Michigan Technological University's Design and Innovation in Zero Emissions Snowmobile Technology.

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ABSTRACT

The Michigan Technological University (MTU) Clean Snowmobile Team is entering the 2016 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 2016, some major modifications and redesign of MTU's ZE snowmobile were performed. The 2015 ZE chassis had failed to pass technical inspection and was unable to compete at competition. This required the ZE team to reconfigure and make improvements on the previous ZE snowmobile. For 2016, the MTU CSC Team continued to use Yamaha snowmobiles, the chassis for the ZE sled was the Viper from 2015, and can be seen in Figure 1. The main objective of the 2016 MTU ZE Team was to design and assemble an electric snowmobile that complies with SAE rules and regulations with increased simplicity and modularity from previous year's competition snowmobiles. From there, troubleshooting and modifications would be planned to have a competitive edge against other teams and outperform other snowmobiles of this category. The core of the snowmobile was designed around a functioning tractive system and battery container from 2015.

Figure 1: Stock Yamaha Viper [1]

BATTERY SELECTION

For 2016, the MTU ZE Team continued to use lead acid batteries. While this chemical composition of batteries is heavier than others, it requires less individual battery cells, while also being simpler and less volatile than lithium based battery technologies. 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 AGM cells, 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 and 2016. 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.

EFFICIENCY

Efficiency is an important factor for producing an electric snowmobile. While testing on lightly packed snow we have achieved a top speed of 40.8 MPH. in a worst case range test in deep snow, the snowmobile traveled a total distance of 3.49 miles in 1/8th mile runs. With efficiency being key for an electric snowmobile to be utilized in a practical application the total amount of distance that can be traveled needs to be maximized. With a capacity of 55 amp hours our worst case efficiency came out to 15.75 amp hours per mile. The battery pack takes 4 hours to fully recharge allowing the snowmobile to travel .87 miles per hour of charge time.

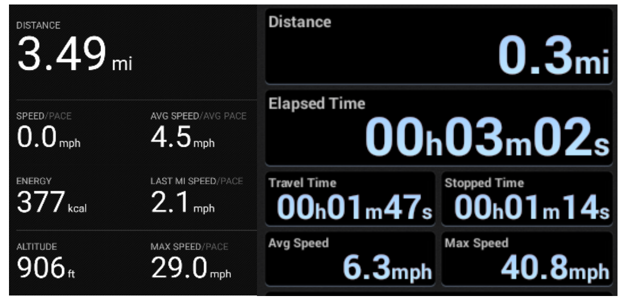

Figure 2: distance and top speed

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 that is 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 was selected because it 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 3 and 4 were obtained.

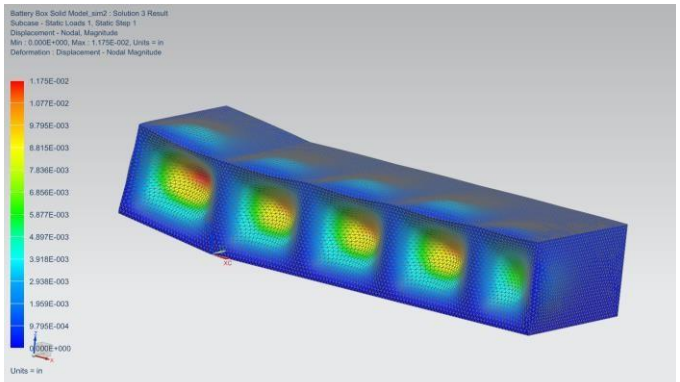

Figure 3: 20g Horizontal Force

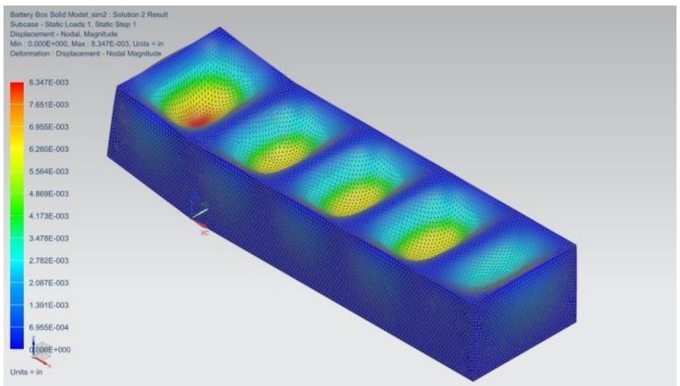

Figure 4: 10g Vertical Force

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 6. 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

