Design and Manufacture of a Zero-Emissions Electric Snowmobile

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ABSTRACT

The Hardrockers Clean Snowmobile Team of South Dakota School of Mines and Technology (SDSM&T) designed and tested a zero emissions electric snowmobile that is a blend between performance and utility. It's HPGC -AC20 motor delivers 100lbf-ft of torque while only requiring 15 kW all while operating at 6500RPM's. The motor is controlled by a Curtis 1238 motor controller which takes in 80V direct current (DC) power and converts it to 3 phase alternating current (AC). To further increase the power and acceleration from the drive train, 2 PA-02 linear actuators which can exert a combined force of 800lbf are used to drive an electro-mechanical continuously variable transmission (EMCVT). This EMCVT provides precise shifting for desired speed and power distribution. A Seeeduino Mega micro-controller is used to calibrate and control the EMCVT and allows for very fine tuning of the shifting specifications. Because of these and many other implications in the vehicles design, the electric snowmobile surpasses all of the National Science Foundation's (NSF) design goals which would improve its use in arctic studies.

INTRODUCTION

The Society of Automotive Engineers (SAE), in partnership with the National Science Foundation (NSF) created an event in the Clean Snowmobile Challenge (CSC) in 2004. The goal of the event was to encourage the development of zero-emissions utility snowmobiles in order help support in scientific research. A number of environmental research efforts taking place at locations such as Summit Station in Greenland and South Pole Station in Antarctica involve collecting samples of the air and snow for global atmospheric pollutants which occur in levels of parts per billion. Attempting to visit or even approach these collection sites with any internal-combustion powered vehicle, to include conventional snowmobiles, can significantly contaminate the measurements of the samples. The Summit Station research facility even has extensive areas around collection sites in which vehicular traffic is prohibited due to concerns about possible contamination from emissions. Because of this, zero-emission transportation for research facility personnel and equipment is needed to ease the operation of distant satellite camp facilities and to improve access to areas which were previously only accessible by foot.

In 2007, the Hardrockers Clean Snowmobile Team of South Dakota School of Mines and Technology (SDSM&T) began development of a zero-emissions snowmobile named "Ramblin' Wreck" and was entered into competition. Since the 2005 competition, extensive testing of the vehicle was performed in South Dakota and changes had been made every year to improve performance and handling. This year, drastic changes were performed in order to bring the "Ramblin' Wreck" to honor.

BASIC DESIGN OVERVIEW

The Hardrocker zero emissions team has chosen to focus on several secondary goals this year in design. The CSC competition has primary focus areas in Range, Towing, and Noise of the electric snowmobile. The CSC also maintains secondary focus in Weight, Handling, and Maintenance. This year's team has addressed all primary and secondary objectives by improving range from 3.7 miles to an estimated 25 miles, Towing from 547.5lbf to a >800lbf estimate, and Noise from 67.8dB to an estimated 65dB level. Weight has been reduced from 823lbf to

<750lbf, while maintaining near stock handling, and maintenance intervals of 500 battery cycles. Applying previous year's faults and oversights, this year's team has added the objectives of Serviceability, Modularity, and Performance. This was accomplished with quickly removable energy storage containers and quick connections on all electrical components. The team has used a minimum amount of mounting material and bracketry to accomplish attachment of all components. The full snowmobile will be able to be stripped to a serviceable condition in <30 minutes. The team has put Modularity and Performance as a focus because of the ever increasing restriction of snowmobiles allowed in some state and national parks. The electric snowmobile as a rental with charging stations along the trail will be the option of the future for enthusiasts who want to explore these areas in the winter time.

ELECTRICAL SYSTEMS OVERVIEW

The South Dakota School of Mines and Technology has made many changes to the electrical system this year. These changes were made while keeping the overall system very clean and serviceable. There are two energy storage containers, one located under the hood and one running along the tunnel. These energy storage containers provide a sealed containment for the batteries and battery management system and all the safety features needed for proper operation. They also keep a semi-stock look to the snowmobile. This is a big change from last year's battery enclosure which was entirely sitting on top of the tunnel, which added weight to the rear suspension and compromised stock look.

The motor being used this year is considerably smaller than last year's model which also provides more under hood room for the front battery enclosure. The motor controller is bit larger than last year but has been used to balance the weight of the EMCVT which resides to the left of the motor bay. The EMCVT itself will be controlled using linear actuators to vary the drive ratio for certain rotational speeds of the motor. The auxiliary voltage is also a big change from last year. The SD-5 DC-DC converter is being used to provide a nominal 12 volts to all the low voltage equipment on the sled including a micro-controller that will read in RPM's from the motor. It also provides voltage to turn the negative contactor on, which will help power the motor controller.

