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Design of Snowmobile Modifications for the University of Minnesota Clean Snowmobile Team Entry at the 2016 SAE Clean Snowmobile Challenge

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Abstract

For the 2016 SAE Clean Snowmobile Challenge, the University of Minnesota selected a 2015 Polaris Indy 600 SP. Powered by a two-stroke Liberty 600 engine, this snowmobile was selected because of its potential for improvement in fuel economy, noise, and emissions. Major improvements for this snowmobile include a customizable engine control unit, added flex fuel capability, catalytic emission reduction, and a new belt drive design. Next steps for the team include the validation of the newly designed systems and components.

Introduction

Whether used for sport, a recreational activity, or as a necessary means of transportation, snowmobiles serve a wide range of consumers around the world. These uses have created a growing snowmobile industry, but with growth arises issues. Many riders have come to find difficulty accessing trails as noise and emissions regulations become more stringent. The current steps to reduce pollution have left only a small portion of riders able to access some of the best trail systems available. Because of this, the Society of Automotive Engineers (SAE) partnered with the Montana Department of Environmental Quality, the National Parks Service (NPS), the Department of Energy (DOE), and the Environmental Protection Agency (EPA) to create the Clean Snowmobile Challenge (CSC) in 2000. The main goal of the CSC was to develop a snowmobile which meets NPS standards. That goal has since been reset to beat current best practices as companies now make snowmobiles which meet NPS standards. The trouble with current clean snowmobiles is that they are predominantly touring models, which represent a smaller portion of the market. This creates the need to focus research and innovation on the heart of the market, made up of the inherently “dirtier” 2-stroke snowmobiles. Popular for their higher power-to-weight ratio, 2-stroke snowmobiles present a great challenge to improve emissions, because the power and performance that makes these snowmobiles so popular is sacrificed when emission control systems are implemented.

The University of Minnesota-Twin Cities Clean Snowmobile Team (UMNCST), founded in August of 2014, has worked to improve the emissions and noise produced from a 2015 Polaris Indy 600 SP snowmobile while balancing the power that it lost with the gains in efficiency. The following paper discusses the ideas and testing the University of Minnesota Clean Snowmobile Team has conducted as an entry in the 2016 Clean Snowmobile Challenge. Included in this paper are details and methods used to more efficiently control the engine, reduce emissions, and control the noise of a popular snowmobile currently on the market. All this was done while maintaining the current handling and ride characteristics of the vehicle.

Engine Control System

The Polaris Liberty 600 semi-direct injected two-stroke engine needed to be fit with a new control system that could accept additional sensor inputs and allow for the tweaking of fuel maps.

The team chose to incorporate a Performance Electronics PE3 engine control unit (ECU) for this purpose. The PE3 was chosen because of its lower price point than many standalone ECU's, even being competitive with piggyback controllers, while still offering more complete control over fuel and spark maps and allowing for more additional inputs.

During the implementation of the PE3, the team discovered some of the difficulties of changing the engine control system completely. The crankshaft position sensor that Polaris had used on the stock engine was unable to be used with the new ECU. The stock setup had two trigger wheels, each with their own VR sensor. The PE3 was only able to accept a single input for the crank position, and only in certain standard profiles.

While the team was working with Performance Electronics to solve this issue, it was also found that the signal output from the VR sensors was unable to be used by the PE3, as the zero crossing of the signal was not clean, due to the size of the teeth and interference from the other wheel that is located close by. A trace of the Stock VR sensor in shown in Figure 1. This data was obtained by using a DATAQ data acquisition unit, which also read the signal from the ignition and fuel injection systems to help with a baseline tune once the PE3 was implemented.

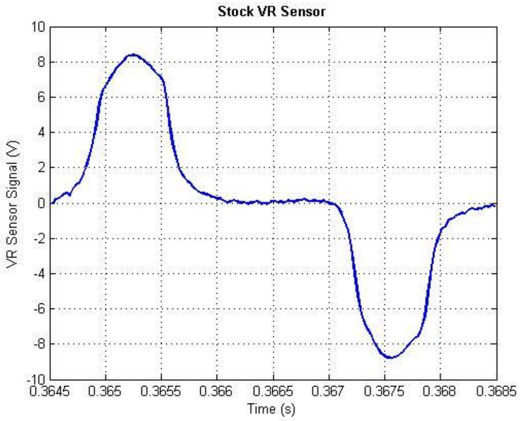

Figure 1. Signal trace of the Polaris stock VR sensor. The elongated plateau between spikes made the zero crossing impossible to track with the PE3 ECU.

Because of these difficulties, the team chose to manufacture a custom trigger wheel, using a standard 12-1 profile, or 11 teeth, located every 30 degrees, with one gap that signifies that the next tooth's signal locates the top dead center position of the first cylinder.

