McGill University Electric Snowmobile Team

SAE CSC 2005 Engineering Design Paper

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ABSTRACT

In 2004, the McGill University Electric Snowmobile Team has undertaken the task of designing and building the first purely electric snowmobile to participate at the SAE Clean Snowmobile Challenge. Despite major problems, much has been learned through this endeavor. The project has evolved in 2005 and finally, data, altough limited, is available for this electric snowmobile prototype. As this is an ongoing project new relevant knowledge, data and information is obtained on a weekly basis. Do not hesitate to contact the team for the latest information pertaining to the project.

INTRODUCTION

Snowmobiles, like most other current means of transportation in North America, use internal combustion engines as the source of power. Most of these snowmobiles are used for recreational purposes and are often driven in national parks and backcountry areas. Emissions and noise from these machines is detrimental to the surrounding environment, causing air pollution, water pollution and noise pollution.

“For many people, the sights, sounds, and smells of snowmobiling degrade or disrupt the quiet and solitude that they seek in natural areas.” “If animals are harassed, they may use scarce energy that they need to survive through the winter. In some cases, animals may become habituated to humans or may be harassed by pets. In Yellowstone, groomed snowmobile routes have become travel corridors for bison and other animals, changing their movements, contributing to increased populations, and bringing them into more frequent conflict with landowners adjacent to the park.” [1]

Snowmobiling, as fun a sport as it is, has up until recently rarely taken into consideration its environment. The SAE Clean Snowmobile challenge attempts to improve the emissions and noise of regular (production) snowmobiles while maintaining or exceeding stock snowmobile performance.

The McGill University Electric Snowmobile Team's objectives are somewhat different from the competition's current objectives. The team's snowmobile, the Wendigo Prototype, is designed with low environmental impact as the ultimate priority and performance as a secondary issue.

HISTORY - The idea of producing an electric snowmobile prototype was thought up by Prof. Peter Radziszewski before the first SAE CSC was even held. As *professeur régulier* in the Applied Science Department at the Université du Québec en Abitibi-Témiscamingue (1991-2000) (Department chair from 1992 to 1997) he worked to develop a full engineering program that caters to the needs of regional industry. It is after looking at some of these needs that the idea of an electric snowmobile prototype came about. The project never saw the light of day until Prof. Peter Radziszewski[2] became Professor of the *Mechanical Engineering Project Course* at McGill University and proposed two groups of three mechanical engineering undergraduate students to look into the possibility of designing and building such a prototype. While participation in the SAE CSC was then an option, such an endeavor was not directly compatible with the course. Two pairs of undergraduate electrical and computer engineering students also looked at the possibility of an electric snowmobile prototype for a period of 3 months (1 semester).

It soon became obvious that the only way this project would succeed at the undergraduate level was if it became an official undergraduate design team in which all students from McGill University could participate in as an extra curricular activity.

At the beginning of the 2003-2004 school year undergraduate student Simon Ouellette set out to organize, structure and manage an undergraduate design team to pursue this idea. All members would be undergraduate students. Given the composition of this team (mostly 1st and 2nd year students with no experience) strong emphasis was put on the learning process and continuity of the team and project.

Registration to SAE CSC 2004 was a hard decision given the general inexperience of the team and the lack of financial and material resources at the time. It was however decided that participation to the CSC 2004 was the key in order to help with continuity and inflow of resources. The decision turned out to be the right one especially when it comes to ressources. However, continuity between 2004 and 2005 has been a problem to the point where team founder Simon Ouellette, despite graduating and pursuing other projects, had to stay involved in the team to ensure some continuity and stability. Thus, much of this year's effort was put into student training and limited effort was put into snowmobile improvement.

GOALS - The goal of the project is to design and build a purely electric snowmobile. A secondary goal is to use this prototype to assess the possibilities of current electromechanical technology in this field.

