Energizing the Future: Rear Driven E-Rush

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ABSTRACT

The Michigan Technological University Clean Snowmobile Team is entering the 2011 Society of Automotive Engineers Clean Snowmobile Challenge with a redesigned 2010 Polaris Rush. The snowmobile had been redesigned to operate as an electric, zero emissions vehicle, using a Thunderstruck AC-20 induction motor, Curtis motor controller, Thundersky 40AH batteries, and an MTU designed rear drive system. The snowmobile has been designed for maximum range on a single charge all while maintaining stock snowmobile performance and appearance.

INTRODUCTION

Global climate changes and the effects of chemical emissions on the environment have attracted a great deal of attention in the last ten years. The effects of emissions on the environment have been closely monitored at Summit Station on the Greenland Ice Cap. Researchers use snowmobiles to travel the area, however, the terrain at the Greenland Ice Cap is very sensitive as it quickly absorbs atmospheric chemicals which are produced naturally or chemicals which are produced as a result of human activity. Because of the sensitive nature of the measurements being taken, a zero emissions vehicle is the only suitable replacement for travel on foot. Emissions output from conventional snowmobiles with two or four-stroke internal combustion engines are enough to introduce detrimental noise to the measurements being taken at the Greenland Ice Caps.

In 2004, the Clean Snowmobile Challenge (CSC) added an additional class of snowmobiles called the Zero Emissions Class (ZE) to begin addressing the above mentioned issues. Zero emissions refers to building a snowmobile that uses an electric motor and a power source usually batteries to power it. Recent advances in battery and motor technology have made a useable zero emissions snowmobile a more feasible task. This non-pollutant emitting source of transportation can make collecting data in more distant locations possible on the ice caps. This utilitarian use of the zero emissions snowmobile was reflected in the design goals for Michigan Tech (MTU) ZE entry. The goals of the Michigan Tech ZE Team can be observed in Table 1 below.

Table 1: MTU Goals for 2011 CSC

Category	2010 Clean Snowmobile Competition Best	MTU ZE Team Goals
Range	10.5 Miles	>15 Miles
Drawbar Pull	737 lbf	>750 lbf
Weight	514 lbs	<600 lbs
Noise	63 dB	<63 dB
MSRP	$14,011.35	<$19,000

DESIGN STRATAGY

The Clean Snowmobile Zero Emissions Competition ranked its scoring criterion in parallel with the Nation Science Foundation's design goals. Because 2011 is the first year the MTU CSC team has entered the ZE class, the team focused on the following aspects for an effective initial design; range, towing capacity, and innovation through rear drive technology. Additional concentration was also placed on weight, handling, acceleration, cost, and durability.

Table 2: Zero Emissions Points

Zero Emissions Events	Points for Passing Event	Maximum Additional Points Awarded for Relative Performance
Engineering Design Paper	N/A	100
MSRP	N/A	50
Oral Presentation	N/A	100
Weight	N/A	100
Range	N/A	100
Draw Bar Pull	N/A	100
Acceleration + Load	N/A	50
Objective Handling And Drivability	N/A	50
Subjective Handling	N/A	50
Cold Start	50	N/A
Static Display	50	N/A
Objective Noise	N/A	75
Subjective Noise	N/A	75
No-Maintenance Bonus	N/A	100
Subtotals	100	950
Maximum Total Points	1050	

MOTOR SELECTION

The team explored several characteristics in the difficult process of selecting a motor. First, the team decided to utilize a 3 phase Alternating Current (AC) induction motor because they have three electrical phases which are offset by 120 degrees; so the output power was constant thus increasing efficiency. The final selection, after analysis of the decision matrix seen below in Table 3, was a Hi-Performance EVs AC-20 motor from Thunderstruck Motors. This was an excellent fit for the snowmobile because it had an appropriate combination of power, torque, weight, and efficiency. In addition, the motor package also came with a Curtis 1238-7501 AC Controller which is well suited for the size of the motor being used, as well as its power requirements. By purchasing a complete package which included the motor and controller, the team could spend more time integrating the motor and controller into the snowmobile and less time picking out a controller and programming it to work with the motor. Horsepower, torque, and current plots can be seen below in Figure 1 and the test apparatus used to collect the data displayed can be seen in Figure 2.

