South Dakota School of Mines & Technology Electric Snowmobile

2009 SAE Clean Snowmobile Challenge

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ABSTRACT

The Alternative Fuel Vehicle Team at the South Dakota School of Mines and Technology took on an unfamiliar task once again this year. The team designed and manufactured a zero emissions snowmobile to compete in the 2009 SAE Clean Snowmobile Challenge. The snowmobile was designed following the fundamental requirements set forth by the team. A design was selected that fit within the constraints. A full analysis to ensure safety and durability was completed before manufacturing could begin. The snowmobile's systems were designed with the main focus being on safety and secondary focus based on optimal performance in acceleration, handling, and appearance. The completed systems are clean, efficient, and can be easily incorporated into any commercially available snowmobile. Testing has proved that the SDSM&T snowmobile performs well in the areas of acceleration, handling, and drivability.

INTRODUCTION

The Alternate Fuel Vehicle team consists of diverse engineering students at South Dakota School of Mines and Technology. These students have designed, analyzed, and manufactured an electric snowmobile and are competing in the 2009 SAE Clean Snowmobile Challenge.

As a member of the Center for Advanced Manufacturing and Production (CAMP) at SDSM&T, the AFV team has had a long standing history of designing alternate fuel systems which have included solar and hydrogen powered vehicles. In October 2006, the team decided to take on a new project which took the form of an electric snowmobile. It was seen early on that resources such as time and money would be hard to obtain, but the team was up for the challenge. The 2007 snowmobile was built on the 1995 Indy XLT chassis and took second place overall in the 2007 SAE Clean Snowmobile Challenge. This year the team has yet another challenge with the addition of a new chassis, which will allow the team to get off to a fresh start. In October 2007 Polaris Industries donated to the team a 2007 touring snowmobile chassis based on the new IQ design to work with for this year's competition. This year's team is still challenged with a limited budget, but the future looks promising with the addition of a new chassis design along with improved electronic technology.
The goal of the team is to design, build, and test a high performance zero emissions snowmobile to promote academic and public interests, in addition to competing in the SAE Clean Snowmobile Challenge. As this being only the third year SDSM&T has built a snowmobile, these objectives were followed for competition:

- Provide a snowmobile that demonstrates the viability of alternate fuel
- Become competitive in all competition criteria for the 2009 SAE CSC
- Overcome a range of power inefficiencies
- Provide a data feedback system for post ride analysis which will lead to system optimization
- Allow for future modifications

With the knowledge obtained over the last two years of competition, the 2009 team will be able to follow and improve upon previously used technologies.
As greater interest is seen for zero-emission vehicles, it follows that the new advances in electric power will be more readily available and incorporated into the team's upcoming designs.

REQUIREMENTS AND CONSTRAINTS

The AFV design team focused its design direction on eight fundamental requirements. The engineering was done by finding the best design available within the given constraints. The decisions regarding the selection of components were based on the desired results agreed upon by the team. The topics are listed in Table 1 and are weighted according to importance.

Table 1: Snowmobile Criteria

Topic	Ranking
Safety	1
Performance	2
Range	3
Reliability	4
Weight	5
Cost	6
Availability	7
Appeal	8

SAFETY

Safety is always first and foremost in every design. The machine will need to be designed so that it is safe for the operator as well as any bystanders. The designers are liable for the safety of anyone who comes in contact with the snowmobile. All moving components will have to be adequately contained within the protective shell of the snowmobile. The object is to keep the rider in full control of the snowmobile at all times. The stock headlight was retained to maintain rider visibility; the tail light was replaced with an LED which will increase visibility and decrease power consumption. In the event of an electrical or mechanical malfunction, a kill switch is located in the stock position on the right side of the handlebar and allows the driver to shut down the machine at any time. A tether switch is also used in the event the driver should fall off of the vehicle while in motion, which will reduce the chance of injury from the snowmobile continuing forward unmanned. All high voltage connections were covered in red which will alert anyone who will work on the snowmobile that there is a danger as well as isolating the electrical connections. Fuses were installed in easily accessible locations in the event a malfunction or short should occur throughout any of the circuits on the snowmobile.

PERFORMANCE

The team decided that performance of the snowmobile should be similar to that of an internal combustion (IC) powered snowmobile. Some important criteria limiting the performance are the overall weight of the snowmobile, torque and horsepower output of the motor, battery current capabilities and motor controller tolerances. All of these were taken into consideration during the design of the snowmobile. When focusing on increasing the acceleration performance, the range of the vehicle will be adversely affected. The range of the vehicle will be improved by the utilization of Lithium Ion batteries that offer a much higher energy density when compared to the previous design which incorporated lead acid batteries.

RANGE

Range is important, but has limitations due to the nature of the competition. Battery capacity is the main limiting factor that extinguishes any chances of being able to compete with the range that an IC based snowmobile is capable of. In order to get the battery capacity required to attain IC snowmobile ranges the weight of the snowmobile must also be increased. Due to the limited space available and the load carrying capabilities of production snowmobiles this range is not yet attainable. Range was ranked as top concern, but acceleration performance will be more of a main priority.

RELIABILITY

The vehicle must be reliable in order to be a practical solution to the problem presented. The vehicle is expected to consistently perform as expected with no repairs and limited maintenance. A well engineered product should be inherently reliable. The team focused on this aspect of the snowmobile so that the team would not have to open the hood during competition and therefore not forfeit any points.

WEIGHT

As any snowmobiler will state, weight is critical to performance. A team goal has been set to only keep the weight of the completed snowmobile comparable to that of a complete internal combustion snowmobile. This is very critical design criteria since the weight affects nearly all areas of performance. A weight between 700 and 750 lbs was sought for the completed machine. Weight is ultimately dependent upon battery selection. Although some consideration was taken to select a motor with relatively low weight, a high torque and high horsepower motor was desired by the team to meet the given criteria. The heaviest component of the design still remained to be the battery pack.

COST

Another main concern of the team was the limited budget that was available. The focus is to design a snowmobile that can be manufactured with a cost that is comparable to that of a current production IC engine snowmobile. Due to team restructuring, there were no initial donations or prior support which would aid in additional funding. This severely limited the components that could initially be purchased. Consequently, the team gave special emphasis upon the upgradeability of the snowmobile for future competitions. Time constraints did not allow for fundraising since the team had to focus on manufacturing a complete design in limited time constraints.

AVAILABILITY

Availability ultimately affects every decision made for the selection of components since a part that is not available in a timely manner cannot be used in an overall design. Some components are simply not available to the general consumer or were backordered at the time they were required. More advanced technologies are not only difficult to attain, but are also cost prohibitive. Certain technologies will become more available in the future, but are simply in the prototyping phase. Availability also affects the ability to repair the vehicle once it is in use. Commonly available items were used in order to ease any necessary repairs. This criterion also includes manufacturability. One aspect of design was selecting components that would be easy to manufacture with the resources the team had readily available, while also considering the availability of materials for manufacturing on a commercial scale.

APPEAL

The vehicle must be aesthetically pleasing for several reasons. This increases the possibility of future donations and sponsorship to the team. Part of creating a good product is also making the product presentable, therefore, displaying the professionalism of the team and making the product look enticing to potential consumers.

ENGINEERING PROCEDURE

Engineering of the snowmobile has taken place over a very short period of time for such a novice team. During the fall semester the team was encouraged to integrate concepts from all areas of engineering into the designs. During that time, the team learned about the fundamentals of the design process, specifications, decision making, and preliminary design. The team focused on the major areas that would be crucial for the performance of the machine. This began with brainstorming to come up with at least ten possible concepts for each area no matter how far fetched they seemed. Many times with design, these far fetched ideas turn out to be a very feasible solution. Then a weighted design matrix was constructed for each set of design concepts and can be seen below in Table 2. An example of this can be seen with the team's issue of transmitting power from the motor to the track.

