Michigan Technological University's Design and Innovation to the E-Viper Zero Emissions Snowmobile

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ABSTRACT

The Michigan Technological University (MTU) Clean Snowmobile Team is entering the 2015 SAE International Clean Snowmobile Challenge with a completely redesigned 2014 Yamaha Viper Chassis. The snowmobile has been modified to operate on 100% electric power. In order to achieve a completely electric snowmobile, specific performance and safety concerns had to be met. The concerns addressed by the MTU ZE Team includes the construction of the battery box, which when all the power sources are connected, create a high voltage environment. The rider must be isolated from this high voltage to avoid risk of injury. The box had to meet SAE specifications to ensure rider safety during traditional operation and also during an impact event, such as a crash or rollover. A location and mounts for the electric drive system also had to be selected and created. The drive system of the snowmobile was also modified from stock in order to achieve more desirable performance. The contents of this paper describe the design process to ensure these specifications are met.

INTRODUCTION

In order to perform research understanding past atmospheric conditions recorded in the Greenland Ice Cap, the design for a Zero Emissions snowmobile is desired. Research conducted on site measures particles in parts per billion (PPB). A traditional snowmobile releases emissions generated by internal combustion process which powers the vehicle. Having these emissions on the research site would greatly affect results, so much so that whatever data was recorded could almost be considered invalid. In an effort to gain truly accurate measurements, a snowmobile that produces zero emissions while operating is needed. Instead of storing fuel in a tank, a Zero Emissions snowmobile must store a power source (batteries) on the snowmobile. This creates the requirement for a snowmobile that must withstand the harsh winter environment, traditional operational stresses and vibrations generated by a snowmobile, and also protect the rider from the high voltage necessary to power the snowmobile.

DESIGN

For 2015, a complete redesign of MTU's ZE snowmobile was performed. The previous ZE chassis had reached the allowable age restriction limit, and as a result a new chassis had to be selected. This gave the opportunity to reconfigure and make improvements on the previous ZE snowmobile. For 2015, the MTU CSC Team switched to Yamaha snowmobiles, the selected chassis for the ZE sled was the Viper, and can be seen in Figure 1. The 2014 MTU ZE snowmobile suffered from numerous electrical errors which prevented it from competing in the 2014 SAE Clean

Snowmobile Challenge. The main objective of the 2015 MTU ZE Team was to design and assemble an electric snowmobile that complies with SAE rules and regulations. From there, troubleshooting and modifications would be planned to have a competitive edge against other teams and eventually outperform other snowmobiles of this category. The core of the snowmobile was designed around a functioning tractive system.

Figure 1: Stock Yamaha Viper [1]

BATTERY SELECTION

For 2015, the MTU ZE Team chose to use lead acid batteries. While this chemical composition of batteries is heavier than others, it requires less individual battery cells. The batteries had to have the characteristics required for snowmobile operation. Optima SC34 DM BLUETOP batteries were selected because they had various desired characteristics. The cells are comprised of a gel, making the batteries vibration resistant, spill proof, maintenance free, and mountable in virtually any position. [2]

Many individual cells and their connections were determined to be the cause of some of the electrical issues. The amount of cells required decreased from 32 in 2014, to 8 in 2015. While the decreased amount of battery cells made wiring much simpler, it posed a challenge on where and how to place them within the snowmobile.

Following the goal of achieving simplicity with the electrical system, all batteries were to be in the same battery box container. This allows for easier wiring and connections. In order to achieve this design constraint, the only place on the snowmobile to place the batteries was determined to be on the tunnel.