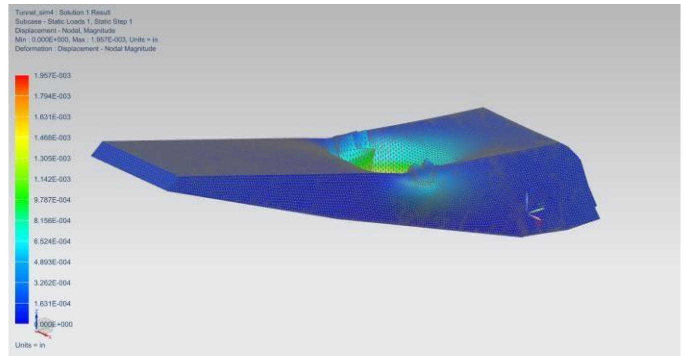

Figure 5: Stock tunnel deformation under load

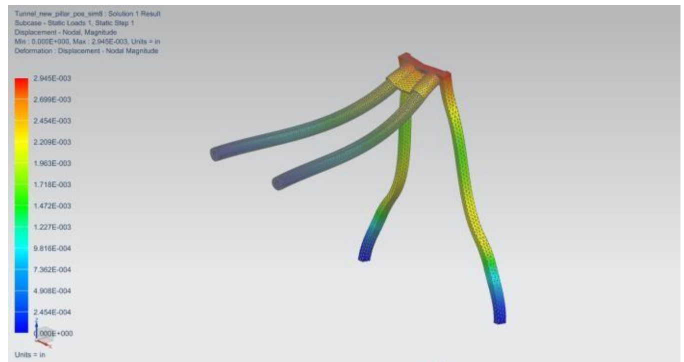

Figure 6: Modified pillar under load

<u>SUSPENSION AND LATERAL SUPPORT</u>

The goal of this project was to use suspension to withstand significant weight that was added to the ZE Viper tunnel. The incorporation of a new suspension that is functioning and has similar characteristics had to be modified in order for the new suspension to fit. The new suspension is from a Yamaha Venture touring snowmobile. The touring class of snowmobiles means the suspensions are stronger, stiffer in torsional and shock valving, and can withstand the weight of two riders and gear. The stock 141” viper suspension could not support the excessive weight of eight deep cycle marine batteries and components of the electrical system. The suspension components and shocks are set up differently between the two suspensions. The venture suspension is seen below on the left and the viper suspension is on the right.

Figure 7: Venture and Viper suspension

The distance from front mounting holes to the rear torque arm mounting hole of the venture suspension was 1.5” longer than the viper suspension. To make the venture suspension work, brackets needed to be created to allow the venture suspension fit in the viper chassis.

After brainstorming some ideas and concepts, the decision was made to utilize the stock suspension holes and keep the same contour and shape of the existing drop bracket that the viper tunnel has. By using the stock suspension holes, the bracket can be mounted in a similar way and dissipate the forces on the existing suspension holes so the main load bearing bolt to the rear torque arm isn’t taking all the load. A cardboard template was cut up and formed to the general shape of the bracket. Using cardboard is cheap, flexible yet rigid, and easy to cut to desired form.

From here, measurements were taken of the overall length, width, and radius. Using a 3D modeling program called SOLIDWORKS, the prototype plate was modeled. Once the file was converted to a .dxf file, the plasma cutter cut out the blank bracket from 1/4” steel. The bracket was held up inside the tunnel. The angle of the tunnel and existing viper bracket made it hard for the plate to lay flush. The rail support brace to the tunnel left rivets in the way. Bending the bracket by 5 degrees cleared the rivets and rail support plate. The holes were marked and then drilled. Once the brackets were installed, the venture suspension was installed to ensure the prototype brackets worked and withstand the weight.

Figure 8: Prototype bracket

The brackets that were created were oversized and had excess weight. Each plate weighted 2.54 kg (5.6lbs). This created an extra 5.08 kg (11.2lbs) to the sled. Going back to 3D modeling in the program NX, the bracket was created and optimized. The optimization showed where excess material was and where it should be kept. The bracket was shortened up and had two slots created to remove material.