Table 3: Motor Selection Decision Matrix

Component	*Weight (1-10 scale)*	*Remy HVH250 (AC 3 Phase)*	*EV1 motor (AC 3 Phase)*	*Net gain Motors Warp 7 (DC)*	***Thunderstruck AC-20 (AC 3 Phase)***
Packaging	4	10	3	6	**6**
Cost	6	2	4	9	**7**
Weight	4	7	4	5	**9**
Availability	5	2	3	7	**8**
Power	9	9	7	4	**7**
Voltage	7	3	3	7	**8**
Total	-	192	151	218	**261**

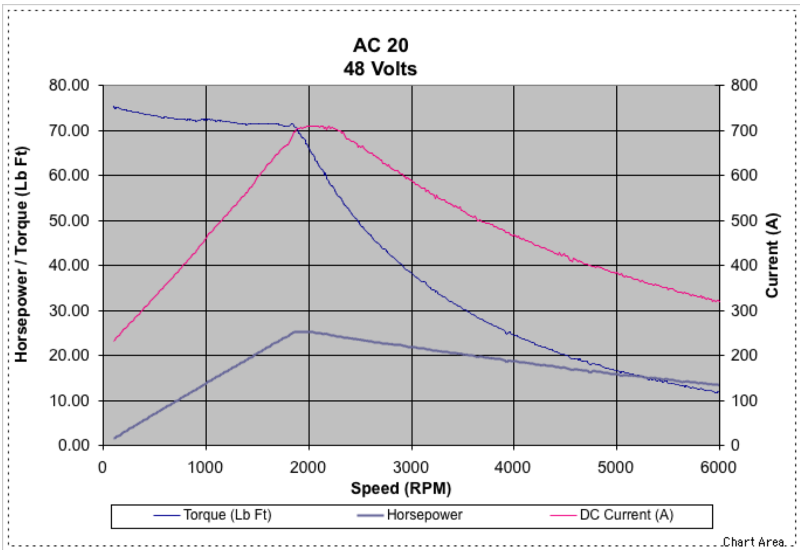

Figure 1: Speed vs. Horsepower, Torque and Current for AC-20 using 48 Volts

Figure 2: Collecting Horsepower and Torque Data

SPEED CONTROL

To control the motor, a Curtis 1238-7501 motor controller was used. This controller was responsible for several vehicle functions. The Curtis 1238, an AC induction controller, had many programmable features for adequate control over all ranges of speed and torque. Curtis has integrated the Direct Current (DC) to Alternating Current (AC) inversion process within the system controls, which is another reason this system was chosen. To display the system parameters a Curtis Spyglass 840 was used; this display was programmed to show the accumulator voltage, current, percent of charge left, vehicle speed, motor temp, and RPM's. Through this controller, the MTU ZE team was able to define many system parameters to tune the controller for maximum efficiency and power for the snowmobile application.

Figure 3: Picture of AC 20 Motor and Curtis 1238 Controller Mounted on Snowmobile

ELECTRICAL DESIGN

When designing the E-Rush, emphasis was placed on the location of components for serviceability as well as for weight distribution. The controller was mounted on the tunnel for its desirable cooling properties and because it would be easy to access if troubleshooting becomes necessary. The charging unit was mounted just above the controller in order to make the E-Rush an all-in-one system, therefore the snowmobile could be charged at any location wherever 120V AC was supplied. By mounting the motor in the rear of the sled, more packaging room was made available in the front, also increasing the electrical system's serviceability. Having the motor in the rear also makes any potential replacement or maintenance of the motor more convenient. Component placement was done to increase serviceability of the sled, but to also disperse the components in such a way that heat soaking and overheating were minimized. A separate 12 volt DC system was implemented for the use of the head light and tail light; using a separate 12 volt system eliminated the need for a 96 volt DC to 12 volt DC converter.

BATTERY SELECTION

Selecting the correct batteries to power the Hi-Performance EVs AC-20 motor would have a large impact on how far the snowmobile could travel. A table was created to compare the strengths and weaknesses of each type of battery. The types of batteries that were considered were Lead-Acid, Nickel-Metal Hydride, Lithium-Ion, and Lithium Iron Phosphate. Seen below in Table 4 is a decision matrix for the four types of batteries suitable for the E-Rush. The information in the table was either found on data sheets for the individual batteries or calculated using the equations below.

$$Energy\ (kW\ hr) = (Amp\ Hours) * (Voltage) * (Number\ of\ Batteries) \quad (1)$$

$$Energy\ Density = \frac{Energy\ (W\ hr)}{Mass(kg)} \quad (2)$$

Table 4: Battery Information and Calculations

Battery	Amp Hours	Voltage	Energy (Watt-Hours)	Amount to get 96V	Energy Per Bank (kWhr)	Entire Amount of Batteries	Mass (kg)	Banks to Reach 8 kWh	Total Energy (kWh)	Mass of Entire Quantity (kg)	Energy Density (watthrs/kg)	Price for One (USD)	Price for 8 kWh
Thunder Sky 40 Ah LiFePO4	**40**	**3.2**	**128**	**30**	**3.84**	**60**	**1.50**	**2**	**7.68**	**90.0**	**85.33**	**$65.00**	**$ 3,900.00**
3.7 Volt 2800 mAh LG Li-Ion 18650 Battery	2.8	3.7	10.4	26	0.269	754	0.05	29	7.81	35.1	222.79	$11.79	$ 8889.66
Optima D51	38	12	456	8	3.648	16	11.81	2	7.30	189.0	38.61	$136.54	$ 2,184.64
NiMH Battery Pack 24 V 10 Ah	10	24	240	4	0.96	32	3.84	8	7.68	122.9	62.50	$240.00	$ 7,680.00