To further aid in creating a baseline tune, the DATAQ unit was again used, taking data from one spark plug, one fuel injector, the ambient temperature sensor, and the throttle position sensor. This data was obtained from riding the snowmobile across a frozen lake, as the team did not have access to a dynamometer. From earlier testing, it was known that the ignition system is a wasted spark design, where both spark plugs fire together, twice each engine cycle, so that one spark ignited fuel, and one is wasted. The fuel injection was a sequential ignition system, where the injectors for each cylinder were opened at different times. These were all necessary details for running the engine with a new standalone ECU, that would not have needed to been known using a piggyback controller. The team decided that this extra effort spent would be worthwhile, as PE3 allows more freedom, with the ability to manipulate the fuel map in terms of injector open time, not just a multiple of how long the stock map opens the injectors. It is also ready to be used on almost any motor the team chooses to use in the future, and has support for other features such as forced induction systems and staged injectors.

Fuel Range Effects

The large "bio content" range of corn-based ethanol from 0% to 85% presents a particular challenge for combustion management. Compared to the energy density of gasoline (112,114 to 116,090 Btu/gal), ethanol contains 76,330 Btu/gal [1]. The lower energy density of ethanol results in decreased capability of producing work. When using E85 an additional 34% of fuel must be consumed to reach an equivalent energy input.

Performance benefits of using ethanol over gasoline include an increased octane number and lower combustion temperatures. Because of these characteristics, ethanol is well suited for high compression engines. While pump station gasoline typically has an octane number between 87 and 91, ethanol's higher octane number of 110 indicates that the fuel is more resistant to auto ignition. When in a stoichiometric mixture, the adiabatic flame temperature of ethanol is also less than that of gasoline. A mixture of E100 and air has a constant volume adiabatic flame temperature of approximately 4765 Fahrenheit, 148 degrees cooler than a gasoline and air mixture adiabatic flame temperature of 4913 Fahrenheit. A high compression engine designed to utilize these properties of operating cooler and resisting auto ignition could see increased performance from using ethanol over gasoline.

To maximize performance of the 3-way catalyst used for the snowmobile, a stoichiometric combustion mixture is needed. Adjusting to varying fuel concentrations requires manipulating the target air/fuel ratio (AFR) in the ECU to maximize efficiency. Figure 2 shows a plot of the stoichiometric AFR as a function of ethanol concentration. An approximation for gasoline of $C_{8.26}H_{15.5}$ was used to create the plot [2].

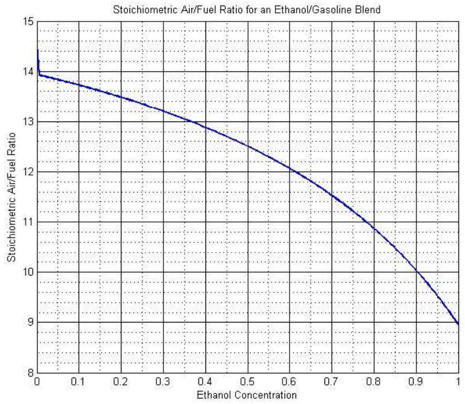

Figure 2. Stoichiometric air/fuel ratio as a function of ethanol concentration in an ethanol and gasoline fuel blend.

Management of Emissions

Initial emissions data for the snowmobile was gathered at idle using an E Instruments E8500 portable emissions analyzer. Because of testing facility restrictions, only idle data was gathered. Table 1 shows emissions data at an engine temperature of 49 degrees Celsius while idling.

Table 1.Idling snowmobile emissions with 49 degree Celsius engine temperature.

Emissions	Percentage/ppm
HC	1.13%
CO_2	2.0%
CO	3.05%
NO_x	40 ppm

Designing a catalyst system for a two-stroke engine presented many challenges. Part of a two-stroke engine's exhaust is uncombusted oil. If oil were to get onto the catalyst, poisoning of the catalytic metals would occur and render the system nonfunctional. The system would also be nonfunctional if the temperature is too low and could even be damaged if the temperature is too high. Positioning the catalyst too close to the exhaust manifold would keep it hot enough, but it could affect scavenging as reflected pressure waves would bounce back quicker than the stock exhaust system. Exhaust gas velocity in a two-stroke is relatively high compared to a four-stroke engine, so having a large cell density would lower emissions at the cost of performance. A 600 cpsi catalyst would be too restrictive and more likely to clog so a 400 cpsi catalyst was chosen. This catalyst provides a balance between emissions control and performance.

Using the initial emissions readings, Heraeus Deutschland GmbH sent 70x74.5mm catalyst samples with 50 g/ft3 loading and a 1:20:1 ratio of Pt:Pd:Rh. This is a 3-way catalyst so that hydrocarbons and carbon monoxide are oxidized and NOx gases are reduced. Because of the catalyst reflecting pressure waves, it was decided to put incorporate the catalyst into the baffling of the expansion chamber. The baffling of the expansion chamber is where the expansion chamber tapers from the widest point down to the diameter of the exhaust. Normally this is where the pressure wave would reflect, so placing the catalyst in this section of the expansion chamber should have minimal effect on the timing of the wave. Previous studies have shown that placement near the muffler has had the effect of moving the power band towards middle range rpm with a very small loss of power [3]. A slight loss of power is acceptable with the gain in emissions control.

