UAF Nanook EV5

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ABSTRACT

The UAF Nanook EV team has been building electric vehicles for 8 years. Conversions include a shuttle bus, golf cart, multiple cars and snowmobiles, and Nanook EV5. EV5 is based on the 2009 BRP renegade chassis and built specifically to meet NSF's requirements of a clean, quiet, lightweight electric snowmobile capable of operating in the harshest temperatures for at least 10 miles on a charge.

INTRODUCTION

The National Science Foundation (NSF) supports research in Polar Regions, which are extremely sensitive areas that are highly impacted by pollution. In 2005 the Clean Snowmobile challenge added the additional category: "Zero-Emissions" in order to promote the use of vehicles which would not contaminate the fragile environments in these regions [1]. Also, it was important to avoid contaminating samples taken from these areas, as engine fumes could adversely affect the samples. Our team was also motivated to design an affordable electric snowmobile due to local high energy costs in Alaska. Gasoline is a precious commodity in rural villages across the state, many of which are not connected to a road system. The price of a gallon of gasoline can be in the $ 10 range. Fuel is shipped to Alaskan villages in the summer by barge when the rivers and other shipping lanes are ice free. In some areas, fuel needs to be flown in, increasing the price even more [2]. The Nanook EV team has focused on finding transportation solutions for rural Alaska that can help reduce villagers' energy consumption, but still maintain their way of life. Electric vehicles have been a very promising solution when paired with locally generated renewable power. The team envisions clean, efficient electric vehicles used as primary local transportation, powered by renewable energy such as geothermal, wind and hydropower. These resources are abundant in rural Alaska but are currently under-utilized. Our snowmobile is designed for the most practicality and performance that an electric sled can offer. At the same time, we strove to demonstrate that electric vehicles can be a viable option for certain applications. To accomplish this, an "innovative, quicker, inexpensive" design philosophy was adopted. The goal was to produce a system that had impressive performance, while still being affordable and easily accessible to the general public. This is this group's fourth year in this competition, and we offer an improved vehicle that is light and comfortable for the rider, along with additional modifications to the original chassis, all while maintaining a clean, flexible, and aesthetically pleasing design. Snowmobiles are an indispensable means of winter transportation in rural Alaska. While these machines are primarily used for recreation in the rest of the country, here they are an important tool that makes life in remote villages possible. Snowmobiles are therefore an ideal candidate for electric conversion. The Nanook EV team has extensive experience in converting traditional vehicles to run on electric power. Members of the team have converted everything from cars and trucks to ATVs and lawn mowers [3].

DESIGN STRATEGY

The main design strategy was to convert the snowmobile to be most successful at the competition. This year's competition scoring is more in line with National Science Foundation (NSF) contractor desires. Currently, over 57% of the events relate directly to their needs to support arctic research. Restriction of the accumulator size is a good competition limitation; it prevents teams with more money from competing with massive battery packs. To this end, we have kept this design parameter in mind. 8 kW·h size has been successful in doing 14 mi runs in Greenland, and UWM did a successful 20 mi run in 2011.

For the acceleration event our team needed a high power density battery, which would also benefit our machine on the objective handling track. We were unsuccessful in obtaining any cutting-edge batteries that boasted mass energy density greater than 142 W·h/kg. These include many lithium-ion based batteries using elements like sodium and silicon. What we settled on was an inexpensive pack of lithium cobalt ($LiCoO_2$), which fit in nicely with our light-weight chassis. This keeps our overall cost low for our final Manufacturer's Suggested Retail Price (MSRP).

Figure 1: 2014 Ski-Doo Renegade in stock form

Our primary goal for this year was to improve our Battery management System (BMS). The parts needed to be low cost yet durable. Emphasis was added on using the best and least expensive parts to make our motor controller, BMS and other key components. This not only kept the MSRP low, but allows repeatability and ease for a pre-fabricated kit to be manufactured, so other users could enjoy and benefit from the use of an electric snowmobile. Although electric sleds have been emphasized in past competitions as tools for research purposes, our sled would also be ideal for the general public. Uses could include transportation to work in rural areas, checking trap-lines, subsistence hunting and fishing, and grooming ski and dog sled trails. We wanted a snowmobile that riders would want to use. Consumers are mostly interested in cost and range, and we feel we have achieved a snowmobile that meets those criteria.