MOTOR

Last year's team used a series wound brushed DC Impulse 9 motor with the 1231 Curtis motor controller. This type of motor was inefficient for the purpose it was being used for. A DC series wound motor is only about 84% efficient. The motor itself is 17 inches long, about 10 inches in diameter and weighs approximately 145 pounds. The Impulse 9 filled the motor bay leaving no room for energy storage or air flow. Because of weight and space restrictions, this year's team decided to invest in an AC-20 motor package. This package includes the AC-20 motor, the 1238 Curtis Motor Controller and the Spyglass 840 display. The AC-20 is an induction type AC motor that is powered by three phase AC voltage which is provided by the motor controller. The AC-20 weighs approximately 48 pounds which is 97 pounds lighter than last year. It is also about seven inches in diameter and 14 inches long, leaving more space than last year. The AC-20 motor has a rated continuous 10 HP but has a peak of 56 HP. Figure 1 shows the torque and HP for a range of RPM's. This motor is around 89% efficient, which is a 5% increase in efficiency from last year's motor.

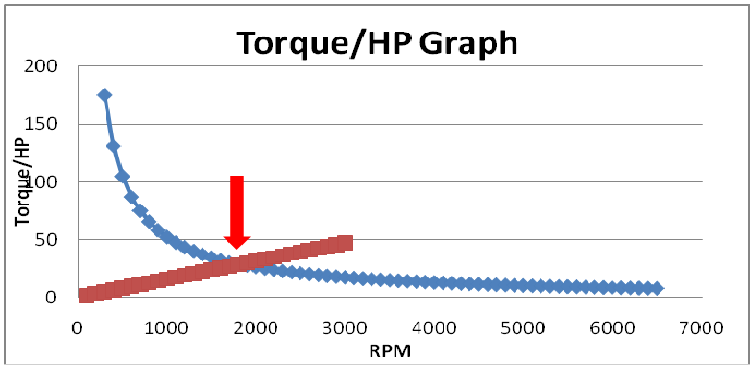

Figure 1: Torque/Horsepower Graph for the AC-20 Motor

MOTOR CONTROLLER

The Curtis 1238 motor controller functions as an inverter, which converts direct current potential into three phase alternating current potential and as the computer for the snowmobile, which is comparable to a controller area network (CAN). This choice in motor controller was ideal because of the voltage ratings of 24-80 V and current ratings of 550-650 [2min] Amps. The motor controller is powered by the high voltage pack by running a fused 10 amp low current wire to the motor controller that runs back through the negative contactor when it is turned on by the key. The 1238 actually turns the positive contactor on after its pre-charge phase has cycled. This circuit functions as a key safety feature in the snowmobile. The positive contactor cannot close if there is no power to the motor controller. This prevents the motor controller from getting burnt out from high voltage and current running through. The 1238 also provides a digital output to a display that shows the RPM of the motor, the motor temperature, and where the voltage level is, using LED's, much like a fuel gauge. The motor controller came with the 1311 Curtis Programmer that can adjust a number of things for desired operating modes based on the purpose of the snowmobile. One example of this is adjusting the speed or torque range for different speed and power curves and adjusting the percent of the voltage that can be used before the motor controller recognizes it and shuts off.

Figure 2: AC-20 Motor and 1238 Curtis Motor Controller

DISPLAY

The display for the sled will use both the stock display system and a secondary display system. The stock display system will give the current speed of the sled. The secondary display system will give current information on the electrical system. These two display systems will give all the information that will be needed to run the sled.

The stock display system will give the current speed of the sled by using the stock speed sensor and display system. It was determined to be easier to use than any other system to monitor the speed of the sled.

The secondary display system is a display screen from the AC motor controller on the sled. This display is able to display multiple bits of data about the AC motor. This display system can show the RPM of the motor, current temp of the motor, and voltage the system is running at. This will allow the rider to monitor the AC motor system and assure everything is running properly.

MICROCONTROLLER

The micro-controller system contains two main components. These consist of the micro-controller and the motor controller. The micro-controller is the heart of the system in that it is what decides how the system will react. The motor controller is what is used to drive the linear actuators on the CVT. These two main components are needed to control our Electro-mechanical CVT.

The micro-controller in the system serves two main jobs. The first job is to read in information from the AC motor controller. The information that it will be reading in is the RPM of the AC motor. From this information the micro-controller will decide if the linear actuators on the CVT should be moved and in what direction. If the RPM is above 3000RPM and the CVT is not fully in, the micro-controller will send a command to the motor controller to move the linear actuators in. This will cause the gear ratio of the CVT to increase. If the RPM is below 1500RPM and the CVT is not fully out, the micro-controller will tell the motor controller to move the linear actuators out. This will cause the gear ratio of the CVT to decrease. If the RPM is between 1500-3000RPM the micro-controller will tell the motor controller to hold the linear actuators where they are at.

By designing the system this way, it will allow fine tuning of the CVT to give us the best performance from the sled. The way to accomplish this is to adjust the shift out and shift in points of the CVT. Shift points are determined by changing the RPM values the linear actuators move at. This will allow control of how the sled handles without having to design a new CVT for each application.

The second job of the micro-controller is to monitor the actuator controller. The micro-controller monitors the actuator controller to make sure that the motor controller is running properly. That is that the wiring of the motor controller is correct, that the motor controller is not over heating, or any other problems that motor controller could have. If there are any problems with the system the micro-controller is set to put the motor controller to a stop state and to flash a general error light on the micro-controller. If the system ever gets to this state it will stay there until it has been reset. This makes it so that if the system senses any problems it will shut itself down protecting itself from harm.