BATTERY CONTAINMENT

In order for the safe operation of the snowmobile, several safety constraints for the battery box had to be met. The box had to be fully enclosed in a vented, non-conductive box, fire resistant per UL94-V0, FAR25 or equivalent, protected from moisture in the form of rain, puddles, or snow intrusion, and able to withstand a 20g deceleration in the horizontal plane and 10g in the vertical plane. In order to meet the fire resistant and non-conductive requirement, Lexan Polycarbonate was selected as the material of choice. The material meets both specifications, and in addition, is also a transparent material. This allows for easy viewing of components to ensure rules compliance, as well as easy diagnosing of potential problems, without having to completely take apart the entire system. While Polycarbonate does weigh more than other potential materials such as aluminum, no extra insulating material or coating that could peel off needed to be applied. This allowed for easier assembly during construction of the container. The design was modeled and analysis was performed in order to determine the required material thickness. When placed under 10g loads in the vertical direction and 20g in the horizontal direction, the stresses and deformations shown in Figures 2 and 3 were obtained.

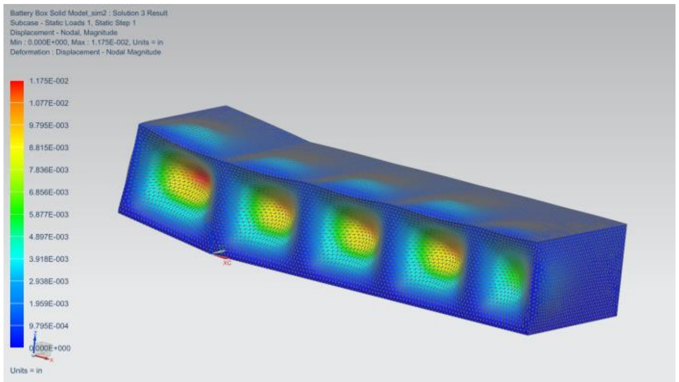

Figure 2: 20g Horizontal Force

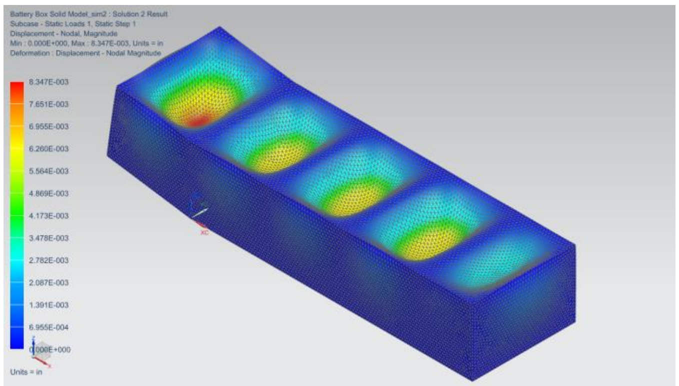

Figure 3: 10g Vertical Force

In order to mount the box to the tunnel, a cradle had to be created. This was constructed out of 1/8" T6-6061 2" angle aluminum, and had to withstand the same loads as the battery box.

In order to fit the battery box on the tunnel, the A-Pillars coming down from the steering post had to be relocated. Analysis was performed on the stock tunnel and pillar structure under load, as seen in figure 4. The pillars had to be relocated to the top cradle on the battery box, in order to keep the same load bearing characteristics that the stock configuration had. Deflections of the stock and modified configurations were recorded (Figure 5). The new location and mounts resulted in less deflection under the same load as the stock configuration, satisfying the constraint that any chassis modification would not result in a reduction of structural integrity.