INNOVATION

Innovation was a key design concept as the team improved upon the first electric snowmobile on the Ski-Doo RevXP Chassis. We designed and built several major innovations:

1. Tubular style chassis caused unique challenges because of its tight pyramidal frame. Working without a tub makes finding space for items more difficult. However we designed it so any part of the machine can be easily removed and replaced. Some examples of these include the BMS master unit and the 12V auxiliary box. Either (or both) of these can be removed in less than 1 minute using only a 10mm nut driver. The traction pack itself can also be removed as a single unit, without disconnecting fusing or sensors.
2. The team developed a robust BMS based on Linear Technologies LTC6803-4 battery management IC. This innovation consisted of PCB design and the programming for a user display that contains battery information, power usage and speed.
3. Not content with current DC motor controllers the team utilized the Open ReVolt plans to come up with a reliable and safe unit.
4. We can charge the 12V auxiliary battery through the 12V accessory port, eliminating a separate 12 V charging jack.

BATTERY MANAGEMENT SYSTEM - We designed and fabricated our own version of a battery management system. There are many systems commercially available, but none of them offered the compact size, affordable price, or flexibility that our design criteria demanded. Some available BMS systems and their price per cell are shown in the figure.

Our design goals were a compact surface mount design capable of monitoring and balancing 12 cells on a single PCB board. We based our system around a Linear Technologies LTC6803 battery management IC. This IC incorporates a 12-bit delta sigma analog to digital converter with 12-channel multiplexer. Using this IC, the system is able to measure all cells on a 12-cell board in 13mS. This is then stored in registers in the IC to be read by the BMS master unit. The 12-cell “slave” boards communicate with the master unit using an isolated differential SPI bus for noise immunity as well as keeping the high-voltage electronics isolated from the 12V systems and display.

Figure 2: Team-built Battery Monitoring board based on LTC6803 chip

Presently, the BMS monitors cell voltage, pack current, pack temperature, and vehicle speed. It uses this information to display total pack voltage on screen, along with highest and lowest cell voltage (and their cell numbers.) It also tracks and displays total current in and out of the pack, and uses this to display pack state of charge (SOC). Additionally, the BMS displays instantaneous power being supplied by the battery, as well as instantaneous energy use per distance (in units of [W·h]/mile). In addition to monitoring pack condition and displaying relevant information, the BMS is also able to control basic vehicle functions. During charging, individual cell voltage is monitored, and throttles the charger back to a trickle charge state so that cells can top balance. The BMS cell boards are capable of balancing at 840 mA (programmable) per cell. When all cells have reached the balancing phase, the charger is shut down completely.

Figure 3: BMS system utilities screen allows accessing and changing many parameters

In additions to the balancing slave boards, the system includes a parallel cell monitoring system. These boards sit in between each parallel cell connection with a 3A fuse inline. The fuses are connected in 2 banks of 6 cells to a set of bi-directional-input opto couplers. This allows us to monitor fuse status of the boards. If a cell was to fail and cause increased current in the parallel circuit, it would cause a fuse to blow. When this fuse blows, the system is notified and the BMS master registers a critical fault and power shutdown. These “Fuse Boards” communicate with the master unit using a unique variation on TWI (two wire interface). The standard TWI output from the onboard microcontroller is transformed into a dual differential signal (One for SCL, One for SDA) and then using a differential CAN transceiver, the signal is transmitted over 2 wires to the master. This yields a higher voltage signal with very nigh noise immunity and capable of parallel connections to each fuse board. All 25 fuse boards are daisy chain connected using 6 conductor flat ribbon cable. This provides the power and data connections to each fuse board.

