Clarkson University Electric Snowmobile

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ABSTRACT

The 2007-2008 Clarkson University Electric Knights S.P.E.E.D. team has taken a 2008 Polaris 600RR and converted it into a fully electric powered snowmobile. After gaining much experience as a team in the past year, a totally new snowmobile, drive system, battery pack, and battery management system were utilized to produce a better electric snowmobile. The new snowmobile is lighter, stronger, and has better suspension, allowing it to handle the weight and forces of the new battery pack and motor. The batteries used this year are lithium polymers and provide an increased energy density, allowing for a lighter and longer lasting energy source. The drive train this year is a direct drive belt system that will provide adequate propulsion from the instant torque of the electric motor. These enhancements will allow the snowmobile to be lighter and faster than last years, as well as more energy efficient. This should make the snowmobile more fit for handling, acceleration, and endurance for both the competition and real life applications.

INTRODUCTION

WHY ELECTRIC?

Despite the modern possibilities of electric vehicles, it is no surprise that the technology has been around since the early 1800's. Engineers such as Robert Scotland, Thomas Davenport, and Gaston Planet made valuable contributions to the early versions of electric vehicles[3]. However, it was no surprise that the electric vehicle was almost forgotten by the early 20th century, when the need for vehicles with long range was essential and the combustion engine dominated the vehicle market. Now, society recognizes the fact that it is paramount not only to invest in electric vehicles, but electric snowmobiles as well.

The need for an electric snowmobile was proposed by researchers on Greenland's ice cap[13]. Researchers at Summit Station sought a zero emissions snowmobile because of their studies on anthropogenic activities. Fossil fuel emissions alter the data collection, to a point where the results become significantly inaccurate. With a zero-emissions snowmobile, researchers can collect data without worrying about flawed results. A zero-emissions snowmobile with long range and high quality battery technology will benefit researchers by allowing them to have more test sites which are farther apart by providing transportation to desolate locations.

Although this competition calls for a zero-emissions snowmobile, it is also important to recognize the impact of electric vehicle technology. Electric vehicles provide an environmentally friendly future that upcoming generations need desperately. Electric vehicles do not emit greenhouse gases and they reduce noise pollution. By investing in electric vehicle technology, consumers and researchers are investing in a better environment for tomorrow.

OBSTACLES ELECTRIC VEHICLES FACE

The adoption of fully electric vehicles into the consumer market has been extremely slow. One of the largest reasons for this is that electric vehicles face a very large obstacle; energy density. Gasoline, the fuel used to power most vehicles in this day and age, has a high energy density, about 8760Wh/l [7]. If an average snowmobile carries 40 liters of gasoline, the snowmobile would have 350400Wh of energy on board. Using a density of 0.73kg/l[6] for gasoline, the average snowmobile would need to carry 29.2kg of gasoline to equal 350400Wh of energy. Batteries on the other hand have a much lower energy density. Table 1 below shows some common batteries, their respective energy densities and charge and discharge efficiencies.

Battery Type	Approximate Energy Density	Charge/Discharge Efficiency
Lead Acid	30-40Wh/kg	70%-92%
Nickel Medal Hydride	30-80Wh/kg	66%
Lithium Ion	160Wh/kg	99.9%
Lithium Polymer	130-200Wh/kg	99.8%

Table 1: Battery Types and Energy Densities[11]

From this table, it can be seen that even using a lithium polymer battery with an energy density of 200Wh/kg and an efficiency of 99.8%, approximately 1756kg of batteries would need to be on board the snowmobile to carry as much energy as 40 liters of gasoline. It is implausible to be able to carry this much weight on a snowmobile.

An important factor has still yet to be considered in our calculations. Gasoline engines are very inefficient in their nature, whereas electric motors are much more efficient. Gasoline engines operate at about 15% efficiency[8]. Electric motors on the other hand have a much higher efficiency. Current electric motors can achieve efficiencies of up to 95%[5].

Propulsion Method	Gasoline	Electric
Energy Used to Propel Vehicle	52560Wh	
Efficiency	15%	95%
Energy Needed on Board	350400Wh	55326Wh
Equivalent Weight	29.2kg	307kg

Table 2: Propulsion Methods and Energy Efficiencies

Since an approximate value for the energy on board a gasoline powered snowmobile is known and the efficiency of a gasoline engine is known, the amount of energy which is actually used to drive the snowmobile can be calculated. This number can bee seen above as 52560Wh. Assuming a 95% efficiency for an electric motor, an electric snowmobile would only be required to carry 55326Wh of energy. If this amount of energy is used to recalculate the weight of batteries needed on the snowmobile, it can be found that the snowmobile would only need to carry 307kg of batteries instead of the aforementioned 1765kg. This weight, even though still quite large, is a huge improvement and gives a glimmer of hope to the dream of building an electric snowmobile which can compete with its gasoline powered counterpart.

PAST EXPERIENCE

Last year (2006-2007) was the electric knights first year designing an electric snowmobile. The first attempt consisted of an Arctic Cat 440 with nickel-metal hydride batteries and a Solectria motor and motor controller. The nickel metal hydride batteries were a mid range power source in terms of batteries, better energy density than lead acid batteries, yet less than lithium type batteries. These batteries gave the team a total power of only 4 KW, not nearly enough to fulfill the motors potential. The drive train consisted of two chain systems, the first one took the place of the conventional clutches and was an ATV chain connecting two sprockets with a 1:1 gear ratio. The second one was the stock chain case with a 2:1 gear ratio. With the batteries and the gear ratio's the snowmobile achieved a top speed of 15 mph, not exactly a typical snowmobile speed.