After extensive research on the subject of electric snowmobiles, it was found that little to no data pertaining to electric snowmobiles was available. The very limited amount of data found was incomplete. After some phone calls to try and gather the missing data did not produce any results, the team took it upon itself to get the ball rolling and provide a valuable data bank and test platform for projects to come.

The team has committed itself to helping the community and promoting alternative modes of transportation. Not only are we trying to build an environmentally friendly vehicle, but we are also trying to educate the people and the community around us. Our mandate goes beyond the goals of the competition and our work extends into local high schools and CEGEPs (French acronym for “Center for General and Professionnal Education”.). Within these learning institutions we conduct conferences on environmental issues associated with transportation as well as expose the students to the possibilities of careers in science and engineering.

Last but not least, we want to help each member attain their maximum potential and give all members unique experience they can use throughout their careers by:

- Encouraging multi-discipline interaction between students from different Departments and Faculties within McGill University
- Giving students the opportunity to participate in all aspects of this one-of-a-kind technological project
- Enabling members to acquire hands-on experience in engineering and other domains such as marketing and management[3]

CONCEPT - There are many complaints about current production snowmobiles. According to some, these problems can only be solved by outright banning snowmobiles from public areas. However, a number of snowmobile related problems can be greatly reduced in magnitude, if not totally eliminated without the need to get rid of the snowmobiles themselves. In the Province of Quebec, three of the main sources of complaints about snowmobiles are related to their gasoline-burning engines:

- Noise
- Emissions
- Efficiency

The team decided to put performance of the prototype as a low priority and focus on the above problems. Performance of the snowmobile would only be addressed once these three parameters were optimized. This approach seems like the exact opposite of what the motor sport industry most often does, which is to design and test for performance and then try to optimize the above three criteria to be better accepted and incorporated into the general market.

It is the team’s belief that the selected approach is very valuable and can provide an extremely useful complement to the “standard” approach. We look forward to the possibility of collaborating with potential partners within the industry to facilitate incorporation of new low environmental impact technology into existing products.

The team's approach did not go unnoticed. Through a demand by the National Science Foundation (NSF), team founder, Simon Ouellette is currently working in collaboration with the NSF and its sub-contractor VECO Polar Ressources on the design of a zero-emission utility snow vehicle (the Mammoth Prototype) for use at the NSF's Summit Research Station in Greenland.

Design – Design wise, the key point of the Wendigo Prorotype is that it runs with an electric motor powered by batteries. Targeting the root of the problem, the internal-combustion engine, and replacing it with an electric motor eliminates a major source of noise, emissions and inefficiency from the system.

In terms of emissions, the direct emissions of the snowmobile should be practically nonexistent as the Wendigo Prototype uses sealed battery technology to provide electricity to our motor. However, it is important to realize that a snowmobile using an electric motor is not necessarily emission-less. The generation of the electricity is the key factor in determining the true amount of emissions (direct and indirect) related to snowmobile operation. In our case, the Wendigo prototype truly is responsible for almost no indirect emissions as 95% of the electricity used to recharge its batteries comes from hydroelectric plants[4].

We believe the main design decision, using an entirely electric drive system, to be the best possible compromise, given the current state of technology, in order to minimize noise and emissions and to optimize efficiency.

PROTOTYPE – The Wendigo Prototype (please visit the team website www.electricsnowmobile.mcgill.ca for more information on the origin of the name) is built on a Bombardier Ski-Doo 2001 S-Chassis Summit 500F snowmobile. This snowmobile was received without motor, clutch, exhaust, etc. The track, the steering, the suspension and the aluminum frame are the only parts remaining from the original snowmobile. Every attempt was made to maintain appearance and aesthetics of a commercial snowmobile. A strong emphasis was put into simplicity of the design to ensure ease of reproducibility and understanding. To add to the aesthetics, the (solid color) hood that came with the vehicle was replaced with a transparent polycarbonate hood graciously donated to the team by BR Tech Racing.