Figure 4: Fully isolated fuse monitoring solution detects possible open fuses and measures temperature of every cell in the pack

During discharge (while the machine is in use) the BMS monitors cell voltage and watches for a low voltage condition on any cell. When the first cell reaches a low voltage condition, the BMS will throttle the controller back. This alerts the driver that the pack is almost empty and needs to return to a charging station immediately, allowing the vehicle to be driven to a safe location in “limp”-mode. However, if any battery cell goes under a pre-set "absolute minimum" voltage, the controller is shut down completely in order to keep from damaging the battery by over-discharging it. In daily use the battery should never be discharged to absolute minimum, but if it does happen, the BMS will ensure that catastrophic damage does not occur. Additionally, this same shut-down procedure is enacted if pack temperature ever goes over a set max temp, such as if the battery were being worked too hard for too long. Because the shutdown procedure consists of opening the main contactors, this will also prevent the pack from overheating in the event of a short circuit or overcharging situation.

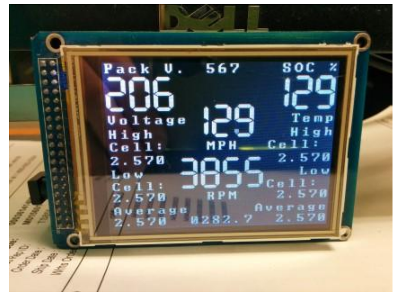

Figure 5: Main screen shows important machine parameters while in operation

MOTOR CONTROLLER - The open source motor controller is the heart of the machine. Without a proper controller, the snow machine would have poor performance and render the machine impractical. The choice of going with the open source motor controller was made for cost and the ability to redesign and modify the controller as required. The open source motor controller project, known as the ReVolt controller [A], got its start in electric car conversions. It was designed to be a low-cost high-performance alternative to existing expensive “dumb” controllers. Most DC motor controllers available in the $ 1 500 category are just very simple analog switching circuits that would take a throttle signal and create a torque command proportionally to drive the traction motor. Torque control was chosen because this is the form of control that a normal combustion engine uses.

Some of the flaws of these controllers are their switching frequency. At high temperature or low duty cycles (small amounts of throttle) the controllers would drop from a switching frequency of 15 kHz to 1 kHz. This would create less heat in power stages due to the smaller amount of transitions of the switching devices per second. The downside to this “feature” is it causes an audible wine in the motor when in this mode. While some people like this to make the vehicle more noticeable to pedestrians, one of the coolest things of an electric vehicle is it can move with almost zero noise. For this reason, the ReVolt controller was design to run at 16 khz. However, when tested with the IGBT’s that we purchased, we found that 8 kHz was a more efficient switching frequency, and is still inaudible. The Revolt controller never changes out of this switching frequency, but instead limits power output if the controller in 8 steps starting at 75 ºC and full shutdown at 95 ºC. As the controller cools down, output will be restored using the same 8 steps but inverted.

The Revolt controller possesses microprocessor control, communication port and extensive safety features. The Atmega168 microprocessor chosen was based on cost, performance, and programming simplicity. This is one of the many AVR based microprocessors. It was set up to run at 16 MHz allowing the 15.625 kHz Pulse Width Modulated (PWM) output frequency as well as 16 kHz interrupt clock running inside the chip to keep functions happening at specific, time sensitive intervals. The communication port is a standard RS-232 protocol running at 19200 baud 8,N,1 allowing devices that supports the RS-232 protocol to talk to the controller. The software runs with a real time data stream that outputs all the values the controller is reading from external sensors and it is internally generated at a user defined interval from 1 ms to 9999 s intervals. Also, all the throttle adjustment and trip point settings, and current limit settings are available through this interface.

Because of the processing power extensive safety features were developed. A major feature is the ability to check multiple inputs for out of range and strange anomalies. In such a case the power stage would be shut down so nothing bad could happen. These inputs include throttle value checking, current sensor value checking and under voltage lockout protection. If any of these values output out of range, the controller will fault and shut down. The current sensor being the most important sensor in the controller, it is treated with more diligence. When the controller is powered up, there is a small delay for the output of the current sensor to stabilize, and then a reading is taken. Since the sensor is designed to output 2.5 V at 0 A, if this first reading is outside this range, the controller will fault immediately. Without a working current sensor, there is no way for the controller to regulate power from the batteries to the motor, thus making the vehicle unsafe to operate. Since the controller is a torque controlled, and torque is proportional to the amount of current being fed into the motor, without a way to measure current, there is no way to control torque. If the current sensor breaks during operation or becomes disconnected, the software will sense this and shut down the output.

