Development of Sustainable Electric Conversion For Modern Snowmobiles

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ABSTRACT

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

INTRODUCTION

The Society of Automotive Engineers (SAE), in partnership with the National Science Foundation (NSF) created an electric snowmobile category in the Clean Snowmobile Challenge (CSC) in 2004. The goal of this category is to encourage the development of a zero-emissions utility snowmobile for support in atmospheric scientific research. A number of environmental research efforts taking place at locations such as Summit Station, Greenland and South Pole Station, Antarctica involve collecting samples of the air and snow for global atmospheric pollutants which occur in levels of parts per billion. Attempting to visit or even approach these collection sites with any internal-combustion powered vehicle, to including conventional snowmobiles, can significantly contaminate the sample measurements. The Summit Station research facility has extensive areas around collection sites in which vehicular traffic is prohibited due to concerns about possible contamination from emissions. Because of this, zero-emission transportation for research facility personnel and equipment is needed to ease the operation of distant satellite camp facilities and improve accessibility to areas previously only accessible by foot. In 2007, the SDSM&T Electric Snowmobile Team began development of a zero-emissions snowmobile named "Ramblin' Wreck" and was entered into competition. Since the 2007 competition, extensive testing of the vehicle was performed in South Dakota and changes had been made every year to improve performance and handling.

DESIGN OVERVIEW

The SDSM&T Electric Snowmobile Team chose to focus on improving the 2011 design while maintaining the CSC goals. The CSC competition has primary focus areas in Range, Towing, and Noise of the electric snowmobile. The CSC has put focus of Weight, Handling, and Maintenance as secondary goals. This year's team has addressed all primary and secondary objectives with a range of an estimated 20 miles over the required 10 miles, Towing with a >800lbf estimate, and Noise is an estimated 65dB level. Applying the previous year's faults and oversights, the team has addressed issues of weak energy storage container designs, proper electrical insulation and rules compliance.

ELECTRICAL SYSTEMS OVERVIEW

OVERVIEW

The South Dakota School of Mines and Technology has made many changes to the electrical system this year. These changes were made while keeping the overall system very clean and serviceable. There are two energy storage containers, one located under the hood and one running between the tunnel and the rider. These energy storage containers provide a sealed containment for the batteries, the battery management system (BMS) and all the safety features needed for proper operation. They also keep a semi-stock look to the snowmobile. The EMCVT will be controlled using linear actuators with Sensofoil membranes to vary the drive ratio for specific rotational speeds of the motor. The SD-5 DC-DC converter is being used to provide a nominal 12 volts to all the low voltage equipment on the sled including a micro-controller that will read in RPM from the motor. It also provides voltage to turn the negative contactor on, which will power the motor controller.

MOTOR

The AC-20 motor was purchased as a package in 2011 that contains an AC-20 motor, a 1238 Curtis Motor Controller and a Spyglass 840 display, which is shown in Figure 1. The AC-20 is an induction type AC motor that is powered by three phase AC voltage that is provided by the motor controller. The AC-20 weighs approximately 48 pounds. It is about seven inches in diameter and 14 inches long. The AC-20 motor has a rated continuous 10 HP but has a peak of 56 HP. Figure 2 shows the torque and HP for a range of RPM's. This motor is around 89% efficient.

Figure 1: Curtis 1238 Motor Controller and the AC-20 Motor.

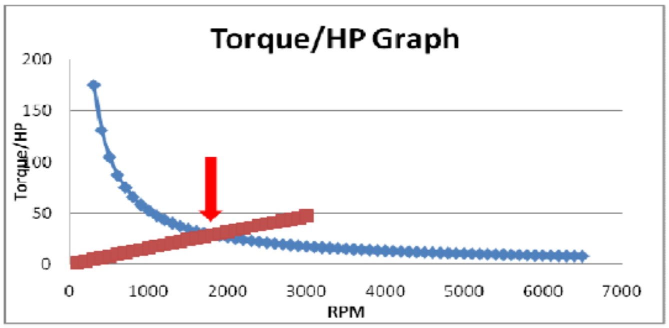


Figure 2: AC-20 Motor Torque/Horsepower Graph.