Figure 9: Bracket

The drilled mounting holes were simulated as holes in the model. Using Finite Element Analysis, the stress points of the bracket when a load was applied were shown. The team determined that there was 295 kg (650lbs) acting on the suspension. Using a dynamic load of a 295 kg (650lbs) force on the suspension hole provided a warrant that the bracket could withstand the weight. More specifically, the 295 kg (650lbs) force would be dispersed over 4 suspension mounting holes. By doing the entire load on one hole, the safety factor was taken into account that the bracket would not fail.

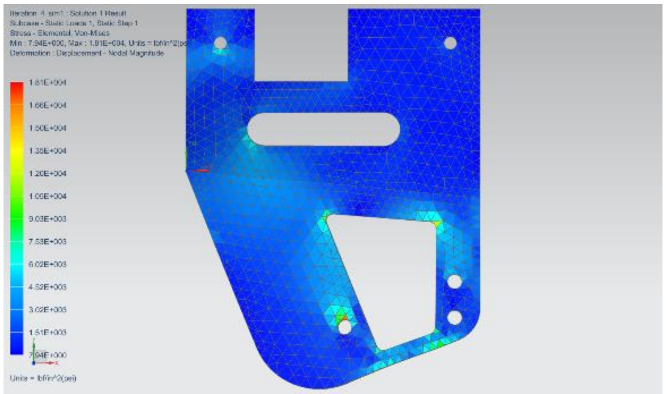

Figure 10: Bracket stress front

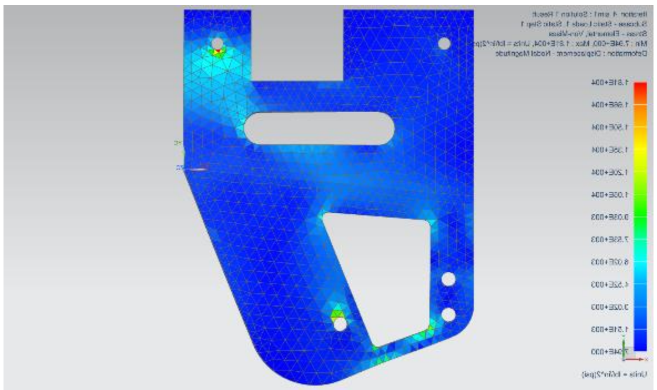

Figure 11: Bracket stress back

The max stress was 124.8 MPa (18,100 psi) shown in red. The minimum stress was 54.75 KPa (7.94 psi) in the darker blue shade. The expected high stress points were shown on the radius of the holes by being a lighter blue to green color, and yellow to red at the highest values.

The next analysis was the deflection of the bracket when the load was applied. The maximum deflection was 0.74168 mm (0.0292in) shown in red on the figure below. This is a very small value and could be smaller by adding lateral supports. Adding lateral supports would double the safety factor of the bracket, and reduce stress in areas. The deflection is occurring in the rear end of the bracket because it is an area that it not tightened down by bolts. The lateral support that will be added will take up most of the space that is yellow and green area. The deflection will have a smaller value due to the lateral supports not allowing deflection of the bracket when the load is applied.

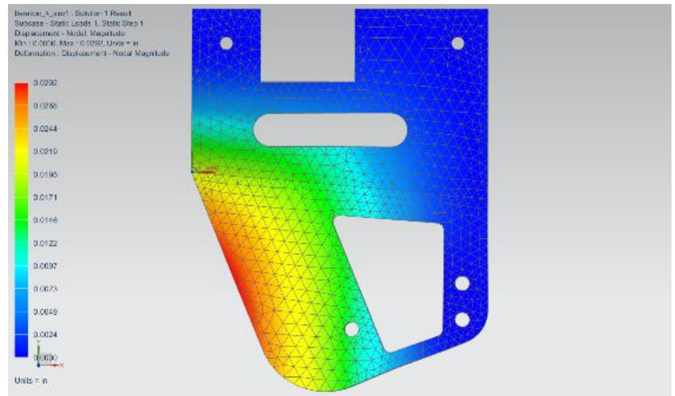

Figure 12: Bracket deflection

To reduce the amount of deflection, lateral supports were created. Using 1/2" tubular steel and a small ¼" steel plate, the lateral support took shape. The lateral support was bent to a slight curvature. One end was welded to the open area remaining on the plate, roughly where the yellow distortion color is in the figure above. The smaller steel plate was welded to the other end, and resided below the running board. There is 3 bolts with washers that hold the steel plate to the running boards on the sled. By adding lateral supports, the overall deflection will decrease, along with supporting the suspensions side to side movements. Such movements would be when the sled is turning causing the track and suspension to push against the brackets. The final bracket with lateral support can be seen below.