BATTERIES

There are many types of batteries available today. Of these, only a few types are commonly used in electric vehicle applications, these include Lead Acid (PB), Absorbent Glass Mat (AGM), Nickel-Metal Hydride (NiMH), and many types of Lithium based batteries. Lead acid and AGM are more commonly used for high power, low range applications such as fork lifts. The Lithium based batteries are the most common battery found in electric cars because of their high energy density. Lithium-Ion (Li-ion) batteries are the most common in this application but can be very dangerous because they can explode if damaged. The batteries being used in South Dakota’s snowmobile are Lithium Iron Phosphate (LiFe-Po4). This type of battery was chosen because of their safety. Unlike Lithium-Ion type energy storage, LiFe-Po4 are non-explosive, and do not heat up rapidly under stress. LiFe-Po4 batteries also keep a very steady voltage until the end of the cycle life, even in extreme cold or heat.

The 3.2V 100 A-h Tenergy LiFe-Po4 batteries were the ones chosen last year. These batteries were arranged into one pack of 30 cells in series to create a 9.6 kW-h energy unit. This year, 5 cells were dropped to give us 25 cells for 80V and 100 A-h to adhere to the addition of the 8 kW-h energy limit. As mentioned earlier, the LiFe-Po4’s have a very steady voltage life. A test was run to show this. Figure 3 shows one cycle of the batteries run on a DC motor that was drawing a constant 20 Amps. The test relates linearly to our pack of 25. The starting voltage of our pack is 80V and the motor controller runs at around 100 amps. The voltage drops to about 60% of the starting voltage by the end of the cycle. This means that our pack will last for about an hour at 20 mph which should give us a range of around 20 miles.

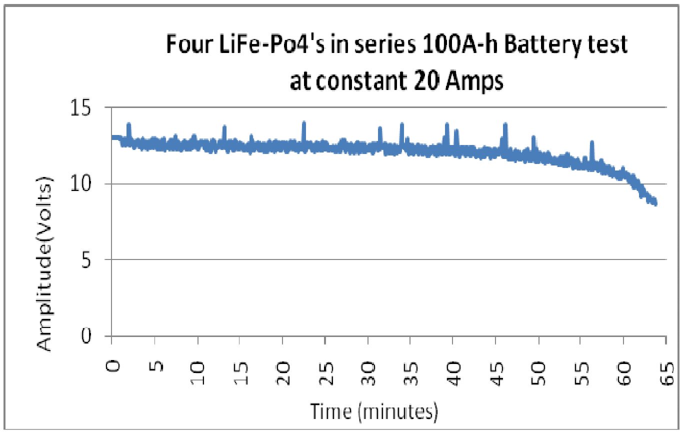

Figure 3: Battery Test Results

CHARGING SYSTEM

One of the issues with LiFe-Po4 batteries is deep charging cycle. There is a certain charging curve that allows for the optimal charge of the batteries. The charger being used is the Zivan NG-1 that was programmed by the United States's Zivan distributor Elcon for an 80V 100A-h pack of LiFe-Po4 batteries. The charger can be powered by 120/240V and also 50/60Hz power outlets. The charging curve for the NG-1 is shown below in Figure 4. A battery monitoring system is being implemented, the eLithion Lithiumate Master Monitor along with the 1PR0106X cell boards made for the prismatic Tenergy cells. The BMS helps keep each cell balanced with the rest of the cells in the bank. The 25 cell pack was split into two banks, one with 8 cells and one with 17 cells. The BMS will keep the voltage balanced between each cell in the entire 25 cell pack.

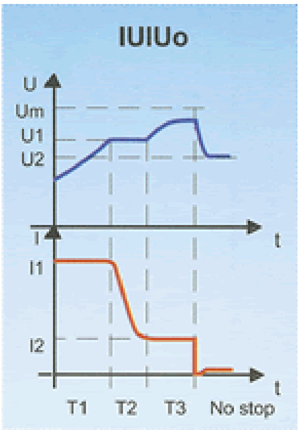

Figure 4: Charging Curve

MOUNTING SYSTEMS

Because of space restraints in the front of the vehicle caused by battery storage, the mounting brackets for the essential components had to be small and multi-purpose. The main components that needed to be mounted were the Curtis 1238 motor controller, HPGC -AC20 motor, PA-02 linear actuators, battery box, and the Seeeduino Mega micro-controller. The motor mount was machined from a plate of ½ inch 6061-T6 aluminum which was bolted directly to the chassis of the vehicle using 6 grade-8 3/8 inch bolts. This mount also supports the linear actuators used to drive the EMCVT, as well as the front battery box which provides auxiliary voltage. The controller was mounted upright to provide direct access from the AC power outputs to the motor and was held in place using a bracket made from ¾ x ¾ inch square tubing that is $^1/_8$ inch thick. This positioning of the controller also allowed the heat sink to face the outside of the vehicle to provide greater cooling. Because there were also cooling concerns with the micro-controller, it was mounted toward the front of the vehicle to receive as much air flow as possible. It was mounted to the chassis by a simply machined bracket made from an $^1/_8$ inch thick aluminum sheet.