This year the team took the knowledge gained from the previous design and applied it to a new and better design. One of the first things learned from the old snowmobile is that more energy was needed in order to properly power the motor. This meant that this years design needed to incorporate either more batteries or batteries with a higher energy density. The next thing the team learned from the old sled was that the new snowmobile needed a quieter and different ratio drive train. The chain drive previously used worked well with the old setup, but with more power and torque planned for the new sled, a different ratio was necessary. A system which would have a higher drive ratio and would operate with less noise would be ideal. The team also came back from competition with the feeling that suspension and comfort play a key role in both winning the competition and real life application. Last year the shocks in the suspension failed while at competition because the force the shocks could withstand was exceeded by the extra weight, something the team did not want to see repeated. With the added weight of the batteries and motor, a better suspension system was needed. This played a role in our chassis selection as our team looked for a snowmobile that had a chassis and suspension capable of carrying the extra weight. Last years results allowed us to learn from both failures and triumphs to improve upon this year's design.

DESIGN GOALS

Based on last years performance and our budget for this years competition, the team came up with a number of goals for this years snowmobile design. Two of the design goals were not related to competition and the others were. One of the teams personal goals was speed. The team wanted to design a snowmobile that would be able to reach speeds of 50mph. To achieve a speed of 50mph it would be necessary to be able to draw a lot of current from the battery pack. This would have a direct influence on the team's choice of batteries and an effect on the gear ratios.

The team had one other personal goal and that was not to alter the exterior of the snowmobile at all. The team wanted the snowmobile to be indistinguishable from its gasoline powered counterpart when viewing it externally. This meant that everything that goes into converting this snowmobile needed to fit into two areas; under the front cowl and inside the gas tank.

Having a sled that looks like its gasoline counterpart and can achieve speeds of 50mph are nice goals but these goals would not help the team win the competition. To win competition, the team would also have to set some other goals. One such goal was to reduce noise. The team decided that having a sled that ran extremely quiet would very advantageous. This goal would effect how the team would choose its drive system.

Another goal that the team set was to have a snowmobile that weighed as little as possible. To achieve this goal, light batteries would need to be used. Next, a light chassis would need to be attained. Finally, the weight of every component put onto the snowmobile had to be conserved.

In addition to the previous goals, the snowmobile needed to be able to travel as far as possible, at least ten miles. This goal would have an effect on the type of batteries chosen and how many batteries were put on board. Also, the gear ratios used would help to achieve this goal.

Handling and rider comfort were another main concern in the design of this snowmobile. Rider comfort would be fairly easy to achieve if the team attained their goal of not altering the exterior of the snowmobile. Special care would be taken to keep familiar controls and any new controls would be intuitive and easy to use. The center of gravity of the snowmobile and the type of shocks would be contributing factors to the handling of the snowmobile.

Cost was the final goal that the team had. The team wanted to create the snowmobile as inexpensively as possible. The team realized that in order to gain the type of power riders want, cost would need to increase. Due to this trade-off between cost and power, the team decided that all of the other goals would be placed ahead of cost. After all, a finished product that worked well in every aspect was worth far more than a snowmobile that did not operate well, was hard to use, and looked distasteful.

SNOWMOBILE DESIGN

The design of this years electric snowmobile encompass three main areas. The design of the electrical system is the first. This system is really the heart and soul of the snowmobile. The second design aspect is the selection and usage of a proper chassis to put the electrical system into. The third part of the design process is the drive train. The drive train is responsible for interfacing the power provided by the electric motor to the track of the snowmobile. Each of these areas is critical to the success of the snowmobile.

ELECTRICAL SYSTEM

At the core of this snowmobile lies its electrical system. The electrical system incorporates the high voltage rail, the batteries and their configuration, the low voltage rail, and the battery management system.

Battery Selection

The first step in the design of our electrical system was to select a battery that would be consistent with our design goals. The choice of batteries would have an effect on almost every aspect of our design goals. Most noted of these design goals would be weight and cost. The batteries would also have a noted effect on aesthetics, handling, and rider comfort, depending on their placement on the chassis.

Batteries are classified in a number of ways. The first major classification would be disposable batteries or rechargeable batteries. Disposable batteries, due to their chemistry, can only be used once. Rechargeable batteries can be recharged from an external source so they can be used many times before their useful lifespan expires. For this project it was obvious that disposable batteries were out of the question. The second consideration for our batteries was the temperature in which they could effectively operate. Since the batteries were to be incorporated on a snowmobile, the batteries must be able to operate in sub-freezing temperatures. The next major classification of batteries would be by energy density. Different batteries have different energy densities. The energy density of they battery will effect the weight. It will also have an effect on the size of the batteries which will in turn govern the placement of the batteries on the chassis. The fourth consideration in choosing a battery is its discharge rate. Some batteries can provide a much higher discharge current then others. In order to achieve our goal of speed, a battery with a high discharge rate must be chosen. Another classification, of considered batteries, was the price and safety of batteries. Price was not a major concern, but safety was of utmost importance. A final classification of batteries would be by their useful lifespan. A batteries useful life span is a measure of how many times a battery can be charged and discharged before it is no longer able to function correctly. Four types of batteries that fit the aforementioned specifications were examined and Table 3 shows the findings below.