Table 2: Example Decision Matrix

Ideas	Reasonable Cost	Weight	Acceleration	Reliability	Safety	Driver Comfort	Manufacturability	**Total**	**Rank**
	15%	10%	35%	15%	10%	5%	10%	100%	
Direct Drive	5	4	2	4	2	3	4	3.2	4
Multiple motors with Gears	1	2	4	2	3	2	1	2.55	9
Conventional CVT	4	4	5	4	5	5	2	4.3	1
Electric CVT	2	4	4	4	5	5	2	3.65	2
Transmission Manual	2	3	4	5	4	2	3	3.55	3
Planetary Gear box	2	3	3	4	4	3	1	2.9	8
Automatic Transmission	1	4	3	3	4	5	3	3	6
Chain Drive	5	4	2	2	3	2	4	2.95	7

This matrix gives different designs versus the requirements and allows for a degree of importance to be assigned to each design requirement. From this, an educated decision can be made as to which design to proceed with. A similar matrix was completed for the major components such as the motor, motor mounts, batteries, battery box, and various other components.

COMPETITION PERFORMANCE

ACCELERATION

It was decided that much of the focus would be put on designing a snowmobile that could perform similarly to an IC snowmobile for short periods of time. After performing poorly in the 2008 acceleration competition, the team found that the fundamental problem with incorporating the use of a CVT was the inverse relationship between motor rotation and mechanical horse power and torque. The 2008 sled was not able to accelerate effective due to lack of horse power and torque as the CVT provided favorable gear ratios for acceleration. To overcome this relationship, the team has created a new conceptual drive train design. The new design is exciting because it has not yet been tested in industry.

DRAW BAR TEST

The 2008 design team was able to compete very effectively in the drawbar competition, by earning the first place award. The main focus for the 2009 competition was to maintain pulling ability while becoming more competitive in other competition areas. To do this the team made minimal changes to the snowmobile's pulling potential. The motor and battery configurations will be the same as the 2008 design; however, modifications have been made to become more effective in the range competition.

COST

The snowmobile has been designed to cost less than $12,000, mainly due to the team's limited budget. This shows that the components selected gave optimal performance at a reasonable price. Consequently, the team gave special emphasis to upgradeability of the snowmobile for future competitions when there is an increased budget available.

RIDER COMFORT

The incorporation of a Continuously Variable Transmission (CVT) into the design of the snowmobile allows for little to no shift shock during acceleration and allows for handling comparable to that of a typical snowmobile. The electric motor allowed for constant torque and horsepower which allows the CVT to operate in a similar fashion to that of an IC snowmobile. Modifications to the suspension to compensate for the added weight of the battery pack gave similar handling and shock absorbance to that of a typical IC snowmobile. A lightweight seat was designed to fit the contours of a typical rider which added to overall comfort.

COLD START

The mechanical components such as transmission and chain case were kept stock so the only area of concern for cold starting was the electrical system. The operating range for the motor was found to be as low as -40 degrees Fahrenheit which was well below the conditions the team would face. Cold Start tests were performed previously with this motor on nights where the temperature reached lows of -15 degrees Fahrenheit and the motor performed flawlessly. Special brushes can be installed in the motor for extreme cold weather operation.

NOISE

Noise is a major issue for snowmobile manufacturers and enthusiasts, which only justifies the cause of designing an electrical snowmobile. It would seem that reducing the noise of the motor of such a machine would eliminate a majority of the issue. The motor selected for operation with this machine was found to be virtually silent. As assumed, it was found that much of the noise resonated from the existing and updated drive train. This noise could only be reduced slightly and not completely eliminated. Through testing it was found that the gearing being used contributed to the noise but the majority resulted from the track running along the runners on the hifax. To reduce the noise of the track running on the hifax, bigger wheels were put on the rear skid to pick the skid up off of the track and thus reducing friction on the hifax. The team also added a small amount of noise with the addition of another jackshaft and a gear reduction unit.

RANGE

The primary concern with the 2009 sled design is that the sled still weighs in excess of 700 lbs. While the Valence Technologies lithium ion batteries create a great deal of potential power, they also drastically increase the load of the sled. To overcome the high inefficiencies of such a heavy snowmobile, the team is taking steps toward a data acquisition system that will provide system feedback. The feedback will provide valuable information to the team such that full system efficiencies can be calculated. Future teams will then be able to utilize the feedback data to optimize the snowmobile design.

DESIGN STRUCTURE

The 2009 team divided the snowmobile into three crucial design categories. By dividing the design parameters in to crucial categories, the group was able to diagnose past inadequacies with the snowmobile. These main categories consisted of the drive train, the chassis, and the electrical system.

DRIVE TRAIN OVERVIEW

Individuals working on this subsystem were given the task of performing analysis on the 2008 drive train and making decisions on how to optimize its performance. The major issue was finding a way to efficiently transmit power from the motor to the track. The team was urged to brainstorm heavily to consider all possible drive train options. The fundamental challenge for the drive train design was overcoming the inverse relationship of the electric motor performance and the stock CVT. The group finally decided on a new prototype design that would allow the two systems to operate independently. The 2009 design utilizes two linear electric actuators to engage and disengage the CVT independently from constant motor rotation. The conceptual design allows for the rider to spin the electric motor at a constant rate where appreciable torque and horsepower are found at a low RPM, while still being able to maintain use of the variable gear ratios provided by the CVT. The biggest difficulty and primary concern with this design is that it is a new design and untested method.

CHASSIS OVERVIEW

The chassis team consisted of mechanical engineering students who devoted their time to modifying and reducing the overall weight of the snowmobile for performance results. With the removal of the two-up seat, a significant amount of weight reduction was accomplished. Other components that were not deemed necessary were also removed to gain minor weight reductions throughout the snowmobile. This year the chassis team focused their time on designing a battery box to locate the six batteries and a seat to cover the box and increase rider comfort. Handling, suspension, and body integrity were also addressed by these individuals.

ELECTRICAL OVERVIEW

The electrical team consisted of electrical engineering students who took on the task of dealing with all aspects of electrical system design. They ensured that the electrical components performed well in conjunction with the eight fundamental requirements and kept safety as a top priority.

DRIVE TRAIN

MOTOR MOUNT

The 2009 team decided to maintain the 2008 motor mount design to allocate more time to the new drive train system. The 2009 design utilizes the motors mounts from the 2008 snowmobile design. A full loading analysis was conducted by the 2008 team. The only changes applied to the 2008 design are the addition of two holes for two linear actuators to pass through the motor mounts. The 2009 team used the analysis from the 2008 design to locate the new actuator holes in areas of low or moderate stress concentrations.

The 2009 design team worked under many assumptions to maintain consistency with the 2008 design. One primary assumption was that the analysis from the 2008 design was accurate. The 2008 team calculated the factor of safety at the highest stress concentration in the plate to be 3.13. The 2009 team made an important assumption that any factor of safety greater than 3.0 would ensure the longevity of the motor mounts with the presence of the new holes. Therefore, areas of low stress concentration were selected for the placement of the new holes. The final assumption made was that the weight added by the actuator assembly was negligible in comparison with the loading caused by the weight and rotation of the motor. Under these crucial assumptions, the 2009 team was able to maintain consistency with the 2008 design.

2008 Motor Mount Design

The 2008 design consisted of aluminum instead of the previously used steel because of its weight advantages. The new motor mounts were built from a flat sheet of ¼ inch 6061 aluminum for this years' snowmobile. The flat plates were designed in SolidWorks® to follow the existing contour of the bulkhead of the snowmobile. Along this contour the plate is bolted solid to the chassis in no less than eight places on each plate using 3/8 inch hardware. Along with the outer contour each plate has a ten inch hole cut out where the motor slides through and a bolt circle around this cutout to safely secure the motor on each end. Along with not only securing the motor solidly in place these bolt circles allow spacers to be inserted and changed in order to make sure the primary and secondary clutches are aligned during operation. After final design both plates were machined from aluminum stock in the CNC mill.

Stress Analysis

ABAQUS® was the program chosen to conduct the Finite Element Analysis on the motor mount. Each side of the mount was studied independently using shell elements. First the weight of the motor (150 lbs) was applied vertically to the motor mounting holes. This was done by applying 1/16 the weight to the 8 holes on each side. Next the max torque capable of the motor was divided equally among each of the mounting holes. The most torque the electric motor being implemented in this design is capable of producing is 80 ft-lbs of torque. Figure 1 shows the contour plot of the Maximum Von Mises stress in the mount. Figure 2 shows the displacement plot of the motor mount.