DRIVELINE COUPLING

The coupling was chosen carefully as it must perform several tasks at once. The coupling shown in Figure 5 allows the team to use any Polaris borne Continuously Variable Transmission (CVT).

This will allow for the use of a stock CVT for budget savings for the team. The coupling must contain the stock Polaris driveshaft taper with a slight interference fit allowing for high torque transfer through the system. This must all be done while simultaneously attaching to a keyed 7/8” electric motor shaft. Because of the limited manufacturing capabilities available to the team, the shaft must have a milled key slot with a containing sleeve fit over the shaft to retain the key. This adapter allows for the use of the team’s selected Electro-Mechanical CVT as well as Polaris borne racing CVT’s.

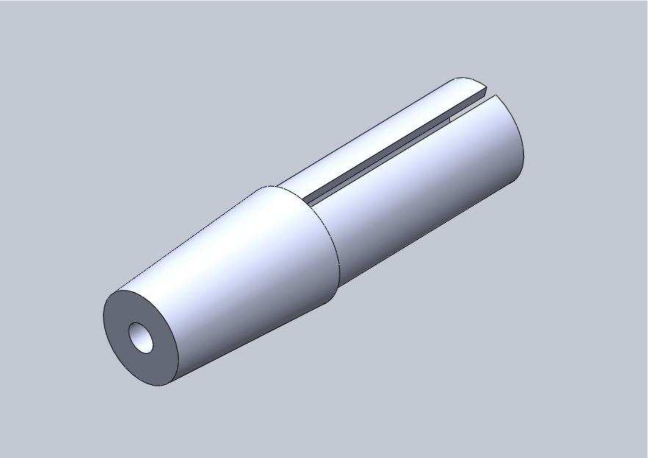

Figure 5: Motor/CVT adapter

DRIVETRAIN

The drive train selected by the team this year was the use of an EMCVT. The decision was made based upon the selection matrix shown in Table 1 below. As shown in the table, this was not the highest ranking decision, yet the benefits not shown in the matrix were determined to be the deal breaker in the choice of a drive train.

While the cost and weight of the direct drive system far outweighed the EMCVT, the team felt that the optimization of efficiency over the entire range of operation would be a far greater benefit than minimally decreased weight. The EMCVT will be controlled by the Seeeduino MEGA micro controller. This will be accomplished by measuring motor shaft speed as well as current draw from the energy storage containers. The current draw will be used to determine the torque rating the motor will be outputting. The motor shaft speed will allow the team to optimize shifting for maximum efficiency when needed.

Table 1: Drive train Selection Matrix

	Complexity	Versatility	Cost	Efficiency	Size	Actuation	Service Life		Totals
V-Belt Mechanical	7	6	8	3	5	7	7		149
V-Belt EM	6	9	7	5	5	8	6	2	165
Conical Chain Drive	7	7	7	7	2	8	7	3	155
Toroidal	4	8	2	8	6	4	5		129
2- Speed Transmission	5	4	4	8	5	3	4		113
Twin Belt actuator	7	4	6	8	7	5	3		140
Direct Drive	9	1	9	9	9	9	8	1	167
Weight	4	6	5	3	3	2	1		

The Progressive Automations Linear Actuators were chosen for their 400lbf linear actuation force as well as the 4" of travel allowed. The team has shown the linear actuators will need a maximum force of 788lbf axially to the primary clutch of the CVT. They will be rigidly connected to the chassis of the snowmobile as well as to the bearing plate of the CVT.

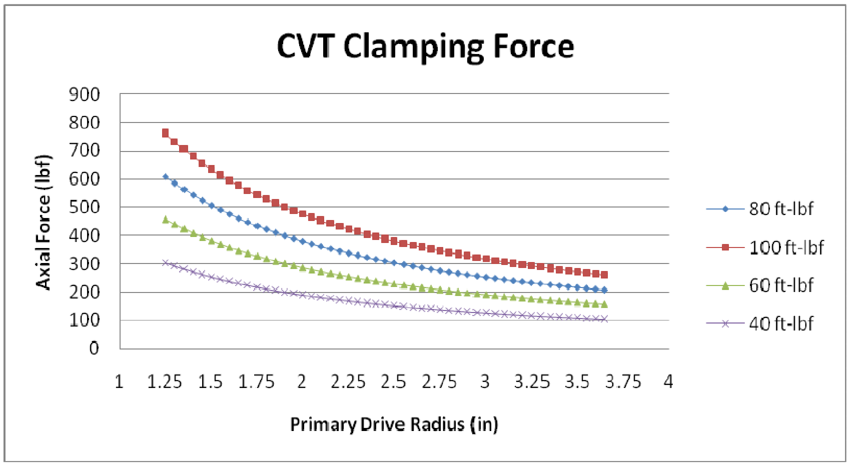

Figure 6: CVT Clamping Force

This bearing plate was manufactured to accept the SNR 57701X thrust bearing. This bearing allows a maximum axial force of 1000lbf at a maximum RPM of 4700. The Bearing will be loaded at 788lbf until 2650 rpm, where the motor will linearly drop in torque output. The AC-20 motor has a maximum rpm of 6500 which is 27.7% higher than the maximum rpm of the bearing. The manufacturer, when consulted, informed the team that the bearing in question would have a 7400 rpm maximum when loaded to <200lbf. When the motor is at high rpm, as shown in Figure 6 the axial force drops well below the 200lbf limit to allow the bearing to function at higher rpm.