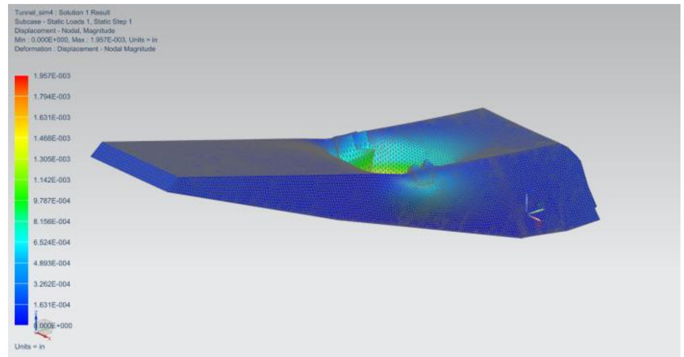

Figure 4: Stock tunnel deformation under load

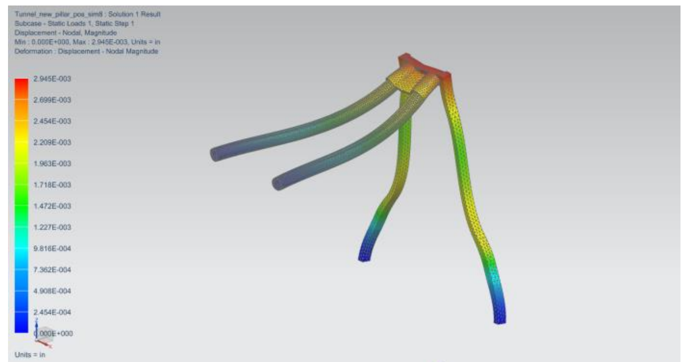

Figure 5: Modified pillar under load

BATTERY MANAGEMENT SYSTEM

A Manzanita Micro BMS is used to actively monitor the batteries and electrical system, and is displayed in Figure 6. The eight BMS's are needed to monitor the battery box, one for each cell. Each of these units is powered by the respective battery that it monitors. The max voltage that the BMS can handle is 15 volts, which does comply with the BMS Settings. The BMS's are daisy chained together by one of the outputs on the board, so they are able to communicate with one another. There is also an input on the boards for the connection to a PC. When the BMS detects a fault, the battery discharge enable relay is opened, safely shutting down the system. The BMS signals battery condition through the use of onboard LEDs. A green light is used to signify proper function, a red light signifies a thermal fault and is accompanied by a signal to shut down the tractive system through the shutdown circuit. An onboard yellow light is a warning that the BMS has recorded an over temperature reading. Lastly, a blue light indicates the board is communicating with the regulator bus, and therefore the rest of the sled. The tractive system connection is located within the battery box while the grounded low voltage connection is located in the front of the sled to isolate them from one another. The BMS's are housed in a 3D printed box, and were designed so they can be easily installed, changed, and wired, as seen in Figure 7.

Figure 6. MK3SMT Digital Lead Acid Regulator

Figure 7: BMS rack enclosed in battery box

CIRCUIT BOX

Located at the rear of the battery box is a compartment reserved for high voltage components, including the battery management system, the high voltage contactors, and the DC-DC converter. This allows the components to be protected from the elements, within close proximity to the high voltage system, and enclosed in a safe manner for operation. The components can also be removed individually relatively easily, or the whole compartment can be removed from the battery box. Figure 9 shows the individual components in the removable compartment.

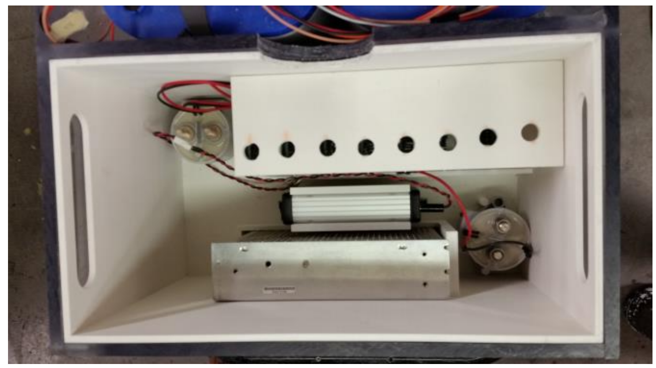

Figure 8. Circuit Box located at the rear of the snowmobile

BATTERY CHARGER

To recharge the accumulator, the Michigan Tech ZE snowmobile contains an onboard charging system. The charger selected is a 1 kW Delta-q, Qui-q charger, pictured in Figure 11. This charger was chosen for its size and adaptability. A notable characteristic of this particular charger is that it is completely sealed, which is very important when being mounted on a snowmobile. It is also very simple to change the charging algorithm, adapting to any desired pack configuration and voltage. Unlike many other chargers available, the Qui-q can be programmed to charge a wide range of battery types. To charge the system, all that is required is plugging the snowmobile into a 120VAC outlet.