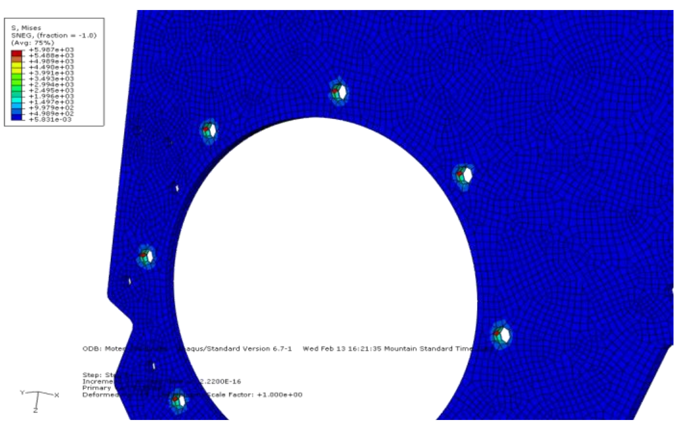

Figure 1: Contour plot of the motor mount showing the Maximum Von Mises stress.

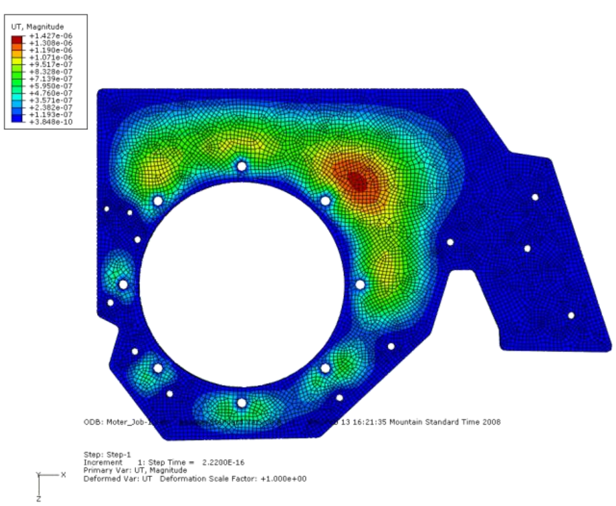

Figure 2: Displacement plot of the motor mount using ABAQUS® .

Table 3: This is the maximum stress and factor of safety that was found for the left and right side of the motor mount.

	Max Von Mises Stress (psi)	Factor of safety	Estimated Error (%)
Motor Mount	11510	3.13	4.69

Table 4: The Von Mises Stress convergence study for the motor mount.

Mesh	# of Nodes	# of Elements	Max Von Mises Stress (psi)	% Difference
1	1365	1247	9.50E+03	--
2	2518	2355	1.02E+04	7.002938
3	5555	5315	1.10E+04	6.927985
4	9042	8738	1.15E+04	4.691573

Table 5: The Displacement convergence study for the motor mount.

Mesh	# of Nodes	# of Elements	Maximum Magnitude of Displacement (in)	% Difference
1	1365	1247	0.07592	--
2	2518	2355	0.07607	0.197187
3	5555	5315	0.0761	0.039422
4	9042	8738	0.07611	0.013139

Frequency Analysis

To ensure that the motor mount would not be able to resonate at any RPM that the motor was capable of producing, a separate analysis was conducted to find the first 5 natural frequencies of the motor mount. Figure 3 shows a graph of the convergence study that was done in this analysis.

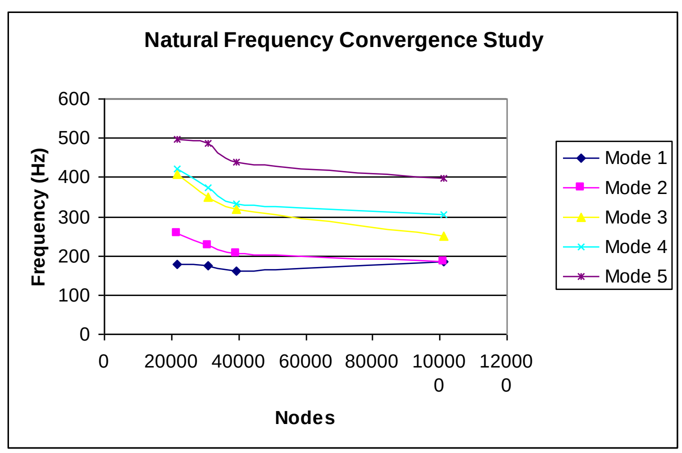

Figure 3: Chart showing the convergence study found in the frequency analysis.

As Figure 3 shows the lowest natural frequency for the motor mount is well above 150 Hz. The operating RPM of the motor is from 0 to 5000 RPM or 83.3 Hz. This means that the motor is clearly not in danger of being run at a frequency that could induce resonance.

TRANSMISSION

Almost every commercially available snowmobile incorporates the use of a CVT, which is a very important part in the overall performance of the vehicle. The CVT offers riders a wide range of gear ratios which provide differential ranges of performance based on the riders' demand. The primary concern about using a traditional CVT for this application is the inverse relationship that occurs between electric motor performance and the traditional CVT. The traditional CVT is designed to achieve increasing gear ratios as the motor accelerates. The increased rate of rotation provides the primary clutch with an increased component of normal acceleration. The increased normal acceleration provides the necessary force needed for the primary clutch to "engage" and provides the rider with a new range of gears. To compliment this new range of gears, the traditional IC engine achieves its highest horsepower and torque at maximum engine rotation.

Conversely, an electric motor achieves its highest horsepower and torque at a minimum or low rotation. Therefore, as the electric motor speed increases, its performance declines. The component of normal acceleration increases to provide the necessary force to engage the primary clutch, but the motor does not provide an appreciable amount of torque and horsepower to effectively accelerate the snowmobile. The relationship between RPM and mechanical horsepower and torque for the Impulse 9™ motor used on the 2008-2009 snowmobiles can be seen in Figure 4.

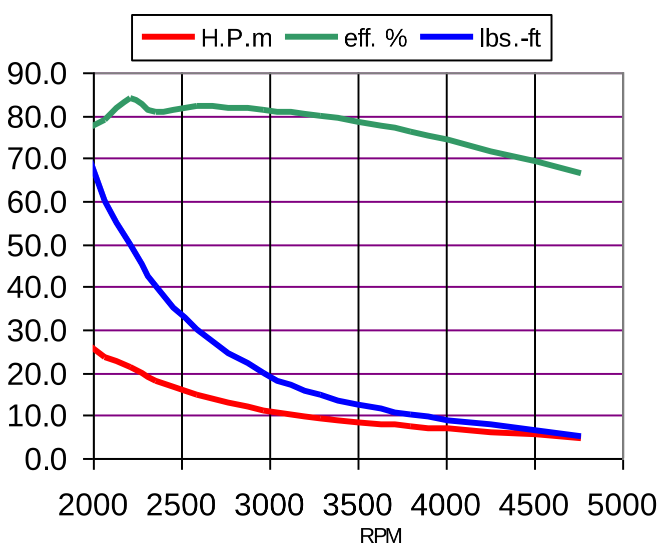

Figure 4: Motor data chart showing how Mechanical Horsepower, Torque, and Efficiency drop dramatically with respect to RPM

Preliminary Design and Brainstorming

The 2009 design members began the lengthy design process by initially brainstorming several alternative drive train applications. The ideas considered were as follows:

- Use existing mechanical CVT
- Create a modified (actuated) CVT
- Incorporate direct drive system
- Incorporate direct drive system with clutch
- Retrofit a hydraulic CVT

These idea concepts were then placed in a design matrix and weighed against several design criteria. The criteria used to analyze the concepts can be seen in the Figure 5. The emerging design concept was to design a modified CVT that could be engaged by actuators, independently from motor rotation.

