Development of a Battery Powered Utility Snowmobile

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ABSTRACT

The McGill University Electric Snowmobile Team, returns to the Clean Snowmobile Challenge in 2006. It will, for the first time, compete against other electric snowmobiles in the all new zero emissions category. For this event the team has engineered an all new snowmobile based on the knowledge gained from previous electric snowmobile prototypes the team has built. The 2006 prototype is expected to surpass the previous McGill electric snowmobile prototypes in all performance aspects as well as in durability, ease of use, ease of maintenance and reliability.

INTRODUCTION

Utility snowmobiles are essential vehicles for a number of people. These strong, reliable, mechanical workhorses of the winter season are used in many different fields. This breed of snowmobiles can be seen at work in all of the northern part of the continent in military, search and rescue, industrial, recreational and scientific applications. While current gasoline powered snowmobiles offered by OEMs fit the basic needs of most of these applications, some utility applications are looking for something which current OEM utility snowmobiles are unable to deliver. One example of that is the need by the scientific community for a zero emission snowmobile for use in ultra-sensitive environments.

The National Science Foundation (NSF), through its civil contractor VECO Polar Resources, has express such a need for a zero emission snow vehicle for use at Summit Research Base in Greenland. Research at Summit includes air and ice sampling in order to determine quantities of various substances in the samples. Given its remote northern location, Summit is an ideal candidate for such sampling since it greatly diminishes the risk of the samples being contaminated by local contaminant sources. In order to further decrease contamination risk, a “no vehicle zone” has been established up wind of the base in order to minimize contamination of samples by the base's vehicles and its electric generator. Unfortunately this also means that access to the zone must be made on cross-country skis thus limiting the amount of equipment which can be brought, extending the time required to acquire the samples and also increasing safety risks in a extremely cold and harsh environment. The use of a zero emission snow vehicle at Summit would enable researchers to keep this zone with minimal contamination while making the research safer and more efficient.

After having seen the need for zero emission snow vehicles by the international research community, the Clean Snowmobile Challenge (CSC), a student engineering design competition administered by the Society of Automotive Engineers (SAE), has decided to add a zero emission category to its 2006 competition. Previously the CSC engineering goal was for students to design, build and implement cost efficient solutions to minimize snowmobile environmental impact while maintaining original snowmobile performance in trail riding conditions. In 2006 the competition has 2 different categories with 2 different engineering goals. The internal combustion engine (ICE) category's goal is to make snowmobiles which meet the needs of tour operators while being acceptable for use in U.S. National Parks and also being in compliance with the 2012 snowmobile regulations. The zero emission category's goal is to meet the needs of the scientific community by designing a safe , reliable, easy to use and maintain, utility snowmobile which has adequate range and power while emitting the least amount of contaminants possible from its power train.

McGill University has engineered a new electric snowmobile based on the knowledge it gained from its 2005 electric snowmobile. The student team which designed this snowmobile has done so with the double objective of satisfying the CSC/NSF needs while also satisfying the needs of the McGill University Vehicle Engineering education, Research and Tech. transfer (VERT) project. The VERT project is a research project at McGill which investigates plug-in series hybrid power trains for sub-2000lbs vehicles of all natures. Thus the McGill CSC snowmobile entry was designed to be a research test bed vehicle which can allow easy drive train component and configuration changes while also being fully instrumented for extensive data acquisition.

The following paper discusses how the knowledge gained from previous year's experience added to the requirements of the CSC/NSF and the requirements of the McGill VERT Project has influenced the design of this one of a kind prototype. The main issues covered in this paper include an overview of the electric snowmobile technology and challenges, the design of the snowmobile for overall performance, range and load transport capacity, and lastly some information on features, user friendliness, maintenance and cost.

FUNDAMENTAL DIFFERENCE: ELECTRIC SNOWMOBILES VS. ICE SNOWMOBILES

Before going into the details of the McGill University Electric Snowmobile Team's design. It is worth taking a few lines to look at why the design of a practical electric snowmobile is such a challenge. The answer to this question is simple: energy density.