The enable relay of the charging system is controlled by the BMS. This relay is spliced into the chargers signal wire attached to the negative pole of the battery pack. Upon applying 120 VAC to the snowmobile, a signal is sent to the BMS verifying safe charging conditions. If determined by the BMS it is safe to charge, the relay spliced into the charger's signal wire closes, allowing charging to commence. If any issues are sensed while charging, the relay is opened, signaling the charger to shut off. [3]

MOTOR CONTROLLER

Curtis is an international company that manufactures motor controls for various electrical applications. MTU chose the Curtis (1238-7601) motor controller, seen in Figure 9. This particular motor controller is designed for hydraulic pumps, or on-vehicle traction drive. The controller is very effective in combining performance and power.

Figure 9. Curtis (1238-7601) motor controller [4]

The ZE snowmobile has eight 12V batteries in series; the total battery pack voltage is 96V. 1238 takes an input of 72-96V direct current (DC) and outputs a three-phase alternating current (AC). It is key that the motor controller converts DC to AC to power the three phase AC-20 motor. The motor controller has a rating of IP65, which means it is completely dust proof, and can withstand high-pressure water from all angles. This is a must have feature in order to pass the water test at competition.

The 1238 has a 35 pin connector on the side of the controller. These connectors have a variety of purposes, including motor temp input, as well as high and low voltage. One of the most important pin connectors is the four pins for the speed encoder. The speed encoder controls the speed of the motor. Another important feature is the ability to allow the rider to see monitor various parameters of the system through the Curtis Spyglass 840 (Figure 10). It can show various defined parameters such as states of charge, current, accumulator voltage, vehicle speed, motor temperature, and motor RPMs.

Figure 10. Curtis Spyglass 840[5]

The motor controller has various functions that allow the snowmobile to function properly and within the SAE rules. One major function of the motor controller that is important for proper functioning within the CSC ZE rules is its ability to assist in fault detection. When a fault is detected by the BMS, a signal is sent to the motor controller. If a fault is detected by the motor controller's monitoring system, a signal is sent to the controller. When a signal is received that shows there is a fault, the motor controller interrupts the high voltage system by opening one of the contactors in the HV system. For this to happen, the motor controller must send a current to the contactor, which shorts the voltage in the high voltage system, thus shutting it down. This properly complies with the rules because the tractive system must be properly shut down if a short is detected.

Another major function that the 1238 controls is the motor speed adjustment. This is controlled by four pins in the 35-pin connector. This encoder takes the throttle position and relays it as a digital signal. This signal tells the controller how much power to transmit to and send to the motor. The amount of power that is transmitted controls the speed of the motor.

Connecting the motor controller to the system is important because it allows for control of the snowmobile's movement and shutting down of the snowmobile. Having an understanding of how the circuits should be connected allow for the team to quickly and efficiently wire the controller into the system. There are two systems of the motor controller that need to be connected: high current and low current. For the high current, two terminals are connected to the batteries, the positive and negative battery terminals (connected to B+ and B-, respectively, Figure 11). The U, V, and W terminals allow for the three-phase motor connections. The low current system connects with the 35-pin connector. The layout of this connector can be seen in figure 12. The speed encoder that was discussed earlier is tied into four pins. These pins are pins 7, 26, 31, and 32. The Curtis Spyglass display signals are tied into 4 pins as well. These pins are 7, 25, 28, and 29.

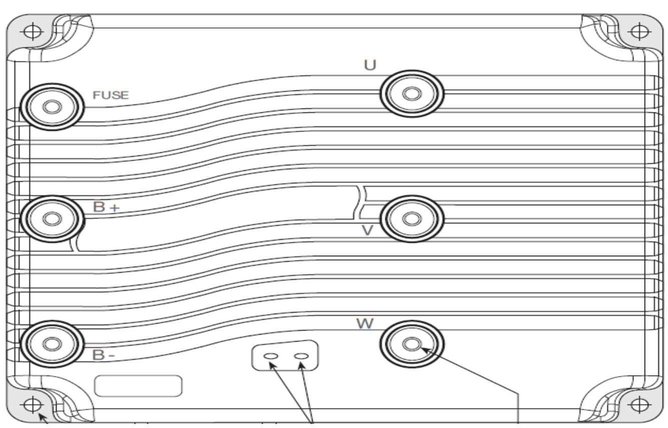

Figure 11. The terminal connections on top of the Curtis 1238 controller [6]