MOTOR CONTROLLER

The Curtis 1238 motor controller, shown in Figure 1, functions as an inverter that converts direct current potential into three phase alternating current potential. It also acts as the computer for the snowmobile, which is comparable to a controller area network (CAN). This choice in motor controller was ideal because of the voltage ratings of 24-80 V and current ratings of 550-650 Amps. The motor controller is powered by the high voltage pack by running a fused, 10 Amp, low current wire to the motor controller that then runs back through the negative contactor when it is turned on by the key. The 1238 turns the positive contactor on after its pre-charge phase has cycled. This circuit functions as a key safety feature in the snowmobile as the positive contactor cannot close if there is no power to the motor controller. This prevents the motor controller from being burnt out from high voltage and high current running through. The 1238 also provides a digital output to a display that shows the RPM of the motor, the motor temperature, and the voltage level using LEDs, much like a fuel gauge. The motor controller came with the 1311 Curtis Programmer that can adjust a number of things for desired operating modes based on the purpose of the snowmobile. One example of this is adjusting the speed or torque range for different speed and power curves. It can also adjust the percent of the voltage that can be used before the motor controller recognizes it and shuts it off.

DISPLAY

The display for the sled will use both the stock display system and a secondary display system. The stock display system gives the current speed of the sled and the secondary display system gives current information on the electrical system. These two display systems will give all the information that will be needed to run the sled. The stock display system will give the current speed of the sled by using the stock speed sensor and the display system. This was determined to be easier to use when comparing any other system to monitor the speed of the sled. The secondary display system is a display screen from the AC motor controller on the sled. This display is able to display multiple types of data about the AC motor. This display system can show the RPM of the motor, the current temperature of the motor, and the voltage the system is running at. This will allow the rider to monitor the AC motor system and assure everything is running properly.

MICROCONTROLLER

The micro-controller system contains two main components, the micro-controller and the actuator controller. The micro-controller is the brains of the system since it decides how the system will react. The actuator controller is the brawn of the system since it drives the linear actuators on the CVT. These two components control the Electro-Mechanical CVT (EMCVT.) The micro-controller has two main purposes: to read in the RPM of the AC motor and monitor the actuator controller. It decides if the linear actuators have to move, and where they have to move. For example, if the RPM is above 3,000 and the CVT is not fully in, the micro-controller sends a command to the motor controller to move the linear actuators in. This causes that gear ration of the CVT to increase. As another example, if the RPM is below 1,500 and the CVT is not fully out, the micro-controller will move the linear actuators out, which causes the gear ration to decease. Between 1,500 and 3,000RPM the linear actuators will hold their position.

With this design, the best performance is achievable with fine tuning of the EMCVT. Fine tuning is done by changing the shift points. Shift points are determined by motor RPM. When the shift points are changed, the application of the snowmobile can be changed. This allows for better handling and performance without changing out CVT's for different purposes. This design also has safety features built in. If the actuator controller is not running properly, over heating or any other problem, the micro-controller is programmed to set the actuator controller to a stop state and flash a general error light on the micro-controller. Once this state is activated, it will stay that way until it is reset. This safety feature ensures that if problems arise, it will shut down without causing any harm to the system.

BATTERIES

A variety of batteries exist today for electric or hybrid vehicles. The most common batteries are: Lead Acid (PB), Absorbent Glass Matt (AGM), Nickel-Metal Hydride (NiMH), and a wide range of Lithium based batteries. Lead acid and AGM are most commonly used for high power, low range applications like forklifts. Lithium based batteries are mostly used for electric cars because of their high energy density. Lithium-Ion (Li-ion) batteries are the most common in car applications but can be very dangerous due to the potential explosion if they are damaged. Lithium Iron Phosphate (LiFe-Po4) batteries are a safer energy source because they do not explode and do not heat rapidly under stress. SDSM&T Clean Snowmobile Team has decided to use the LiFe-Po4 batteries because of this key safety feature. An additional feature is that these batteries will keep a very steady voltage until the end of the cycle life, even in extreme temperatures.