After analyzing the data from the table and looking at the availability of the batteries, the Thunder Sky 40 Ah Lithium Iron Phosphate ($LiFePO_4$ or LFP) batteries were chosen. The LFP batteries have many advantages over typical Li-ion batteries. LFP batteries are safer because they do not have the volatile thermal issues that Li-ion batteries do. They also have a recharge life cycle of up to 2000 charges compared to about 400 cycles for lead acid batteries. Additionally, the LFP battery packs are very durable; a critical characteristic when subjected to the harsh environment they will experience in the MTU E-Rush snowmobile. Another advantageous characteristic of the LFP batteries is that they are not affected by temperature as much as other types of batteries are. This translates to predictable stable battery life in both cold and warm temperatures. LFP batteries are also able to retain charge when not in use or when stored for long periods of time. This means that the E-Rush can be parked or stored when not in use and can be immediately used when needed without the need for a recharge. Graphs of these characteristics are seen in Figure 5 below. A picture of the battery can be seen in the Figure 6 below.

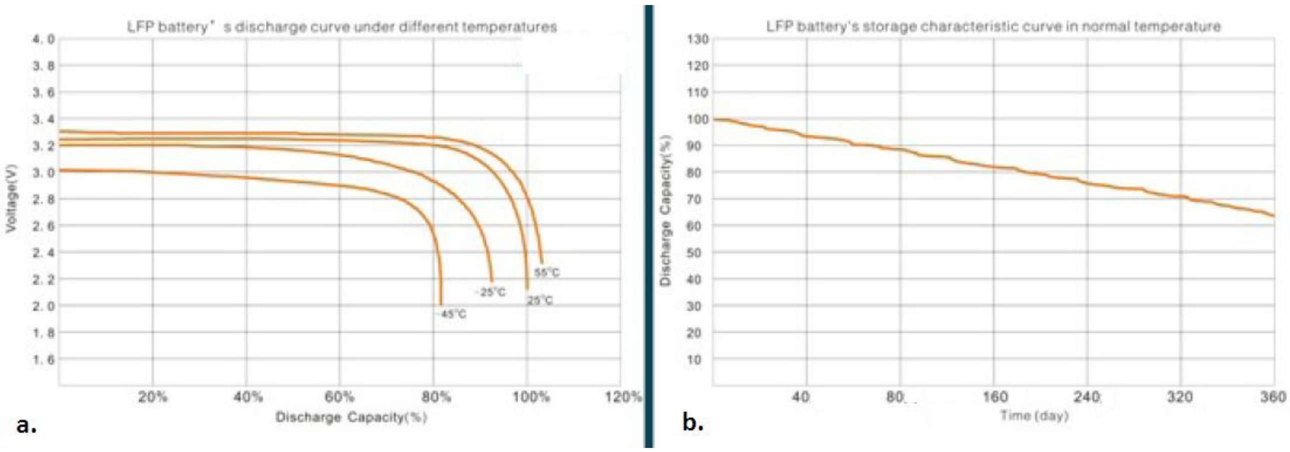

Figure 5: a- Plot of the Effects of Temperatures on the Discharge Capacity b- Plot of the Effect of Time the Discharge Capacity

Figure 6: Thundersky 40 Ah Battery

The Thundersky 40 Ah batteries enabled the team to create an accumulator with a high energy density, 85.33 W-hr/kg. This high energy density translates to a large amount of power and a minimal amount of weight which is well suited for the team's goal of maximizing range on a single charge. A total of 60 batteries were wired together. 30 batteries wired in series to make up 96 volts, then two banks of 30 batteries each were wired in parallel to be able to draw current faster and doubling our capacity which again translates into traveling farther on a single charge. The E-Rush has a total energy of 7.68 kW-hr from the 60 Thundersky 40 Ah batteries wired together which was under but close to the 8 kW-hr limit as specified in the competition rules.

Michigan Tech's E-Rush contained ample room to place batteries. The batteries were mounted in such a way that weight was as evenly distributed as possible and so that the batteries were serviceable in the event that maintenance was required. The team made small banks of six batteries in a box and then wired them together. The battery mounts made for the E-Rush have the same general construction but are built onto different bases depending on where in the chassis they mount. The boxes were made out of 6061 Aluminum and plexi-glass which together made a water resistant, durable mount. The placement and box construction can be seen below in Figure 7.

Figure 7: Battery Mounts

SYSTEM CHARGING

To charge both of the systems of the Michigan Tech Zero Emissions sled, two different chargers are needed to accommodate for the different battery types. To charge the $LiFePO_4$ a 1500W high frequency/power factor control (HF/PFC) battery charger was chosen. This specific charger was chosen because it had the ability to change the charging cycle depending on the type of battery. The charger also had a sensor for temperature and voltage as a safety control. Charging the E-Rush is a simple process. The charger is mounted under the hood of the snowmobile and recharging the batteries is as simple as running an everyday extension cord from the wall to the snowmobile.

