if there is a point that it would pull harder than others. There is also another G-Force meter app that we can use to effectively measure the G-Forces generated.
- Top Speed- This test will measure the overall top speed of our snowmobile and will serve as a direct comparison to factory sleds, since this is one of the tests that is highly touted by most manufacturers.

In addition to performing multiple trials for each of these tests, we will also look at testing them at different ambient temperatures. This could prove to be a huge factor in both performances, but also other factors could come into play such as decreased range and other battery related issues.

We will also look at the overall temperatures for the battery and motor to see how they react to tests throughout the day and how their temperatures affect performance.

With our snowmobile utilizing an electric motor compared to an internal combustion engine, there will also be some variation from typical OEM tests.

These tests will consist of:

- Battery Range- This will be a test of how far we could go on a single charge.
- Charging time/rate- This will test how quickly we could charge the snowmobile. We will perform this test at different battery percentages to see if it charges quicker or slower at first and vice versa.
- Comparing results at different ambient temperatures
- Comparing results at different battery/motor temperatures

Results:

Test Performed	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**
Acceleration (0-60mph)				
Deceleration (60-0mph)				
Max G-Force during Accel/Decel?				
Top Speed				
Battery Range				
Charging Time	**From 0%**	**From 25%**	**From 50%**	**From 75%**
@ freezing (32F)				
@ room temp (65F)				

Maintenance Manual:

Electric snowmobile startup and use procedure.

1. Verify the red service switch is turned 90 degrees from the lockout position.
2. While sitting on the seat, turn the key to the run position.
    1. Verify the controller light turns green.
3. Using the selector switch, select either the forward or reverse position.
    1. If selected and the sled does not move, go back to neutral and turn off the key. Then start again from step 2
4. Once a gear is selected, use the thumb throttle on the right handle to accelerate.
5. Use the left handle brake to slow from fast speeds. At slow speeds the sled will stop itself
6. Do not change gears while the sled is in motion to avoid damaging the motor, track, or chain system.

Shutdown Procedure

1. With the sled stopped, return the shifter lever to the neutral position.
2. Turn the key to the off position and verify the light turns off.
3. If performing maintenance or going near the high voltage batteries, turn the red service switch to the lockout position.
    1. The switch will be vertical, with the ability to lock it from rotating.

Maintaining the Batteries

1. Take note of the charge levels of the batteries
2. Do not let any of the battery cells drop below 3.5 Volts, this could cause critical failure and kill the batteries for good.
3. Keep track of usage miles put on the sled for battery deterioration.

Track Maintenance

1. Always inspect the track before use

   Look for signs of wear(fraying, dry rot/cracking, missing pieces)

2. Ensure all roller bearings are well greased to ensure there is not any premature track wear.

3. If a track replacement is needed, follow OEM(Polaris) guidelines for replacement.

Future Projects off Platform:

This project will open many new avenues for future projects or practicing skills around the shop. A few of the potential projects could include a cooling system, a tire system, an additional battery, and a display system with sensors.

A cooling system for the snowmobile would be a timely and good skill-filled project for future students. The motor runs around 100V through it at any given time, this produces a fair amount of heat. A large amount of heat could cause damage to the motor and other components of the snowmobile. Along with the motor generation heat, the batteries and cables have a high amount of voltage and current that cause a good amount of heat. Batteries can be permanently damaged through excessive heat to the point where they won't be able to hold a usable charge. The cooling system would provide a way to keep the system at a lower temperature as the snowmobile is in use. This would help increase run time and prevent damaging the components.

Another issue that the snowmobile has currently, is that it is strictly a snow-going vehicle. The track of the snowmobile is also wearing thin. It had been worn down by the previous owners and will need to be replaced shortly anyway. Making it usable indoors poses an interesting chance to make an outdoor vehicle usable indoors. This would include making hubs to fit the front two ski mounts, a third wheel with a swing arm and new gearing, or a new track for other uses. Adding a swing arm would require additional suspension components. Along with that, a new drive train would have to be added. This would give us more control over gear ratios and the type of power outputs. Once the drive components are implemented, a new braking system would be needed. The current setup has a very small rotary braking system and relies on the friction of the track on the ground to stop. The motor can help apply some assistance in braking but not enough to go without upgrading other components.

Like most automobiles, an indication of battery level, speed, and RPMs should be displayed to the operator. This is a safety issue for new operators. This leads to another possible project for future students. The addition of sensors is necessary if we were to produce or pitch the idea of production of this electric snowmobile. A monitor is available from NetGain, but it is rudimentary and would need some time and minor tweaking to make it accurate in what it displays. Having this display will help users operate the vehicle, giving them the necessary knowledge that is needed to be known about the system. Along with the display, NetGain has a battery monitoring system. This would tell the user how well the batteries are running, charging, and energy left. The monitor would make for safer charging along with creating a longer lifespan for the batteries. This will result in a greater value of the snowmobile.