Tenergy 3.2V, 100 A-h, LiFe-Po4 batteries were chosen and purchased for the 2010 competition and remain in use today. The batteries are arranged into 2 battery packs consisting of a front box with 8 batteries and a back box with 17 batteries. These batteries are combined in series to produce 80V and 100 A-h to adhere to the 8 kW-h energy limit. It is estimated that at 20mph, this battery pack will last for 20 miles. This is shown with an experiment where a battery was connected to a DC motor with a constant draw of 20 Amps. Figure 3 shows the result of this test. This test relates linearly to the pack of 25 batteries with a starting voltage of 80V and a draw of 100 Amps.

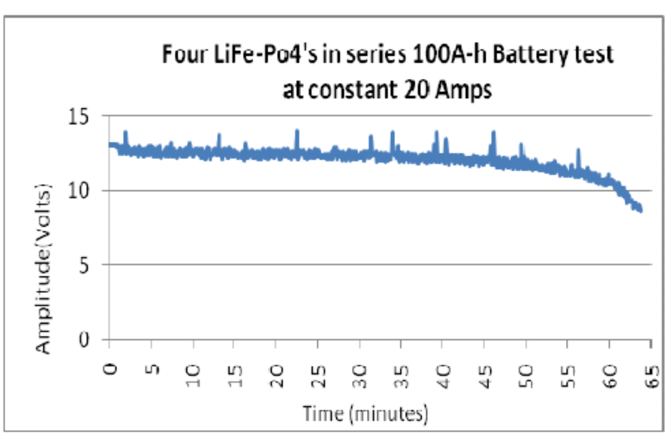
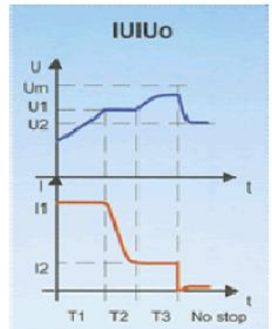


Figure 3: Battery Test Results for One Cycle.

CHARGING SYSTEM

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

Zivan NG-1 Charger



Charging Curve for Zivan NG-1

Figure 4: Zivan NG-1 Charger and its Charging Curve.

MECHANICAL SYSTEMS OVERVIEW

OVERVIEW

With the conversion of a stock IC snowmobile to a hybrid snowmobile, many parts need to be changed or added for safety and mounting of the conversion packages. All parts related to the IC engine must be removed and replaced with mounting fixtures for the new conversion parts. The drivetrain has to be modified to run on an electric motor and the shocks in the chassis must be replaced to account for the increased weight on the snowmobile. Battery boxes and other containers have to be manufactured to fit in the constraints of the standard chassis and a cooling system has to be incorporated for the motor.

MOUNTING SYSTEMS

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

DRIVELINE COUPLING

The coupling was chosen carefully as it must perform several tasks at once. The coupling shown in Figure 5 allows the team to use any Polaris borne Continuously Variable Transmission (CVT). This will allow for the use of a stock CVT for budget savings for the team. The coupling must contain the stock Polaris driveshaft taper with a slight interference fit allowing for high torque transfer through the system. This must all be done while simultaneously attaching to a keyed 7/8" electric motor shaft. Because of the limited manufacturing capabilities available to the team, the shaft must have a milled key slot with a containing sleeve fit over the shaft to retain the key. This adapter allows for the use of the team's selected Electro-Mechanical CVT as well as Polaris borne racing CVT's.

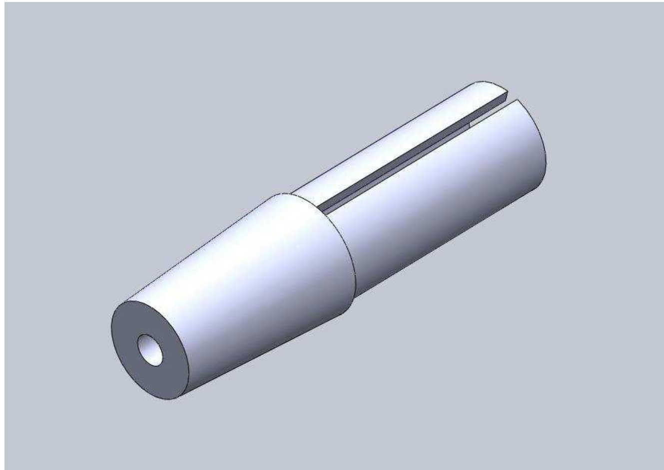


Figure 5: Motor/CVT adapter

DRIVETRAIN

The original CVT (Continuously Variable Transmission) snowmobile was designed to keep the internal combustion (IC) engine operating at optimal conditions. Since the gasoline engine, fuel tank, and all the other associated parts were removed to convert the stock snowmobile into a 100 percent electric snowmobile all this changed. An electric motor acts differently than an IC engine in that an IC engine provides more torque at higher speeds whereas an electric motor provides near instant torque at low speeds.