Battery Type	Energy Density (Wh/kg)	Price ($US)	Disadvantages	Recharge Cycles	Peak Discharge Rate times cell capacity (A)	Operating Temperature (°C)
Lead Acid	30-40	5-8	Weight, Short Life Span	500-800	3.5x	-40 to +60
Nickel Medal Hydride	30-80	1.37	Weight, Low Discharge Rate	1000	2.3x	-30 to +60
Lithium Ion	160	2.8-5	Volatile, Cost, Low Discharge Rate	1200	2x	-20 to +60
Lithium Polymer	130-200	2.8-5	Cost, Short Life Span	500	5x	-10 to +60

Table 3: Battery Types & Energy Densities[11]

The decision as to what batteries were to be used was reached after much deliberation. Batteries with a lower energy density such as nickel medal hydride and lead acid, had major cost advantages but due to the low energy density, a huge mass and volume of these batteries would need to be incorporated in the snowmobile design. The large mass and volume would have extremely adverse effects on major goals such as weight, aesthetics, handling and rider comfort. This decision left the team to choose from either lithium ion batteries or lithium polymer batteries. Due to safety concerns with the lithium ion batteries, lithium polymer batteries were the teams final decision. These batteries would come with a high price tag and would have a more limited life span but would be small, lightweight, safe, and operate in a cold environment.

Lithium polymer batteries were chosen and the team began looking at the offerings of different manufacturers. After looking at the offerings of a number of manufacturers, BatterySpace was chosen because they offered the right size battery for a reasonable price. The cells chosen were 3.7V cells with a storage capacity of 10000mAh. These cells have an energy density of 171Wh/kg. Each cell weighs 210 grams[2]. Two hundred such cells were purchased at a price which consumed most of the teams operating budget. A photo of the cells can be seen in Figure 1.

Figure 1: Lithium Polymer Battery[2]

Main Power System

The 200 cells purchased from BatterySpace will provide the power to drive the motor and make the snowmobile move. Since the motor that was chosen requires a 144v nominal supply, the 200 batteries will be wired in an interesting configuration. Batteries will be put into forty groups of five batteries each. The groups of five batteries will be wired together in parallel. The forty packs will then be wired together in series. This will give the overall battery array a voltage of 148v, almost exactly what is needed to power the motor. A figure of the wiring diagram can be seen in Figure 2.

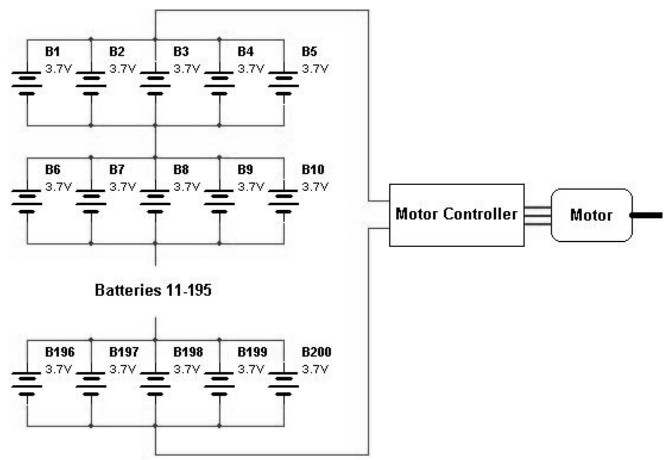

Figure 2: Battery Wiring Diagram

After a battery wiring schematic was derived, it was time to wire the batteries. As can be seen in Figure 3, the batteries shipped with very small tabs which were very prohibitive in their wiring flexibility. The tabs are made of .004" thick nickel. This nickel was somewhat fragile and the wiring scheme needed to take that fact into consideration. After some deliberation, it was decided that the tabs of the batteries needed to be extended in order to wire them. The team ordered thin sheet nickel to cut into short lengths to extend the battery tabs. It was first decided that the nickel extensions would be welded onto the existing tabs. This method appeared to work when it was tested but due to some unknown circumstances, the welding machine did not to function correctly. The decision was then made to solder the extensions to the existing tabs of the batteries. This method presented a few challenges. First, soldering would take much longer than the aforementioned welding procedure. Secondly, the heat from soldering could impose a threat to the batteries. Even with these challenges, no other options presented themselves so the team decided to move forward with soldering. Holes were put into the end of each tab of the battery so that the batteries tabs could be bolted together to easily connect the cells in parallel.

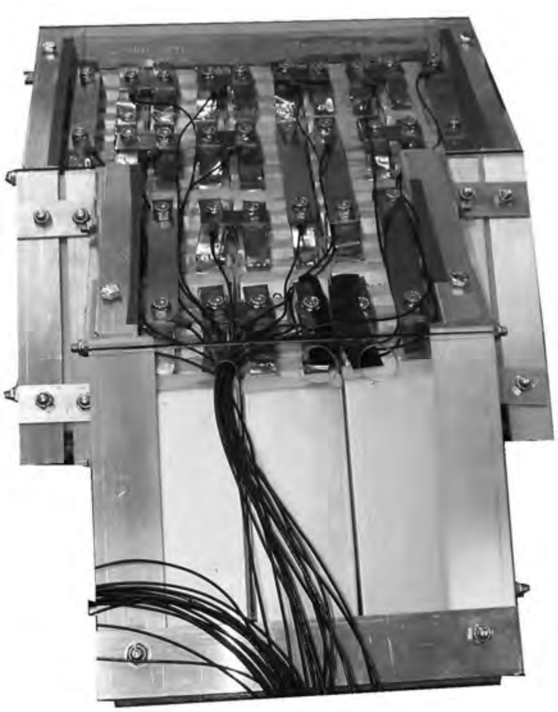

Figure 3: Battery Tabs and Connections

Battery Management System

With a 200 cell battery pack comes many challenges. One of these challenges is attempting to maintain all battery voltages at same level. This ensures that each battery is delivering the same amount of power to the motor and that no single battery is under performing. Under performing batteries can have detrimental effects on the entire battery system. To ensure that all batteries would be maintained at the same voltage level, the team devised a battery management system or BMS for short. Knowing that the cells which were in parallel would balance out themselves due to the fact that they were wired in parallel, the team only needed to make sure that each of the forty battery packs were maintained evenly, not each individual cell.