This was determined using the derived equation (1).

$$T_p = ((2*F_p*R_p*\mu)/(\mathrm{Cos}(\alpha))) \quad (1)$$

Where T_P is the Torque transmitted through the primary, F_P is the axial force required to actuate the primary, R_P is the running radius of the primary clutch, μ is the average coefficient of friction between the clutch plates and the torque transfer belt, and α is the sheave angle of the clutch plates.

BATTERY BOX DESIGN

Previous designs for the battery storage container consisted of a single container holding all of the batteries. This design was large, bulky and did not use the available space efficiently. This design also caused unnecessary wear on the rear suspension due to the large amount of weight placed on the rear of the machine. To improve the balance of the machine, remove some of the bulkiness and make better use of the available space, the batteries were split into two separate boxes. This allowed the smaller box to be concealed under the hood directly above the motor and the rear box to be changed from two batteries wide to one battery wide lying down. This made the box to hold the batteries much shorter and skinnier but it did end up slightly longer. This is acceptable because the snowmobile will be more comfortable, have a lower center of gravity and still have less weight over the rear shock than in previous years.

The other main change made to the battery boxes was the material used to make them. They were previously made out of UHMW plastic. This was very heavy and hard to form. The CSC competition rules also dictate that the battery boxes are to ideally be electrically insulating, mechanically robust, fireproof, and transparent. There must be one layer of fire proof material between the driver and the energy storage container, a mechanically robust insulating material between any live electrical parts and conductive portions of the container, and adequate structural robustness for the weight of the accumulator. The boxes must also be able to contain a battery failure at any time.

To meet all the stipulations set forth, make the boxes as light and space efficient as possible and still be able to manufacture the parts, the front and rear boxes were made out of different materials. The front box is made from aluminum and lined with Nomex. The rear box is made with carbon fiber, fiberglass and foam.

The front box is made out of .063 sheet aluminum. The aluminum was cut, bent and then welded together by a student on the team. Aluminum was chosen for the front box for many reasons. The most important reason was the ease of manufacture. The initial intent was to make the box out of composite materials but the design of the box due to space limitations was too complicated to be feasibly done with composites. Aluminum is the lightest and most structurally sound material that the box could be made out of. A solid works drawing of the front box is shown in Figure 7.

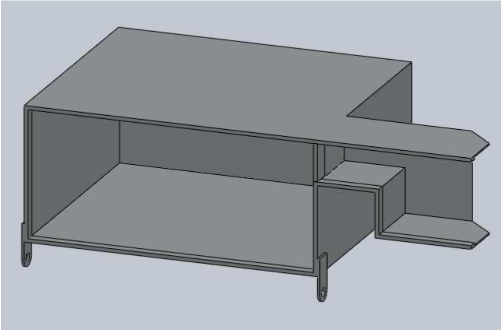

Figure 7: Model of the Front Battery Enclosure

The 1/8 inch thick 1 inch wide strip aluminum was added as bracing around the open edge of the box after initial analysis was done using Cosmos. The box would have held with a factor of safety of 2 but the deflection in the box was more than could be accepted. The final analysis was performed with the bracing in place and the factor of safety is 4.25. The areas of maximum stress are shown in Figure 8. The front box was mounted to the snowmobile using tabs welded onto the box. The box will be bolted to the frame and motor plate.

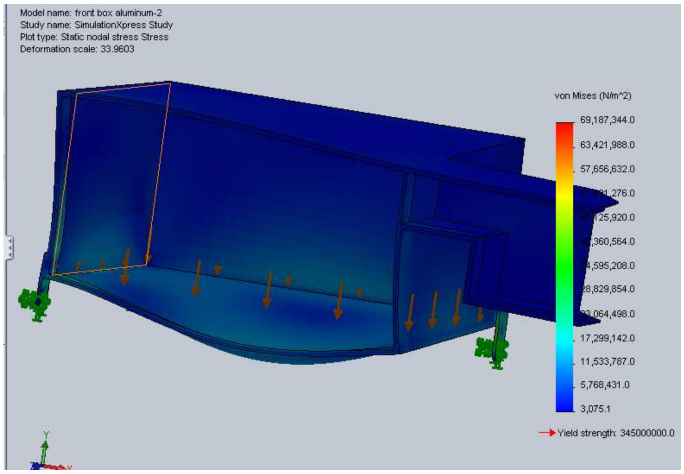

Figure 8: Analysis of Front Battery Enclosure

Because the material used to make the front box is very conductive, the box will be lined with Nomex. Nomex is a fireproof insulating material and will prevent any arcing between the batteries and the aluminum. The front and side of the box will be made out of Lexan. This material was chosen because it is fireproof, insulating, structurally sound and more importantly clear. This allows all of the connections and the battery monitoring boards to be viewed. Weather stripping will be used to seal out any moisture. Using these materials, the front box is able to meet all of the stipulations set forth for battery boxes.