The energy density of gasoline is 12 700Wh/kg [1]. In comparison, the energy density of large sealed lead-acid batteries is 34.1Wh/kg at C/10 discharge rate (down to 1.85 volts per cell (VPC)) [2]. The same batteries will see their energy density drop down to approximately 28Wh/kg at a C/2 discharge rate and down to approximately 17Wh/kg at a 2C rate. Thus in order to have the same amount of energy as a snowmobile with a gasoline tank containing 33kg of fuel (typical), an electric snowmobile drawing energy from its batteries at a 2C rate (typical) would have to carry 24,652kg of lead-acid batteries. More advanced battery technologies have greater energy density than lead-acid batteries. One of the most promising type of batteries are lithium based batteries. A quick search through the offerings of some of the main manufacturer shows that they can have about 120 Wh/kg at C/2 rate [3]. Assuming one would use high voltage in order to keep discharge rate at C/2, even then one would have to carry close to 3500kg of lithium batteries to equate the amount of energy in a 33kg tank of gasoline. When adding to this the fact that energy density of these battery chemistries decreases as temperature decreases, one can definitely get a feel for the challenges of designing and building an electric snowmobile.

As a reference, the 2005 McGill University CSC entry snowmobile had, energy wise, the equivalent of 0.185 liters of gasoline on board (at typical 2C discharge rate). In weight, this amount of energy represents 91kg of batteries.

Therefore, in order to build a practical electric snowmobile, careful attention must be placed in making sure that the maximum amount of energy can be extracted from the batteries and that this energy is used as much as possible to propel the snowmobile.

OVERALL PERFORMANCE

In 2005, the McGill Electric Snowmobile CSC entry was a 700lbs electric snowmobile which could drive 10km at 25km/hr on groomed flat terrain. Using this prototype as a reference for many design decisions, the team believed it was possible to surpass the 2005 overall performances by a factor of two with the 2006 prototype.

Figure 1: 2005 McGill University "Wendigo" Electric snowmobile Prototype

In order to build an electric snowmobile conversion 4 main items are required: a chassis, a battery pack, an electric motor, and a motor controller/drive. The battery can be seen as analogous to the gas tank, the motor to the engine and the controller to the engine control unit (ECU).

From past experience, both successful and failed attempts, in designing and building electric snowmobile prototypes the team has learned a lessons which has been one of the guiding principles in building this prototype. What the team learned was that, when it comes to performance, an electric snowmobile is analogous to a chain; it is only as good as its weakest link. In the case of the electric snowmobile this means that extreme care must be taken in selecting all components so that they are all compatible and at the same level in terms of performance.

One example of this is the choice of a motor. One may be tempted to use some of the more powerful compact motors available. However, one must make sure that ALL other electrical components in the snowmobile can feed the motor the amount of power it can output for a suitable period of time. Failure to do this will in most cases result in a loss of efficiency both performance and cost wise. With that in mind, the McGill Team looked at the different choices of electric motors available for its 2006 snowmobile. While there are many different types of motors, 3 types were evaluated in depth. A large number of AC, DC brushed and DC brushless (BLDC) motors were compared on the basis of cost, efficiency, max power, power curve characteristics, weight, power/weight ratio, power/volume ratio, availability, ease of use and compatibility.

After investigation, a 72V eCycle CMG Double Stack BLDC motor was chosen [4]. The fact that its efficiency (at expected operating power) is above 90% and that it weights less than 30lbs made it a strong candidate early on in the process. Also, the eCycle CMG series has integrated controls which makes it possible to drive this highly efficient motor using a Brushed DC motor drive. Furthermore, its low operation voltage (relative to many AC motors which require well over 200V) made it a motor which the team knew would be compatible with many different batteries. While it may only output close to 15HP, the team believed, given the data gathered from past prototypes, that this would be sufficient for light utility applications. Previous experience tends to show that past a certain amount of motor power, given today's technology and the requirements and constraints of snowmobiles, compatibility and weight issues with controllers and batteries become a problem.