Idea	Cost	Safety / Reliability	Performance	Time	Noise	Motor Efficiency	Weight	Total
Design Weight Percentage	10%	10%	20%	15%	15%	20%	10%	100%
Existing Mechanical CVT	5	4	3	5	3	2	3	3.1
Modified Mechanical CVT	4	4	4	4	3	4	3	3.45
Direct Drive	4	5	2	4	4	4	5	3.3
Direct Drive w/ Clutch	3	3	3	3	4	3	3	2.85
Hondamatic Transmission	2	3	5	2	4	5	3	3.4
		best = 5		worst = 1				

Figure 5: Design Matrix

Actuated CVT Design vs. Traditional CVT

Based on the manufacturer's motor data the team decided the best transmission would be capable of allowing the motor to remain between 1500 and 2700 RPM. The 2008 design maintained the use of a traditional CVT to operate the snowmobile with in this range of rotation. The team found that tuning the traditional CVT to respond in such a low range of rotation was very difficult. The primary problem was tuning the CVT to engage around 500 RPM and be completely shifted out by 2700 RPM. This is a problem since a typical snowmobile CVT engages around 3500 RPM and becomes fully shifted out around 8000 RPM. Thus, the team decided upon modifying the existing Polaris P-90 primary clutch and matching secondary clutch, which are designed for lower RPM ranges.

Actuated CVT Design

The actuated primary clutch will work by utilizing the linear motion provided by two electric linear actuators to draw the clutch into the engaged position. The actuators are set up such that at full extension, the primary clutch is fully disengaged. As power is supplied to the linear actuators, the clutch is drawn inward and engages. The secondary clutch remains a traditional response system and counteracts the motion of the primary clutch. Figure 6 shows a Solid Works® model of the actuated primary clutch.

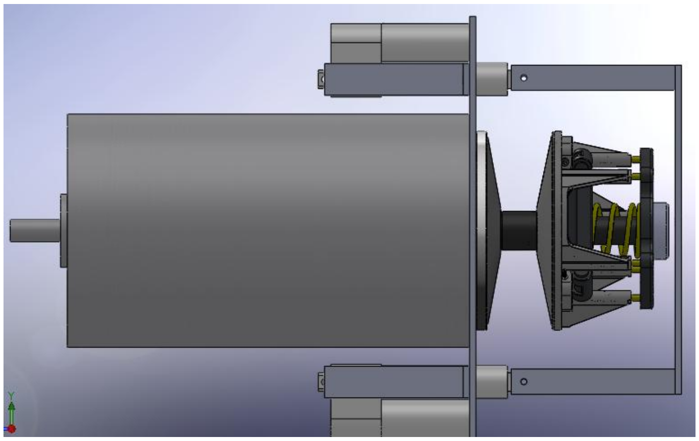

Figure 6: SolidWorks® drawing of actuated primary clutch

The 2009 team defined the most crucial design aspect for the actuated CVT as the two actuators which are used to engage the primary clutch. After researching electric linear actuators, the team decided to use two 150 lbf Firgelli Automations 2 inch stroke actuators. The actuators supply a combined load potential of 300 lbf. This potential was found to be more than enough to engage the primary clutch at a low range of RPM. The actuators run on a 12V, 3-5 amp power supply and were easily tided into our existing low voltage system of 12V, 18amp. Figure 7 shows a Solid Works® model of the actuators used.

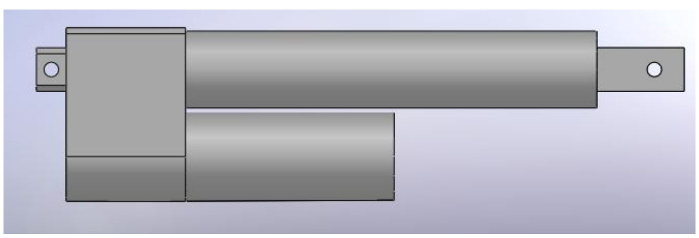

Figure 7: SolidWorks® drawing of electric actuator

Another crucial design requirement was being able to transmit linear motion to a rotating system. To achieve this feat the group incorporated the use of a standard thrust bearing. The team initially created a Solid Works® of the existing front face plate of the primary clutch. The group then was able to add an extruded feature that would house one side of the thrust bearing on the face plate. Once the face plate design was completed the group was able to move forward to machining the part. The material selected for the part was 1/2 inch 6061-T6 aluminum alloy. Upon completion of machining the part, the group was able to press fit the thrust bearing into the face plate. A Solid Works® model of the completed face plate can be seen in Figure 8.

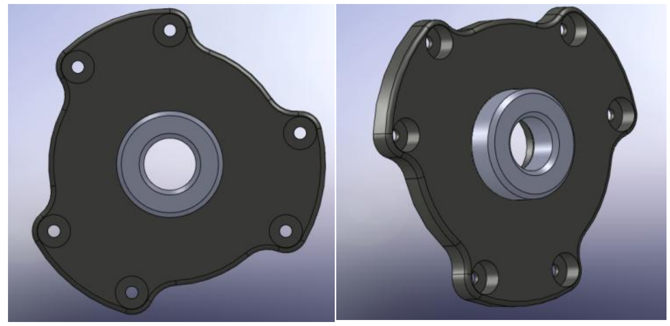

Figure 8: SolidWorks® drawing of primary face plate

CHASSIS

SUSPENSION

In order to properly tune the suspension an accurate reading of weight distribution needed to be obtained. In the 2008 design, it was found that the snowmobile without a rider put 185 lbs on the front right suspension, 210 lbs on the front left suspension, and 370 lbs on the rear for an overall weight of 765 lbs. The 2009 goal was to balance the uneven distribution of weight between the front skis. To balance the overloaded left side, the motor was shifted right by 2 inches. This shifted the motors center of gravity by 2 inches as well. The resulting distribution was 194 lbs on the left ski and 201 lbs on the right ski. A view of the major component layout and can be seen in Figure 6.

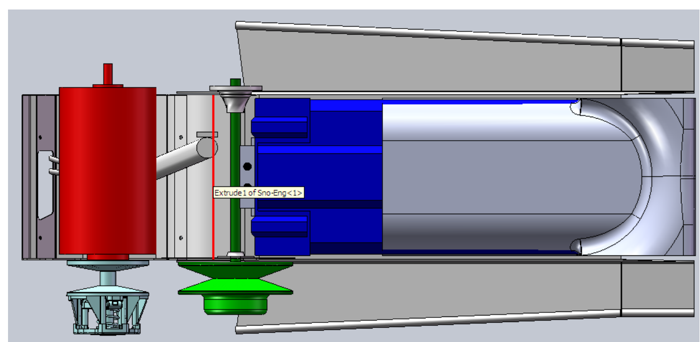

Figure 9: CAD drawing of major components added to the snowmobile shell

By showing a side view of the components seen in Figure 7 and by knowing the weight of each component the team was able to get an approximate center of gravity for the machine. The center of gravity of the snowmobile was found to be in the front left quadrant of the battery box, roughly six inches from the front of the battery box and four inches left from center.

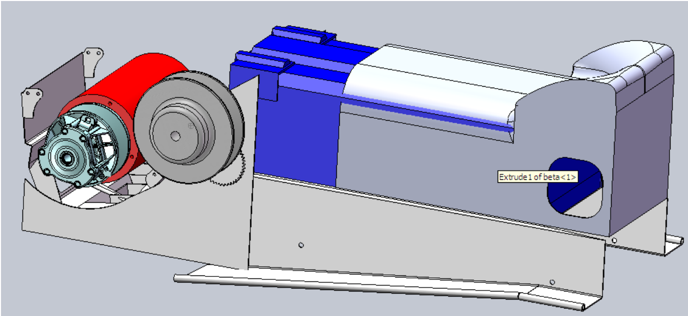

Figure 10: Side view of major components

Originally the team was looking into modifying the front and rear suspension to accommodate the additional battery weight, but testing proved the suspension to be sufficient for the loads it would see during competition and under normal riding conditions. This is due to the fact that the snowmobile was originally a two-up touring snowmobile which was built to accommodate two passengers and the extra weight of a larger seat. Testing showed that with a rider and battery pack with a total of 620 pounds on the back of the snowmobile, the suspension barely deflected and still had full travel. With that the torsion springs were adjusted to the high setting to be safe and the rear shocks and springs were adjusted to get the smoothest possible ride. The front shocks and springs were tested similar to the rear skid. With the weight of the motor and other electrical components mounted under the hood, the front springs and shocks had plenty of travel and, with a few normal adjustments, were found to be sufficient for competition.