The rear battery box was made out of composite materials. The choice to make the box using composites was made using a decision matrix. The decision matrix can be seen below in Table 2.

Table 2: Battery Enclosure Selection Matrix

	reliability	**strength**	**weight**	**cost**	**conductivity**	**manufacturing**	**containment**	**aesthetics**	**total**
Weight	**5**	**4**	**3**	**4**	**5**	**3**	**4**	**2**	
Carbon-insert- carbon	7	8	8	4	4	7	8	9	198
carbon - insert - fiberglass	7	8	8	6	8	7	8	9	226
carbon fiber with ribbs	7	7	9	6	4	5	4	8	181
uhmw plastic	8	8	2	6	8	8	8	4	206
aluminum	9	9	4	9	2	8	9	5	209

After the decision to construct the battery box out of composite had been made, the correct layup of the composite material had to be determined. Many options were chosen ranging from a fully carbon box to a partially carbon and partially fiberglass box to a fully fiberglass box and many in between. It was determined that the inside layer needed to be fiberglass so that the box would be electrically insulating. The outer layer would be carbon due to the extra strength and rigidity that the carbon would give. The number of layers to be used in the making of the box was also determined. The choice ranged from 1 inside and 1 outside to 3 inside and 3 outside. The material to use for each layer was also determined. Finally the core material also had to be determined along with its thickness.

The program Abaqus was used to perform finite element analysis on the rear box. All the different layup options were analyzed using Abaqus. The best options were organized into a matrix and the best option was chosen. The matrix for this decision is shown in Table 3.

Table 3: Rear Battery Enclosure Layup Selection Matrix

	strength	**weight**	**cost**	**conductivity**	**manufacturing**	**containment**	**aesthetics**	**total**
Weight	**6**	**3**	**4**	**5**	**4**	**4**	**3**	
1C,.250f,1C	6	10	6	3	4	6	10	175
2C,.125f,2C	9	9	6	3	6	9	10	210
2C,.250f,2C	10	8	5	3	5	10	10	209
1C,.125f,1F	5	9	9	8	6	5	9	204
1C,.250f,1F	6	8	8	8	5	6	9	203
1C 1F,.125f,2F	8	7	8	8	9	7	9	232
1C 1F,.250f,2F	9	6	7	8	8	7	9	227
1F,.125f,1F	2	8	10	10	10	3	6	196
1F,.250f,1F	4	7	9	10	9	4	6	201
2F,.125f,2F	6	6	9	10	10	5	6	218
2F,.250f,2F	7	5	8	10	9	6	6	217

As the table shows, the layup chosen for the rear box is a 1/8 inch foam core with 2 layers of fiberglass on the inside and one layer of fiberglass surrounded by one layer of carbon fiber on the outside. This was the best combination of the strongest, lightest, cheapest, and easiest to make part. The part was first drawn in Solid Works and then drawn in Abaqus. Figure 10 shows the solid works rendering of the Rear box.

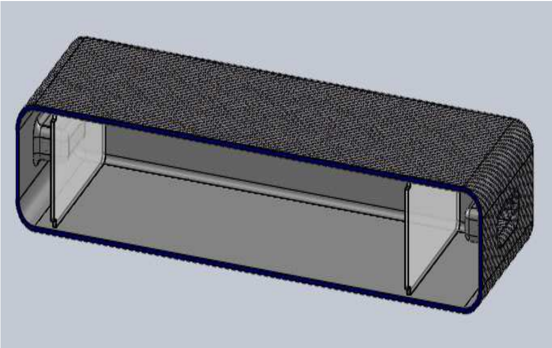

Figure 10: Model of Rear Battery Enclosure

The carbon fiber weave that was chosen was a 9 oz. twill weave mat. This was cut and laid into place in the mold. There were two different types of fiberglass mat. The two that were closest to the foam core were 20 oz. coarse weave and the layer on the very inside of the box is a 6 oz. fine weave mat. The coarse weave fiberglass will allow the resin to flow to the outer edges of the part better.

The analysis was done using Abaqus and was extensive on the rear battery box layup that was chosen. The Von-Mises stresses were determined. The stress was very high in the handles and they are made with extra layers but the program couldn't handle that so they were removed so that the rest of the part would show more correct stress contours. The displacements were also calculated and analyzed. This analysis was done for any possible scenario that the team could think of. The analysis was conducted with the Lexan front attached to the box. The box was analyzed this way because that is the only way that it will be used. The Lexan gives rigidity to the front of the box. The analysis was run without the Lexan front for the basic carrying scenario and the box was proved to still hold together. The Lexan was removed from view after the scenario was run to allow viewing of the rest of the part. The Von-Mises stresses for the carrying scenario with the handles in the box are shown in Figure 11. The Von-Mises stresses for the carrying scenario with the handles not shown in the box are shown in Figure 12. The displacement magnitudes for the carrying scenario with the handles not shown in the box are shown in Figure 13.