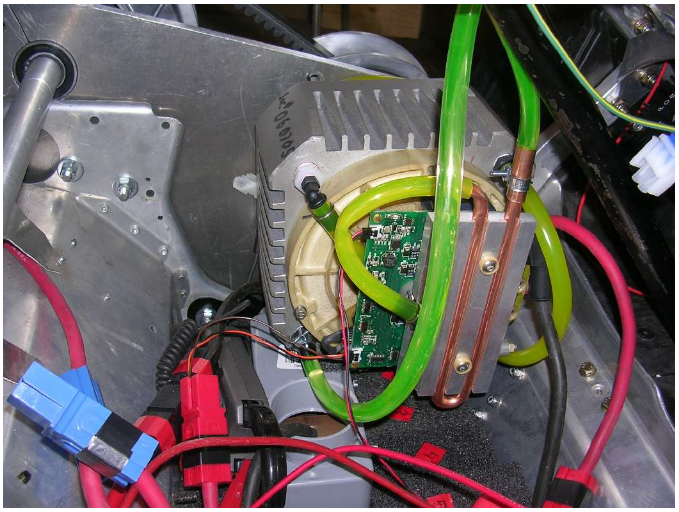

Figure 2: eCycle CMG motor (rear view) mounted on snowmobile.

The motor output power capabilities of the eCycle BLDC motor is superior to the power required to move the 700 lbs 2005 prototype at 25km/hr. However, the team wanted to further improve the snowmobile's overall performance. It was thus decided that reducing overall snowmobile mass and reducing rotational mass inertia of the 2005 drive components would be key objectives. A 50% reduction in motor weight has been achieved by replacing the 2005 motor with the eCycle motor. Further reduction in weight was achieved by using one of the lightest chassis the team could find: BRP's new Skidoo RF Chassis. Once stripped if its ICE system and drive components, the RF chassis weights less than 300lbs. Another major contribution to weight reduction was achieved when the new lithium-ion battery pack was chosen to replace the 2005 lead-acid system. This replacement alone saved over 150lbs of weight on the snowmobile. Smaller weight savings were also obtained by replacing the steel driveshafts, chain drive and brake system by aluminum shafts, a synchronous belt system and a lightweight brake system from the early A.D. Boivin Snowhawk vehicles.

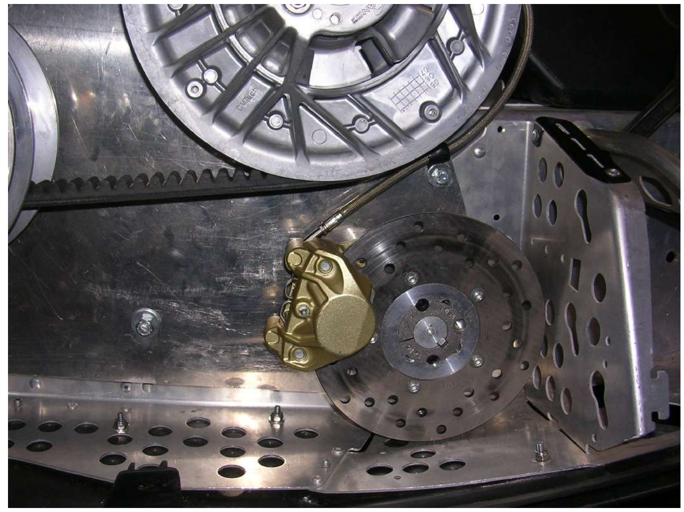

Figure 3: Light weight brake system

Overall, a 30% weight reduction was achieved for the 2006 prototype relative to the 2005 prototype.

Another key performance aspect the team wanted to improve relative to the 2005 snowmobile was the handling characteristics of the snowmobile. In acquiring the RF chassis platform, the team was well aware that it had one of the most nimble and easy to maneuver snowmobiles on the market.

