South Dakota School of Mines and Technology Electric Snowmobile

2007 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 a new task this year. The team has designed and manufactured a zero emissions snowmobile to compete in the SAE Clean Snowmobile Challenge. The snowmobile was designed following fundamental requirements set forth by the team. A design was selected that were within the constraints. A full analysis to ensure safety and durability was completed before manufacturing could begin. The snowmobile's systems were designed with a focus on optimal performance in acceleration, handling, and appearance. The systems are clean, efficient, and easy to be incorporated into any commercially available snowmobile. Testing has proved that the SDSM&T snowmobile performs well in acceleration, handling, and drivability.

INTRODUCTION

The Alternate Fuel Vehicle team consists of diverse engineering students at South Dakota School of Mines and Technology. The students have designed, analyzed, and manufactured an electric snowmobile and are competing in the 2007 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 history of designing alternate fuel systems which include 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 a challenge. Design began immediately on the systems and was revised to be incorporated into the 1995 Indy 500 XLT snowmobile purchased in mid November. Manufacturing and modification of the sled began in mid January 2007 and a working sled was ready by February 7, 2007. This gives an idea as to the motivation and abilities of the engineering students at SDSM&T.

The initiation of this project has provided the team with additional interested students and faculty and due to the well defined competition the future of the team looks very promising. 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 the first year SDSM&T has built a snowmobile, these objectives were followed for competition:

- Provide a competitive sled that demonstrates the viability of alternate fuel
- Obtain a benchmark for future design teams
- Present a vehicle that runs at its most efficient ability
- Be competitive in the 2007 SAE CSC

With the knowledge obtained this year for the design and competition results, future teams will be able to follow and improve the 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

As with all types of designs, there will be constraints to deal with. The AFV design team focused its design direction on eight fundamental requirements. The engineering was done by finding the best option for design 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

Topics	Ranks
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. This machine will need to be safe for the operator as well as any spectators. The designers are liable for the safety of anyone who comes in contact with the sled. All the components will have to be adequately contained within the shell of the snowmobile. The object is to keep the rider in control at all times. This was the intention of the rules which means that stock lighting such as headlight and taillight were kept to maintain rider visibility. In case of electrical or mechanical malfunction, a kill switch is located on the right side of the handlebar; this is located in the same position that a typical snowmobiler expects. A tether switch is also used in case the driver falls off of the vehicle while in motion. This will reduce the chances of injury from the sled continuing forward. All high voltage connections were covered in red which will alert anyone who will work on the sled that there is danger as well as isolating the electrical connections. Fuses were installed in case of malfunction or shorts in every single circuit on the snowmobile.

PERFORMANCE

The team decided that performance of the sled should be similar to that of an internal combustion (IC) based snowmobile. Some important criteria affecting performance is the overall weight of the snowmobile, torque, horsepower of the motor, battery current capabilities and motor controller tolerances. All of these were taken into consideration when designing. When focusing on the acceleration performance, the range of the vehicle will drop. This can be compensated in the future as battery technologies improve.

RANGE

Range is important, but has limitations due to the nature of the competition. Battery capacity severely limits any ability to compete with the range of an IC based snowmobile. In order to get the necessary battery capacity, the weight of the snowmobile must be increased. Due to the small size of a snowmobile, this is not possible. Range was ranked as a concern, but acceleration performance will be more of a focus.

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 little or no repairs. A well engineered product should be inherently reliable.

WEIGHT

As any snowmobiler will state, weight is critical to performance. A team goal is to only add an amount of weight that is similar to a fully functional internal combustion snowmobile. This is very critical 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 on 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. The heaviest component still remained the battery pack.

COST

The team was limited to a small budget. The focus is to design a snowmobile that can be manufactured with a cost that is comparable to a currently available fuel powered sled. 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 be purchased. Consequently, the team gave special emphasis to upgradeability of the snowmobile for future competitions. Time constraints did not allow for fundraising since the team had to focus on manufacturing.

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. Some components are simply not available to the general consumer or were backordered. 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 for repairing the vehicle in the future. Common items were used in order to ease repairs. This also includes manufacturability. One aspect of this was selecting components that would be easy to manufacture with the resources the team had 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. Part of creating a good product is making the product presentable, therefore, displaying the professionalism of the team.

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 a performance machine. This began with brainstorming to come up with at least 10 possible concepts for each area no matter how far fetched they seemed. Many times with design, these far fetched ideas turn out to be the best 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 design 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 motor, batteries, battery box, among others.

COMPETITION PERFORMANCE

ACCELERATION

Given the limits on battery technology, the team knew that being able to construct a high performance snowmobile that could perform over a long distance would be virtually impossible. 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. Although range would be compromised there would still be adequate results in acceleration, draw bar, rider comfort, cost, etc. This meant that there would be a smaller energy capacity of for the battery pack, but was found to be sufficient for the distances needed to be traveled for the majority of competitions.

DRAW BAR TEST

As previously stated, the focus of this project was designing a snowmobile that would be able to perform optimally for short periods of time. An electric motor has the largest amount of torque at its lowest rotational velocity, so utilizing an optimal gear ratio has allowed for a larger towing capacity. Along with the torque, a demand on horsepower was also needed.