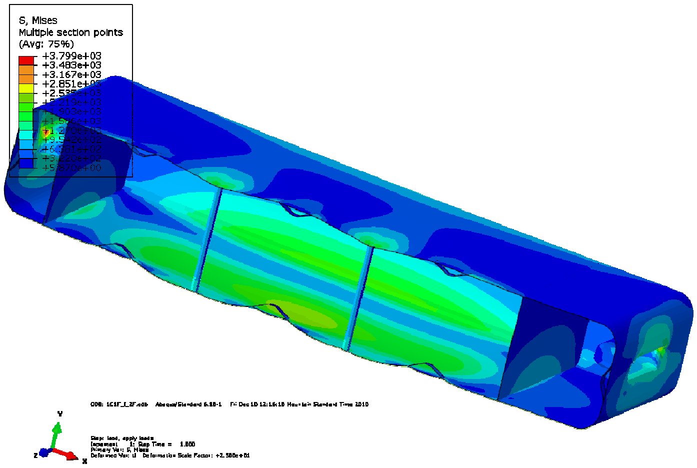

Figure 11: Von-Mises Stress Contours with Handle

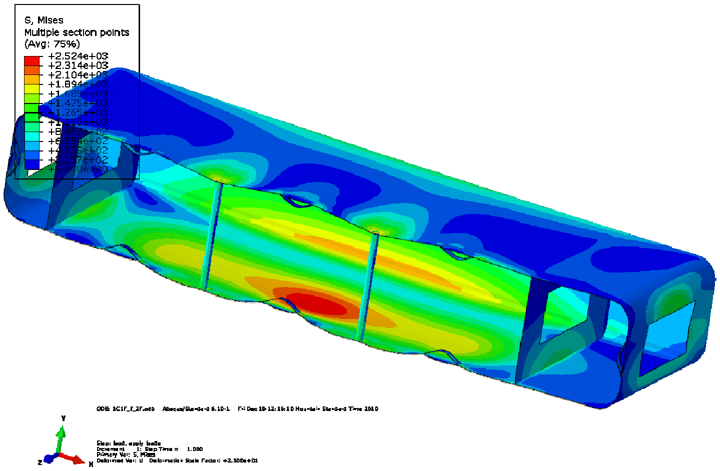

Figure 12: Von-Mises Stress Contours without Handles

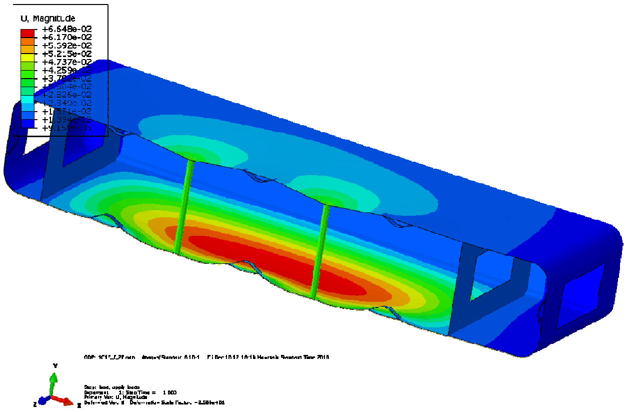

Figure 13: Displacement Magnitude

As the analysis shows there is a large factor of safety for the rear battery box. The rear battery box with the fiberglass inner layer, Lexan front, and carbon outer shell is a very light means of meeting all of the stipulations set forth for the battery boxes.

CHASSIS MODIFICATIONS

Last year's vehicle design included significant modifications to the chassis such as removal of part of the back tunnel as well removal of the front strut tower braces. This decrease in bracing caused the sway bar to prematurely fail in last year's competition. Because of this, the chassis of this year's vehicle was left intact. This will decrease the amount of vibration in the vehicle as well as help keep its structural integrity while in use. This is very important considering the added weight to the stock chassis. The stock snowmobile that the chassis was used from weighs roughly 600 lbs, where this year's design snowmobile weighs in at approximately 720 lbs. This 120 lbf increase also proved the rear shock to be inadequate, so a stiffer spring was added to compensate for it as well as improve handling.

RANGE

Effective range of the snowmobile was determined using several methods. First method was to use the overall efficiency of the system with the expected range of the stock snowmobile. This was done by research and analysis of the stock 2010 Polaris Switchback 600. The snowmobile in stock form achieves an average gas mileage of 15.7 mpg. A gallon of gasoline has an average energy stored within of approximately 12kW-hr. Using an average of 40% efficient internal combustion engine it can be shown that the snowmobile requires 4.8kW-hr of energy to achieve 15.7 miles. Using the LiFePo battery pack with 100% Depth of Discharge capability, the team will have a useable 8kW-hrs of energy. This puts the snowmobile in stock form at a range of ~26 miles. This shows what the team should achieve given near perfect conditions and equipment.

Using a more qualitative approach, the team used efficiency modeling to determine power required vs. power available. As shown from the efficiency model in Figure 14, the efficiency of the electric converted snowmobile was determined to be 68.8%. This is an over 15% improvement over the stock snowmobiles efficiency model. From testing on the previous chassis, it was determined that the snowmobile requires 6.4kW-hr of energy at 20 mph. This gives the snowmobile a 25 mile range. This is in line with the early range predictions.