The design that the team came up with was simple. The BMS would measure the voltages across each pack of batteries. The battery packs with the highest voltages would have a resistor put in parallel with it to drain some of the excess power and stabilize the voltages across the system.

Implementing the system however proved to be more difficult. Step one was to measure the voltages across each pack. To do this a programmable logic device (PLD) was set up in conjunction with analog multiplexers and an analog to digital converter to measure the voltage of a battery pack. Having a configuration to measure all of the packs voltages at the same time would have been difficult, so the PLD was programmed to send a signal to the multiplexers to tell it which battery voltage to measure and in turn the analog digital converter converts the voltage of that battery pack into a digital signal that the PLD can utilize. The PLD determines the lowest voltage and for every battery pack whose voltage was above the lowest voltage a signal would be sent to a relay to activate a resistor across each of those battery packs to balance their voltages. The analog multiplexers, however, failed to deliver the desired results in this application so the team was forced to use relays to accomplish the correct operation. The use of analog multiplexers would have resulted in a simpler design and a lot less work to implement the BMS.

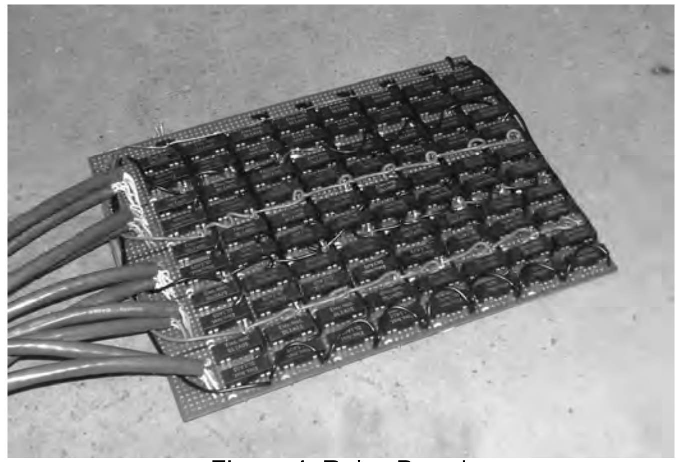

Figure 4: Relay Board

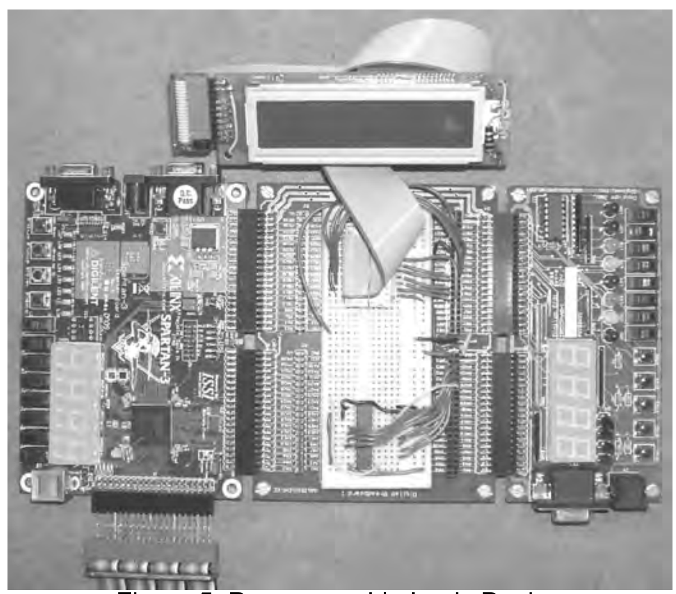

Figure 5: Programmable Logic Device

Auxiliary Power System

For the implementation of our design, a low voltage power rail was needed to power both the motor controller and our battery management system. Two options were available to supply this power rail. The first option would be to use a DC to DC converter to lower the voltage from the main battery pack. The second option was to add another low voltage battery to our snowmobile to provide this power. The decision here would affect the goals of cost, weight, and ease of use. Table 4 below shows the two different options and the considerations for each.

Option	Price	Approximate Weight	Ease of Use
DC-DC Converter	High	.2 kg	Requires no extra work on users part
Low Voltage Battery Pack	Low	4 kg	An Extra Battery Would Need to be Charged

Table 4: Auxiliary Power Rail

Since nickel medal hydride battery packs were available to use from last years sled at no cost, and a DC-DC converter would have cost a substantial amount, it was decided that the low voltage power rail should be provided by NiMH batteries. This decision will increase the weight of the snowmobile, but not by a considerable amount. Also, this battery pack will need to be charged separately from the main battery pack. This will decrease the ease of use by a small margin.

Thermal Considerations

Thermal considerations were taken very seriously in the design of the batteries and battery management system. The batteries would need to operate in cold weather but also may need to be cooled if they got warm or even hot during charging or discharging cycles. It is important for the batteries to be able to properly cool so their operation could be optimal. The cells were spaced so that air could flow between them. Also, the PLD that will be used for the battery management system will also be employed to monitor the temperature in each battery box. This temperature monitoring system will be able to turn fans on and off that are attached to each battery box. It will also alert a user if there may be a hazard and in an extreme situation, shut down the snowmobile.

Safety Considerations

Safety was an utmost concern in every aspect of the design, especially in the electrical system. Since the designed battery pack would be able to provide very large voltages and currents it was necessary to utilize proper safety precautions. The first and most basic safety precaution was to make sure that all batteries and battery connections were secure. Vibrations or sudden motions could cause objects to move if not properly secured. The design of the battery box made sure that cells were fit snugly together and that connections would not move during operation.