Figure 13: Bracket with lateral support

The ZE suspension bracket to fit the 141" Yamaha Venture suspension was a challenging task. There was many measurements and calculations that had to be done in order for it to work. The venture suspension was chosen because it was at our availability and can withstand the weight of the batteries and electrical components. The project was done at minimal costs for parts. The main cost was the steel material, 12 bolts, and 12 nylock nuts. The suspension did not cost anything but if an individual was going to purchase a full suspension it would cost around $900-$1100. The brackets can easily be removed to utilize the stock 141” Yamaha Viper suspension if desired. The goal of creating a suspension and bracket design to support the weight added to the tunnel was met within its time parameters and looking to expand upon the bracket by adding rust resistive primer and paint to give a clean and finished look. Analysis and testing of the sled in action will occur in the next couple weeks before competition.

NOISE

This section discusses the overall noise level on our 2016 competition snowmobile. All testing was performed on snow under SAE J1161 standards. The data is A weighted.

The team was able to perform noise testing to determine overall noise levels of the snowmobile. Here we found that the ZE snowmobile produced a peak sound of 62.8 dB. During testing, two current production 4 stroke snowmobiles were also tested, a Yamaha Phazer and a Yamaha Apex, both of which were completely stock. The Phazer produced a peak sound level of 70.9 dB and the Apex made 71.8 dB. Figure 1 illustrates all these values. This proves that the ZE snowmobile was 8-9 dB quieter than snowmobiles that are currently on the market.

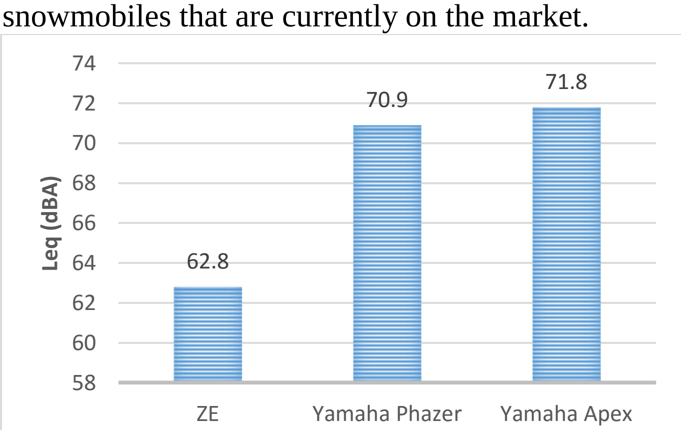

Figure 14. Peak noise levels of 2016 ZE

Competition snowmobile and other OEMs

Furthermore, Figure 2 is a 1/3 Octave Spectra plot which illustrates noise levels produced by the snowmobile at various frequencies. This figure shows that our highest noise levels occurred at low frequencies, concluding that driveline related noises are the largest contributors towards the overall sound level. This graph will allow the team to continue to hunt down specific noises produced at certain frequencies to further make the snowmobile quieter.

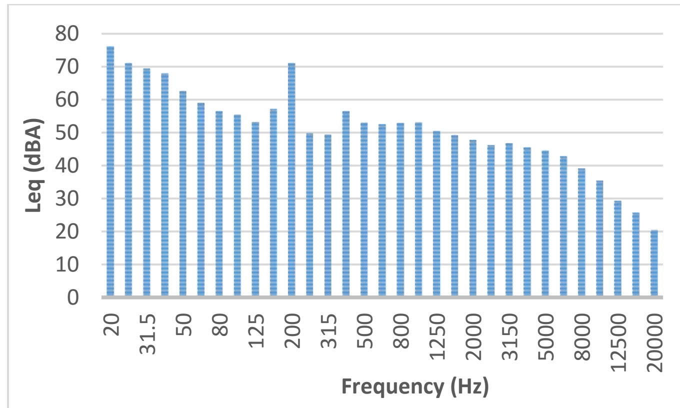

***Figure 15**. 1/3 Octave Spectra Graph of 2016 ZE Competition Snowmobile*

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.