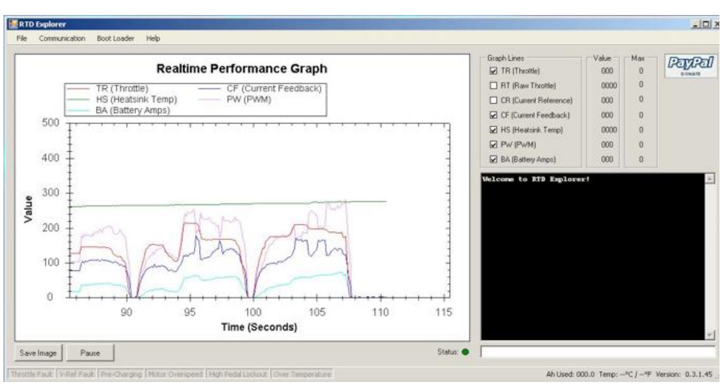

Figure 6: RTD Explorer allows viewing real time data of the snowmachine, while parked or in operation

We improved the motor controller's logic board. We built a controller that was on the leading edge of innovation using some of the highest quality parts while still being cost conscious. To achieve our goals we decided to go with a film capacitor and bus plate power stage using half bridge Insulated Gate Bipolar Transistor (IGBT) switching devices. This would allow us to keep the form factor relatively small while achieving incredibly high performance. Our design requirements include the ability to withstand a nominal battery pack voltage of 201 V and achieve a sustained 600 A motor current while being able to handle acceleration loads of 1 000 A. To accomplish this, we decided to go with an SB Electronics Power Ring film capacitor. This capacitor features an extremely high handling ripple current. The film feature uses no electrolytic which is prone to drying out. The capacitor has eight terminals per pole allowing very low inductance and series resistance. This is very important in motor controller designs to reduce inefficiencies. By using this capacitor, we have the ability to use a design technique known as laminated bus design. This consists of a plate of copper sandwiched with a layer of insulating substrate. This again leads to a super low inductance design as the two power planes are as close to each other as physically possible. Three IGBT modules are placed right to the side of the capacitor. The plates connect to the terminals of the modules and the capacitor with copper spacer washers and brass screws. Some of the holes in the plates are oversized to allow them to fit around things like terminals or washers and allow isolation while others contact thermals directly. This allows all the connections to be made without bending the plates out of shape. The only external connections that need to be made would be the two battery connections and the two motor connections.

The IGBT modules are controlled by a custom designed Powerex VLA-501 12A driver module. The dual voltage output of the driver module is specific to IGBT modules. To turn an IGBT off quickly, you must use a negative voltage. The VLA-501 switches the gate of the module from -8.2 V at off to an on of 15.8 V. This allows for strong gate signals and high noise immunity. This module features full isolation design and includes an onboard DC-DC converter that takes 15 V input and creates 15.8 V and -8.2 V for driving the IGBT's. The driver board commands all three IGBT's in parallel and is optimized for matched inductance and delay to each module. This allows all the modules to turn on within nanoseconds of each other allowing all 3 modules to share current evenly. By building our own controller, we were able to suit our needs perfectly while achieving the performance of controllers that cost over $3,600. Our cost for this controller was less than $560.

Using open source design has the benefits of collective productivity. We created a rough concept for RTD Explorer, and now it exists. This program uses the serial communication connection of the controller. It features real time graphing, with data logging, configuration and firmware upgrading, all in one easy to use interface. The graphing feature takes advantage of the real time data stream, coming from the controller, generating line graphs of: throttle, motor current, battery current, heat sink temperature and duty cycle. This allows for easy diagnostics and view of the commands and control values in the controller. Data is pulled every 0.1 s, ensuring a very smooth update rate. Other useful features are the ability to export the data stream to a CSV file to be opened later on in a spreadsheet program. The program also displays all fault codes that are active in the controller, which makes it very easy to see what is going wrong. Lastly, the program contains an interface to the boot loader utility, which allows easy field upgrade of the controller's firmware. All that is required is to select the file you want to upgrade to, and select the start boatload option and the program takes care of the rest. First, it restarts the controller, then loads and verifies the new software and finishes by starting the restarting the controller. This can all usually take place within 30 seconds.