CHASSIS

The chassis selection was a very important process in the design of the snowmobile. Once the chassis was selected it was important to make sure that the center of gravity was maintained when mounting components such as the battery boxes and the motor.

Selection

The first improvement of this year's design started with the selection of the proper snowmobile chassis. Since the batteries and electric motor add a little more weight than a common internal combustion, careful considerations had to be made to choose a suitable chassis. Not only must the chassis be light, but it must also be dependable enough to carry all the bulk and weight of the batteries. Four main considerations were taken into account. These considerations were the size, weight, suspension handling, and cost. The overall size of the snowmobile was one of the biggest concerns, as larger size usually means less maneuverability. The snowmobiles considered had to be small, yet fit all the necessary components such as electric motor, batteries, and motor controller. Weight is also a large factor in chassis selection. A heavier snowmobile causes worse handling and less maneuverability. Keeping the weight as low as possible is highly ideal and also a factor in competition. This means the sled must be lightweight, yet strong enough to support the added weight of the batteries and the rider. The suspension is another major part of the design of a snowmobile. The suspension must be stiff enough to support the weight of the sled, but also it must be soft enough to dampen the vibrations from the surrounding conditions. The suspension also plays a role in the handling of the snowmobile, if the suspension is too stiff the snowmobile will not be able to take corners well. Last year, the suspension chosen was not strong enough and therefore was a big concern in this year's design.

An important aspect in all forms of design is cost. An electric snowmobile is by no means a cheap endeavor, so a low cost chassis is ideal for keeping the overall price low. After a substantial amount of research into various snowmobile chassis was conducted, three snowmobiles were chosen as candidates. The three candidates were the Ski-Doo Freestyle 300, Polaris 600RR, and the Arctic Cat Firecat Sno Pro 500. All three sleds are light, compact, and have a good suspension. To decide which one to choose a table was made and is shown below in Table 5.

Snowmobile	Dry Weight (kg)	Suspension	Overall Dimensions (LxW)"	MSRP ($US)
Ski-Doo Freestyle 300	168	Stock Spring & Damper	112 x 38.2	$4,149
Polaris 600RR	215	Walker Evans Gas Shocks	110 x 48	$10,299
Arctic Cat F5 Sno Pro	207	Fox Float Air Suspension	121 x 48	$7,399

Table 5: Snowmobile Comparison Chart[1,9,12]

The above chart shows an overall winner in each category, but it took more research to determine which snowmobile to use. The Freestyle was the lightest and the smallest, but it had the least adjustable suspension and the smallest ski stance. Ski stance is important because the wider the ski stance, the more stable the sled. The Polaris had the best suspension and was the shortest sled, making it favorable for handling, but it was also the heaviest and most expensive. The Arctic Cat is the mid range, not the lightest yet not the heaviest, and has a nice suspension. It is longer than the others though and the price is rather high. After more research, the team decided to use the Polaris chassis since it had the largest motor and removing it should remove a lot of weight. Also the suspension is adjustable on the fly and capable of handling the heavier weight from the batteries. The price of the sled can also be offset by selling off the more expensive 600 motor. Figure 6 shows a photo of the stock Polaris 600RR.

Figure 6: Photo of Stock Polaris 600RR[9]

Center of Gravity

An important aspect in the handling of any vehicle is the center of gravity, where the majority of the mass is centered on the snowmobile. This is important to handling because if the center of gravity is too high the snowmobile tends to lean or tip while cornering. To improve handling, mass is placed on the skis rather than on the track. The more mass on the skis, the more the snowmobile tends to follow the path of the skis. Most sled manufacturers achieve this by lowering the engine and removing weight from the rear, a strategy our team tried to mimic. For our sled a center of gravity around the middle front of the sled was desired to make the sled handle as well as or better than stock. To keep the center of gravity in the front, all the batteries were placed in either the front or the middle of the sled while the motor was mounted down low in the front of the sled.

Battery Boxes

One of the challenges in switching energy sources from gasoline to batteries is determining where to store all the batteries. Since the team didn't build our own battery cell, the battery pack had to be capable of conforming to both each battery cell and the snowmobile. In consideration of the center of gravity of the snowmobile, the battery boxes were placed in the middle and front of the snowmobile. To mimic the original center of gravity of the sled the majority of the batteries were placed in the original location of the gas tank, under the front of the seat. Mounting the batteries under the seat allowed them to be hidden, keeping the stock look of the snowmobile. Not all of the batteries could fit in the location of the gas tank so another battery pack was made and located in the front of the snowmobile. Figure 7 shows the side view of the snowmobile with the placement of battery boxes highlighted.

Figure 7: battery box mounting locations[10]

These boxes were then built with 6160 aluminum and Lexan. The box designs are shown below in figures 8, 9, and 10. Figure 8 is the bottom box, figure 9 is on top, and figure 10 is the two boxes on top of each other. The last box is not shown, but holds 80 cells and is a square box with the dimensions 1'x1'x1'.