COST

The snowmobile has been designed to cost less than $8000 due to the team's limited budget. This shows that the components selected gave optimal performance at a low cost. Consequently, the team gave special emphasis to upgradeability of the snowmobile for future competitions when there is a larger budget present.

RIDER COMFORT

The incorporation of a Continuously Variable Transmission (CVT) into the design of the snowmobile would allow for little to no shift shock and gave the handling of a typical snowmobile. The electric motor allowed for constant torque and horsepower which allows the CVT to operate in a similar manner to 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 snowmobile. A lightweight seat was designed to fit the contours of a typical rider which added to rider 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 on nights were the temperature reached lows of -15 degrees Fahrenheit and the snowmobile operated.

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 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 track and drive train. This noise could be reduced slightly, but not 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. Since the snowmobile chassis selected was used, it was soon realized that many of the components from the gearing to the hifax needed to be replaced to reduce noise emissions.

RANGE

During the initial stages of design it was seen that competing for top marks in range would be simply unattainable with the resources available. A goal was to design a snowmobile that would have performance characteristics of a typical snowmobile for short periods of time. In future years the lack of range could be compensated for with more advanced technology in batteries.

DESIGN STRUCTURE

When looking at a snowmobile of any sort, it is seen that there are many things contributing to its performance. For this years sled, all the minor components were grouped into the drive train, chassis, and largely on the electrical system.

DRIVE TRAIN

Individuals working on this subsystem were given the task of performing analysis on the original drive train and making decisions on how to optimize its performance with the new electric motor. The major issue was finding a way to efficiently transmit power from the motor to the track. This proved to be a challenge on account of the nearly opposite specifications of an electric motor versus the original internal combustion engine. After serious consideration of the multiple ways of transmitting power, it was found that a CVT would best utilize the low end torque while giving speed at higher RPM. The team did find that tuning a CVT to operate from 0 to 2500 RPM would be a bit of a challenge. Other things included with the drive train analysis were the motor mounts, brakes, gears and noise reduction of the track.

CHASSIS

The chassis team consisted of mechanical engineering students who devoted their time to modifying and reducing weight to the body of the snowmobile. Due to time constraints, a significant amount of weight reduction wasn't accomplished. Components that were not needed were removed and minor weight reduction was done to the suspension. This year the chassis team focused their time on designing a battery box and seat. Noise reduction, handling, suspension, and body integrity were other issues addressed by this team.

ELECTRICAL

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 operated in conjunction with the eight fundamental requirements and kept safety for motor testing and analysis as a top priority.

DRIVE TRAIN

MOTOR MOUNT

The motor mount was designed to withstand the rigors of both testing and competition. It was important to ensure that the mount would safely secure the motor in any eventuality. To do this the motor is supported on both sides, each side of the motor mount is independent. Abaqus was used to conduct a Finite Element Analysis on the motor mount.

<u>Stress Analysis</u>

Each side of the mount was studied independently using shell elements. First a weight of 150 lbs was applied to the mount. This was done by applying 1/8 the weight to the 4 holes on each side, this force acted straight down. Next the torque of the motor was applied to each of the mounting holes. This was equal to a total of 80 ft-lbs of torque which is the maximum torque of the motor. The final load that was applied was to represent a 4 G side impact. To do this a partition was made that was in the position of the surface of the motor; to this a pressure equivalent to 300 lbs was applied. This last force was found to cause the largest portion of the stress in the part. Figure 1 shows the contour plot of the Maximum Von Mises stress in the left side mount and Figure 2 shows the same in the right.

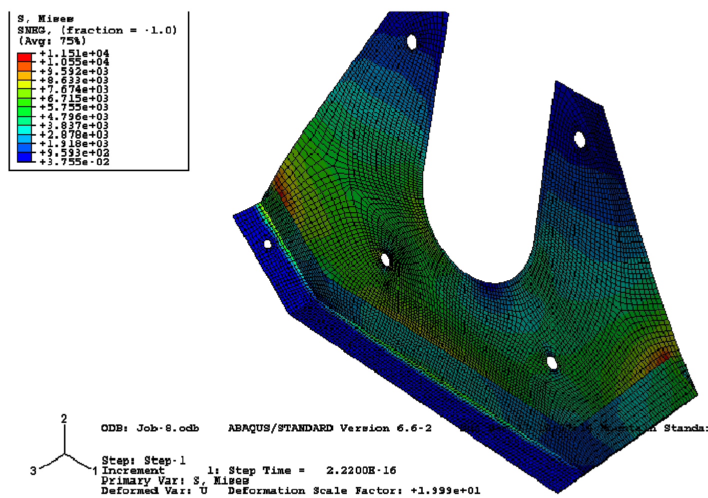

Figure 1: Contour plot of the left side motor mount showing the Maximum Von Mises stress.