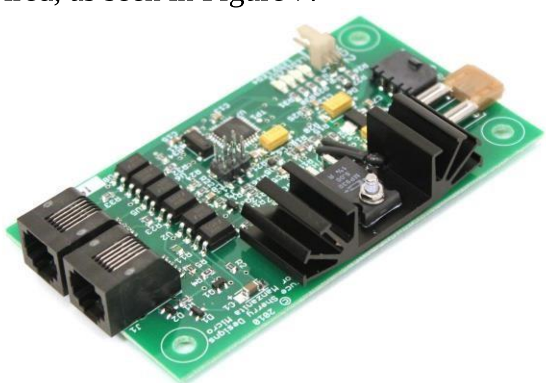

Figure 16. MK3SMT Digital Lead Acid Regulator

Figure 17: BMS rack enclosed in battery box

CIRCUIT BOARD

The shutdown circuit for a Zero Emissions snowmobile will include a shutdown switch, disconnect tether, master switch, key switch, insulation monitoring device (IMD), all required interlocks, and the battery management system (BMS). All of the current driving the battery isolation relays will be directly carried through the shutdown circuit. If the shutdown circuit gets opened or interrupted, the voltage in the tractive system will drop to under 40VDC or 25VAC RMS in less than five seconds after opening the shutdown circuit, and the tractive system will be shut down by opening all battery isolation relays. If the shutdown circuit gets opened by the BMS or the IMD, the tractive system will remain disabled until manually reset by a person other than the driver, and it will not be possible for the driver to re-activate the tractive system while sitting on the snowmobile. All circuits that are part of the shutdown circuit will be designed in a way that in the de energized or disconnected state, they will interrupt the current controlling the BIR's.

To simplify troubleshooting of the shutdown circuit and to assure compliance with competition rules and regulations, a circuit board will be populated with the relays and signal circuitry that control the BIR's. To even further simplify troubleshooting, each major electrical component will be completely removable from the circuit through the use of TE Connectivity AMPSEAL™ Waterproof Connectors. The IMD interfaces the shutdown circuit through a transistor and a DPDT relay, which carry the current of the BIRs. This setup ensures that if the IMD throws a fault or is disconnected from the system, power to the BIR's is discontinued. The IMD fault light will be run on the normally closed side of the relay and will light when the relay gets power, but is not switched. The BMS will also be incorporated into the shutdown circuit board through a transistor and a DPDT relay. This setup will also carry the current of the BIRs and ensure that if the BMS is disconnected from the system or throws a fault, the power to the BIRs is discontinued. Similar to the IMD fault light, the BMS warning light will be run on the normally closed side of the relay and will light when the relay gets power, but is not switched. Once the fault is detected, the signal is then passed on to the contactors that break the connection of the system which shuts down the snowmobile. In the case of a tripped IMD or BMS, the BIR's will open and the snowmobile will be unable to move until the fault is manually reset. In the event of a tripped IMD, the reset function of this circuit is within the GLV circuit with the use of a low voltage interrupt push button switch. The push button is located on the side of box housing the IMD, which is located under the hood. The BMS is a self-resetting unit, therefore a latching circuit will be implemented in the circuit board with a manual reset switch. A diagram of the GLV circuit board can be seen in Figure 18.

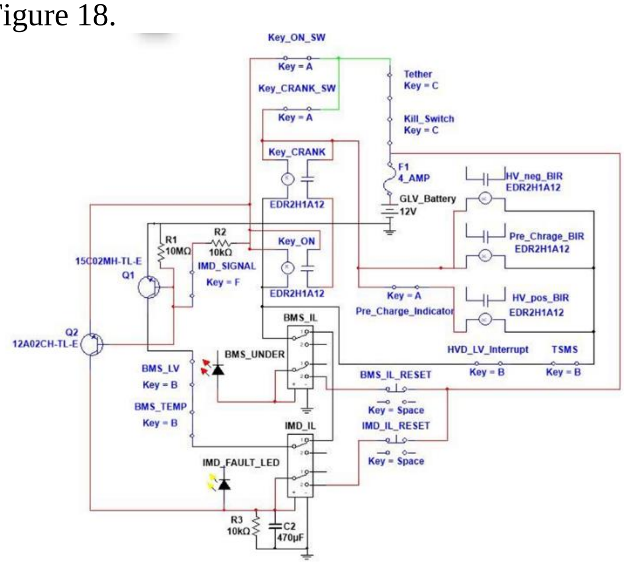

Figure 18. GLV Circuit Board Diagram

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. 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, a fault is latched, and the charger is shut off. [3]

MOTOR CONTROLLER

Curtis is an international company that manufactures motor controls for various electrical applications. MTU chose the Curtis (1239E) 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 19: Curtis (1239E) Dual-Voltage AC Induction Motor Controller [4]

The ZE snowmobile has eight 12V batteries in series; the total battery pack voltage is 96V. 1239E 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 1239E motor controller 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 20). It can show various defined parameters such as states of charge, current, accumulator voltage, vehicle speed, motor temperature, and motor RPMs.