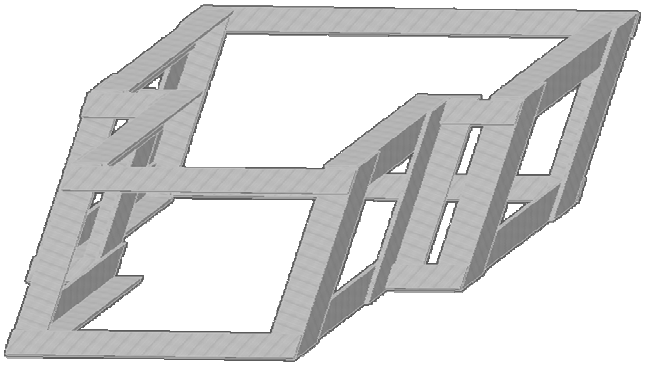

Figure 8: Battery Box 1

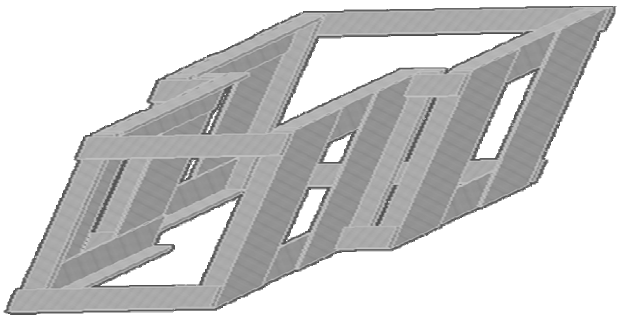

Figure 9: Battery Box 2

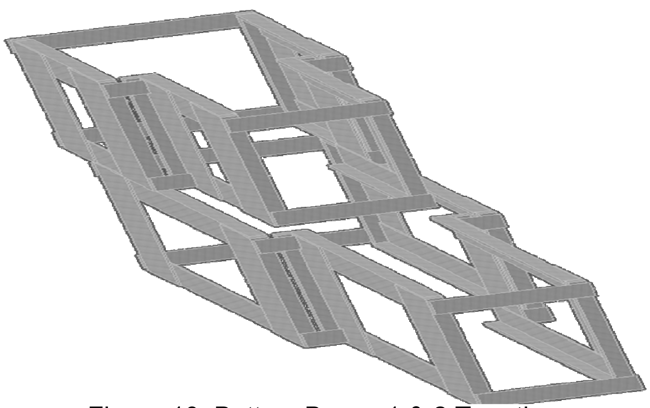

Figure 10: Battery Boxes 1 & 2 Together

In order to get the batteries to fit in the box, they are tilted at 37 degrees. Also lateral supports were added that aren't shown above, and they add more rigidity to the box and make sure the box can hold up to the forces submitted by the snowmobile. The two boxes under the seat were attached to the snowmobile with aluminum braces to the tunnel. The third box in the front was attached to the snowmobile with a steel brace across two points on the frame and an aluminum brace holding up an aluminum plate that the box is mounted to.

To keep the batteries secure and safe from the vibrations of the snowmobile, foam was added to the boxes. The foam was placed on the sides of the box to keep the batteries snug and insulated. The Lexan that provides the shell of the battery box is non conductive and so protects the batteries from shorting out on the aluminum structure. Silicon sealant and weather stripping was added to keep the box away from the outside elements and prevent electrical shorting.

DRIVE TRAIN

The drive train is the third aspect in the design of the snowmobile. It involves the selection of the motor and motor controller. It also includes the mounting of the selected motor. Also of note in terms of the drive train is the selection of the drive train and drive train ratios.

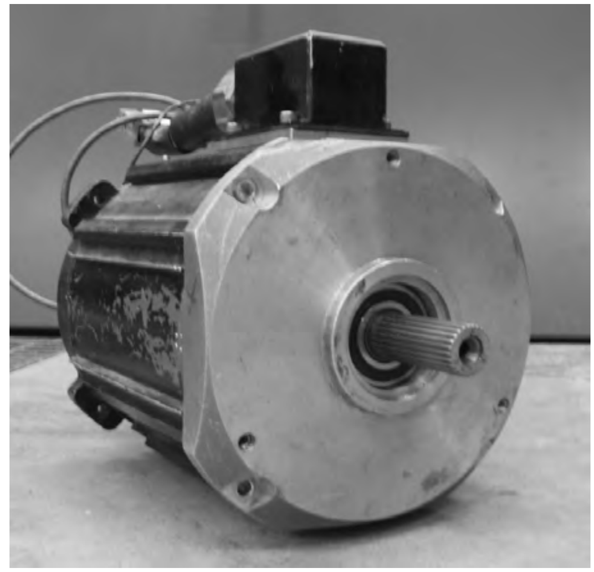

Figure 11: Photo of Solectria AC21-A Motor

Motor Selection

The motor was an important part of the design of this years snowmobile. The decision was made early on in the design process to keep the Solectria AC21-A motor that was previously utilized. A photo of this motor can be seen in figure 11. This is a high-efficiency brushless, 3-phase AC motor capable of providing a peak torque of 90Nm and handling a current up to 240Amps. The motor weighs 39kg which is a fair trade off for the amount of power it provides. It is capable of providing 37kW of power and will be receiving almost that full amount of power from the battery pack[14]. This motor was also used in the 2007 Clean Snowmobile Competition and the team is already familiar with it. By providing the motor with more power the team hopes to unleash most of the motor's potential as a big improvement from the last snowmobile.