BATTERY MANAGEMENT

To manage the $LiFePO_4$ batteries, a battery management system was purchased. This system was designed to detect if a battery cell's voltage was too low or damaged. This system included two basic components: the cell module which was located on each set of batteries in parallel, and a relay control board was also placed on the system to control the entire accumulator. A photo of the battery management system can be seen in Figure 4 below.

SAFETY PRECAUTIONS

Because the MTU E-Rush has an accumulator voltage of 96 volts, it is considered a high voltage system and extra safety precautions were taken to ensure the electrical system was as safe as possible. Because the accumulator has the highest energy content in the system; the accumulator received extra attention in its safety protocol. Lithium Iron Phosphate (LiFePO4) batteries were not only chosen because of their higher energy density but also because $LiFePO_4$ are more stable than Lithium Ion, making the pack safer and more predictable. The snowmobile had several areas which contained different electrical potentials within the system to operate properly; special measures were taken for each of these areas based on the potential voltage. All systems over 30 volts that were exposed had Electri-Flex Liquidtight Flexible Nonmetallic Conduit placed over the wire to protect them from any human contact. All potential differences of less than 30 volts had orange split loom to protect the wiring from corrosion, which could short the system and create a system failure. Proper safety instructions were distributed to allow the MTU ZE team to be aware of the possible dangers.

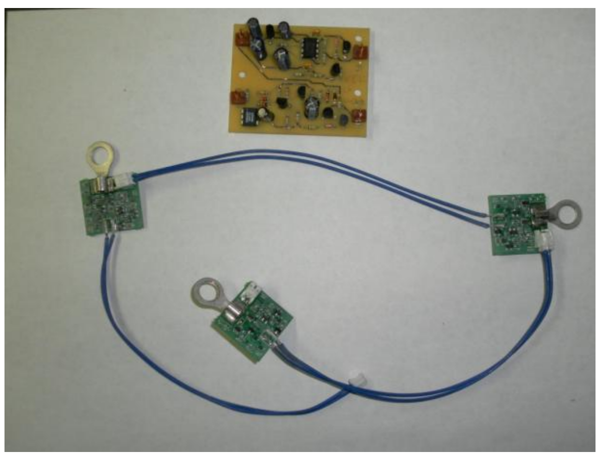

Figure 4: Battery Management System

CHASSIS SELECTION

For the 2011 SAE Clean Snowmobile Competition Michigan Tech chose to use a 2010 600 Polaris Rush chassis. There were many design criterions that were considered when choosing a chassis for the competition. Some of the criterion which played a role in the selection were vehicle weight, vehicle handling, rear drive motor mount options, and storage for the electrical devices. This chassis was chosen for its lightweight tube-frame construction and mono-shock design, progressive rate rear suspension, and most importantly because the rear suspension design adapted well to the rear drive construction planned for the E-Rush.

The rear suspension of the Rush chassis is easily adjusted based on the weight distribution of the sled as well as for the rider. The snowmobile came equipped with Walker Evans clicker shocks; the mono- shock in the rear has 19 clicker positions and provides a suspension travel of 14 inches. The adjustability of the suspension on the Rush chassis allows for simple suspensions changes to be made to compensate for the extra weight of the electrical components added to the snowmobile. The stock Polaris Rush chassis used as the base platform for the E-Rush can be seen below in Figure 8.

Figure 8: Stock Polaris Rush Unmodified

WEIGHT

The bare Rush chassis weighs 271 lbs. The light weight chassis was chosen because a significant amount of weight will be added to the snowmobile after the electrical components are mounted. In order to reduce the final weight of the snowmobile as much as possible the bare chassis should begin as light as possible. The LFP batteries chosen weigh about 3.3 lbs individually which equates to a total weight of about 200 lbs for the accumulator. The motor was an added weight of 53 lbs and the controller weighed 12 lbs. This was an added weight to the chassis of 265 lbs. The final design weight of the E-Rush is expected to be less than 650 lbs.

The Polaris Pro-Ride chassis has an easily accessible large engine compartment. This was beneficial as it helped with the storage of the electrical components used to power the snowmobile, as well as increase the ease for maintenance of the E-Rush. For an increase in the storage capacity of the sled the original gas tank was used to create a carbon fiber shell. This carbon fiber shell creates more storage area for electrical components as well decreases the final weight of the snowmobile. Because the engine compartment was used to house the batteries the E-Rush maintains a clean stock appearance. The batteries were placed in the engine bay to allow for a more equal distribution of weight. With the electric motor in the rear of the snowmobile and the batteries in the front, the two heaviest components of the electrical system work to maintain a balanced distribution of weight.

