Design and Construction of an affordable Zero-Emissions Snowmobile

Michael Golub, Mark Nelson, Peter Morris, Malcolm Deighton, Matthew Van Atta, Lisa Stowell
University Alaska Fairbanks (UAF)

ABSTRACT

Figure 1: Malcom Deighton drives the Nanook EV on the UAF Campus (Photo by Jesse Hoff).

The University of Alaska Fairbanks Nanook EV team has built an electric snowmobile to enter in the 2009 Clean Snowmobile Challenge, as well as to become a model for the practicality and performance that an electric sled can offer, and to show that electric vehicles can be a viable option for certain applications. To accomplish this, we adopted a "better, faster, cheaper" design philosophy. Our goal was to produce a system that had impressive performance, wile still being able to be affordable and easily obtainable by the general public. Being a first year team, we have the opportunity to start the design from scratch, letting us do minimal modifications to the original chassis, maintaining a clean, flexible, and aesthetically pleasing design.

INTRODUCTION

Energy is a precious commodity in rural Alaska. All fuel must be shipped to Alaska villages in the summer when the rivers and other shipping lanes are ice free, and these shipments must last through the winter. Needless to say, energy use is not something that is taken lightly. The Nanook EV team has been working on finding transportation solutions for rural Alaska that can help reduce their energy consumption wile still being able to maintain their way of life. Electric vehicles have been a very promising solution when paired with locally generated renewable power. We envision clean, efficient electric vehicles used for primary transportation powered by renewable energy such as geothermal, wind and hydropower, resources that are abundant in rural Alaska, but are currently under-utilized.

Snowmobiles are an indispensable means of winter transportation in rural Alaska. Wile snowmobiles are a primarily used for recreation in the rest of the country, here they are an important tool that makes life in villages that are off the road system possible. This makes them an ideal candidate of electric conversion. Our team has extensive experience in converting traditional vehicles to run on electric power. We have converted everything from cars, to lawn-mowers. However, converting a snowmobile electric power has proven to be the most challenging yet.

DESIGN STRATEGY

Our main design strategy was to convert the snowmobile to electric power using available and affordable parts.

We wanted the parts to be low cost and yet durable. Another emphasis was to use “off the shelf” components that were common to electric forklifts and electric vehicle enthusiasts. This not only would keep our Manufactures Suggested Retail Price (MSRP) low, but allow repeatability in that we could pre-fabricate a kit that other people could use in order to enjoy the use of an electric snowmobile. Although the use of electric sleds for research purposes has been emphasized in past competitions we have designed a sled that the general public could use. These uses could include transportation to work in rural areas, checking trap-lines, and grooming ski and dog sled trails.

RANGE

When designing the Nanook EV One, our main focus was excellent range capability. In order for a vehicle to be practical it must be able to transport people and cargo over a usable range. There were many design decisions made in order to reach this goal.

ENERGY STORAGE - To attain sufficient range the component of main importance is energy storage. We selected Lithium Iron Phosphate batteries. These batteries are the least expensive Lithium battery available. They are heavier, have less energy density and power output than Lithium Cobalt, but they are inherently safer because of their lower Lithium content. The recent emphasis on designing a safer electric snowmobile has convinced the design team that the only acceptable batteries are Lithium Iron. We are using 30 Thunder Sky Lithium batteries. These batteries have a 3.3 nominal voltage making our total pack size 99 volts.

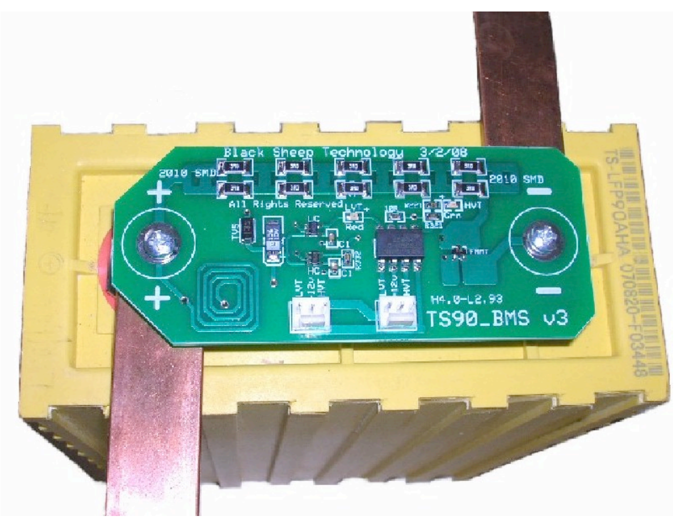


Figure 2: Battery Management System (BMS) mounted on top of Thunder Sky’s Lithium Iron Battery. (Photo by Ronald Anderson).