When exploring drivetrain options, the team came up with seven different types that were looked into further. The decision was made based on the decision matrix shown in Table 1. The table shows the most logical choices for the drivetrain based on the teams weighted grading. Noise, safety, innovation, reliability, complexity, versatility, efficiency, size/weight, service life, and cost were all put into account for each drivetrain design. Looking at the scaling for each category, the higher the score meant the better the design for that category. The categories were then all added up for each design and the highest score was ideally the most logical solution. As the table concludes the best choice was the CVT with the use of two linear actuators (electro-mechanical CVT). The total values came out being fairly similar between the top three choices. The benefits that are shown and those that were not shown in the matrix made the decision for the drivetrain a hard one but in the end the team came to a consensus on the electro-mechanical CVT.

Table 1: Drivetrain Decision Matrix.

	Noise	Safety	Innovation	Reliability	Complexity	Versatility	Efficiency	Size/weight	Service Life	Cost	Total	Results
Direct Drive	4	9	5	10	4	2	11	4	10	8	67	3rd
CVT – regular	4	10	0	10	0	1	9	3	10	10	57	
CVT – 1 actuator	4	9	9	8	4	3	14	2	9	7	69	2nd
CVT – 2 actuators	4	9	10	8	4	3	15	2	9	6	70	1st
Gear Drive	3	9	5	8	3	2	11	3	8	7	59	
Rear Drive	2	7	10	6	5	2	11	1	7	3	54	
Chain Drive	2	8	5	8	3	2	11	4	8	7	58	
Weighting Scale	5	10	10	10	5	10	15	5	10	10	90	

The electromechanical CVT was the chosen design for last year's teams' drivetrain but problems with actuation control was the main downfall to the design. This year the team felt it would be best to continue with this design but incorporate linear potentiometers (for feedback purposes). This would allow both actuators to work in sync with each other in the actuation process.

A Seeeduino MEGA micro controller will be used to control the electromechanical CVT. This will be accomplished by measuring the motors shaft speed as well as the current drawn from the energy storage containers. The current drawn will then be used to determine the torque rating that the motor will be outputting. The motor shafts speed will allow the team to optimize the shifting points, resulting in maximum efficiency.

Calculations showed that the linear actuators would need to be able to actuate a maximum axial force of just over 600 pounds to the primary clutch of the CVT as shown in Figure 6. This would mean that each linear actuator would need to be able to actuate an axial force of at least 300 pounds. They would also need to have a stroke length of at least four inches to account for the total clamping distance, two inches, and extra length for lining both actuators up with each other.

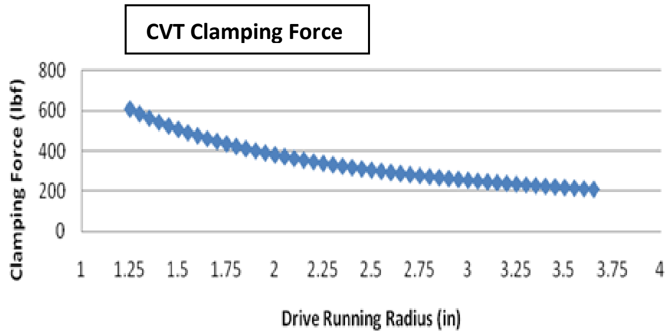


Figure 6: CVT Clamping Force.

The Progressive Automations Linear Actuators were chosen for this application. These actuators did not have incorporated potentiometers on them so the team decided to use Sensofoil to solve this problem. Sensofoil is a membrane potentiometer by Hoffman + Krippner and is the perfect ultra-flat linear and rotary position sensors. The team made this choice due to the fact that these potentiometers are inexpensive and easily applicable.