ENERGY STORAGE OVERVIEW

Batteries generally available for traction applications consist of metals such as lead, nickel and lithium. Thomas Edison designed the first traction batteries using nickel iron (NiFe) [4]. His battery (and his electric car) was later replaced with lead acid batteries (PbA) in the early 20th century. The nickel battery has evolved to such variants as the nickel cadmium (NiCd) and nickel metal hydride (NiMH) battery. Using nickel was an improvement over lead, except for cost and safety to the end user. Both lead and nickel exhibit a poor mass energy density of under 75 W·h/kg. However, when using the lightest metal available, lithium batteries promised excellent mass energy density. At first, a non-rechargeable lithium battery was developed and dubbed "Lithium Metal". When the first lithium secondary cells were promoted, they were distinguished from non-rechargeable primary cells as "Lithium-Ion", or "Li-Ion." Today there are four major types of Lithium rechargeable batteries in production and available for resale. They are: lithium cobalt ($LiCoO_2$), lithium manganese ($LiMn_2O_4$), lithium nickel ($LiMn_xNi_yCo_zO_2$), and lithium iron phosphate ($LiFePO_4$).

BATTERY SELECTION

For the 4th year in a row we have chosen lithium batteries that are used by many Remote Control (RC) hobbyists. RC LiPo batteries are a hybrid lithium polymer battery. The correct name for this type of battery is lithium-ion polymer, but the battery world of today simply calls them lithium polymer even though they are not a true dry type LiPo battery. By introducing a gelled electrolyte into the polymer, the ion exchange rate is improved. Since the electrolyte is gelled, there is less chance of leakage, but it is still flammable. LiPo hybrids are not as dangerous as Li-Ion's but they can still catch fire or explode if over charged, shorted, or punctured. When first introduced, LiPo batteries were more expensive than Li-Ion because they are more difficult to manufacture. Prices have dropped substantially. LiPo hybrids use the same flat cell structure as their dry counter parts meaning they have the same flexibility with sizes and shapes.

RC LiPo battery cell is packaged in a foil pouch called a pouch cell. Again, our team chose the lithium-ion polymer for our electric snowmobile. Our primary reasons were mass energy density, availability and cost. These batteries are the least expensive lithium batteries available based on mass energy density. We installed 50 Zippy Flightmax batteries. These batteries have a 37 V nominal voltage. Connecting five of these batteries in series gives the machine 185 V. Higher voltages allow a smaller amount of current, which produces less heat and less wasted energy [7]. The batteries were confirmed to exhibit a low internal resistance during loading. Resistance values per cell are 0.003 Ω. Having a low internal resistance allows the snowmobile motor to draw more power. This is a huge improvement when compared to lead acid batteries. Charger efficiency is also increased because less energy is wasted in heat.

For competition years 2009-2012, to attain sufficient range, we placed great importance on obtaining the largest energy storage capacity possible. In 2013, we tried a different approach of using a smaller more efficiently sized pack. This year we have taken from past experiences and have assembled a pack which we feel is ideally sized for the competition.

Our batteries were designed for high "C-rate" RC applications. C-rate is a measure of how many amps the cell can produce, based on battery capacity. Each battery is 5.8 A·h, and can allow 145 amp peak current draw. This pack is capable of producing a peak 134 kW at 25 C-Rate. We selected these cells because they are very affordable and widely available. All of the BMS development we have done is targeted towards making these cheap hobby batteries a viable electric vehicle solution. These batteries allow 1500 cycles when discharged at 80 % in each cycle. After extensive battery research, we decided to use the cells manufactured by Zippy Flightmax. They were affordable and had a 40 % increase in mass energy density compared to commonly available lithium-ion cells. The team is currently designing a battery pack to utilize much larger capacity cells based on the same technology. However the larger cell capacities are not yet commonly available. This will be addressed hopefully by CSC 2015.

BATTERY PACK CONFIGURATION - Our pack consists of twenty five 10-cell packs, arranged in five separate strings of five packs each. Each string is separately fused with a 50 amp series fuse. Each parallel cell is connected to its neighboring cell with a 3 amp fuse, monitored by the BMS, which ensures that cells discharge evenly.