We are protecting our batteries using a Battery Management System (BMS) made by Black Sheep Technology. These BMS boards output high voltage and low voltage warnings as well as protecting the battery from overcharging at 4 volts. The use of the BMS will provide a durable battery system that can do 3,000 cycles while only contributing a 22% increase in cost of each battery.

We were able to confirm the batteries to exhibit a low internal resistance during loading. Resistance values per battery are in the 0.001 to 0.007 Ohm range. Having a low internal resistance allows the snowmobile motor to draw more power. This is a huge improvement when compared to lead acid batteries. You also get increased charger efficiency because less energy is wasted in heat.

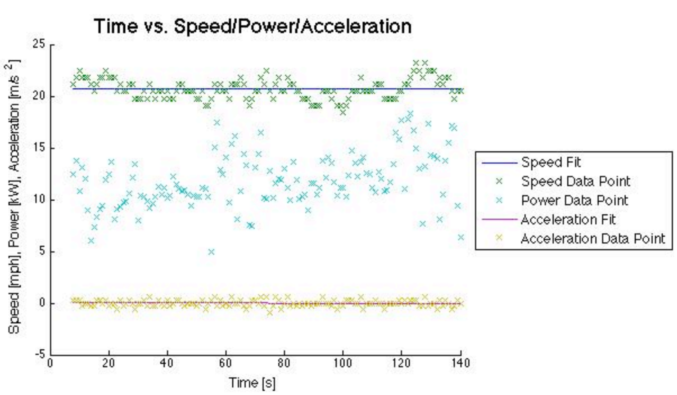
ENERGY STORAGE CONTAINERS - In order to safely house all the batteries necessary to meet our range goal we designed and fabricated a robust energy storage containment system. The containers are constructed of 1/8” thickness aluminum. In order to provide insulation the internal surfaces are coated with spray in bedliner. There is also a layer of Nomex for increased protection from fire. The boxes are mounted directly to the upper surface of the tunnel. This placement necessitated deletion of the seat and significant alteration of the gas tank. By modifying the gas tank but not removing it we were able to retain the structural components integrated into the tank. The energy storage containers now perform dual purposes, to house the batteries and act as the frame for the seat. The seat consists of two inches of foam covered in weather resistant Naugahyde. Two inches of foam increase rider comfort compared to the one inch required for competition. As with all the other components added, the location and construction of the energy storage containers contribute to the reproducibility and practicality of design.

DRIVETRAIN - Another way we increased the range of our design was by increasing the drive train efficiency. The original CVT in the machine was designed to keep the internal combustion engine operating at its optimal range. This however, is not an issue with an electric motor as a power source. Our design utilizes a standard industrial V-belt system for increased efficiency over the stock CVT. By using a conventional V-belt we were also able to stay true to our low cost, easily reproducible design strategy. Using tables provided in the Martin Sprocket and Gear catalog [1], the minimum pulley diameter and belt type were chosen. The BX type belt was chosen due to its performance at higher rpm service, which could be reached at the vehicle’s top speed. This belt is capable of safely handling only half of the total motor output horsepower, so our application uses two belts. The ratio of the sheaves allow for 2000 rpm at the motor while traveling at 20 mph. This ratio allows for efficiency at cruising speeds while still allowing for a higher top speed.

MOTOR MOUNT - One obvious component deletion was the internal combustion engine. This deletion created a major design challenge: to develop an electric motor integration system. To maintain drivetrain efficiency we designed a mounting system for the motor that integrates belt tensioning. The system design does not require the use of a tensioner or idler pulley, which increases both efficiency and belt life. It is very similar to an automotive alternator V-belt tensioning apparatus. The motor pivots about an axis to lengthen or shorten the distance between the two pulleys. The mount is constructed from 6061-T6 aluminum for long term durability as well as for its availability which is important to practicality and reproducibility.

ENERGY EFFICIENCY - To evaluate the efficiency of the Nanook EV 1 we chose to do a comparison analysis with a standard production snowmobile. Assuming the best mileage a production IC snowmobile gets is 20 mpg, driving 20 miles uses about 125,000 Btu of fossil fuel. Which translates to 125,000 Btu / 20 miles = 6,250 Btu of fossil fuels per mile. Our snowmobile achieved 0.8 kWh per mile. Converting to Btu 0.8 kWh/mile * 2413 Btu/kWh = 1,930 Btu of electricity per mile. Depending on how the electricity is generated will give us a Btu comparison value, unless the sled can be recharges using alternative energy such as wind or solar power. The worst example would be a coal fired power plant with an efficiency of 33%, the fossil fuel input is 3 times the electricity output, i.e. 3*1,930 Btu/mile = 5,790 Btu of fossil fuels per mile. This number still shows the electric snowmachine is more efficient than a production gasoline sled. The large discrepancy in energy density from a gasoline powered sled to an electric sled is demonstrated by these numbers.