Figure 4: RF Chassis

Thus, when transforming it into an electric snowmobile, on top of trying to keep it as light as possible, much effort was directed towards keeping the mass distribution and center of gravity as close as possible to the original snowmobile. The team achieved this first of all by mounting the eCycle electric motor in almost the exact same position as the original 300cc engine. The 33kg battery pack was designed to sit as close to the bottom of the chassis as possible and near its center line on the opposite (right) side of the chassis relative to the motor. The brake assembly has been moved to the left hand side on the track shaft to help counter balance the battery pack and keep a low center of gravity. Lastly, the electrical box found its home in the gas tank thus ensuring that the snowmobile is not too front heavy in order to offset the weight of the DC/DC converter and the on-board battery charger housed in the nose of the vehicle.

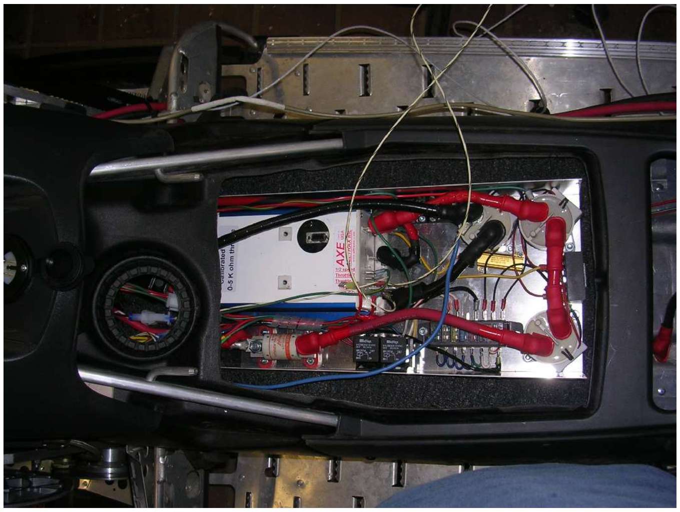

Figure 5: Electrical box under seat

In order to test handling, the team has set up a trail on top of jagged snowbanks on the road which leads to its lab. The electric snowmobile prototype was driven repeatedly over this very rough terrain. A true indication of the handling characteristics of the prototype was that even 1st time snowmobile riders were able to maneuver through, over and around the obstacles without a problem.

RANGE

The range of a snowmobile is highly dependent on the amount of energy available on-board. Also, the efficiency of the electrical and mechanical drive system in a given set of conditions can largely affect snowmobile range.

Assuming that a 30% lighter snowmobile than in 2005 would likely reduce the load on the motor in various conditions, the team attacked the range issue by focusing on the choice of batteries and on the optimization of drive components to get the most mileage out of every charge.

Extrapolating from data gathered from previous prototypes, the team based its battery choice on an expected continuous battery power requirement close to 7 kW.

A number of battery chemistries were evaluated based on performance characteristics, size, weight safety, availability, charging requirements, compatibility and cost. After having evaluated two dozen possibilities, the team decided to use lithium based cells. An agreement for a 20S1P (1 parallel string of 20 cells in series) prototype pack was reached with Lithium Technology Corporation (LTC). The pack has its own battery management system and its string of 20 cells is made of 45Ah HP-602050 cells of 3.6 V(nominal) each, for a total of 72V. These cells are rated at a C/5 discharge rate. However, based on the team's expected discharge requirements, the cells need to perform at a 2C discharge rate. The prefix “HP” in the cell name means “High Power”. What this means is that these cells were specifically designed to keep a maximum of available energy at high discharge rates thus perfectly suiting the needs of the electric snowmobile application. The 2C rate is within the manufacturer recommended continuous discharge rate.