The 2004 prototype adorned a big and bulky seat which also served as a battery box. The 2005 battery pack design has been refined to the point where the big and bulky seat/box was unnecessary and could be removed. It has been replaced with a standard Ski-Doo snowmobile seat.

The battery pack is now a de-centralized system composed of 5 plastic boxes each housing 2 batteries. Three boxes are housed where the original gas tank used to be mounted while the other 2 are mounted on an aluminum rack, along with the controller, where the snowmobile's original internal combustion engine used to be mounted.

<u>Power source</u> - The power source (i.e. the battery pack) is the main factor limiting the performance of this snowmobile. It is evident that as the battery pack of the snowmobile increases in energy content, so do its volume and mass. The increase in mass of the pack tends to be a greater concern than the increase in volume. Since the weight of the snowmobile and rider compresses the snow on which it travels, the snowmobile often travels somewhat through rather than above the snow, the weight issue became a big concern for the prototype.

Typically, a snowmobile's power source (gasoline) takes up approximately 40 liters of space and weights 40kg [5]. However a large quantity of the energy contained in the gasoline is lost due to the inherent inefficiencies of the internal combustion engine and all other systems required to run a snowmobile.

The electrical alternative is very attractive on the basis of efficiency. Well chosen electric motors and controllers can have above 90% efficiency and coupling the electric motor directly to the track drive shaft can eliminate most "under the hood" drive train related inefficiencies. The batteries remain however the main weakness in terms of efficiency for an electric snowmobile. While they can be very efficient, the usual operating temperature of a snowmobile lowers the battery pack efficiency. It is possible to greatly diminish this effect with the use of a heating blanket, provided it is well managed. The amplitude of such an effect depends on the battery type.

Some of the main types of battery technologies available on the market are:

- Lead acid
- Nickel Cadmium (NiCad)
- Nickel Metal Hydride (NiMH)
- Lithium-Ion (Li-Ion)
- Lithium-Polymer (more realistically Li-Ion-Poly)

The table below gives approximate figures for total energy density (in Watt-hours per kilogram) and specific energy (in Watt-hours per liter) for each technology:

Table 1

	Wh/kg	Wh/l
Lead Acid (our pack)	31	85
NiCd	50	90
NiMH	70	150
Li-Ion	140	200
Li-Poly	120	143

(ref: 6, 7, 8, 9)

Cost increases as you make your way down Table 1. Ballpark figures of prices for a single 120V pack can range from the hundreds of dollars for a lead acid pack to anywhere between 10 000$ to 100 000$ for lithium technology. In between the two extremes, a nickel based packs pack can be purchased for a few thousand dollars.

The pack, which is currently installed in the Wendigo Prototype, is made of 10 Hawker Genesis EP 12V/26Ah lead acid batteries. Nine of these batteries are connected in series to power the motor and the tenth battery is used to run the 12V circuit.

The most convenient way to charge this pack is to have a 120V charger with a charging circuit between all 10 batteries. This option is in the process of being implemented. For now, each battery is individually charged with a 200W charger (5 chargers were purchased to minimize charging time). While this option is not very practical, it does have some benefits: it ensures that all connections and batteries are checked at regular intervals and it also ensures a well balanced pack after every charge; a key factor too often overlooked in electric vehicle applications.

We calculate 10 kW to be a typical power draw to run a snowmobile at 30mph. (NOTE: this will vary due to many factors such as vehicle mass, temperature, snow conditions, type of motor and controller, type of batteries, etc.). Looking at the numbers in the above table (Table 1) we can immediately see that a fully charged 100kg pack, even with the best possible technology, will not last much more than 1 hour at 30mph. However, note that here in Quebec, charging this pack would cost under 50 cents US[4].

We can conclude that a purely electric snowmobile prototype currently has limited potential in terms of range. However, there are a number of applications in which a range of less than 30 miles is more than acceptable. We believe there is a small but growing market for these extremely environmentally friendly machines. This growth is fueled by both environmental concerns and the constant improvement in battery technology, which is in turn currently pushed by the telecomunication market's need for higher density energy storage devices.