RANGE TEST - We drove the snowmobile on a 0.83 mile track for the range test. The sled was driven at a constant speed of 20 mph. You can see in Figure {3} that the speed and acceleration were fairly constant. 0.48 kWh were used for this test. Starting with 0.48 kWh x (3600 s/1 hr) = 1,728kJ. Power is equal to Energy/time which results in 1728kJ/135s = 13kW. We can then forecast our range. We have a 99 volt, 90 amp hr pack;



which gives an 8.91 kWh pack. Converting Figure 3: plot of acceleration, power, and velocity vs. time.

0.48kWh/0.83mile = 0.578 kW/mile. Then 8.91kW/0.578kW results in a 15.4 mile range. This exceeds the old 10 mile standard which is still listed as a design criterion in the competition rules.

DRAWBAR PULL

The drawbar pull is an interesting event in that many of the qualities that lead to success can be detrimental to performance in other events. Chief among these qualities is weight. A heavy snowmobile will be able to get a lot of traction, thereby being able to pull more. On the other hand, that weight does a lot of harm in the events like the range and acceleration tests.

Judging from real-world experience, it was apparent that the limiting factor in the event would not be power, but traction. In order to help improve traction, we placed the batteries, the heaviest component of the snowmobile, directly over the track. This would dramatically improve traction without overly affecting handling. In order to test the snowmobile's performance in the drawbar pull, we attached the back end of the snowmobile to back end of a truck with a tow strap and force meter Figure {XX}. The truck was put into neutral, and the snowmobile began pulling it at 4 miles per hour. Once this speed was reached, the brakes on the truck were slowly applied to progressively increase the resistance the snowmobile was pulling against, until traction was lost. The highest measured force was recorded. The force meter used was simply a piece of 1 inch by 0.25 inch aluminum with a strain gauge attached.

During testing we recorded a maximum force pulled against of 280 pounds. At this point the track lost traction and began to spin out. The consistency of the snow at the test site was a loosely packed, dry powder. Loss of power was not a limiting factor during the test. Maximum pulling force can easily be improved with a different snow consistency.

ACCELERATION

The acceleration event is very challenging for the zero emissions category. The high power demands of the event require high electrical currents being fed to the motor (upwards of 400 amps), and the large forces involved push the mechanical components to their limit. As with the drawbar pull event, traction is a major concern, though not as critical.

The most important aspect of preparation for this event is adequate motor sizing. If too small of a motor is used, then the snowmobile will not be able to meet the minimum performance criteria. If too large of a motor is used, the snowmobile may do well in the acceleration event, but the excessive loads that it places on the electrical system will hurt its performance in the distance event and harm its long-term durability. We believe the motor we selected is the perfect size to provide both versatility and performance.

For testing the snowmobile's acceleration performance, we simply did a timed drag. 500 feet were measured out in a straight line over which to do the test. Speed, time, and distance where all recorded using a Garmin Legend HCx GPS. Two test runs were made.

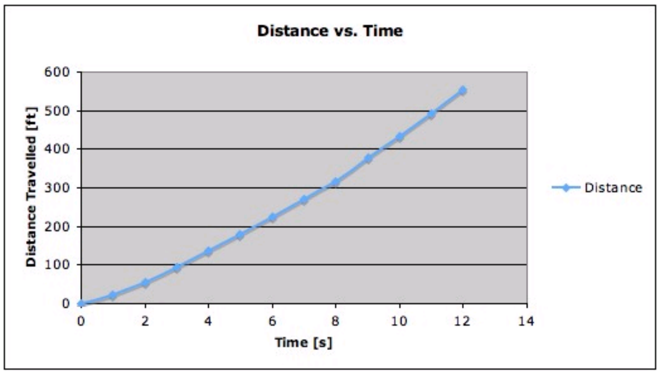


Figure 4: Plot of distance traveled vs. time for acceleration test.

During the test, we were able to cover the 500 foot course in 11.2 seconds. We are confident that we will be able to complete the competition course in less than 12 seconds which will give 50 points for meeting minimum requirements. During the test, both voltage and current levels remained within levels that can be safely handled by the motor.

NOISE

The overall sound output of the machine was found to be quite minimal. In fact, to reach the maximum sound level allowed for the competition of 78dBA it was necessary to conduct the sound measurement at one meter distance from the sled. To address subjective sound quality, the ducting for the external cooling fan contains sound dampening fiberglass insulation to reduce noise. The ducting and fan are easily obtainable items which remain true to our low cost, easily reproducible design strategy.