Figure 6: Lithium Ion battery pack

Knowing that, based on its conservative estimate and battery manufacturer data, the snowmobile would have just barely enough energy on board to achieve the range requirement, the team put considerable effort in an attempt to lower the snowmobile's cruising power requirement below 7kW. Keeping the overall and the rotational mass to a minimum as discussed earlier was one of the steps taken to reduce power requirement. The team also changed the snowmobile's original chain drive system for a Gates Synchronous dive system which Gates claims has superior efficiency [5].

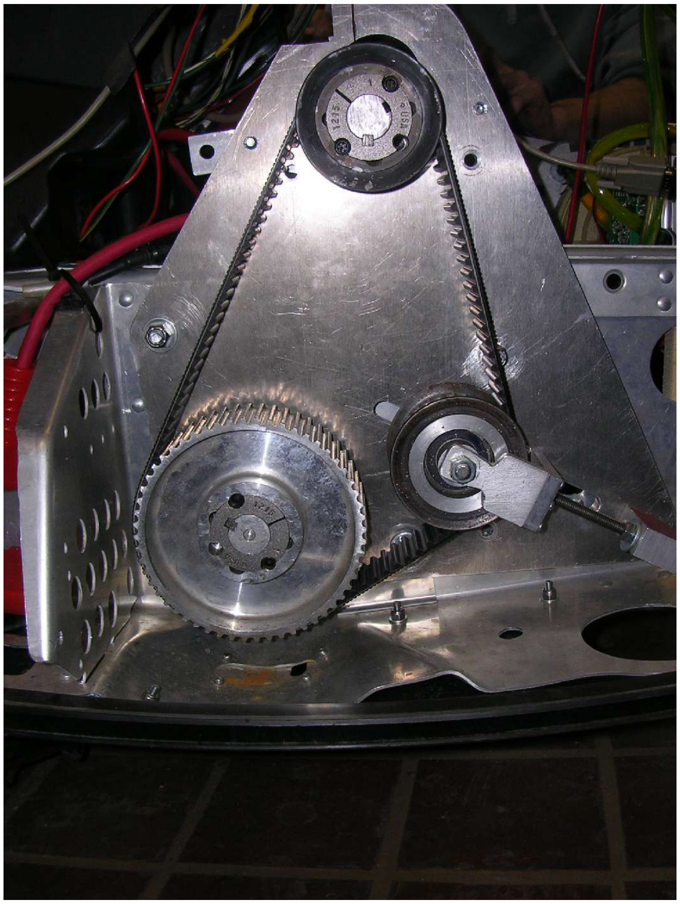

Figure 7: Gates PolyChain GT 2 belt drive system

Electrical system efficiency is another target the team aimed its efforts at in order to lower power requirement. When purchased, the chosen eCycle motor had an efficiency of 92% at expected operating power. However, after talking to eCycle's Eastern Canada representative over the course of the winter, the team learned that some recent upgrades were available from eCycle which from preliminary test results could add an extra 2% of efficiency to the motor. The motor what thus sent back to eCycle for upgrading. The motor's drive, manufactured by Alltrax Inc., was also selected based on it high efficiency of 95% [6]. To ensure minimal energy losses, all electrical connectors have been soldered.

Preliminary tests show that the 2006 snowmobile typically draws 2000W when running under no load (lifted track). Further testing showed that it draws under 4000W of power at a speed of 25 km/h. This result surpasses in efficiency the performance of the 2005 prototype. Further CVT adjustments in order to exploit 100% of the motor capabilities must be made. So far the team has only been able to tap into 1/3rd of the motor's available power. However, extrapolation from these preliminary results tend to show that the power requirements of the snowmobile at 20 MPH will typically be lower that 7000W. Thus the team is confident it will be able to complete 100% of the distance in the range event.

DRAW BAR PULL

Torque and traction are the key elements in being able to move 1500lbs with the electric snowmobile. From past experience, the team believes that the challenge is not in the 100ft distance to cover but more in actually taking off with 1500 lbs. On flat terrain with even conditions, past prototypes have shown a tendency to require more power at takeoff than at steady slow speeds. Thus the team concentrated its efforts in ensuring that the snowmobile would be able to have enough torque at the start. In order to do so, the team is using a CVTech R&D custom made 0 RPM engagement CVT transmission between its eCycle motor and the snowmobile's counter shaft. In its lower ratio, the CVT can increase torque by a factor of 3.