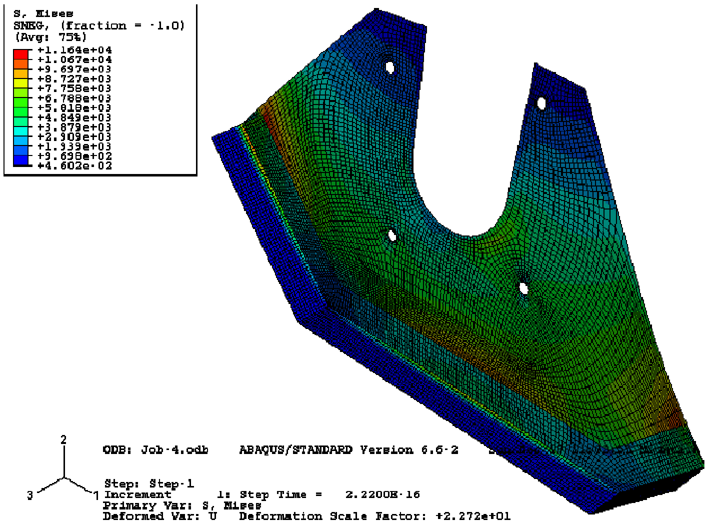

Figure 2: Contour plot of the right side motor mount showing the Maximum Von Mises stress.

Table 3 shows the results from this analysis. Tables 4 and 5 show the convergence study that was conducted for the left and right side of the motor mount respectively.

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 (%)
Left Side	11510	3.13	4.69
Right Side	11640	3.09	3.26

Table 4: The Von Mises Stress convergence study for the left side 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 left side 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

The right motor mount produced nearly the same amount of deflection and stress as the left plate.

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 to in this analysis.

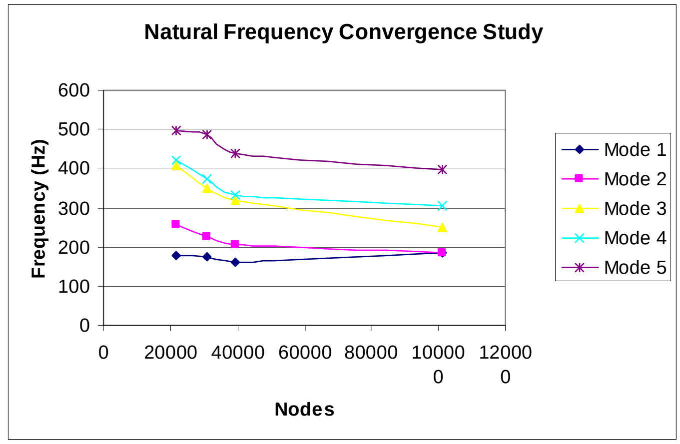

Figure 3: Chart showing the convergence study found in the frequency analysis.

As Figure 3 shows the lowest natural frequency for the motor mount is 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 not in danger of being run at a frequency that could induce resonance.

Summary

The motor mount has been analyzed for conceivable methods of failure. First, the stress analysis verified that the mount will be robust enough to withstand testing and competition. Then the frequency analysis assured that the mount will not resonate at any frequency expected in the sled. This motor mount should prove to be a reliable component of the completed sled.

TRANSMISSION

After selecting the motor and batteries, additional efficiency would have to be attained through the proper tuning of the transmission. Almost every commercially available snowmobile incorporates the use of a CVT which is a very important part in the performance of the vehicle. This type of transmission is ideal because it will allow the motor to be operated at a constant rotational velocity. The most efficient operating conditions of the motor can be found and can be followed by properly tuning the transmission to keep the motor running at that ideal point. In the case of an electrical motor, it would allow for a lower amp draw by giving a range of gearing. Since more focus was put on efficiency of systems, a CVT was the initial design transmission. Testing revealed that a direct transmission would work better with an electric motor, but more testing was needed.

CVT versus Direct Drive Transmission

The CVT was weighted against a direct drive system at the given gear ratios. The direct drive system would give adequate performance, but wouldn't allow for the extra low end torque accompanied with a high top speed and low amp draw. A focus could be put on one area, but the other would have a negative effect. In order to find how to transmit the power most effectively, a closer analysis was taken at the motor specifications from the manufacturer as well as test data. The ideal operating conditions can be found by observing Figure 4.

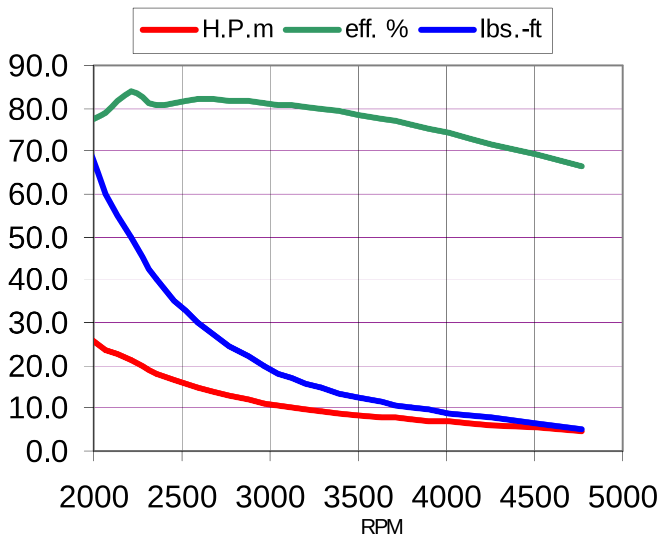

Figure 4: Motor Specs showing how HP, Torque, and Efficient drop dramatically with respect to RPM

The above figure shows that the most efficient operating points of the Warp 9 motor occurs at the lowest RPM. This low RPM gives the highest torque, horsepower, and efficiency. As RPM is increased, power is lost. Therefore, the team decided the best transmission would be capable of allowing the motor to remain between 1500 and 2500 RPM. This would be possible with a direct drive system or a CVT. The problem with this becomes tuning the CVT to begin shifting around 500 RPM and be completely shifted out by 2500 RPM. This is a problem since a typical CVT allows for an idling speed of around 3000 rpm and an engagement of roughly 3500 RPM with operating speeds around six or seven thousand RPM.