ROLLING RESISTANCE

The rolling resistance was reduced in the track by removing the small bogey wheels on the rear and adding an eight inch big wheel kit in its place. Bigger bogey wheels were added along the rear rails to lift the track up off the hifax, reducing friction from the track on the rear skid. The addition of the extrovert drivers also reduces friction, because the track doesn't have to be as tight. It also requires less power to turn the track reducing the overall system friction. Graphite hifax runners were researched, but with the addition of the bigger bogey wheels the current hifax were found to be adequate.

Skis

With the addition of a newer modeled snowmobile the team considered the stock skis to be sufficient for the type of conditions we would see at competition. As stated previously the snowmobile was a touring snowmobile which would mostly be confined to hard packed trail type riding. The team decided that the conditions at competition would be similar to the conditions of a groomed trail, with little powder so the stock skis should perform. Although our snowmobile is heavier than the stock snowmobile the dual carbide skis performed well during initial testing similar to that of trail riding.

BATTERY BOX

The battery box used for the competition will be the battery box fabricated for the 2008 snowmobile. The design factors were cost, structural integrity, and weight distribution of the batteries. Six batteries were placed inside the insulated box. A model of the box can be seen in Figure 10 and Figure 11.

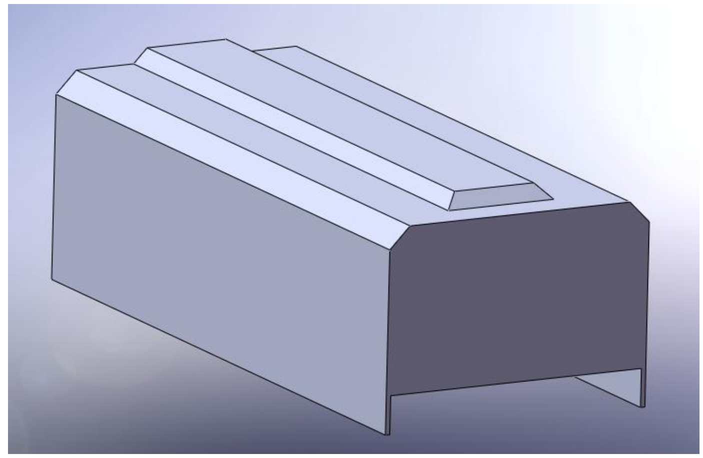

Figure 11: Top battery box piece

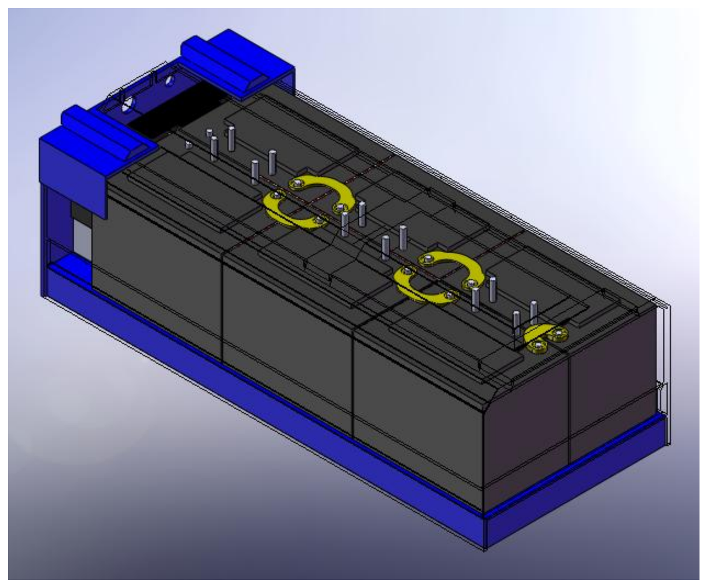

Figure 12: Bottom battery box piece

The team determined the fiberglass battery box is the best choice based on the following requirements:

- SAE standards
- Light-weight
- Self-sealed container
- Ease to change batteries with quick adjustment
- Driver comfort
- Simple and aesthetically pleasing
- Ease of manufacturability
- Non-conductive

The battery box meets all requirements according to SAE rules and standards. The box is made of fiberglass and lined with a rubber lining, which is non conductive and acid resistant in case of a spill. The box is also sealed and vented. The team chose fiberglass as the material for the battery box because it is light weight, inexpensive, nonconductive, and strong. The biggest down side to using fiberglass is the manufacturing process because it is very time consuming.

The manufacturing process consists of many steps:

1. Design a mold
2. Build the mold
3. Sand and prepare the mold for the lay-up
4. Cut all material needed for the part
5. Lay the material in the mold
6. Build two vacuum bags
7. Set up resin traps and vacuum tubes
8. Mix resin and pull it through the material
9. Keep vacuum on the lay-up for 24-hours
10. Pull the part out of the mold after green cure is finished

The desired budget for the battery box was found to be $150. This figure may seem low, but it was due to the privilege of using the School of Mines Composite Lab (CAPE). Time and material was donated to help complete the seat. The team put about eighty-eight man hours into the finished product.

<u>Cost</u>

- Fiberglass - Free
- 210oz. Epoxy Resin Kit - Free
- 3/8" Stainless Steel Pan Tapping Screws - $5.56
- Molding supplies - $105.00

  ____
- Total - $110.56

In order to determine the structural integrity of the battery box an 18in by 18in plaque was fabricated replicating the same lay-up as the pieces. The ASTM 790 testing procedure was used to determine the modulus of elasticity. The testing specimens, from the ASTM 790, were fabricated based on the depth of the material testing. With length being either the larger of 16 times the depth (.125*16 = 2 inches) and the width is one fourth of the length (2 inches/ 4 = 1/2 inch). The samples were then placed in a three point bending test at a rate of .1 mm/mm/min until destruction and results were measured. Statistical significance was verified with a minimum of 5 samples tested.

Since one piece was to be exposed to temperatures different than those of a laboratory setting another replication was conducted. The second replication samples were taken from the same plaque, but were then subjected to temperature conditions that would simulate an environment that a snowmobile would be in. They were placed in a freezer at -10 F. The pieces were then subjected to the same three point bending test. Results were then measured and compared.

With all the analysis it was found that the fiberglass battery box would adequately serve the purpose of insulating and protecting the batteries.

ELECTRICAL SYSTEMS

The basic requirements for completing the final product are broken down into items shown in Figure 12. The transparent box shows the requirement for a motor, power converter, user interface, and a power source. All components are found under these main systems.

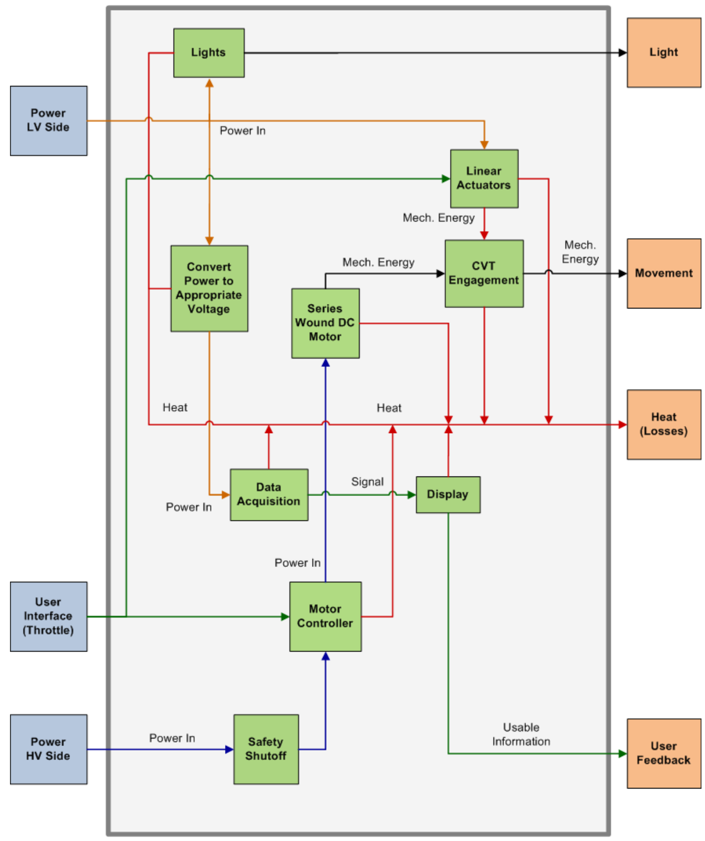

Figure 13: Transparent Box

<u>Motor</u>

For this year's competition, the team had hoped to invest in a new motor, possibly a three phase motor. Unfortunately, due to budget constraints the team was unable to purchase a new motor. Thus this year's design incorporates the motor from the 2008 design. The decision to choose this motor was based on the Pairwise Comparison Chart shown below in Table 8.