BATTERY CHARGER

The team selected an Elcon CE-listed battery charger. This 2.5 kW model can charge a competition sized pack in 6 hours at 110 VAC or 4 hours with 230 VAC. With our smaller pack recharge time will be shorter-about 4 hours on 110 VAC. Over 88 % of power taken from the grid is converted to real power to charge the battery. The intelligent microprocessor controller has optimized charge algorithms setup to charge different battery chemistries. We selected an algorithm that would work with our Lithium-ion batteries. Utilizing the correct algorithms helps improve battery life and minimize maintenance. Its rugged, lightweight and intelligent design provides continuous operation in any application.

ENERGY EFFICIENCY

To evaluate the efficiency of the Nanook EV, a comparison analysis with a standard production snowmobile was used. Assuming the best mileage a production IC snowmobile gets is 8.075 km/L (19 mi/gal), driving 30.5 km (19 mi) uses about 114 000 Btu of fossil fuel. This calculates to 3,738 Btu/km.

The electric snowmobile averaged 250 W·h/km (400 W·h/mi.) If we include charger efficiency of 88%, this comes to 455 w-h/mi. Converting to British thermal units we calculate 970 Btu/km. This means the electric machine can be almost 4 times as efficient as the best internal combustion machine.

If the electricity used to charge the machine comes from a power plant, the efficiency of the plant must be considered, but the beauty of an electric machine is that we are no longer forced to use fossil fuel if we desire not to.

Also, it is interesting to point out that even if the energy consumption is the same in either using gasoline or electricity to power a snowmobile, there are additional energy needs in order to bring that energy to a gas tank or a wall outlet. Argonne National Laboratory's The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model [11] can do a Fuel Cycle analysis, also known as "Well to Track."

This modeling software allows researchers to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. We used this modeling software to compare snowmobile combustion vs. electric snowmobiles. We estimated that an electric snowmobile operated with an 11 % reduction in CO2 emissions and a 10 % reduction in Greenhouse Gases (GHG) based on energy generation in Fairbanks, AK [12]. The software will also give you modeling data on other emissions as well.

RANGE

When we first started competing, we focused more on the range event than anything else. With the energy storage restriction enacted in 2011, it has become harder to justify this focus. 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 to reach this goal. We didn't achieve our goals in 2009 since we expected to travel 50% further than we actually did. What we didn't anticipate were extreme wet snow conditions. We have classified snow into three categories as shown in Table 5: Slush, Ice and Powder [12, 13]. Using data from the last four years of the CSC and Auth's Thesis [14] we calculated a rolling resistance coefficient. We also show our range estimation for our current sled depending on conditions. More information about calculating rr is in a previous design paper [10].

Table 1: Rolling Resistance Effect on Range

Snow Condition	Rolling Resistance [rr]	Distance	
		km	mi
Slush	0.377	18.81	11.28
Ice	0.252	26.59	15.98
Powder	0.15	40.22	24.14

RANGE TEST

Results at the 2012 CSC showed our snowmobile range at 24 km (15 mi). In 2012, the snowmobile was driven on a 1.33 kilometer (0.83 mile) track for range testing in Fairbanks, AK. The sled was driven at a constant speed of 32 km/h (20 mi/h). We kept the speed constant to maintain zero acceleration as much as possible. We ran the machine until the BMS alerted us that the machine needed to be recharged. We obtained 30 km (18 mi) on hard-pack snow, which we calculated to be 266 W·h/km by dividing 7.992 kW·h and the 30 km. This exceeds the old 16 kilometer (10 mile) standard which is still listed as a design criterion in the Clean Snowmobile Challenge rules, and this range can be exceeded or reduced with different snow conditions. [1] Knowing this, we tested again on a warmer day and ran the sled out on a river's surface; we were able to drive 20 km (12.42 mi) before receiving the BMS warning. This was calculated to be 400 kW·h/km. This amount is much higher than the power draw we saw in the first test, and shows the large amount of variability that exists due to snow conditions.