Clutch Tuning

Since it is difficult to model the behavior of a CVT, the team began by finding the theoretically best options for weights and springs and began testing. First engagement at 0 RPM was needed to take advantage of the motors efficiency. To arrive at this, a belt was selected that was slightly wider than the spacing between the primary sheaves. Radical combinations were used to find the lowest engagement of the clutches. In the primary, 74 gram weights were combined with springs with spring constants of 20 lb/in. Testing provided data that would show that the needed RPM would be reached, but a drop in HP would also occur in conjunction with this. The team then decided under the conditions of limited time and budget, the best option would be a direct drive transmission. The CVT was then adjusted to provide a 1:1 ratio while additional gearing was experimented with in the chain case to find the best option.

Gearing

When finding top performance of a snowmobile, it is necessary to find the correct operating speeds of the motor by tuning the CVT and following this with proper gearing to obtain the necessary speeds. The team decided to use the stock CVT and chain case due to the time and budget constraints. The original Polaris CVT used in the sled starts with a 3:1 gear ratio and is followed with a 0.75:1 ratio at complete shift out. . The CVT was set to a 1:1 ratio to allow for accurate calculations. Mounting the CVT itself required manufacturing of an adapter to mount to the keyed motor output shaft and connect to the tapered primary sheave. For this an analysis was done on the keyway to ensure a proper factor of safety. This analysis is shown in Table 6.

Table 6. Keyway analysis

1035 Cold Drawn Steel		
Material Properties		
Yield Strenth (Sy)	=	66.72 kpsi
Physical Properties		
Shaft Diameter (D)	=	1.125 in
Shaft Radius (R)	=	0.5625 in
Key Width (w)	=	0.25 in
Key Length (L)	=	1.25 in
Factor of Safety (n)	=	2.5
Torque (T)	=	960 in*lbs
Force (F) at surface of the shaft = T / r = 1,706.67 lbs		
Sy / 2*n = F / w*L		
Sy = (2*F*n)/(L*w) = 27.3 kpsi		
27.3 kpsi < 66.72 kpsi so the key DOES NOT fail		

Finite Element analysis was done with an adapter of basic geometry to ensure that yielding wouldn't be reached. The torsion load was simulated with point loads on the shaft. A maximum von Mises stress was found at 8 kpsi which was well below the yield stress of 66 kpsi. A diagram showing the stresses can be seen in Figure 5.

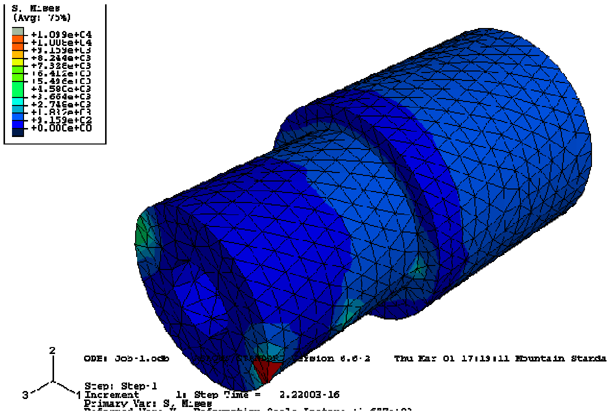

Figure 5: Stress analysis of adapter

After additional analysis was done it was found that aluminum could have be the material of choice. The application of the part was then considered which showed that the part would have to be applied and removed many times during testing. From this the team decided on 1035 steel as the material since it would resist wear more readily.

Additional gearing was done to find the best combination of HP and speed. A calculation showed when the sled was on the ground with a 200 lb rider, the motor would need 48 lbs.-ft of torque to move the track. According to the data seen in Figure 5, at a 2:1 gear ratio, the motor would operate at 18 HP and 81% efficiency. Theoretically, this seemed like the best ratio and testing at alternative gear ratios proved that a 2:1 ratio in the chain case gave the most efficient operating points of the motor. The following chart compares the different gear ratios and their affect on speed.