The bearing plate was used from last year's design but altered to fit the new Grainger cylindrical roller thrust bearing. This bearing allows a maximum axial force of 39,000 N (8,767.50 lbf) at a maximum RPM of 6,600. The bearing will be loaded at about 610lbf until it reaches approximately 2650 RPM, at which the motor will linearly drop the torque output. The AC-20 motor has a maximum rpm of 6500 which is just under the maximum rpm of the bearing. This means that new bearing meets all the requirements for this application.

SUSPENSION MODIFICATIONS

The stock snowmobile that the chassis was used from weighs roughly 600 lbs, where this year's design snowmobile weighs in at approximately 800 lbs. This 200 lbf increase requires replacements of torsion springs to compensate and improve handling. The replacement torsion springs double from 147 lbf to 301 lbf load assuming a 30° preload. The track sliders are also replaced with graphite sliders to reduce the resistance forces from fiction.

BATTERY BOX DESIGN

Safety is the key factor when dealing with energy storage containers (battery boxes). The snowmobiles battery boxes are designed to be electrically insulated, mechanically robust, fireproof, and transparent on at least one outer face to allow easy inspection. To comply with the safety of the rider and the snowmobile, both energy storage containers along with their mounts were designed to withstand a 20g static force.

The rear container is mounted in a tunnel between underneath the rider. This container contains 17 of the 25 LiFEPO4 battery cells. To make the container mechanically robust and fireproof the container was built out of aluminum and two of the sides out of Lexan to provide a view into the container.

The front battery box is mounted under the hood of the snowmobile directly above the motor. This box contains the remaining 8 battery cells, the Battery Monitoring System, 2 of the 4 contactors, and one 300 Amp fuse. The front battery box consists of two sections, the front section which is made entirely out of Lexan and the back section which is made out of aluminum. The latter devices are housed in the Lexan portion of the box with the batteries in the aluminum portion safely containing all components within one box.

Because aluminum is conductive, the boxes are lined with Nomex. Nomex is a fireproof insulating material that prevents any arcing between the batteries and the aluminum. The front and side of the rear box are made of Lexan. This material was selected because it is fireproof, an insulator, structurally sound with relatively high yield strength, and it is transparent. This allows all of the connections and the battery monitoring boards to be viewed. Weather stripping is used to seal out any moisture on the cover. Using these materials, the battery boxes are able to meet all of the regulations set forth for energy storage containers.

After the decision to construct the battery boxes out of Lexan and aluminum had been made, the thicknesses of the material had to be determined. The boxes along with their mounts needed to be able to withstand a static force of 20g. To solve for the thickness of the materials the materials properties would be needed. Based off of the aluminum and Lexan yield strength and the moments that were calculated, a thickness of 1/8 inch and 1/4 in were needed to withstand the static 20g force requirement. The moments were calculated for each battery in each box so that way the max moment could be found. This then allowed for the minimum thickness of each material that would be needed to contain the batteries safely.

Both the boxes were designed and build to comply with all safety rules and regulations as provided by the CSC rules. While maintaining safety and reliability, the boxes are also aesthetically pleasing with large Lexan pieces for easy inspection of the inside of each box, without the need for opening them.

MOTOR COOLING SYSTEM

Cooling of the snowmobiles motor compartment was found to be needed because of the lack of ventilation. Lack of ventilation was a result of waterproofing the snowmobile in order to avoid any damage to the electrical components. A solution for cooling the air in the compartment without allowing for the entry of water as well as a method for the built up heat to escape was implemented.

Some of the methods discussed involved the use of coolant, air movement, and a simple addition of vents to the hood. With trying to avoid the entry of water which could cause damage to the electrical system, having a coolant filled cooling system did not seem to be in the best interest of the machine. If there was a leak in system that went unnoticed, the coolant could possibly cause electrical damage or even contamination to the environment. Opening of the current vents on the hood appeared to be an easy solution but run the risk of water entry. There are screens available to help reduce the possibility of water entering the compartment but they are not 100% effective. Air movement that could be controlled throughout the motor compartment was the safest solution for cooling the motor.