MTU ZE POWER TRANSMISSION

The E-Rush features a very unique rear drive system which is a first for Clean Snowmobile Challenge. The driveshaft of the E-Rush was relocated from the front of the track and skid to the rear where the idler shaft generally resides. This change was made to increase driveline efficiency of the snowmobile by pulling the track directly down the rails of the rear suspension rather than pulling the track from a more remote location and using idlers to direct the track around the skid. Effectively the rear drive system has the portion of the track which is “slack”, or not under tension, making changes in direction around idler pulleys in the suspension rather than having a track under high tension making these same changes in direction. Because the driveshaft and drive motor have been moved to the rear of the snowmobile, the chaincase internals can be eliminated to reduce the weight of the E-Rush and this facilitates the need to relocate the braking system of the snowmobile. The front driveshaft will remain in its current location and will be extended so that the brake rotor and caliper act directly on the driveshaft to slow the snowmobile. This adds an extra factor of safety when compared to a stock snowmobile in that braking ability is still maintained in the event of a chaincase failure.

In order to move the driveshaft of the snowmobile from its original location to the rear of the machine a custom driveshaft was required. A piece of one inch hexagonal steel stock was used to provide a press fit with the hex drivers used. The ends of the driveshaft were then machined round to an outside diameter of one inch and mounted in mounted pillow block bearings which were bolted to the rails of the rear suspension. The mounted pillow block bearings used were sized and selected based on a bearing rating equation, Equation 1, which calculates hours of life based on rated load, actual load, operating rpm, bearing quality, and a life adjustment factor. Equation 1 is based on L_{10} life which means that ninety percent of a group of bearings will survive for the calculated number of hours if mounted, maintained, and operated according to the parameters used to calculate the given life value in hours.

$$L_{10}=\left[\frac{Radial\ Rating\ (lb)}{Radial\ Load\ (lb)}\right]^3 * \frac{B}{Operating\ rpm} * Life\ Adjustment\ Factor \qquad (3)$$

Bearing life, in hours, was calculated using the radial load rating of an available flange mounted bearing, 3,147 pounds, a worst case anticipated radial load value of one fourth the final weight of the snowmobile, 150 pounds, a constant B value $\left(\frac{10^6}{60}\right)$ dictated by the ISO bearing certification method, and an average operating speed of 1027rpm (27.5mph). Because the bearings will be subject to cold temperatures, moisture, salt, dirt, and other contaminants, the life adjustment factor was set to one half. Using these parameters a bearing life of 75,000 hours was calculated which at an average speed of 27.5mph is well over 10,000 miles, the average life expectancy of a snowmobile. The bearings chosen for the rear drive system have been left oversized for two reasons. The more robust bearings will provide more reliability and the one inch inside diameter of the bearings works well when machining one inch hex shaft for driveshafts because this is a standard driver configuration. Should rear drive units become standard, use of already available parts would create an advantageous manufacturing situation.

In order to accommodate the bearings used for the driveshaft to spin, the back portion of the rails needed to be enlarged to allow clearance for the one inch driveshaft to pass through them. The rear portion of the .1875" rail was removed from the stock Polaris suspension rails and replaced with a thicker and larger square area portion of .25" aluminum to provide more area for the flange of the mounted bearings as well as to cope with the added stress of the drive components. A 1.125" slot is located in this rail addition in order to allow for a .0625" clearance on each side of the 1.00" O.D. driveshaft. In addition, square bushings were machined to ride inside of this slot to serve two purposes. First, the bushings fill the space between the flange of the bearing and the bolt head giving a clamping surface to tighten the bolts and secure the bearing to the rail. Second, the bushings allow the mounted bearings and therefore the driveshaft to slide forward and backwards in the 1.125" slot allowing for track tension adjustment using a track tensioning bolt. Figure 7 below shows the basic components of the MTU ZE rear drive system