We believed early on that there existed a niche market for electric snowmobiles within the utility snowmobile market. The individuals and oranizations have contacted us to enquire about our prototype tend to confirm that this niche market exists.

Motor/controller/drive train – There exists a wide range of electric motors on the market. The motor in the Wendigo Prototype is an e-TORQ 14” DC Brushless Motor from Bodine Electric Corporation[10]. DC Brushless motors tend to mislead people since while their common name implies the use of DC current; these motors actually run on 3-phase reconstructed AC current. Their performance curves (data included in appendix) have the same shape as DC commutated motors, however their efficiencies are much higher since there is no friction due to brushes. Hall effect sensors are used to monitor the position of the rotor at all times in order to synchronize the stator currents. This means that the only mechanical parts in the motor are the bearings. This construction is extremely reliable and requires no regular maintenance while at the same time providing high efficiency and reliability. These are definitely a combination of characteristics well suited for an electric snowmobile application.

The e-TORQ’s continuous rating is 8HP at 96V and its maximum power output is approximately 40HP. However, it must be noted that efficiency in an electric motor drops as current input increases. Also, current input is roughly linearly proportional to torque output. Running the motor at maximum power would require an extremely large current drain or a very high voltage battery pack. Because of this, maximum power output of an electric motor in a snowmobile should not be regarded as a key factor in the development of an electric snowmobile prototype. It is very easy to find motors with high power outputs, but as it was explained previously, the energy available in the battery pack will be the limiting factor. Adding to this the cost and mass of a more robust electronic system to accommodate the high power input to the motor makes the choice of an overly powerful motor an unwise decision. The key in motor selection is to hit the “sweet spot”, i.e. find the motor with the best efficiency in the most often used power output range. Our e-TORQ has the right sweet spot for this application with an efficiency coefficient superior to 90% over the range of what we consider to be “normal use” in a snowmobile. Our e-TORQ even has 95% efficiency in the middle of this “normal use” range.

The cost of such a motor is higher than the cost of a DC commutated motor and Bodine Electric Company graciously donated ours. In order to reach the full potential of the motor, it must be coupled with a sophisticated controller. Our current Wendigo prototype uses an NGM EV-C200 controller[11]. The current cost of such a controller is high due to the low volume of demand. However, an increase in production would reduce the costs by an order of magnitude.

This controller can accomplish many functions, but its main task is to convert the DC current from the batteries into the 3-phase reconstructed AC needed to run the motor. The NGM EV-C200 is fully programmable. This feature makes it possible to fine-tune it to obtain maximum efficiency for our application. As our performance database grows, this characteristic of the controller will have a strong impact on the overall efficiency of our system.

The controller is interfaced with the driver via a spring loaded potentiometer. The driver can control the potentiometer's resistance via the snowmobile's original thumb throttle which is attached via cable to the rotary potentiometer's spring loaded swing arm. Controller current output is roughly linearly proportional to potentiometer resistance.

The potentiometer is located under the hood at the front of the snowmobile in the Wendigo Prototype's electrical box. The box contains all the systems which make the synchronization between the motor and controller possible. It also houses the controller's pre-charge circuit and all the fuses and breakers required to ensure safe and sound operation of the snowmobile.

The NGM EV-C200 is capable of regenerative braking. However we have not implemented this possibility in this prototype. Regenerative braking is something the team hopes to look at in the future. We do not expect regenerative braking to have significant positive impact on the snowmobile's range but we would nonetheless like to try it for research purposes.

In the 2005 Wendigo Prototype, the motor is mounted in the place of the snowmobile's original CVT clutch and is coupled directly to the snowmobile's original countershaft. The snowmobile's original brake and chaincase systems which had been removed in the 2004 prototype have been re-installed in the 2005 prototype.