DRAWBAR PULL

The drawbar pull is an interesting event in that many of the qualities that lead to drawbar pull success can be detrimental to performance in other events. Chief among these qualities is weight. A heavy snowmobile will achieve lot of traction, and thus be able to pull more. On the other hand, that weight is cumbersome in 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. We may use studs to increase performance depending on course conditions. To test the snowmobile's performance in the drawbar pull, the back end of the snowmobile was attached to the back end of a parked truck with a two sets of triple blocks and a fish scale. The highest measured force was recorded. During testing, the maximum recorded force pulled against was 2.6 kN (590 lbf) 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. This test was really close to what we attached at KRC in 2012. We obtained 2.7 kN (594 lbf).

NOISE

The overall sound output of the machine was found to be quite minimal. We experimented with different tracks from Camoplast and Kimpex and on light powder the sled was performing below 60 dB. To address subjective sound quality, the motor used this year has an internal fan which is much quieter. Using the Poly Chain and the Silent Track technology has lowered our sound output. This 137 inch silent track (Ski-Doo part number 504152755) is a Camoplast track with added rubber to where the wheels meet the track. Since this is newer technology we thought it would also be considered an innovative in keeping sound levels low. An added benefit of this track is that it is narrower than the stock Renegade track that our machine came with, as well as having a 1" lug height instead of 1.25. Weighing the two tracks, we found that the new silentrack weight 38 lbs, while the stock track weighed 50. This reduction in rotating mass will help to increase our efficiency and range. In 2013 we added the Tricked Toys 9" wheel kit. However when tested, it was found that the wheel kit made the machine much louder, due to the wheels being made of aluminum rather than rubber.

HANDLING

The additional weight added to the snowmobile resides in the engine compartment. This allows for a low center of mass that the team wanted. 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 snowmachines. The sled is geared primarily for range by running the motor at its optimum rev/min while turning the track at a speed of 32 km/h (20 mi/h). As a result it can't pull the skis off the ground during rapid accelerations on flat ground, but it will easily stand up if the throttle is applied in any amount of deep snow.

BRAKING - The machine still employs the stock hydraulic disk brake system mounted on the paddle drive. In preliminary acceleration tests, where quick emergency style braking was required, the brakes showed little or no sign of fade. The stock rotor never showed signs of excessive heat buildup. This is attributed to the excellent job that BRP did when they designed the braking system, which is cooled directly by snow thrown up from the track.

BALANCE - The snowmobile is well-balanced front to back and side to side. Since the gas engine and clutches were spatially replaced with a motor and battery pack that weighs more, the weight over the front skis is greater than the stock values. This allows for better steering of the snowmobile. We have learned from previous competitions that having too much weight over the track was not helpful in the subjective handling test. As weighed on a pair of bathroom scales, there was no difference in weight between the left and right sides.

OVERALL HANDLING - The snowmobile exhibits a high overall level of comfort and performance. The seat is slightly elevated to simulate the popular high-rise aftermarket seats, decreasing the angle of the rider's knee and thus reducing joint and leg fatigue. The gauges are located in the stock locations, which still permits easy visual access. The original cable style throttle block was retained, and is more 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 to be. Aesthetically, it still retains its performance oriented styling and stance. Although some snowmobiles are used in commercial or research applications, the majority of the market is driven by recreational consumers. With this in mind we feel it is important that our final result still retained its original ability to provide a fun and comfortable ride, which the Nanook EV5 surely does.

WEIGHT

Adding the published dry weight with necessary fluids gives a wet weight of 232 kg (512 lb) for stock snowmobile. The Nanook EV3 tips the scales at 212 kg (481 lb) this year. This new weight allows our machine to be extremely competitive with many four-stroke gasoline powered snowmobiles available. The team did some weight calculations to determine how weight affects range. It appears about 27 kg (50 lb) can reduce range by 3 km [10] . We hope the event organizers would be happier with a smaller and safer battery pack; It may prove to be an adequate compromise. In the future the team will use more exotic materials to lighten the sled, and attempt to find a lighter battery pack with even higher energy density.

ACCELERATION

The acceleration rate is very challenging for an electric snowmobile. The high power demands of the event require high electrical currents being fed to the motor (upwards of 600 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 optimization for this performance is adequate motor sizing and gear selection. If the motor is too small, then the snowmobile will not be able to meet the minimum performance criteria for enthusiasts. If the motor is too large, 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, at 15.47 kW (21.75 hp), is the perfect size to provide both versatility and performance.