Figure 20: 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. If a motor related fault is detected the motor controller will throw an error code that can be easily looked up in the controller manual. Another major function that the 1239E controls is the motor speed adjustment. This is controlled by four pins in the 35-pin connector. An 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 is proportional to the speed or torque output of the motor.

Connecting the motor controller to the system is important because it allows for control of the snowmobile's movement and can disable the snowmobile in the case of a fault. Having an understanding of how the circuits should be connected allow for the team to quickly and efficiently troubleshoot the controller and electrical system.

The 1239E has two separate isolated systems that need to be connected: high voltage tractive system and low voltage logical control. For the tractive system, two terminals are connected to the batteries, the positive and negative battery terminals (connected to B+ and B-, respectively, Figure 21). 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 22. 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.

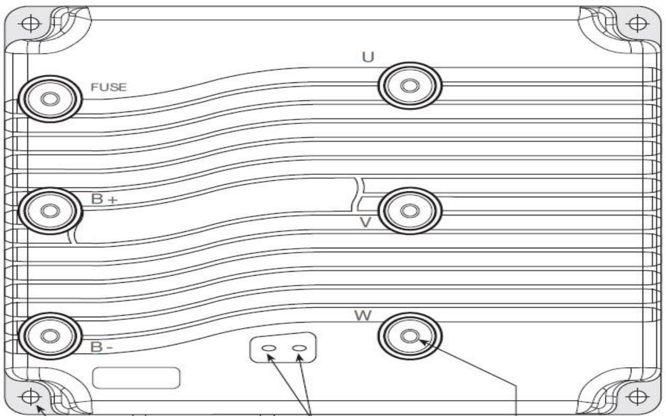

Figure 21: The terminal connections on top of the Curtis 1238 controller [6]

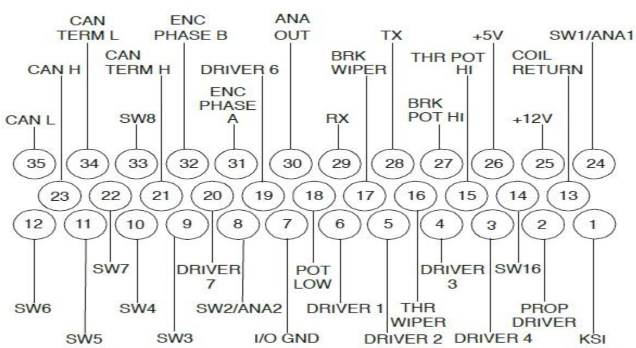

Figure 22: 35-pin layout [7]

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. 3/0 gauge wire, with a continuous amp rating of 365A 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 350A, 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 23). 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 23: 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 to prevent over stressing 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

MOTOR MOUNT

The mount is built out of aluminum to reduce overall weight. Utilizing the three slots along with the tensioner bolt and turnbuckle located in line with the gear the belt can be tensioned evenly. The three bottom slots are tight to the bolts so that the motor will move straight in line with the belt. The bottom plate is bolted to the frame of the snowmobile to maintain structural integrity of the frame.

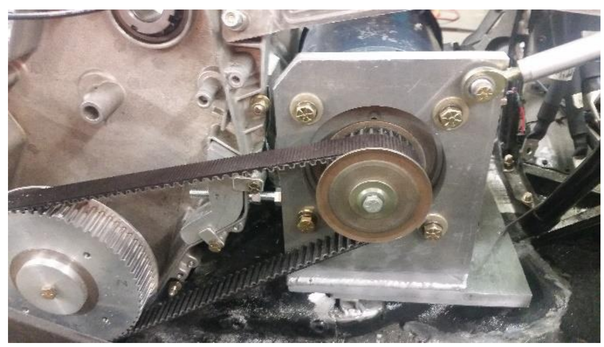

Figure 24: Motor mount

COST

The estimated MSRP for the 2016 MTU ZE EViper is estimated at $18,879.37. 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.

SUMMARY/CONCLUSIONS

The 2016 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 2016 Clean Snowmobile Competition how well it can operate.

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- 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