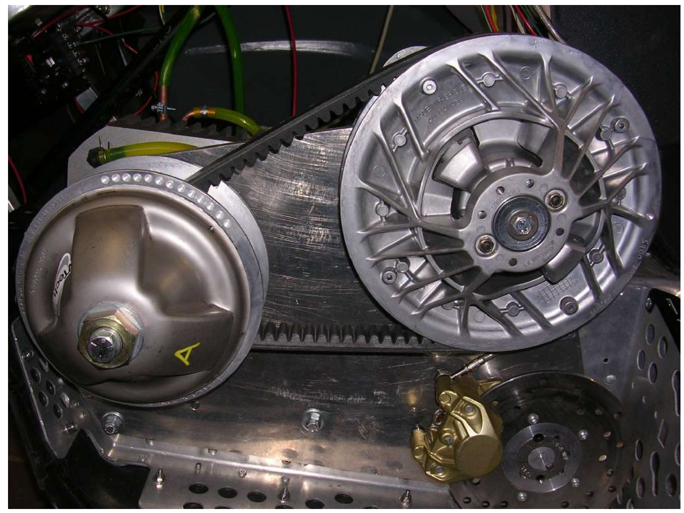

Figure 8: 0 RPM engagement CVT

This ratio is supplemented with a fixed 2:1 belt drive ratio between the counter shaft and the track shaft thus giving a 6:1 torque advantage at the track relative to the motor shaft. This contrasts with the direct drive system of the 2005 prototype which had a 1.85:1 ratio between the motor shaft and the track shaft. However, given the different torque characteristics of the 2005 and the 2006 motor, overall torque at the track should experience a 50% increase in continuous operation and slightly more than double for peak requirements relative to the 2005 prototype. Knowing that the 2005 prototype has successfully carried 1100lbs of weight (snowmobile mass + passengers and on-board cargo) on a very mild uphill incline in the past, the team then set its target from ensuring sufficient torque to ensuring sufficient traction.

While they would most likely have helped with traction, the team decided against using traction studs to improve traction. The reason behind this choice is not a technical one but a practical one. The electric snowmobile prototype is in high demand all year round for trade shows, exhibitions and conferences. Most places it visits are indoor venues. The team often replaces the skis on the snowmobile with wheels to drive the vehicle indoor. Unfortunately, having a studded track would likely have a VERY negative impact on this feature of the electric snowmobile... thus the team had to find another way of ensuring sufficient traction. The selected tactic was to mount as much of the cargo weight as possible over the track of the vehicle to increase the normal force on the track, which in turn the team expects will translates in better traction. Thus the long-track version of the RF chassis with its tunnel extension was chosen as the base snowmobile. This allows for the mounting (in an “easy-on/easy-off” cargo box) of a portion of the load to carry right over the rear of the snowmobile's track.

With the current configuration, the snowmobile is capable of pulling sufficient loads on flat terrain with enough traction. However, in order to increase its top speed, the team will have to modify the custom made CVT system. One potential problem is that CVT slippage may occur on high loads once the CVT is adjusted to achieve higher speeds. Thus in order to increase its top speed while still maintaining its towing capacity the team will have to achieve a good balance between CVT weights and springs.

FEATURES

When it comes to comfort, practicality, ease of use and overall user satisfaction, many will say that “the Devil is in the details”... Well aware of this, the team has, on top of designing for performance, put special attention to the small details. Here are some interesting ones:

-The team decided that, for the 2006 snowmobile, in order to simplify charging and maintenance, while increasing safety, reliability and durability, the auxiliary 12V battery would be replaced by a fully isolated DC/DC converter. The DC/DC converter can easily be operated and monitored by the user via a switch and LED lights on the dashboard.