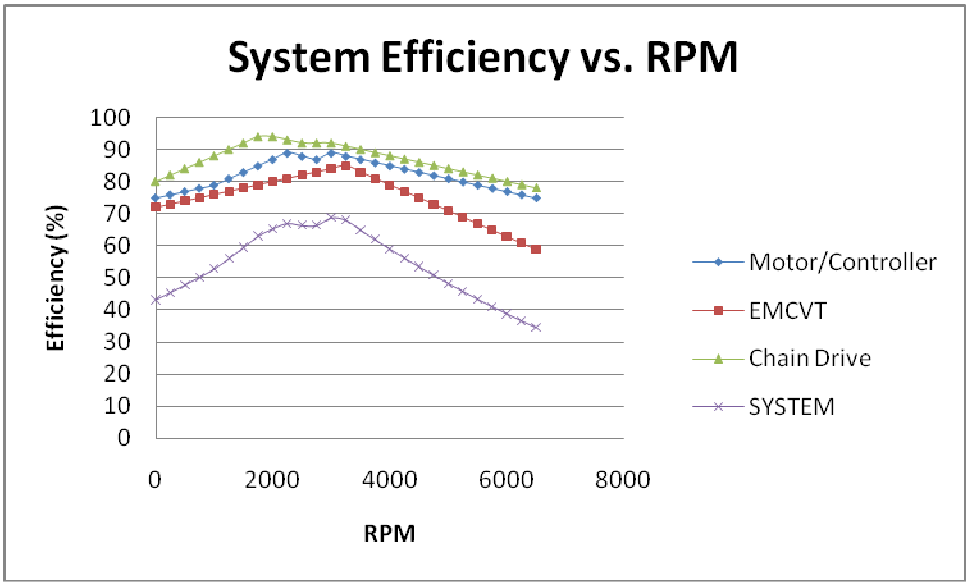

Figure 14: System Efficiency

EFFICIENCY

Efficiency modeling of the snowmobile was done throughout the entire system to get an estimate of the required power for the snowmobile. The AC-20 electric motor has an efficiency of 89% when run at 2000 rpm. This is the highest efficiency for the motor and controller package and was chosen for the optimum rpm for the range event. The EMCVT when actuated with slip prediction and control can achieve a maximum efficiency of 93%. Because the team has not yet perfected the slip prediction system, the maximum efficiency of the EMCVT, as shown in Figure 14, was given to be only 86%. This is attributed to the team choosing a slightly higher clamp force to allow a safety factor against slip of 2.5. Allowing the chain drive from jack-shaft to track-shaft to have the stock rated efficiency of 90%, the snowmobile team has shown that 68.8% of battery energy can be transferred to the track for forward motion of the snowmobile.

PULLING CAPABILITY

The previous chassis configuration allowed for a pulling ability of 547.5lbf. This was accomplished with an Impulse 9 Series wound DC motor and a direct 2 to 1 synchronous belt drive. This allowed for a track shaft torque of 82lbf-ft. This year's design has a ratio through the CVT and chain drive equaling 4.96 to 1. A motor torque of 50lbf-ft has been estimated. Mating this to the drive ratio and efficiency model of the system, the team has an estimated 178.4lbf-ft of torque at the track shaft. This is an increase of 218% from the previous year. Using a shorter track, slip will need to be monitored and controlled through the Seeeduino Mega micro-controller. Allowing for minimal slip and maximum torque transfer, the team is expecting a draw-bar pull of >800lbf this year.

SAFETY

The safety protocols in place are currently working well. SOP's are in place for all projects on the snowmobile. Team members that will be working with machinery have gone through CAMP's machine safety training. Research has been completed for insulating certain hand tools for safety while working with electricity. Insulating tool dip was purchased and a set of insulated sockets, drivers and extensions were manufactured. Two pairs of class 00 NOVAX rubber gloves were purchased. The team has multiple sets of standardized safety glasses, face shields and gloves, organized into the rolling tool box.

PROJECT MANAGEMENT

This year the Industrial Engineering student on the team will be heading up the project management. This is the first year with a project manager on the team. With the complete systems and the multiply parties involved in building the snowmobile the management is very busy keeping everyone on track. Each week we have a senior design team meeting and a full team meeting, at these meetings budgeting and scheduling is updated. The budgeting is kept in a Microsoft Access database and also in an excel spread sheet, the project scheduling is kept in a running Microsoft Project Gantt chart.

SUMMARY

The Hardrockers Clean Snowmobile Team of South Dakota School of Mines and Technology (SDSM&T) successfully designed and tested a zero emissions electric snowmobile for use as a zero emission utility vehicle at various research facilities including Summit Station in Greenland. Its innovative design which includes an electro-mechanical CVT provides a large range of torque as well as increased acceleration. The newly integrated AC motor provides longer ranges of performance from the 8 kW-hr Lithium Iron Phosphate batteries and will run up to 20 miles on a single charge.

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