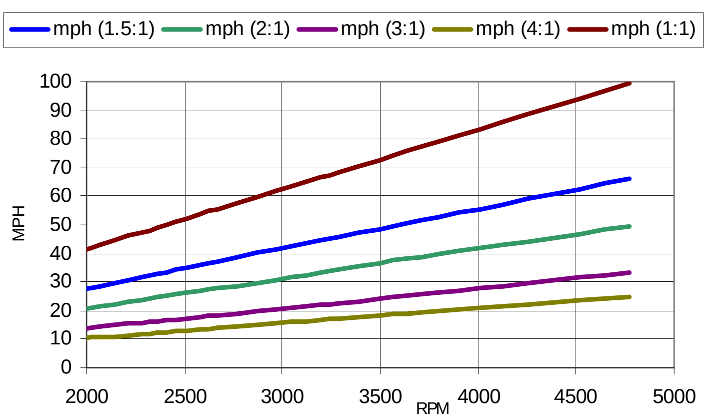

Figure 6: Gear ratio affect on operations

Remember from Figure 4 that the ideal operating point lies below 2500 RPM. Figure 5 shows that with a 2:1 gear ratio and 2500 RPM, a speed of 27 mph will be reached. Obviously gearing this low will require a greater amp draw, but will give a performance machine for short periods of time. Perhaps a more accurate view of data can be seen in the Table 7.

Table 7: Motor operations versus at various gear ratios

rpm	lbs.-ft	amps	H.P.e	H.P.	eff. %	mph (1:1)	mph (1.5:1)	mph (2:1)	mph (3:1)	mph (4:1)
4770	5	70.9	6.8	4.5	66.4	99	66	50	33	25
3798	10	98.6	9.5	7.2	76.0	79	53	40	26	20
3285	15	121.5	11.7	9.4	80.0	68	46	34	23	17
2965	20	143.8	13.9	11.3	81.4	62	41	31	21	15
2584	30	186.2	18.0	14.8	82.1	54	36	27	18	13
2358	40	230.7	22.3	18.0	80.7	49	33	25	16	12
2215	50	260.6	25.1	21.1	83.8	46	31	23	15	12
2071	60	310.6	30.0	23.7	78.9	43	29	22	14	11

With the complete analysis and testing the team decided that the gear ratio of choice would be near a 2:1 with a 2358 RPM and a 230 amp draw which would only occur upon initial acceleration of the snowmobile. Testing has shown that the amp draw is reduced once the sled obtains a rolling momentum.

In future years, with more time, the team would like to incorporate a working CVT designed to transmit power efficiently while reducing the overall amp draw from the batteries. Newer battery technologies will support a larger amp draw and thus add to the range performance.

CHASSIS

SUSPENSION

In order to properly tune the suspension an accurate reading of weight distribution needed to be obtained. It was found that a the snowmobile without a rider put 195 lbs on the front right suspension, 187 lbs on the front left suspension, and 410 lbs on the rear for an overall weight of 792 lbs. The goal weight of the sled was given as 750 lbs which was not met due to the weight of the battery pack. A view of the major component layout and can be seen in Figure 7.

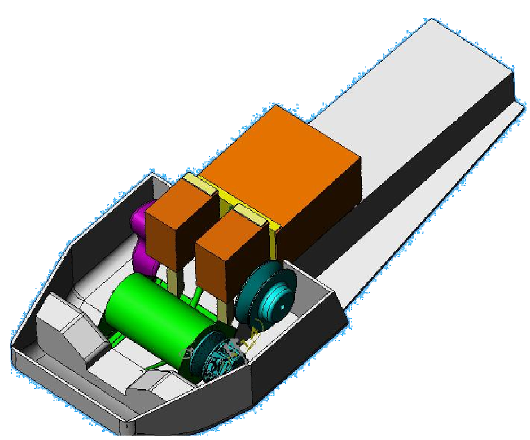

Figure 7: CAD drawing of major components added to sled shell

By showing a side view of the components seen in Figure 8 and by knowing the weight of each component it was found that the center of gravity was located at the front quarter of the large battery box.

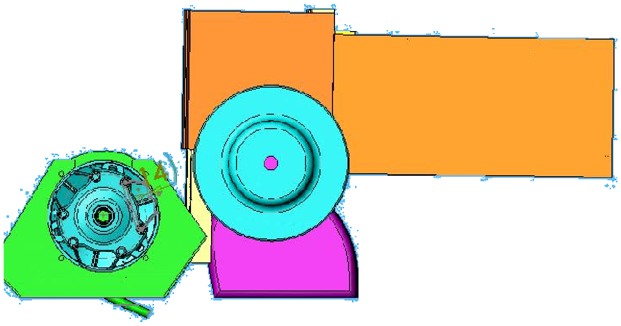

Figure 8: Side view of major components

The center of gravity at this view in Figure 9 was found to be nearly exactly at the center, in a close vicinity of the steering column.

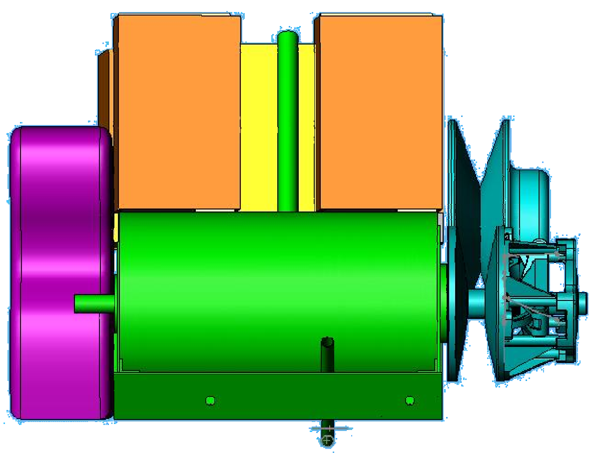

Figure 9: Front view of systems

The Fox® shocks used on the sled were all removed and recharged to meet the weights as close as possible. The front suspension was at the rated limit, but gave at least six inches of travel which was the goal. No additional tuning was done to the front shocks. The rear shocks were recharged and remounted and it was seen that they weren't strong enough to support the 400 lbs on the rear. Simple understanding of the suspension system showed that the shocks were strong enough, but simply needed a stronger helper spring. The original snowmobile incorporated a torsional helper spring. To suffice for the added weight to the rear, adjustment was provided to the torsional spring to add more pretension to the spring which in turn made a stiffer reaction to the weight.