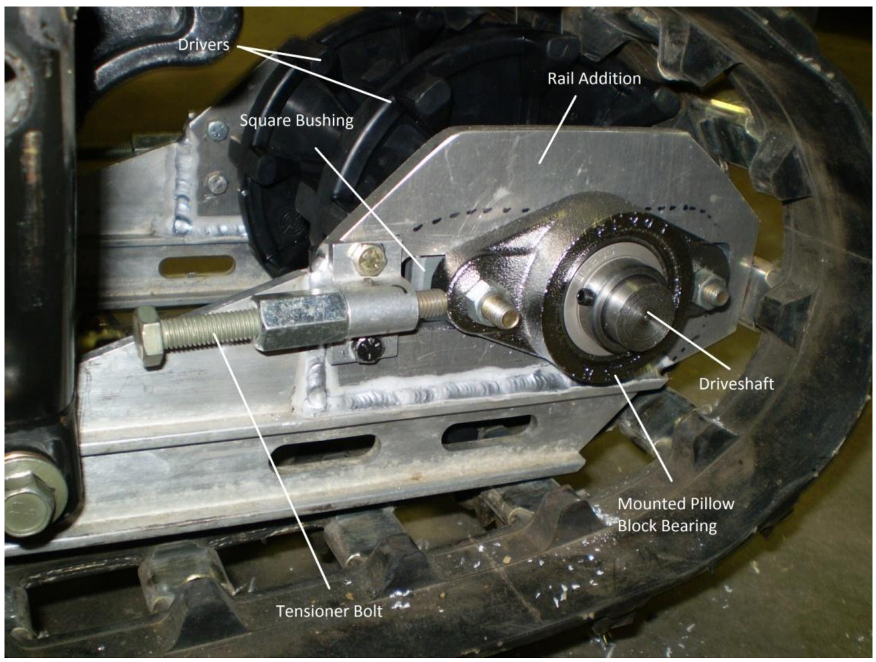

Figure 7- MTU ZE Rear Drive

Because an electric motor is being used which requires less complex plumbing and fewer supporting subsystems to operate, the motor can be mounted in a more remote location making a rear drive system more feasible. The ability to easily mount the motor near the driveshaft means that extra drive system components which serve only to transmit power from one location to another are not necessary. In a standard snowmobile power moves from the primary clutch to the secondary clutch, across the jackshaft, through the chaincase, and then to the driveshaft and drive cogs. The E-Rush uses only one major transfer of power in its power transmission system and that is from the drive pulley mounted on the output shaft of the motor to the driven pulley mounted directly on the driveshaft. Because there is an efficiency loss associated with each transmission of power, the fewer moving components in the system the greater its potential efficiency will be.

MOTOR MOUNT

Because the E-Rush uses a unique rear drive system a motor mount designed specifically to function with the E-Rush rear suspension had to be fabricated. The motor mount is designed to move with the rear suspension of the snowmobile so that belt tension is constant regardless of the position of the rear suspension. The first step of creating the motor mount design for the E-Rush was determining the major sources of stress that would be placed on it. Michigan Tech's E-Rush AC-20 motor is capable of creating a torque of 105 ft-lbs and it weighs 53 lbs. These two motor performance values formed a basis for the stress analysis on the motor mount. Several design concepts for the motor mount were modeled in Unigraphics. Below, in Figure 8, are two of the ideas that were modeled and then imported into a Finite Element Analysis (FEA) program called Abaqus.

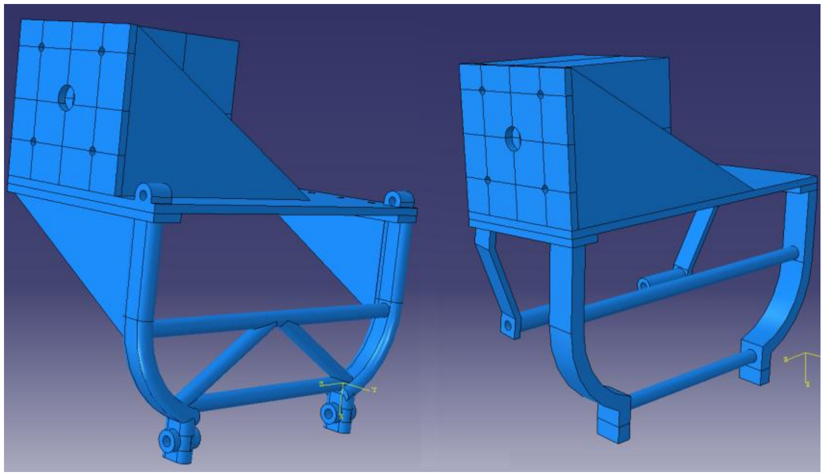

Figure 8: Two design concepts for the E-Rush motor mount

Boundary conditions, loads, material properties and a finite element mesh were applied to all motor mount concept designs. The analysis was run and the program output was used to determine what areas of the design showed high stresses and could potentially fail. In Figure 9, the final output from Abaqus of Von Mises Stresses on the final design that was implemented into the E-Rush can be seen. Through design iterations based on outputs from Abaqus the motor mount was made lighter while retaining the required strength to hold the AC-20 electric motor in dynamic riding situations. Without the effective implementation of FEA while designing the motor mount the material switch that was made from steel to aluminum would have not been made and a significant weight loss for the E-Rush would have been missed. Table 5 below summarizes the three best concept designs that were modeled and analyzed for the motor mount.