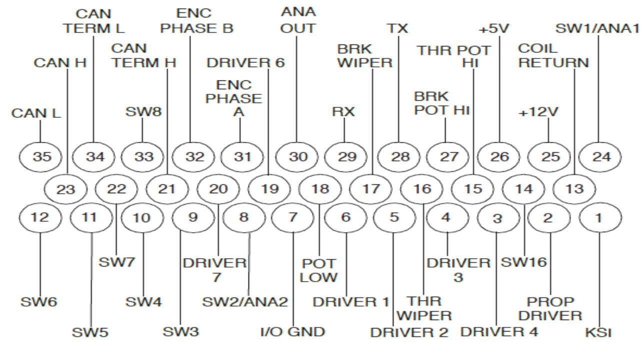

Figure 12. 35-pin layout [7]

HIGH VOLTAGE FUSING

Per competition rules, various fusing techniques are required based on the battery pack configuration. The fuse must be rated for the pack voltage and continuous ampere rating of the wire used within the pack to complete connections between cells. Zero gauge wire, with a continuous amp rating of 250A was used to make these connections. Since the controller has the capability to draw up to 650A, a Bussman Slow blow fuse was utilized. This particular fuse has a continuous rating of 250A, complying with the rules. However, being a slow blow fuse over-current can be achieved for a period of time without the fuse blowing. This property allows for max draw and power to the motor. [3]

DRIVE SYSTEM

Converting to a belt driven drive system allowed for simplicity within the drive system. In a belt driven system there are four main components: a drive gear, a driven gear, a belt, and a tensioner. The belt drive system is a standalone system that does not need to be lubricated because it is supported by sealed bearings. On the contrary, a chain driven system has to be lubricated and in a sealed oil bath chain case. This is a much more complicated and maintenance intensive system when compared to a belt drive.

The belt drive system implemented on this vehicle has a total rotating mass of 9.54 pounds, which includes both gears and the belt. This is much lower than any rotating mass of a chain drive system that would fit this application. Using a traditional snowmobile drive system, rotating mass comes from the primary and secondary clutches, jackshaft, upper and lower gears, chain, and the chain case housing. These are the major advantages of using a belt driven drive system over a chain driven system.

While designing the belt drive system, obtaining the proper gear ratio was a major concern. Knowing that the drive gear is limited by size due its diameter, the driven gear dimensions were based off obtaining stock manufacturing final gear ratio and clearance within the chassis.

Furthermore, an adapter was added to this design to allow an aluminum driven gear to be ran on the stock steel driveshaft (Figure 13). This eliminated the risk of shearing the splines off the aluminum driven gear, if it were mounted directly to the steel drive shaft. Another purpose of the adapter is to allow for easy changing of driven sprockets and gear ratios to obtain optimum performance.

Figure 13: Adapter mounted to driven gear

According to Gates Corporation (the manufacturer of the belts), while running a 8mm pitch, the minimum pitch diameter than can be applied is 2.307 inches, in order to not over stress the belt as it flexes around the drive gear.

Using Equation 1.1, the pitch diameter can be converted into a tooth number. According the pitch diameter and using Equation 1.1, the lowest number of teeth that can be ran on the drive sprocket is 23. For the driven gear, clearance measurements were taken. A 6.50 inch diameter gear was the maximum pitch diameter that was obtainable due to clearance issues around the existing chain case housing. Using Equation 1.1, the driven gear equates to 66 teeth. Therefore, the lowest gear ratio that can be obtained with this system is 2.87 to 1. A drive sprocket of 30 teeth was chosen to for the current set up in order to match the manufacturer's final drive ratio.