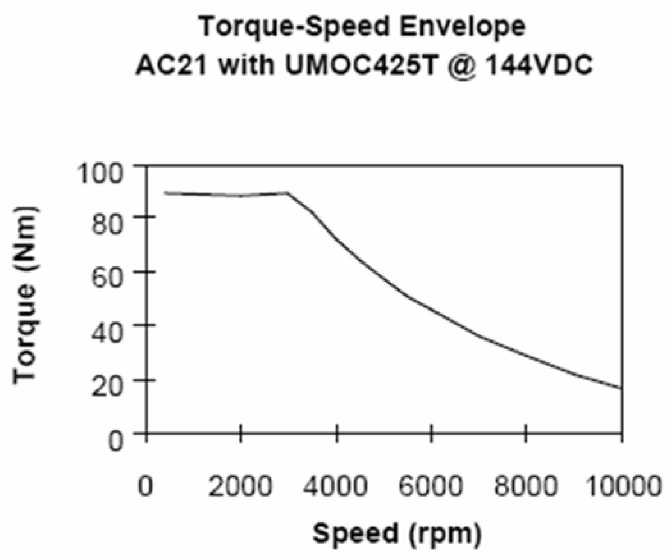

Figure 12: Torque Motor Speed plot Solectria AC21-A[14]

As can be interpreted from figure 12 above, this motor was also chosen due to the fact that it has excellent torque and efficiency at low speeds. High torque at low speeds is important because most of the competition will be run at low speeds. Therefore, a motor with high efficiency at low speeds is desired to do well in competition.

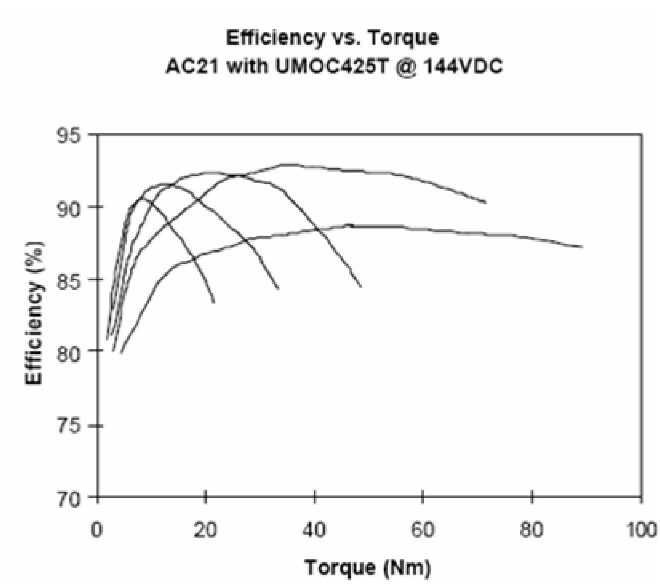

Figure 13: Efficiency vs. Torque Solectria AC21-A[14]

Figure 13 above shows the torque and efficiencies of the Solectria motor at different motor speeds, this motor is ideal because looking at the highest torque figure the efficiency is around 85%. From figure 12 this peak torque would occur around 2,000 to 4,000 rpm, this motor speed that would give us the 20 mph needed for the competition and 85% efficiency. The Solectria motor is a good match for the amount of torque and speed we need, to do well in competition.

Motor Mount

The motor mount was built to accommodate the drive system. The contours of the snowmobile made it hard to mount the electric motor. To overcome this, the team built two steel brackets to span the contour of the snowmobile, creating a flat mounting surface. The steel brackets are mounted to the chassis with rubber motor mounts to reduce vibrations from the snowmobile. Across the top of the steel brackets is an aluminum plate for the motor to rest on. This plate is bolted to the steel brackets, but is adjustable to accommodate for the drive system by allowing for minor adjustment. In order to keep the motor in place while it is running, it is necessary to include vertical mounts to restrain the motor from moving while it is experiencing torque. The vertical mounts consist of aluminum faceplates that are welded to the aluminum baseplate that lies across the top of the steel brackets. The faceplate has a cutout for the drive shaft and bolt holes, so that the motor's original support connections could be utilized. The second vertical plate, the backplate, is much smaller and on the opposite side of the faceplate. The reason for this plate was to take some stress off the faceplate and to keep the motor snug and in place. It is not welded to the baseplate but attached using angled aluminum and bolts for easy installation of the motor. The faceplate, backplate, baseplate, and their arrangement can be seeing in the figure 14 below.

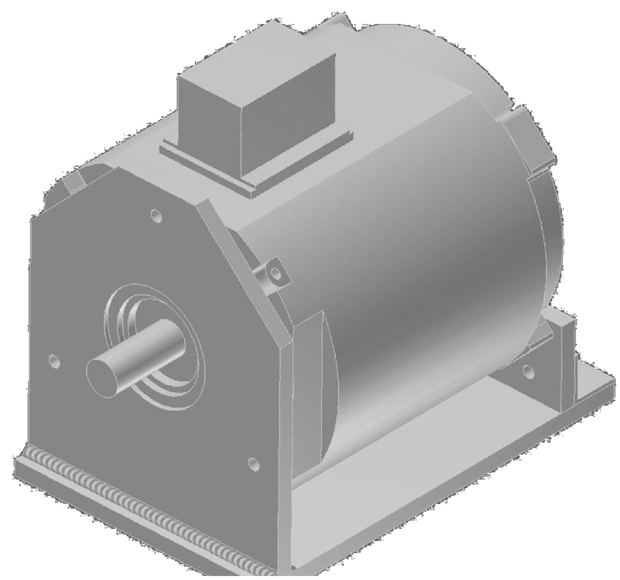

Figure 14: Completed Motor Mount with Motor

Drive Train Selection

One of the key differences between an internal combustion 2-stroke motor and an AC electric motor is the rpm range that the peak torque is reached. With an internal combustion motor, the peak torque is somewhere around 4,000-5,000 rpm. However, with an electric motor, the peak torque is instant as is shown in figure 12. To solve the problem of low torque at the beginning of the rpm range, combustion snowmobiles use a continuously variable transmission utilizing two clutches. For our motor we have no use for the primary clutch because of the instant torque produced by the motor.