To accomplish the task of bringing in cool air and pushing out the heated air, two 120mm computer fans were used. Both of the fans were mounted into modified air ducting to allow for directional control of the air's movement. The air ducting also allowed for sturdy mounting of the fans to the snowmobile and proper placement. Cool air that was to be brought in needed to come from a fairly well protected area of the snowmobile. Behind the windshield are two vents that allow for cooling of the stock machine. Utilizing the left side vent, because of interference from the steering on the right side, a fan was placed to pull air in through the vent and blow cool air down into the motor compartment. To achieve this placement thin gauge aluminum was used for support brackets. The support brackets were secured to the frame of the snowmobile and fastened with easily removable bolts for cleaning or replacement of the fan. Even with the vents placement behind the windshield there was still the risk of water entry. Mesh screens were installed to help reduce the likelihood of this occurring.

In the motor compartment the space is extremely limited with the front battery box and motor controller utilizing the area of the stock exhaust. The only area for a feasible exit for the heated air was underneath the motor controller's mount plate. This would allow for ample protection from water entry as well as the ability to incorporate the existing exhaust hole from the stock exhaust system. With the limited space under the mount plate the exhaust fan did protrude from the bottom of the snowmobile slightly. Because of the base of the fan being exposed a protection plate made from aluminum was constructed to protect the fan from any debris that may contact the bottom of the snowmobile.

With the addition of the cooling system the snowmobile will be able to run maximum performance without the fear of overheating. This will also allow for testing of the machine inside on a stand when weather conditions do not permit.

RANGE

Effective range of the snowmobile was determined using several methods. The first method was to use the overall efficiency of the system with the expected range of the stock snowmobile. This was done by research and analysis of the stock 2010 Polaris Switchback 600. The snowmobile in stock form achieves an average gas mileage of 15.7 mpg. A gallon of gasoline has an average energy stored within of approximately 12kW-hr. Using an average of 40% efficient internal combustion engine it can be shown that the snowmobile requires 4.8kW-hr of energy to achieve 15.7 miles. Using the LiFePo battery pack with 100% Depth of Discharge capability, the team will have a useable 8kW-hrs of energy. This puts the snowmobile in stock form at a range of ~26 miles. This shows what the team should achieve given near perfect conditions and equipment. Using a more qualitative approach, the team used efficiency modeling to determine power required vs. power available. As shown from the efficiency model in Figure 7, the efficiency of the electric converted snowmobile was determined to be 68.8%. This is an over 15% improvement over the stock snowmobiles efficiency model. From testing on the previous chassis, it was determined that the snowmobile requires 6.4kW-hr of energy at 20 mph. This gives the snowmobile a 25 mile range. This is in line with the early range predictions.

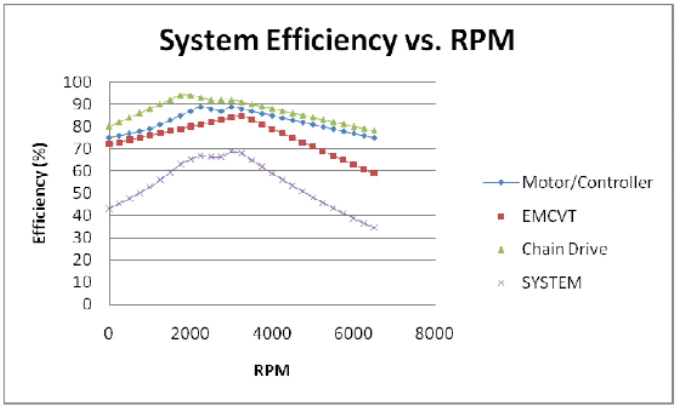


Figure 7: System Efficiency

EFFICIENCY

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

PULLING CAPABILITY

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

SAFETY

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

SUMMARY

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

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DEFINITIONS/ABBREVIATIONS

SDSM&T	South Dakota School of Mines and Technology
CVT	Continuously Variable Transmission
SAE	Society of Automotive Engineers
CSC	Clean Snowmobile Challenge
CAN	Controller Area Network
PB	Lead Acid

AGM Absorbent Glass Matt

NiMH Nickel-Metal Hydride

Li-ion Lithium-Ion

LiFe-Po4 Lithium Iron Phosphate

BMS Battery Monitoring System

IC Internal Combustion

APPENDIX – ELECTRICAL SCHEMATIC