COST

One advantage in working on a limited budget during this project is that our Manufacturer's Suggested Retail Price (MSRP) is extremely low. We went with a brushed DC motor to save $ 3 000 off the final price. We used lithium polymer batteries to save another $ 2 000. However, using Gates Poly Chain increased our cost by $ 700.

This $ 4 300 in savings should make us competitive against other teams, and make more researchers interested in acquiring a machine. Recent commercial snowmobile pricing has been on the rise for the last several years. This makes most chassis used in 2014 prohibitively expensive to convert to electric. We are thankful that the rules allow for a credit on the original motor; however this is not a realistic idea if you were planning a conversion business. Unfortunately none of the four major snowmobile manufacturers have taken an interest in a commercial electric sled. We realize there are major shortcomings in electric snowmobiles for certain user groups. However, a recent start-up company named Premier Recreational Products and other overseas vendors have developed a gasoline powered family-sled for under $ 4 000 [18]. Even though it is a smaller "three-quarter" sled, the 96 inch track would be usable in many situations. Using a chassis like this in a conversion would have an instant weight savings, and would be less expensive overall to convert. However, the Ski-Doo MX Z is so well engineered that C3 Power Sports has made a complete carbon fiber chassis. The excessive cost is high, but could afford an extra 10 km (6.1 mi) in range.

2014 SPECIFIC INNOVATION

Hardware on the machine for 2014 (and thus the design paper) has remained much the same as in the past two years. However, this year has brought some very radical changes to the battery management system, battery box, and user interface.

The battery box is now entirely separated into 7 separate compartments. The first compartment is sized to hold the maintenance disconnect and negative bus bar. The five mid compartments are each sized specifically to hold a parallel group of cells. The compartments are constructed so that in the future, the accumulator could be increased to six parallel strings (instead of five) without any major changes. Each of these compartments accommodates fireproof ceramic-based felt material to insulate the batteries and provide fire protection. The final compartment houses the BMS and other control wires necessary for monitoring the battery status.

The battery management system is based on an entirely new monolithic integrated circuit built my Linear Technologies. This allows much faster cell monitoring, very robust communication and error handling, and the possibility to upgrade to an active balance system (as opposed to passively bleeding cells off as heat.)

The user interface has also seen a complete re-design, now using a 3.2 inch pressure sensitive touch-screen to display data and change settings. This is a huge upgrade from the team's previous BMS, which used to require individual re-programming of 48 separate micro-processors.

CONCLUSION

The Nanook EV5 has been designed from the ground up to be a competitive, cost-effective electric snowmobile which meets NSF's and the clean snowmobile challenge's requirements. Great care has been taken to ensure the utmost safety of every component, while keeping in mind the design goals of the competition. By designing our own motor controller and battery management system, we have kept costs down while maximizing the flexibility of the design. Our design is extremely adaptable to changing requirements and we feel that our team will be competitive at CSC 2014.

ACKNOWLEDGMENTS

2 Cool Air Vents Advanced Circuits Alaska EPSCoR Alaska Fun Center Arctic Cat Inc. ASME Northern Alaska Subsection ASUAF AVL C3 Power Sports Case Assembly Solutions College of Engineering and Mines Compeau's Ski Doo Conoco Philips Curtis Deutsch Group Epoxies, etc. Fairbanks City Bed-Tax Flint Hills Resources Gates Gates Gigavac Helwig Carbon HMK Holland America Institute of Northern Engineering John Deere Kimpex Learn Twice Linear Technologies Logisystems Controllers Lynden Transport Maxim Maxim Integrated National Science Foundation Net Gain Motors NetGain Motors Northern Power Sports Panduit Paul Holmes Peter Perkins Product Components SBE Inc. Solidworks Spangs Fab Synlube TE connectivity Thermik Tri Star Industries U.S. Fish and Wildlife Service UAF Alumni Association UAF Sustainability Fee UAF Technology Board University Alaska Fairbanks Provost's Office Usibelli Foundation Walmart Wilderness Ski-Doo Worldwide Bearings

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

BMS: Battery Monitoring System, measures pack parameters

CSC: Clean Snowmobile Challenge

LiPo: Lithium Polymer batteries