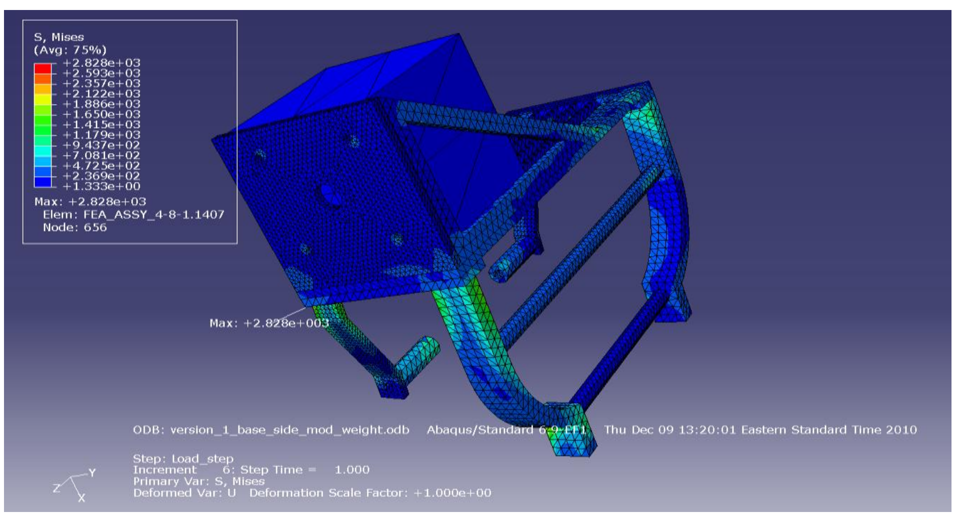

Figure 9: Von Mises Stress Plot from Abaqus of Final Design

Table 5: Maximum Stresses seen per design along with Factor of Safety and Weight

	Max Stress (psi)	Max Displacement (in)	Yield Stress (psi)	Factor of Safety	Weight
Design 1	3,106	0.01136	36,000	11.5	48.06
Design 2	2,726	0.001636	36,000	13.2	36.26
Mod Design 2	2,828	0.001871	36,000	12.7	25.75

TRACK SELECTION

In a further effort to increase the efficiency of the E-Rush the stock Rip Saw track was replaced with another commercially available track. A Pugh matrix was developed in order to select the track. Some of the qualitys deemed important are weight, studs, pitch, and lug height. All of these factors would contribute to the overall performance of the snowmobile. A track with low mass, aggressive lug height, and that was studded would provide for better traction and performance. Pitch and single-ply construction were important in reducing rotational mass thus increasing efficiency. The tracks were chosen because each provided a unique feature. The Ice Ripper was chosen overall because it scored well in all of the categories as can be seen below in Table 1.

Table 6: Track Selection Matrix

Track Selection						
	Relative Weight	Ice Ripper	Stock	Ultimate Ice	X-Force	Ice Attak
Weight	30	4	5	4	3	2
Pitch	20	5	5	2	2	5
Studded	25	4	1	5	1	5
Single-Ply	15	5	5	2	1	5
Lug Height	10	5	5	5	5	3
Sum	100	4.45	4	3.65	2.2	3.9

The Ice Ripper is a commercially available, one piece, molded rubber track as specified for use in Clean Snowmobile Challenge rules. The track is 15” by 120” with 1.25” lugs, which is the same as the stock Rip Saw track. However, the Ice Ripper is a 2.86” pitch track compared to the Rip Saw which is a 2.54” pitch track. This means that there are fewer reinforcement rods in the track reducing its overall weight. Weight loss in the Ice Ripper track also comes from the fact that the track is of one ply construction and not made of multiple layers of rubber. In addition the Ice Ripper track has studs which are built into the tips of the lugs of the track rather than bolted to the flat sections of the track. The Ice Ripper track is lighter than a conventional track which is studded as there is no need for nuts or backer plates that are used with regular snowmobile studs. The studs molded into the track serve to decrease acceleration and braking times and will increase traction for the draw bar pull test as well as cope with the high amounts of torque delivered by the electric motor at low speeds

RANGE

Range is one of the most critical performance aspects of the ZE competition at Clean Snowmobile Competition. Because so much importance is placed on the distance the E-Rush can travel in one charge several design aspects, some of which were mentioned above, were modified in order to increase range as much as possible. One of the largest factors which impacts the range of the E-Rush is the electrical hardware which has been chosen. The LFP batteries, Curtis motor controller, and AC-20 motor were chosen together because they have been purposefully packaged with one another. The synergy between the three major electrical components works to produce the greatest possible range. In addition, several mechanical aspects of the snowmobile were altered in order to decrease any mechanical losses that may be present in the system. The primary means by which mechanical losses were minimized was through the implementation of the rear drive system. This reduced the number of moving parts in the system as well as the number of times power is transmitted from one system to another. This reduction of moving parts and reduction of power transfer directly results in less friction and less wasted energy. A reduction in wasted energy equates to greater range. The final design parameter used to increase range was continually working to reduce weight. A reduction in weight means the electrical system has less mass to power and can then move the snowmobile a farther distance. Weight was kept as minimal as possible by selecting a light weight chassis and optimizing designs such as the motor mount to make them as light as possible while maintaining strength.