SUBJECTIVE HANDLING

With our goal of designing a sled for general recreational use much importance was placed on the snowmobile's handling. To this end we had an experienced rider put the Nanook EV 1 through its paces. The rider judged cornering, ride, braking, powertrain response, balance, and overall handling

CORNERING **-** The snowmobile's cornering ability is not reduced in any measureable manner. The wide 43 inch ski stance and aftermarket Kimpex Arrow dual carbide skis work well to provide a stable and responsive platform. In conjunction with Fox Zero Sno Pro shocks and stock sway bar the machine has very a predictable response to cornering, showing very little tendency to rolling when cornering at speed in trail conditions. Even novice riders have felt very comfortable when performing tight turns on hard pack.

RIDE - The 2004 Arctic Cat F7 base model came with Arctic Cat Gas (IFP) Shocks with adjustable preload springs front and rear. Our machine was purchased with upgraded Fox Zero Sno Pro shocks with stiffer springs in the front and rear. This upgrade helps to diminish the effects of the added weight associated with the batteries. The machine soaks up bumps over a variety of terrains extremely well, producing a smooth and consistently comfortable ride with little rider fatigue. Although the conversion was designed primary for trail use, the machine retains much of its off-trail riding ability. Despite its additional weight, the machine carves, climbs, and side hills extremely well.

POWERTRAIN RESPONSE - The sled responds instantly to throttle input, a benefit associated with electric motors. Increases in speed can be made smoothly and quickly without the hesitation or 'jerking' often attributed to CVT clutches found in a traditional snowmachine. The sled is geared primarily for range by running the motor at its optimum rpm while turning the track at a speed of 20 MPH. As a result it can't pull the skis off the ground during rapid accelerations, but it does have enough torque to start and maneuver through relatively deep powder.

BRAKING - The machine still employs the stock hydraulic disk brake system. Arctic Cat uses Willwood master cylinders and calipers. Since these brakes where engineered to slow the original 480 lbs. sled from speeds in excess of 100 mph they exhibit excellent performance while slowing the additional weight from much lower speeds. In preliminary acceleration tests where quick emergency style braking was required, the brakes showed little or no sign of fade. The stock rotor, which is drilled to aid in cooling, never showed signs of excessive heat build up.

BALANCE - The snowmobile is well-balanced front to back and side to side. Since the engine and clutches that were removed were spatially replaced with a motor that weighs approximately the same, the weight over the front skis is near the stock values. The weight on the track, originally from the 75 lbs. of fuel, has been replaced by approximately 210 lbs. of batteries. With this additional 135 lbs. only setting adjustments to the overload springs and the rear coil are required to maintain a stock level of performance. The only balance that is significantly affected is the center of gravity which is slightly elevated over the track. This is due to the weight associated with the rear battery box. This only affects the sleds performance when laying it on its side during carving maneuvers.

OVERALL HANDLING - The snowmobile exhibits a high overall level of comfort and performance. Using risers, the mountain style handlebars are elevated to accommodate a more aggressive rider-forward stance. Additionally the seat is elevated to simulate popular high rise aftermarket seats, decreasing the angle in the rider's knee reducing joint and leg fatigue. The gauges are located in the stock locations which still permit easy visual access. The original cable style throttle block is removed in favor of a resistor trigger which is more comfortable, reducing wrist and thumb fatigue which is common on traditional snowmobiles. While the power was reduced and the weight was increased, the sled is still enjoyable to ride. It is by no means bulky or sluggish as many would envision an electric snowmobile. Aesthetically it still retains its performance oriented styling and stance. Although some snowmachines are used in commercial or research applications the majority of the market is driven by recreation minded consumers. With this in mind we feel it is important that our final result still retain its original ability to provide recreation, which the Nanook EV One surely does.

WEIGHT

The published dry weight for the original sled is 480 lbs. Filling all the fluids adds conservatively 80 lbs. bringing the total to 560 lbs. The Nanook EV 1 tips the scales at 633 lbs. The net weight increase is limited to 70 lbs. This small weigh increase will allow our sled to be competitive in not only the weight category but many of the other events as well.

CONCLUSION

Having completed preliminary testing of the Nanook EV1 we feel that we have stayed true to our design goals. We produced a zero emissions snowmobile capable of excelling in the areas of range, acceleration, pulling power, noise, handling, and weight that has a broad range of uses outside the scientific research market. The Nanook EV1 is a low cost, durable, easily reproducible snowmobile with a vast array of uses.

ACKNOWLEDGMENTS

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REFERENCES

1. Martin Sprocket and Gear Catalog 60.

CONTACT

Michael Golub, fourak@gmail.com, 907-347-4363

DEFINITIONS, ACRONYMS, ABBREVIATIONS

Snowmachine: Alaskan term for snowmobile

Sled: Snowmobile.