Data – The team has recently been donated a V6 Professional Data Acquisition System from Isaac Instruments. The team is currently designing and fabricating the sensors required by the Isaac system and also familiarizing itself with the use of the system. Data from the Isaac system can be downloaded to a computer for storage and analysis. It can also be viewed in real time by the snowmoblie driver on a PALM handheld portable organizer which is mounted on the snowmobile's hood.

RESULTS – The 2005 Wendigo prototype has been up and running for just a few days at the time this paper is being written, thus results are very limited. Only one instrumented test run has been achieved in time for this paper. Sound tests have yet to be performed.

Sound – While no direct measurement of sound has been made so far, a comparison between the sound of the snowmobile running normally on snow and the snowmobile running with its track off the ground indoors is sufficient for the human ear to notice that the dominant noise is that of the track when it is being driven on the snow.

When driven on snow, close bystanders can notice 2 very distinct sounds. The diminant one is the “clapping” track noise. This is accompained by the steady humming of the e-TORQ motor which most bystanders so far have compared to the characteristic sound often used on television and in movies when futuristic “flying hover vehicles” are heard.

The motor can also emit 2 other characteristic sounds. On start up, the e-TORQ has a singular “squeeking” sound which lasts no more than 2 seconds. The motor also produces a “knocking” sound when increasing current is applied to it while its shaft is maintained in a stalled position.

Performances – In the 1st and only instrumented test achieved so far, the snowmobile was driven non-stop at a constant motor output shaft speed between 1000 and 1100 RPM in 6-7 inches of new snow on a closed loop. The temperature was 14 Farenheight.

The test lasted 25 minutes and the batteries were depleted down to 65-70% depth of discharge (DOD) at the end of the test run.

Nominal battery voltage to the controller was 96V.

The ratio between the motor shaft and the track shaft was a 0.545 step down ratio. Thus we estimate the speed of the snowmobile was 12-13MPH.

Power consumption on the flat section of the loop remained constant for the whole test at just under 4000W.

A portion, of the loop has a moderate incline. Speed in this section remained constant but current drain increased on the uphill and decreased on the downhill.

CHALLENGES - In an industrial context, the engineering design challenges faced in making a safe and reliable electric snowmobile are very manageable. However, given the current state of technology, performance cannot be on par with gasoline-powered snowmobile. Many of the technological challenges of an electric drive system have been covered in the prototype section as the main items on the snowmobile were presented. The following section will cover more the challenges particular to our specific endeavor than those of electric snowmobiles in general.

It was fortunate that McGill University also produces a solar car since there are many similarities between the technology used in the iSun solar car[12] and the Wendigo prototype. The knowledge gained through the experience of the solar car team did not solve all potential problems of the electric drive system of the Wendigo prototype but it did give a good starting point to attack some of the challenges which were faced along the way.

On the electrical side of things, motor and controller compatibility was a key issue as most of these often come as pairs which are made to work with one another. However, in our case, the e-TORQ motor and NGM controller we are using are not made to be connected directly together. As we discovered, having these two pieces of equipment, which are the heart of the snowmobile, running in synchronous fashion is a daunting task.

On the mechanical side of things, the main challenges came from mounting all the components of the electric snowmobile on a frame which was obviously not designed to receive these components.

CONCLUSION

Current battery technology cannot provide performance on par with gasoline-powered snowmobiles. However, the rapid progress in battery technology in recent years combined with new legislation makes it such that electric snowmobile alternatives do have a potential for small niche markets in the short-term.

While not capable of performances similar to current production snowmobiles, electric snowmobiles do greatly diminish some of the main negative effects of gasoline-powered snowmobiles.

Any application requiring a very low or no emission snow vehicle for use in sensitive areas should consider the use of an electric snowmobile.

The electric snowmobile project, which is the subject of this paper, is an ongoing project and we hope to be able to provide more data as the project progresses. The McGill Electric snowmobile Team is always on the lookout for people and organizations who would like to join their efforts with those of the team in order to further advance knowledge and technology pertaining to electric snowmobiles.

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APPENDIX