DRAW BAR PULL

One of the main design concerns that the MTU ZE team faced was the drawbar pull. After choosing the AC-20 high torque electric motor additional factors that affected the pulling ability of the snowmobile were taken into consideration. Mounting the motor on the rear of the snowmobile helped to distribute weight towards the rear of the machine and place weight onto the track increasing traction. Additional traction for the draw bar pull is provided by using the Ice Ripper XT pre-studded track. The studs in the Ice Ripper track are placed in the tips of the lugs for the best possible penetration in ice and snow and will aid in the snowmobiles pulling ability. Equations 4 and 5 below are used to calculate the draw bar pull force of the E-Rush.

$$\text{DP} = \frac{TxR}{r-RR} \quad (4)$$

$$\text{RR} = \frac{GVW*R}{1000} \quad (5)$$

DP- Drawbar Pull (lbs)
T- Torque of motor (in-lbs)
R- Gear Reduction
r- Radius of drive wheel (in)
RR- Rolling Resistance (lbs)
GVW- Gross Vehicle Weight (lbs)
R- Rolling resistance of the surface (lbs)

Equation 4 has been used to calculate the drawbar pull of multiple types of vehicles such as trucks and trains and the MTU team has applied these same equations to the E-Rush for a rough estimation of pulling power. The rolling resistance was calculated using Equation 5, with the rolling resistance of the surface, 37 pounds, being obtained from a table of rolling resistances for various materials. When inputting a torque of 105 lbs, rolling resistance of 24.05 lbs, gear reduction of 2 and the radius of the drive wheel of 3.5 inches, the estimated drawbar pull was calculated to be 695 lbs.

COST

The cost of building any electric vehicle is often very large when compared to other sources of propulsion. Because battery, motor, and motor controller technology is new and in high demand it often carries a large cost. Care was taken in the design of the E-Rush to use readily available and in production parts whenever possible. In addition, any custom fabricated parts that were made for the E-Rush can be easily machined using computer numeric controlled machines. The final price computed for the E-Rush is $21,536.81. This price is high compared to currently available internal combustion snowmobiles but the technology used in the E-Rush is currently in high demand and under intense development. Time and further development of the electrical components available on the market will act to decrease the cost of the E-Rush.

SAFETY, PERFORMANCE, AND RELIABILITY

Throughout the design process several key aspects of the E-Rush were kept in mind. The E-Rush was designed for safety, manufacturability, reliability, and serviceability. The safety of the E-Rush was maintained from stock and improved by relocation of the braking system to a fail-safe location which cannot be effected by drivetrain failures such as breaking a chain. With the reduction of noise from exhaust and engine noise it becomes easier for the rider to hear things that are going wrong with the snowmobile thus increasing rider awareness and safety.

The manufacturability of the E-Rush was held in high regard during the design process. The rear drive system is constructed of readily available parts which need minimal modifications to operate properly on a subsystem level. This means that extra machining process have been minimized to as great an extent as possible. The mounted pillow block bearings used in the rear drive system need only a small flat machined in their end to interface with the track tensioning system. In addition, only simple machining processes need to be performed to a standard one inch piece of hexagonal stock to create the rear driveshaft used to interface with already available hex shaft snowmobile drivers. The focus on design for manufacturability allows for existing snowmobile manufacturers to integrate zero emissions options on already existing snowmobile platforms with the need for only a few new parts or machining processes.

Because the Clean Snowmobile Competition Zero Emissions Category is based on utility for scientific advancements in a harsh environment, reliability and serviceability were a key aspect of the E-Rush design. Reliability was attained by using oversized and greaseable bearings. Proper lubrication was vital to long life and smooth operation of rotating assemblies especially those operating in extremely cold and wet conditions. In addition, the overall design of the E-Rush has been kept as simple as possible with few moving parts for easy maintenance and service. The rear drive configuration allows for only one power transmission from the motor's output shaft to the driveshaft eliminating problems that can be encountered with the many moving parts associated with clutches and chain cases. Additionally, the snowmobile's rear drive system can be completely disassembled and reassembled with basic hand tools. The theme of serviceability continues with the two piece design of the motor mount which allows for the arms which bolt to the rails of the rear suspension to be removed from the cradle and bolt circle which hold the motor. This makes motor installation easier while working around the track, allows for replacement of smaller components rather than one large one reducing the cost of replacement parts, and also makes manufacturing the motor mount simpler (design for manufacturability).

SUMMARY

The E-Rush has been designed to provide an effective mode of transportation for summit station scientists on the Greenland Ice Cap where emissions from an internal combustion engine cannot be used due to their adverse effects on measurements being taken. The overall goals of the E-Rush were to maximize the range of the snowmobile on a single charge as well as to maintain the stock platform performance. The MTU designed rear drive system serves to increase driveline efficiency, reduce weight, and reduce design complexity. Electrical design for the snowmobile has also had the same focus. The Hi-Performance AC-20 motor was chosen for its high rated power as well as its efficiency, the Lithium Iron Phosphate batteries were chosen for their high power density and relatively small size and weight, and the fully programmable Curtis Motor Controller was chosen to maximize the effectiveness of the motor and batteries together. The design decisions for the E-Rush have kept both the design goals as well as competition constraints in mind to create a practical solution for zero emissions transportation on snow.

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