Another potential improvement for the project is to add another battery to the system. While there are some constraints including limited space available within the snowmobile and time concerns now, adding another battery would be beneficial for the motor. This would increase the runtime and the power given to the motor. The snowmobile would be able to accomplish more while in use. This would allow for maximum output by the motor as currently it is limited to a max output of 125V. The motor is rated to work at a maximum of 144V in total.

With limited time and space available in the interior of the sled, we will most likely not be able to mount and connect the charger to the snowmobile before the end of the semester. This project will most likely be addressed next semester. Luckily, because all five batteries were delivered with a charge, the snowmobile will be able to fully function without the charger being installed. Although the charger not being installed isn't an immediate problem, if we want to be able to recharge the snowmobile and use it more than a few times the charger must be set up. This will be the most important aspect of this project soon. Once the charger is complete, we will be able to run the snowmobile frequently and be able to charge it using a typical 120V outlet. The ability to run and recharge the snowmobile will help us to analyze its performance and will lead to new ideas of what improvements can be made to the project.

Waterproofing:

One of the many challenges the club had with this project was waterproofing the battery and all the wiring that comes with it. Due to this snowmobile previously being a combustion engine snowmobile, it did not come with much previous waterproofing. This is because a battery was not the intended power source when the original engineers designed the snowmobile so they did not need to waterproof to the extent that we needed too. This presents a new challenge to our group as we had to modify the existing model to reflect the safety features needed for our new model to run smoothly and safely.

To accomplish this task we acquired some high density polyethylene panels and silicon sealant. Our plan is to cut the polyethylene panels to the size of all the various vents in the hood of the snowmobile. After cutting them to size we will use the silicon sealant to hold the panels in place over the vents and to plug up little holes or openings that may occur from human error in the panel cutting process. Plugging all the vents on the hood of the snowmobile will make sure as the snowmobile drives all the snow in front won't penetrate the hood and potentially ruin our battery.

One concern with this design is how heat will escape from under the hood now that the vents are plugged. Now since the snowmobile is battery operated and will only be used in the winter and snow where it is cold there is a chance the battery could never give off enough heat to cause any issues. However, if this does become an area of concern putting in an exhaust that comes out the backside of the snowmobile should be considered.

Website:

The club has created a user-friendly website that is easily accessible to other students on campus. The website serves as a platform to showcase the club's work, provide information about the club's current situation, share future plans, and allow interested students to contact the club.

The website features a detailed section on the club's purpose, goals, and objectives. This section explains the club's focus on the innovation of electric vehicles, and how they plan to achieve their goals through a team effort. It also provides information about the club's history and achievements to date, to give interested students a sense of the club's progress.

Another important section of the website is the Snowmobile Gallery, which showcases the progress of the snowmobile being worked on. This section includes pictures and videos of the snowmobile, highlighting the club's accomplishments and how it has evolved over time. This gallery also serves as a motivation for current and future members, as they can see the tangible results of their hard work.

In addition, the website includes a section on future plans of the club. This section outlines the goals the club aims to achieve in the near future, providing a clear vision for the club's direction. This information is essential for interested students to understand the club's long-term objectives and how they can contribute to achieving them.

Moreover, the website includes a final report section, which contains comprehensive information about the snowmobile's final design, including its technical specifications, the challenges faced by the club during the design process, and the solutions implemented to overcome them. This section provides a detailed and transparent overview of the project and is essential for any student who wants to learn about the technical aspects of electric vehicle design.

Lastly, the website includes a contact section, where interested students can find contact information for the club. This includes email addresses, social media handles, and physical locations. This section is essential for interested students who want to learn more about the club and potentially join the team.

Overall, the club's website is an excellent resource for undergraduate students who have an interest in electric vehicle innovation. The different sections provide comprehensive information about the club's progress, goals, and objectives, while the gallery section showcases the club's tangible results. The website also serves as a platform for interested students to contact the club and join the team, further promoting innovation and the development of electric vehicles.

Conclusion:

Our team was able to successfully convert a gas snowmobile to a fully electric one. Given the time constraints, the sled is far from finished. To fully optimize this sled, we must continue with the engineering process and test, analyze, and improve the system. The sled has many electric and mechanical parts all working in unison and as with all things, the components have room for improvement. Granted this project had several issues caused by supply chain issues and poor customer service. These issues resulted in long wait times and wrong parts being shipped. Regardless, even with these issues, our team was able to build a functioning electric snowmobile. This snowmobile is one of the first of its kind and our team is proud to have been given the privilege to build one. We are excited to see what future teams do to modify and alter the electric snowmobile for it to reach its full potential.

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