There are, however, still problems regarding oil poisoning the catalyst and the catalyst temperature. A temperature of around 250 degrees Celsius is necessary to burn off uncombusted oil, and also for the catalyst to achieve a more efficient operating range as this temperature is considered the highest efficiency for catalytic converters [4]. When placed in the baffling of the expansion chamber the catalyst would take too long to reach 250 degrees Celsius, especially when trying to cold start. A cold start without a warmed catalyst could lead to the catalyst being poisoned with oil. To prevent this, a metal heating cuff was used to heat the catalyst from the outside to avoid the potential problems that have been noted. Powered by the stock 12V snowmobile battery, the heater reaches a high enough temperature on the inside of the cuff to get the catalyst to the desired temperature. The cuff's external temperature is lower than the internal temperature but still high enough to potentially damage coolant hoses and wiring in the vicinity, so exhaust wrap was utilized to add some insulation and protection.

Design of Drivetrain Modifications

A design for a belt drive system was developed as a replacement to the current chain drive system. The advantage of the belt drive is a 1.099 kilogram reduction in rotating mass. It is also anticipated that the belt drive will also produce less noise than the chain drive during operation. The system was designed without any modification to the drive shaft, jackshaft, or brake placement so that the belt drive could easily be swapped for the original chain drive. The belt drive is lighter than the chain drive, but energy loss due to belt slippage or friction could cause a lowered efficiency than the chain drive system. Figures 3 and 4 contain SolidWorks models of the new belt drive sprockets.

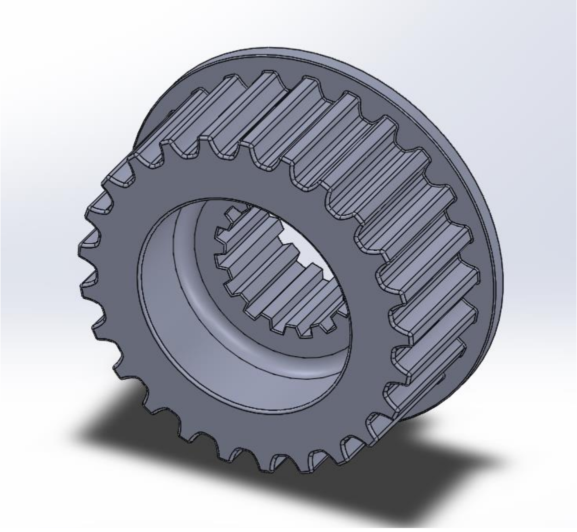

Figure 3. New design for the belt drive upper sprocket.

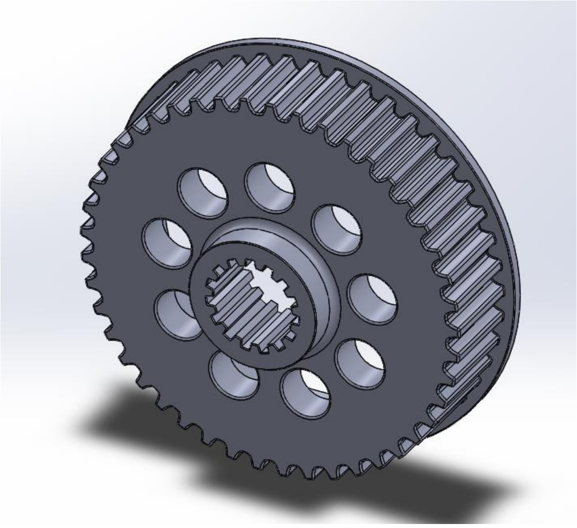

Figure 4. New design for the belt drive lower sprocket.

MSRP

The base snowmobile used by the UMNCST was a 2015 Polaris Indy SP with a base MSRP of $9,199.00. Parts that were replaced or added were compared in their respective manners. Depending on the cost that was quoted or used, some parts did not add any value to the snowmobile. Parts that were considered stock replacements were also left out of final cost calculations.

The parts that the UMNCST replaced include new tachometer with GPS to work with a new ECU, which was considered a stock replacement. New parts that were added to the snowmobile include a pin style hitch for approximately $13, an ethanol sensor for $92, and a catalyst for $50. The skis and a track were also upgraded for a total cost addition of $476. There were no fabrication costs included with the MSRP as all work was minimal and considered costs for production. With no other costs added, the resulting MSRP of the snowmobile rose to $10,225.00.

Conclusions

The UMNCST was able to conceptualize many great ideas for the 2016 CSC. From a new ECU to a Belt Drive and Catalytic converter the work conducted by the team agreed with theory and previous findings, and each project showed promising results. Due to restrictions in funding, testing capabilities, and time, not all of the projects were able to be fully validated and/or implemented in time for competition. Next steps include acquiring sufficient funding to manufacture all of the needed parts, finalize the validation process for each project, and then to report out results. The team is hopeful that the next iteration of the design process will prove to be much more successful and lead to greater innovations for the CSC and the snowmobile industry as a whole.

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