So for the selection of our drive system the CVT clutch idea was a possibility, but it would have to be heavily modified. Three drive systems were weighted and thought about before the final belt drive system was chosen. The three drive systems were belt, chain, or belt with clutches. The advantage of the belt is that its quiet, cheap, simple, requires no lubrication, and can run at higher speeds than a chain. The chain drive system has the advantage of being a long life solution and capable of sustaining higher torque. Chains are very loud though, and require lubrication. The belt drive clutch system is the most complicated but offers a wide range of possibilities because it is capable of infinite drive ratios. It also suffers from the same problems of the conventional belt drive along with a decrease in efficiency because this belt can potentially slip. Shown below is a chart used to weigh and determine which drive system would be utilized.

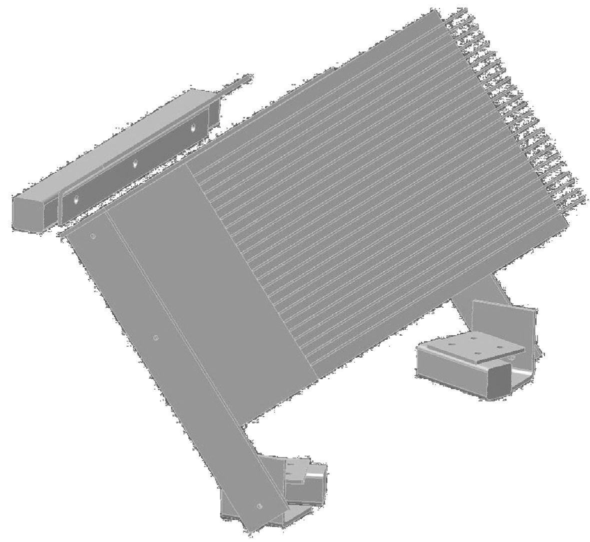

Figure 15: Motor Controller With Mounts Added

Drive Type	Life Span	Noise	Lubrication	Cost ($US)	Gear Ratios
Belt	60,000 miles	60 dB	none required	633	one (fixed)
Chain	60,000 miles	80 dB	oil bath	400	one (fixed)
CVT	3,000 miles	60 dB	none required	650	infinite

Table 6: Drive train Comparison Chart

After weighing all of these options, the decision was made to use a Gates Polychain belt. This is a synchronous type belt, but it is designed for power transmission rather than precise synchronization. The interlocking teeth design is similar to that of a chain, allowing the belt to transmit more torque than conventional flat or V belts. The Polychain belt, because of the aramid tensile cords inside the belt can be run at high speeds and withstand high impact, shocks, and surge loading. The Polychain belt can last just as long as a chain if aligned correctly, but requires no oil bath and is quieter.

Drive Ratios

The cumulative drive ratio from motor to track is 5:1. This ratio lets the motor run at its most efficient revolutions of 4000 rpm at a forward speed of approximately 20 mph. Since the speed limit during competition is 20 mph, this ratio will aid the sled during the endurance run by drawing the fewest amount of amps per mile possible. The maximum speed of the snowmobile is approximately 50 mph, assuming that the motor provides enough torque to accelerate the sled to this speed.

The ratio was determined using the size of the drive cog, chain case ratio and diameter of the two pulleys. Equation 1 shown represents the angular velocity, ω, and the radius, r, of the two belt pulleys.

$$\omega_1 r_1 = \omega_2 r_2$$

Equation 1: Angular Velocity

Since the chain case was attached to the drive pulleys through the jack shaft, the ratio from the equation of 5:1 was then divided by two because of the 2:1 ratio of the stock chain case. So the overall ratio for the two belt pulleys was determined to be 2.5:1.

Motor Controller Mount

The motor controller is a crucial part of an electric snowmobile, it provides DC to AC conversion, as well as regulation of motor speed, regenerative braking, and the output of the battery system. To reduce the use of 2 gauge wiring, we needed the controller to be near the motor, so the best place for it was under the cowl. The controller generates heat due to the amount of power it transfers. The team chose to mount the controller on top of the front frame rails under the cowl. This position provides valuable airflow, and is a convenient location for mounting. With fans mounted on the inside of the cowl and the ambient temperature during the winter season, this should provide adequate cooling for the motor controller. The main challenge of this prime position was to overcome the small space and limited supports for mounting.

Vibrations are harmful to the electrical components inside the motor controller. For this reason the vibrations from the sled needed to be minimized. With vibration in mind, he motor controller was mounted to the front frame rails with 6061 aluminum, two pieces of aluminum on each side of the controller connected to shock absorbing motor mounts, and one bar of aluminum at the top of the controller connected to the frame with the use of motor mounts. The side aluminum bars allow no torsional bending of the motor controller so it is held steady through any strange impacts from snowmobile trails. The top bar serves as the prevention against tensile or compressive loads put on the controller. The three supports surrounding the controller keep it firmly in place as well as absorb the shock thrust upon it. The motor controller is shown in figure 15 with supports

CONCLUSION

Compared to last year's model, the team believes that this year's electric snowmobile is truly one of epic proportion. Every part, from the design process to the build, had problems to overcome and successes that kept the team going. Through all the challenges, the team created ingenious solutions to cover all the design goals. Overall, it is clear that the team gained knowledge, acquired valuable experience, and understood teamwork throughout this design challenge. The end result yielded an amazing snowmobile. The Electric Knights have produced a 100 percent zero emissions snowmobile, and one that creates very little noise pollution. Our team created an easy to use and comfortable snowmobile, due to the fact it looks no different from standard snowmobiles on the market today. Not only is our snowmobile eco-friendly, but it weighs approximately the same as the average gas powered snowmobile, and has an impressive range and speed, considering it is an electric vehicle. The only downside to our product is its cost. Regardless of its cost, it is the technology of the future, providing generations to come with an environmentally sound world.

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