Tuning the gear ratio for this application is simple, and only requires changing the driven gear. Since the driven gear is custom designed to fit the adapter and the drive gears are mass produced by Gates, it would be more economical to swap drive gears for tuning purposes. However, the adapter implemented in this system allows the option to change the driven gear if needed. The range of gear ratios that can be used on this setup are listed in Table 1. Furthermore, a belt tensioner will be applied to this application to maintain at least 15 drive teeth in contact with the belt, to prevent belt shearing under load.

Equation 1.1:

$$Pitch\ Diameter = \frac{(\#\ of\ teeth) \times (pitch\ length)}{\pi}$$

Table 1. ZE belt drive gear ratios

	Highest	Current	Lowest
Tooth count drive gear	40	30	23
Tooth count driven gear	66	66	66

Gear Ratio	1.65:1	2.20:1	2.87:1

COST

The estimated MSRP for the 2015 MTU ZE E-Viper is estimated at $17,950.01. The highest cost component of this sled is that of the chassis. A "premium" chassis was selected, that, when compared to other sleds has many more creature comforts and features that would be desirable when riding a snowmobile. The chassis is the most modern offered by Yamaha, it is not a leftover or older chassis that is put into a "budget" snowmobile package. Other major costs associated with the sled include that of the motor and motor controller, and also the batteries. These costs are relatively hard to minimize as the products selected have to meet specific safety criteria as well withstand harsh snowmobiling conditions.

WEIGHT

The largest component of weight on the snowmobile is that of the batteries and battery box. Each battery weighs 43lbs for a total weight of 344 lbs. [2] plus the weight of the battery container, which is approximately 41 lbs.

The stock Viper has a 10 gallon gas tank, that when full weighs 97.6 lbs., the assumed weight of a rider with full snowmobiling gear was determined to be 210 lbs., the stock tunnel is intended to support approximately 308 lbs. With the added weight from the batteries and container, the tunnel now has to support 594 lbs., almost double the previous amount. However, the weight without the rider and subtracting the weight of the full gas tank leaves the snowmobile to support an additional 286 lbs., only 76 pounds more from what was considered an average size rider.

Most snowmobiles have the capability to support 2 passengers plus gear and storage without any chassis modification, only suspension and seat changes. As a result of this observation, the ZE team decided to take the suspension components out of a Two-Up Yamaha Venture Touring, including the rear torsion springs and shock, and place them in the stock skid. No actual modifications to the stock skid were necessary, just a parts swap. With the snowmobile full of all components and a rider, the suspension has approximately 6" of travel until full compression is achieved. The rules require a minimum of 3", the additional suspension travel helps ensure a smooth, comfortable ride for the rider over rough terrain or trails.

SUMMARY/CONCLUSIONS

The 2015 MTU ZE snowmobile has been designed to meet the demands of the SAE International Clean Snow Competition. The snowmobile has a user friendly design because of its emphasis on simplicity, which easily allows snowmobile components to be inspected and changed if necessary. The design will be to prove itself during the 2015 Clean Snowmobile Competition how well it can operate.

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CONTACT INFORMATION

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ACKNOWLEDGEMENTS

A special Thank You to all of the companies and people that help to support the Michigan Tech Clean Snowmobile Team, our successes would not be possible without you.

- YAMAHA
- ARCTIC CAT
- BASF
- CONTINENTAL
- CAMOPLAST-SOLIDEAL
- PERFORMANCE ELECTRONICS
- 3M
- ALCOA MILL PRODUCTS
- ARCELORMITTAL – INDIANA HARBOR
- AUTODESK
- CATERPILLAR
- CHRYSLER
- CUMMINS
- DENSO
- FORD MOTOR COMPANY
- GM
- PI INNOVO
- JOHN DEERE
- MITSUBISHI ELECTRIC
- OSHKOSH CORP
- HMK
- V-CONVERTER
- HAYES
- SPD
- STRAIGHLINE PERFORMANCE
- INDUSTRIAL GRAPHICS
- MERITOR
- GATES

DEFINITIONS/ ABREVIATIONS

BMS Battery Management System

FEA Finite Element Analysis

IC Internal Combustion

MTU Michigan Technological University

LV Low Voltage

HV High Voltage

ZE Zero Emission