Table 6: Motor Pairwise Comparison Chart

Goal	Amps	Efficiency	Torque	HP	Cost	Weight	
Amps	**********	1	0.5	1	1	1	4.5
Efficiency	0	**********	0	0	1	0.5	1.5
Torque	0.5	1	**********	1	1	1	4.5
HP	0	1	0	**********	1	1	3
Cost	0	0	0	0	**********	0	0
Weight	0	0.5	0	0	1	**********	1.5

The 2008 team decided to favor the performance side of the competition and selected the Impulse 9 Series Wound DC

Motor. Figure 13 illustrates the specifications of the motor supplied by the manufacturer, NetGain Technologies.

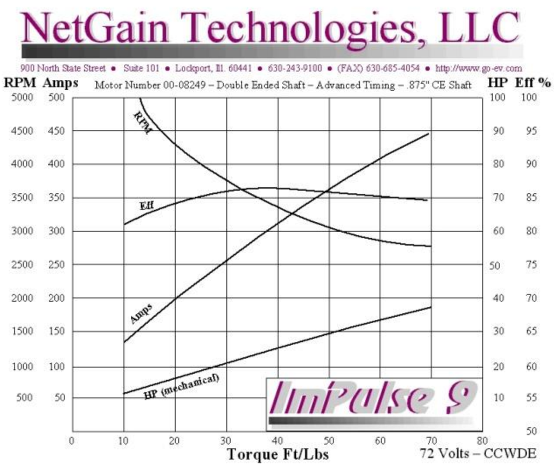

Figure 14: Manufacturers Motor Specifications (NetGain)

Motor Controller

For the 2009 competition, it was necessary to replace the motor controller used in previous designs due to an internal failure. When seeking a replacement, the team decided to simply purchase a new Alltrax 7245 motor controller. The motor controller was selected based on availability, cost, and compatibility. This motor controller is capable of handling 72 Volts at a current of 400 Amps. One nice feature of this motor controller is the ability to interface with a computer for programming and output data. The selected motor controller was also the one recommended by the motor manufacturer, so compatibility is verified. A 0-5kohm potentiometer is used to control the throttle. The throttle potentiometer is setup in a slightly different configuration than in years past. The design is different in the following ways: 1st the potentiometer is relocated away from the right handle bar to a more centrally located position, (Using a turn style potentiometer, the rider can preset the desired motor speed); 2nd engagement of the CVT is controlled by means of two electric linear actuators enabled through a rocker switch. The rocker switch is mounted in the same place that the thumb throttle would be on a stock sled.

Battery Pack

Due to the cost of purchasing new batteries for the 2009 competition it was decided to continue with the Valence U-Charge® XP batteries purchased by the team for the 2008 competition. This decision was also based on the fact that the batteries were not a performance hindering issue during the 2008 competition.

Battery selection is the most critical component when building an electric snowmobile. The 2008 team used the following criteria for battery selection. A battery selection matrix was compiled and can be seen in Table 9. Lithium ion batteries are a desired technology when comparing storage, performance, and weight classifications. The main drawback to this technology is cost. Nickel metal hydride batteries have similar costs and performance characteristics when compared to lithium ion, however, are significantly heavier simply because each cell only has a voltage of 1.2 volts. The number of cells would have to be increased to reach the desired voltage.

Table 7: Battery Selection Matrix (Free Energy News)

Energy Storage Selection Chart

Criteria	Lithium-ion	Ni-MH	Ni-Cd
Environmentally Friendly	Green	Green	Red
Availability	Green	Green	Green
Price	Orange	Green	Green
Safety	Orange	Green	Green
Continuous Current Discharge	Orange	Green	Green
Maximum Current Discharge	Orange	Green	Green
Voltage	Green	Orange	Orange
Required Batteries to Achieve Voltage	Orange	Orange	Orange
Capacity	Orange	Green	Green
Dimensions (L*W*H)	Green	Green	Green
Weight	Green	Green	Green
Charging Time	Orange	Green	Green
	Qualified--->	Qualified--->	Disqualified--->

Red: Indicates Automatic Disqualification
Orange: Indicates a Concern
Green: Indicates Acceptability
Yellow: Indicates Unknown

Criteria	Lithium Ion	Ni-MH	Lead Acid
Price per unit	4.95	9.69	154
Price Total	3663	4069.8	1848
Continuous Current Discharge	?	35	500
Maximum Current Discharge	41	50	500
Total Maximum Pack Discharge	1517	350	1000
Voltage	3.7	1.2	12
Required Batteries to Achieve Voltage (series)	20	60	6
Capacity (Ah)	2.2	12	41
Required Batteries to Achieve Ah (Parallel)	37	7	2
Total Required Batteries for 80Ah	740	420	12
Dimensions (L*W*H) or (Dia, H) mm	(18.4, 65.1)	(33, 91)	(9 5/16in, 5 1/16, 8 15/16 in)
Weight (g)	44.5	235	11818.18
Total Weight (kg)	32.93	98.7	141.8182
Charging Time	2 hrs	1 hr	6 hrs

Lithium ion batteries were selected because of their energy density, lighter weight, and cold weather characteristics. These batteries are capable of producing the maximum amount of current the controller can handle, even in cold weather. Also, they offer a much higher energy density compared to traditional batteries, which will allow the snowmobile to increase its range significantly. Lithium ion batteries were also selected for their quick recharge times. The Valence U-Charge® XP batteries can be recharged in 2.5 hours which is significantly faster than lead acid batteries.

The lithium ion battery pack that was selected has a storage capacity of 100 Ah. This is an ideal value, but does not take into consideration the fact that the faster the batteries are discharged, the lower the actual storage capacity becomes. This is due to the nature of the chemical reactions within the battery pack. If the batteries are discharged quickly, the voltage will drop significantly, but will recover soon after the batteries are no longer being discharged. This will definitely affect the range performance of the snowmobile.

Assuming ideal conditions, the range should be just over 11 miles assuming a constant current draw of 150 amperes and an efficiency of 68% with all of the power losses taken into consideration.