ROLLING RESISTANCE

The rolling resistance was reduced in the track by removing the small bogey wheels and adding an eight inch big wheel kit in its place. New hifax were also installed to help reduce both rolling resistance and noise caused by the track.

<u>Skis</u>

With handling being harder to obtain with a heavier sled, new skis were purchased that would help the handling and aid in overall rider comfort. A set of used Powder Pro® skis were purchased that would show exceptional performance on any type of surface such as snow powder, packed snow, ice, etc. The operations of the skis are summed up in Figure 10 below.

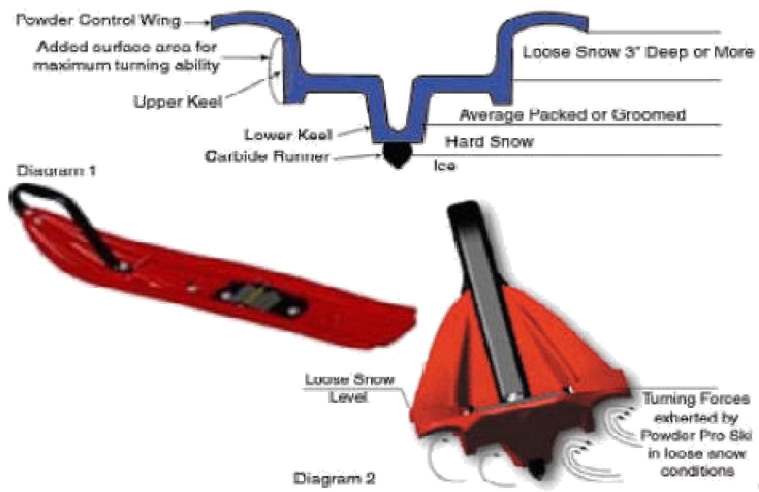

Figure 10: Powder Pro Skis

BATTERY BOX

The battery box was chosen to be placed in the same vicinity of the original gas tank to help with the distribution of weight. Six batteries were placed inside the insulated box. A model of the box can be seen in Figure 11.

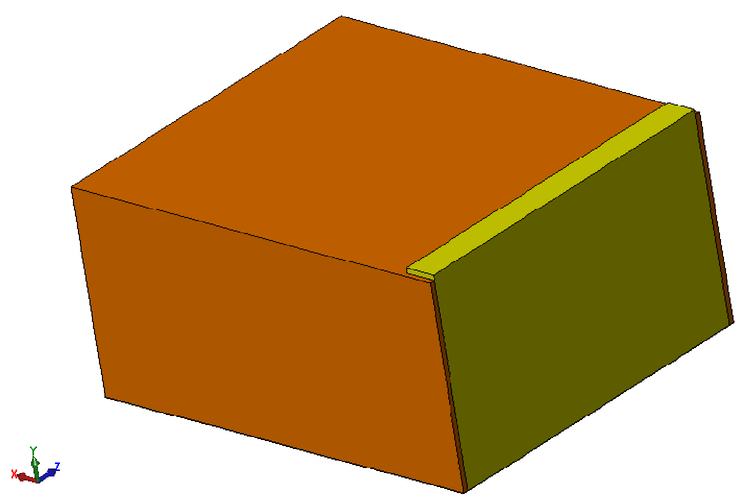

Figure 11: Six Pack Battery Box

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 of 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
- 64oz. Epoxy Resin Kit - Free
- 3/8" Stainless Steel Pan Tapping Screws - $5.56
- Molding supplies - $105.00

- Total - $110.56

A finite element stress analysis was done for the battery box. The material properties for fiberglass had to be input into Abaqus in order to get a proper stress and deflection reading. We tested the box for a 3g roll and found the deflection on the top of the box was minimal or under a quarter of an inch. The deflection distribution of the top of the lid can be seen in figure 12.