-This prototype is equipped with an ultra light 99% power factor corrected on-board charger capable of charging the lithium battery pack at C/4 with 90% efficiency. A GFCI outlet and a 20 amp circuit breaker ensure operator safety and reduce the risks of overloading the facility from which the snowmobile is charging. Even the electricity input location has been thought out to ensure ease of use. The inlet plug is located in the place of the original gas tank inlet.

Figure 9: Electric inlet

-This being a light utility snowmobile, the “easy-on/easy-off” cargo box is definitely a plus. But what makes it even more interesting is that it can serve as a cargo box AND a battery rack. The box can be divided in sections such that one section is large enough to house a second 20S1P module of HP-602050 cells with room in the other section for more cargo. Thus, in such a “range extension configuration” the electric snowmobile can carry twice its standard amount of energy.

Figure 10: “Easy-on/easy-off” cargo box

-In terms of ergonomics, the design rules were set as soon as the chassis was acquired: unless absolutely necessary, rider position must stay the same as the original snowmobile. The team successfully managed not to change the original rider position. Furthermore, switches and other controls were kept in their original location.

-On top of playing a central role in drive component selection, energy efficiency was thought of in the selection of auxiliary items. An example of this is the incandescent rear light which has been replaced by LED's.

-This being a research prototype, it is equipped with the latest data acquisition system (V7 Pro) from Isaac Instruments. The system can have up to 20 data logging inputs and is equipped with a GPS receiver. On top of being recorded and saved for future retrieval, data can be displayed in real time to the driver, via the Palm Pilot display on the dash board or it can be sent via the RF antenna to a base station within a 30km range and displayed live on a computer at the base station. Data can easily be processed using Isaac's data acquisition software.

-When the Palm Pilot display is not in use, the driver can still receive vital information on the snowmobile energy use via easily readable analog gauges on the dashboard.

Figure 11: Dashboard

-Constant monitoring of energy use is also achieved by the battery management system (BMS) which ensures that batteries are always operating in good conditions. The BMS also ensures cell balancing for prolonged battery life. It also opens a main contactor if conditions are judged unsafe. Thus the BMS greatly improves vehicle safety, reliability and durability. A good measure of durability is the following characteristic provided by the manufacturer: at 100% depth of discharge (DOD) under C/2 cycling, the batteries can last 1000 cycles before reaching 60% nominal capacity.

-Another interesting aspect of the snowmobile in terms of durability and reliability is the fact that having a DC brushless motor eliminates the need for motor maintenance (i.e. frequent brush changing) of DC brushed motors.

-In terms of operator safety, all electrical wiring is fused and the high power system also has an easily reachable breaker in series with the high power fuse. This way in the event of a minor overload, the driver only has to reload the breaker; no need to change the relatively expensive ultra-fast acting semi-conductor fuse. However, in the case of a major short circuit which could by-pass the breaker, the ultra-fast acting fuse can save thousands of dollars worth of electronic equipment (motor, drive, batteries, etc).

COST

It is very difficult to judge the value of a one of a kind item. The added safety of the researchers in Greenland and the high quality data a prototype like this one can enable researcher to have access to are, in a way, priceless.

Based on 60% retail and 5000 unit costs, the 2006 electric snowmobile has an added cost of 4263US$. Batteries make up over 70% of this cost. The other two main contributors, motor and drive, represent 23.5% and 6% of this cost respectively.

CONCLUSION

The McGill Electric Snowmobile Team has achieved its goal of designing an electric utility snowmobile prototype superior to it predecessors in all aspects. From higher top speed to superior range and torque, the 2006 prototype surpasses the 2005 in all performance categories. Furthermore, the 2006 prototype is an intuitive, user friendly light utility snowmobile with numerous attractive features in terms of safety, reliability, comfort and durability. The team believes that this completely new design can successfully fill a void in the range of vehicles the four main snowmobile manufacturers are currently offering. This one of a kind prototype shows that the need of the scientific community for a zero emission snow vehicle can be met.

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