Table 8: Manufacturers Data Sheet for battery specifications (Valence Technology, U-Charge® XP family)

Specifications		U1-12XP	U24-12XP	U27-12XP	UEV-18XP
Voltage		12.8 V	12.8 V	12.8 V	19.2 V
Capacity (C/5)		40 Ah	100 Ah	130 Ah	65 Ah
Dimensions including terminals (L x W x H)		197x130x182 mm 7.75x5.2x7.2 in	260x173x225 mm 10.24x6.8x8.6 in	306x173x225 mm 12x6.8x8.6 in	268x148x269 mm 10.55x5.8x10.6 in
BCI Group Number		U1R	Group 24	Group 27	N/A
Weight (approximate)		6.1 kg / 13.4 lbs	15.8 kg / 34.8 lbs	19.5 kg / 42.9 lbs	14.8 kg / 32.7 lbs
Terminals, female-threaded		1/4-20	M8 x 1.25	M8 x 1.25	M8 x 1.25
Specific energy		84 Wh/kg	81 Wh/kg	85 Wh/kg	84 Wh/kg
Energy density		110 Wh/l	126 Wh/l	140 Wh/l	117 Wh/l
Standard Discharge @ 23°C	Max. cont. current	80 A	150 A	150 A	120 A
	Max. 30 sec. pulse	120 A	300 A	300 A	200 A
	Cut-off voltage	10 V	10 V	10 V	15 V
Standard Charge	Charge voltage	14.6 V	14.6 V	14.6 V	21.9 V
	Float	13.8 V	13.8 V	13.8 V	20.7 V
	Recommended	20 A	50 A	65 A	30 A
	Charge time	2.5 hrs	2.5 hrs	2.5 hrs	2.5 hrs
DC internal resistance		15 mOhm	6 mOhm	5 mOhm	10 mOhm

One auxiliary battery is used to run miscellaneous components such as the headlight, taillight, relays, and gauge backlighting. A second auxiliary battery is used to power the actuators that control the clutch assembly. These are both 12V 18 Ah Sealed Lead Acid batteries from Interstate Batteries. The reason for the separate batteries is for ease of installation. This eliminated any extra current draw from the main battery pack and an expensive DC to DC converter was no longer necessary. This size of battery has proven to provide adequate power to all auxiliary components far longer than the main battery pack supplies power to the propulsion system.

Charge Manager

The charge manager "U-BMS-XP-LV" is manufactured and recommended by (Valence Technology, Inc) the same company that produces the Lithium-Ion-Polymer batteries that are powering this year's sled. The charge manager is setup to monitor and control anywhere from 1 to 10 Li-Ion batteries in series (10 to 150V); this added protection keeps the temperature, voltage and current balanced between each battery. In the event of a system fault the charge manger commands all the batteries to open their internal contactor, shutting off all primary power. The batteries' SOC (status of charge) can be monitored directly from the charge manager. The 'Data Acquisition System' takes advantage of this option. This data is readable as a dc voltage (0V to 5V) that linearly relates to the SOC.

Battery Charger

The Quick Charger Series/MQPA6-127v/6A is a battery charger capable of charging 60 lead acid cells. This is equivalent to 10 lead acid batteries rated at 12V. When connected in series all batteries are charged simultaneously which is necessary to keep the batteries in the vehicle during charging. The charger is not equipped with an automatic shut off. An outlet timer is used to turn the unit off. Charge time has to be calculated based on the battery capacity and state of charge shown on the battery meter. When a full charge is necessary it would take up to 17 hrs to achieve full capacity under near ideal conditions. Overcharging can cause the batteries to emit a flammable gas (hydrogen), which can be dangerous and will decrease the performance of the batteries.

Cable

Cable selection is important because of the high current required for this application. These cables must have the ability to carry the full 450A that the motor controller is capable of drawing. Copper wire sizes were researched and 3/0 AWG cable was the smallest diameter cable able to handle this current. According to competition rules the cable needs to be protected by a UL rated insulation. Welding cable was selected to provide flexibility when making connections between terminals.

Resistance is dependent on diameter. 3/0 AWG cable has a resistance of 0.0001884 Ohms per meter. This is very small with respect to the power loss of the rest of the system. Approximately two meters of cable were used.

Contactor

The team chose the Albright SW200 contactor which is capable of handling 96 Volts and 400 Amps continuous. The contactor acts as a large relay and will open in case of an emergency, which will stop power from going to the motor controller. There are three, rider friendly, ways to open the contactor: push the kill switch, turn the key to the off position, or remove the tether kill switch. The inner contacts of the contactor are coated with a synthetic material, which prevents arching that could ultimately keep the contactor from operating properly.

Ground Fault Detector

Safety should always be of the utmost importance and the competition rules have one more directive that will help ensure the safety of participants. This new requirement listed as "FH-2.1.1 Ground Fault Detectors", provides a means by which all electrical systems will be instantly shutdown in the event of a short circuit between any high to low voltage reference point. The GFD in 'Figure 14' represents the model being implemented in this year's sled. This GFD can be configured to trip at insulation resistances of 20kohms all the way up to 200kohms, making it well suited for the target value of 40kohms.

Figure 15: Bender™ IR-125Y GFD

Data Acquisition System

One more improvement the team is planning to implement this year is a data acquisition system. This system is designed with the goal of providing better rider feedback by gathering and displaying performance data, such as: current, total battery voltage and the status of charge remaining in the six primary Li-Ion batteries. This system given enough testing, will allow the team to optimize the sled for better ride dynamics. The chosen method for displaying numeric information, such as the voltage and current is with a 2x16 LCD display and as for the SOC, it will be displayed using ten bar segmented LEDs (red yellow & green) that correspond to increments of ten percent charge capacity. The following concerns are addressed in the design: readability, reliability and the ability to integrate into future designs (see figures 15 and 16).

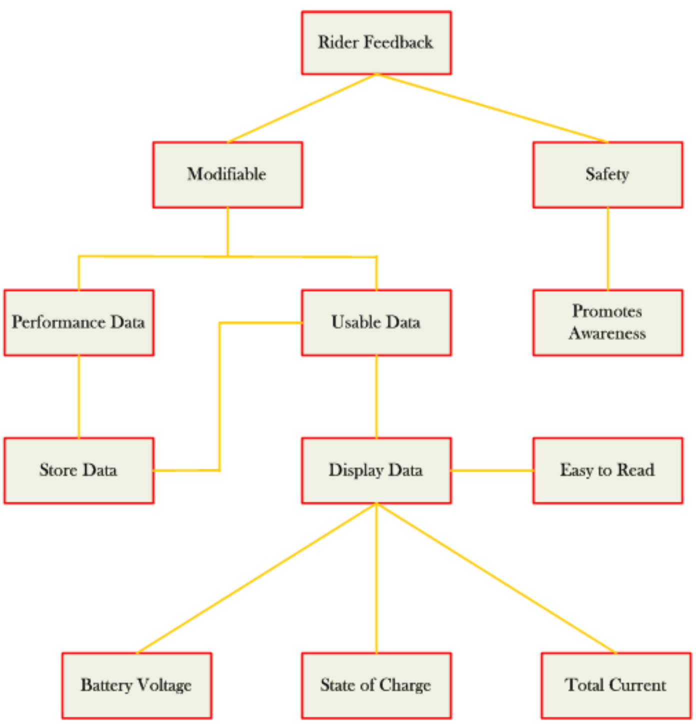

Figure 16: Objective Tree

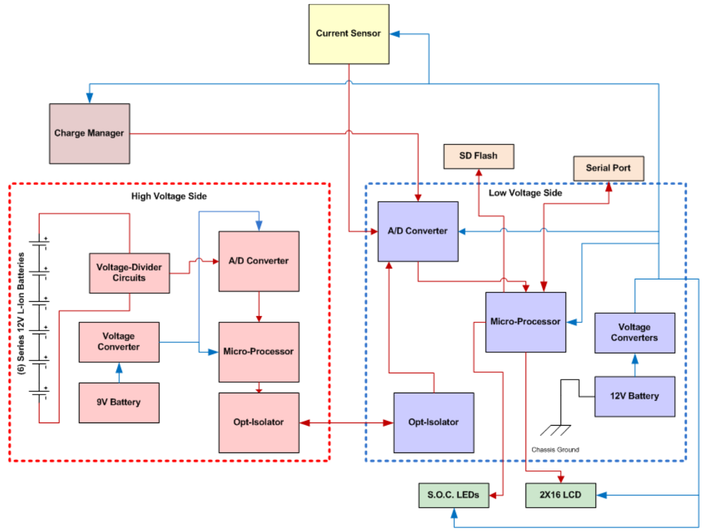

Figure 17: Transparent Box

Miscellaneous

Other components that are necessary for proper operation include: headlight, taillight, gauge backlighting, relays, fuse block, auxiliary battery, tether kill switch, push/pull kill switch, speedometer, tachometer, and small gauge wire. The stock headlight was reused. LED taillights were used to reduce power consumption. LEDs use far less power compared to an incandescent light. The stock speedometer was used because it directly linked to the track, which was not modified. An aftermarket tachometer was used. It is linked to the secondary shaft of the motor using a magnetic sending unit. Relay, gauge backlighting, headlight, and taillights are powered by one of the auxiliary batteries.