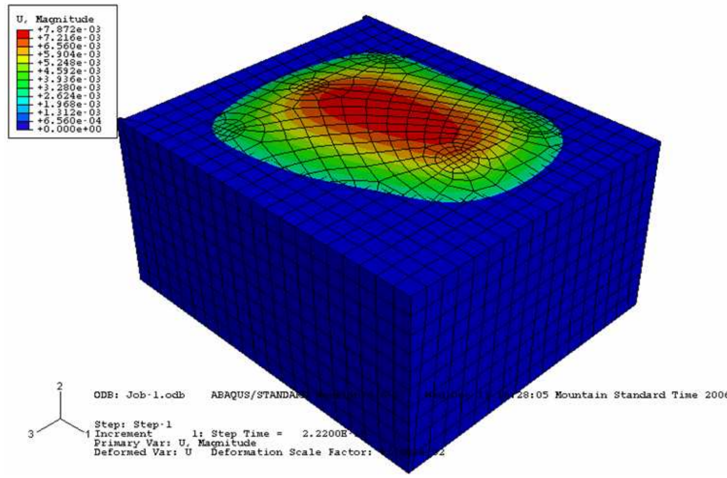

Figure 12: Abaqus Deflection Analysis

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

SEAT

The seat was constructed in much the same manner as the battery box. In order to gain experience, the team decided to build the seat out of carbon fiber instead of fiberglass. Up until this point, the team hadn't done much work with this type of composite, but was willing to learn. This material had similar material properties as the battery box material, so the battery box analysis was also used for the seats integrity. The mold was milled with a CNC machine which allowed for an ergonomically design suited for driver comfort. A CAD model of the seat can be seen in Figure 13 below.

Figure 13: Carbon Fiber Seat

ELECTRICAL SYSTEMS

The basic requirements for completing the final product are broken down into items shown in Figure 14. 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.

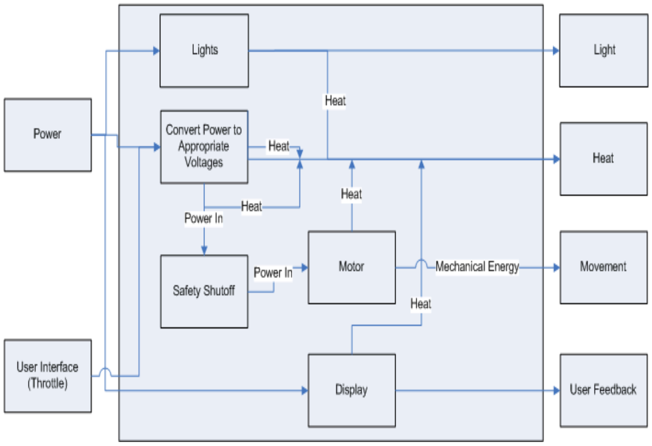

Figure 14. Transparent Box

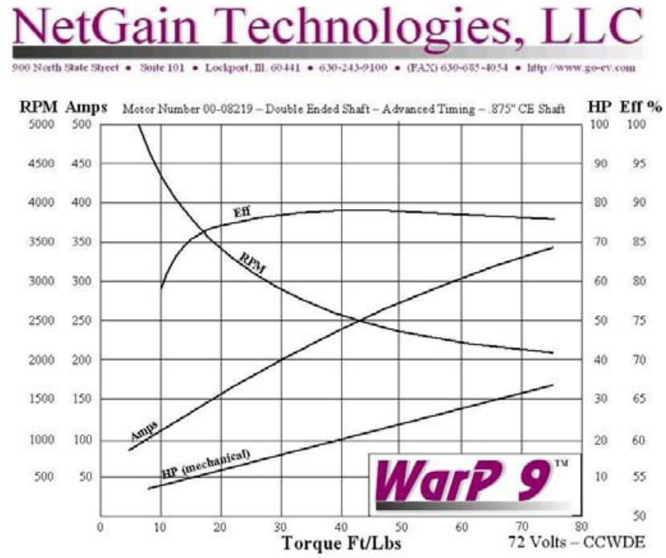

Figure 15. Manufacturers Motor Specifications (NetGain)

Motor

Several motors were considered for this application. Decisions were based on the following pairwise comparison chart shown in Table 8.

Table 8. 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 team decided to favor the performance side of the competition and selected the Warp 9 Series Wound DC Motor. Figure 15 illustrates the specifications of the motor supplied by Net Gain Technologies. This motor has a larger current draw when compared to a DC brushless motor. The DC brushless motor, however, costs significantly more than the Series Wound DC motor which eliminated this motor type as a viable option.

Motor Controller

The motor controller was selected based on availability, cost, and compatibility. The Alltrax 7245 motor controller was selected. 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. This motor controller was recommended by the motor manufacturer so compatibility is verified. A 0-5 kohm potentiometer is used to control the throttle. The potentiometer is designed to mount on the handle bar of the snowmobile and has a spring return to mimic the stock thumb throttle.

Battery Pack

Battery selection is the most critical component when building an electric snowmobile. Results are hindered by battery performance. 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 9. 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-->

Colour	Meaning
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

Lead acid batteries were chosen because of availability and cost. This technology also performs well in cold temperatures with a higher current discharge rate than many other technologies. The Odyssey PC1200 sealed lead acid battery was selected by the team. Table 10 shows the discharge rate for each Odyssey battery. The battery that is being used can deliver 900 amps for 20 seconds. This is twice the rated current of the motor controller. The battery uses spiral cell glass matte technology which increases output by increasing surface area for chemical reaction.

The battery pack that was used has a storage capacity of 38Ah. This is ideal and does not take into consideration the faster the discharge rate, the lower the actual storage capacity. 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. Assuming ideal conditions, the range should be just over three miles assuming a constant current draw of 130 amperes and an efficiency of 62% with all of the power losses taken into consideration.

Table 10. Manufacturers Table for Pulse Discharge (Odyssey)

Battery	Pulse discharge in amps to 7.2V		
	5 sec.	10 sec.	20 sec.
PC545	545	495	420
PC680	680	595	525
PC625	625	545	480
PC925	925	870	765
PC1200	1200	1090	900
PC1700	1700	1540	1355

Sealed Rechargeable Drycell™ - Deep Cycle Batteries

One auxiliary battery is used to run miscellaneous components such as the headlight, taillight, relays, and gauge backlighting. This is a 12V 18 Ah Sealed Lead Acid battery from Interstate Batteries. The reason for the separate battery was 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. This uses a separate charger that will be linked into the same charging plug as the main pack charger.

Battery Monitor

The PakTrakr is a battery monitor with an LED indicator of the battery condition and state of charge. This was selected for ease of use and was necessary to avoid damage to the battery pack. The battery pack should not be discharged more than 75% of capacity or an individual battery voltage of 11.8V to avoid damage. The meter is capable of monitoring up to six batteries in series. There is an individual indicator for each of the following: individual battery condition, uneven pack voltage, battery pack state of charge, and individual battery malfunction.

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. 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 amperage in this application. The cable must be able to sustain handling the current that the motor controller is capable of outputting which is around 450A. Copper wire sizes were researched and 3/0 AWG cable was the smallest diameter cable able to handle this current. The cable is covered with a red insulator in compliance with competition rules. The cable is used in welding applications which gives it some flexibility for connecting ease.

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. Only approximately one meter of cable was 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 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.

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. Light emitting diodes 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 the auxiliary battery.

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 a separate battery box in the bulkhead 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 drivetrain. 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 a 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. This was mounted behind the motor controller, therefore, reducing cable length to make connections to the motor controller.

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 bulb.

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 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.

<u>Electrical Schematic</u>

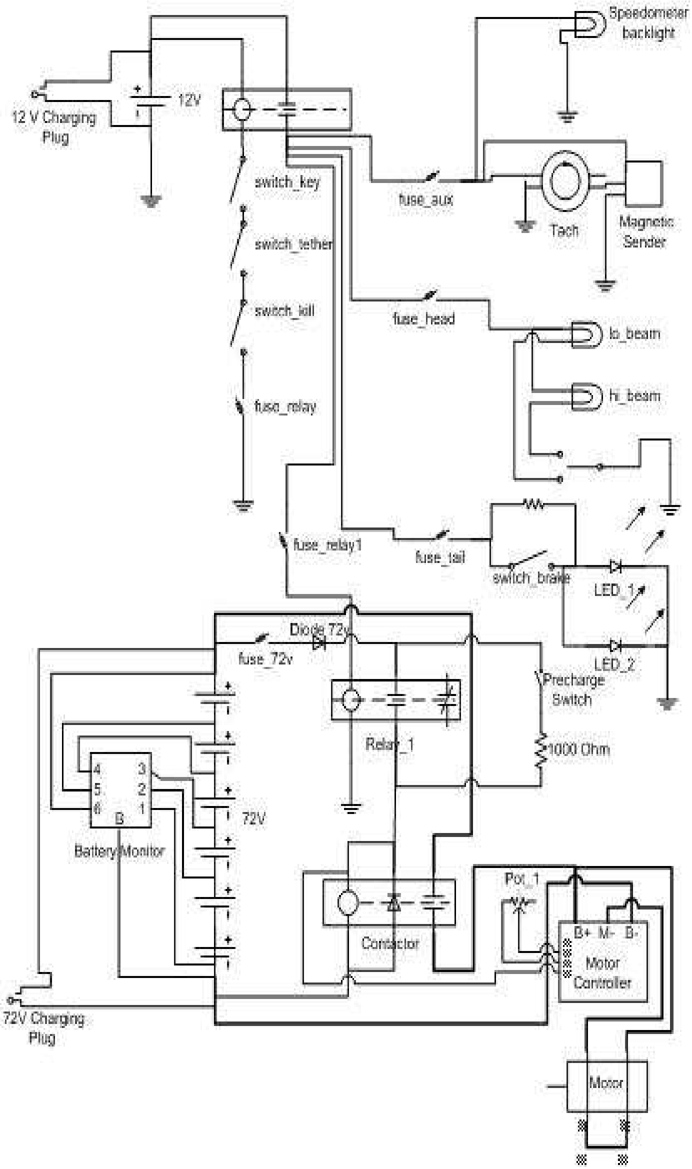

Figure 16. Full Electrical Schematic

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 2007 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 sled are easily adaptable to any stock snowmobile.

The team is very proud of the accomplishments made in the 5 months given for the project. It is anticipated that with experience, time, and money gained during the production of a first working prototype, the team will be able to grow and improve during the upcoming years.

ACKNOWLEDGMENTS

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   www.electricvehiclesusa.com
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DEFINITIONS, ACRONYMS, ABBREVIATIONS

AC: Alternating Current

DC: Direct Current

CSC: Clean Snowmobile Challenge

CVT: Continuously Variable Transmission

HP: Horse Power

IC: Internal Combustion

RPM: Revolutions per Minute

SAE: Society of Automotive Engineers

SDSM&T: South Dakota School of Mines and Technology