ELECTRICAL ASSEMBLY

Battery Pack

Electrical connections were established using bus bar and cable. Cables were manufactured using 3/0 AWG welding type cable. Each end had a terminal attached using a crimping tool and soldering. Heat shrink tubing was applied to each end in order to reduce the chance of electrical shock or shorts. Bus bar was used to interconnect the batteries in the battery pack. This reduced resistance and ultimately power loss. Battery terminal stresses are a concern; however, time does not permit the manufacturing of a better solution. The condition of the terminals will be closely monitored for safety.

The lower voltage system was connected using 14 AWG wire to power the headlight, taillight, relays, and gauge backlighting. The auxiliary battery for this system was installed in the same battery box on the tunnel of the snowmobile. A main power wire was connected to a relay with a 5A fuse installed. This keeps high current isolated from the ignition switch and kill switches.

The main battery pack and the auxiliary battery were connected to a plug located by the key. The charger was then modified to plug into the plug, which allows for ease of operation. Through this single connection, the auxiliary battery and the main battery pack are charged simultaneously.

Motor

The motor was configured to operate in a counterclockwise rotation to be compatible with the drive train. The main shaft was utilized at the connection point for the CVT. The secondary shaft was used to attach the magnetic sending unit for the tachometer. This configuration required cable connections between S1 and A1. S2 and A2 were then attached to the motor controller.

Motor Controller

The Alltrax motor controller was connected according to manufacturer's recommendations. This included an ANN400 type fuse in line with the battery pack. A linear potentiometer was attached to pin 2 and pin 3 of the motor controller. Pin 1 has a high voltage, low current source connected to it to enable the motor controller. This is powered when the key is turned on with both kill switches in the closed position. A precharge circuit was used to prevent damage to the capacitors in the motor controller by giving a gradual increase in charge instead of charging too quickly which damages components over time. The precharge circuit has a switch installed in order to have the ability to completely disconnect the battery pack.

An Albright SW200 96V contactor was used to act as a high power relay to give the ability to disconnect the battery at the push of a button.

Miscellaneous

LED taillights were utilized in order to reduce power consumption. The stock brake controls were maintained. The taillights were at the rear of the seat.

The headlight circuitry remained stock with a hi-low switch and the normal bulbs.

A standard tether kill switch that is readily available was used in the motor controller enabling circuitry. This was connected in series with a standard on-off key switch as well as the GFD and a normally closed kill switch. Once again, this is to allow for easy repairs because both parts are easily attained.

All low voltage wires have quick connect terminals that are covered in plastic. This keeps an isolated circuit and allows for easy component removal.

Electrical Schematic

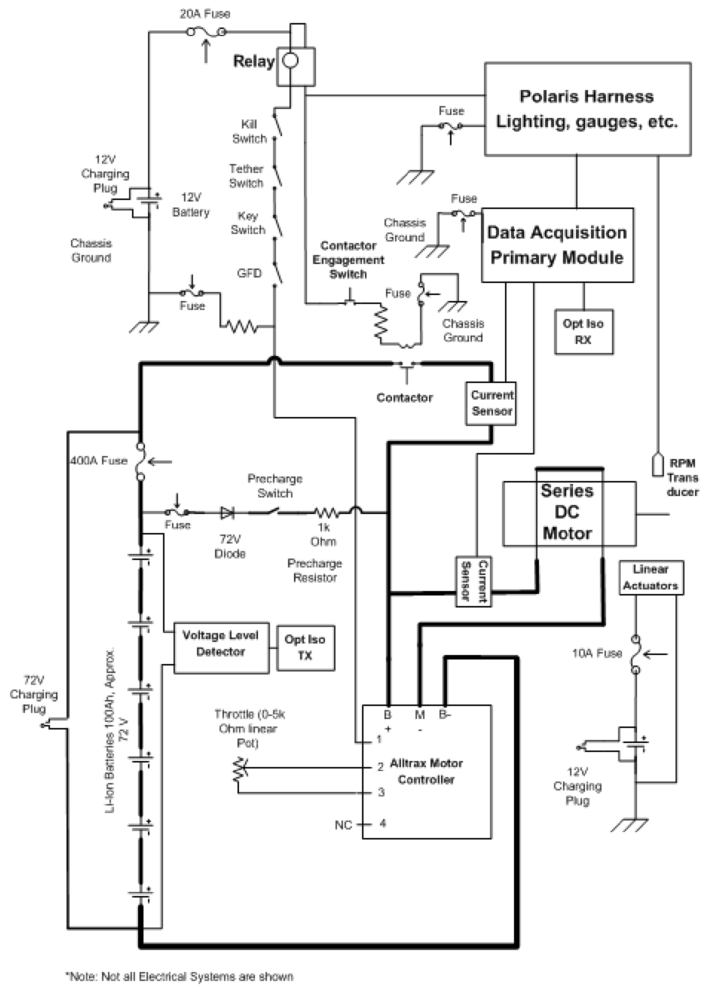

Figure 18: Full Electrical Schematic

SOCIAL IMPACT

There are several negative aspects of a snowmobile that have raised much concern about the use of snowmobiles. First, snowmobiles are inherently very loud. This is caused by the exhaust system, track, and the type of engine being used. An electric snowmobile practically eliminates noise other than the noise caused by the track.

Second, snowmobiles produce a large amount of pollutants. Most snowmobiles utilize a two stroke internal combustion engine in order to deliver top performance. This type of engine produces an excessive amount of pollution. Four stroke snowmobiles are starting to come out, but still produce a certain amount of pollution. Electric snowmobiles do not release any pollution in the environment that they are used in. Obviously, electric snowmobiles must be charged using a power source which comes from a polluting power plant. The important part, however, is that the pollutants are not being released in the natural areas like parks which is the usual riding place.

Lastly, the competition itself raises a positive viewpoint on electric snowmobiles. The entire idea is to raise awareness of a growing concern in society. All around the globe, serious focus has been placed on any object that produces excessive amounts of pollution. By raising awareness, new thoughts and concepts are developing every day that will help preserve the environment and this competition plays a major role in those ideas.

CONCLUSION

The South Dakota School of Mines and Technology's Alternate Fuel Vehicle Team have designed, built, and tested a zero emissions snowmobile in a very short amount of time. The team and snowmobile will compete in the 2009 SAE Clean Snowmobile Challenge. Design stemmed from efforts on safety, performance, cost, and ease of manufacturing. Completed analysis was performed in every aspect of design to ensure safe and reliable operations. At a glance, the SDSM&T snowmobile is clean, efficient, and cost effective. The technologies incorporated into the snowmobile are easily adaptable to any stock snowmobile.

ACKNOWLEDGMENTS

The SDSM&T AFV team would like to acknowledge the many sponsors who helped to make this project a reality. A special thanks for the resources found in the Center for Advanced Manufacturing and Production (CAMP) and in the Composite and Polymer Engineering (CAPE) Laboratory. Thanks also to the teams advisors, Dr. Batchelder and Dr. Dolan, and to the many other faculty who offered expertise. Thanks also to other local sponsors:

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Coatesville PA 19320
(800)356-4266
www.bender.org

6. Electric Vehicles USA
2615 Hwy 153
Unit B5, Piedmont
South Carolina, 29673, US
(864)220-5548
www.electricvehiclesusa.com

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430 E. 1200 N.
Logan, UT 84341
www.evsource.com
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DEFINITIONS, ACRONYMS, ABBREVIATIONS

AC: Alternating Current

DC: Direct Current

CSC: Clean Snowmobile Challenge

CVT: Continuously Variable Transmission

GFD: Ground Fault Detector

HP: Horse Power

IC: Internal Combustion

RPM: Revolutions per Minute

SAE: Society of Automotive Engineers

SDSM&T: South Dakota School of Mines and Technology

SOC: Status of Charge