SnowDawg's: 2014 Clean Snowmobile

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ABSTRACT

The University of Minnesota – Duluth Clean Snowmobile Team the Snowdawg's has redesigned a high performance snowmobile with reduced noise and emissions and improved fuel economy to compete in the 2014 SAE International Clean Snowmobile Challenge. A 2014 Arctic Cat ZR7000 LXR was used as the base model. The snowmobile was redesigned to run on a mixture of iso-butanol and gasoline with the addition of a GM flex-fuel sensor and a Performance Electronics standalone ECU. For the improved emissions, a 3-way catalyst from Heraeus was used. To reduce noise output, a quiet track was installed and the exhaust chamber was redesigned. To improve fuel economy, a bearing roller drive sprocket was designed and the reverse was removed. With the addition of these technical features, the snowmobile will surpass industry standard expectations and improve the overall riding experience.

INTRODUCTION

Due to pressing green lobby influences on the Environmental Protection Agency (EPA), new regulations have been developed forcing snowmobile manufactures to decrease the amount of emissions of their machines to reduce their environmental impact. For this reason, the Clean Snowmobile Challenge was created allowing students to develop innovated designs to assist in reducing the environmental impact of snowmobiles.

After failing to develop a working sled with a two-stroke engine last year, it was decided to incorporate a four-stroke engine. Thus, it was found that the C-TEC4 was the appropriate engine for our needs. A four stroke engine was decided upon for the increased efficiency and emission advantage over a two-stroke. The engine being used for competition has a displacement of 1049cc over three cylinders. A higher horsepower engine was chosen to allow for the maximum performance capabilities with keeping the snowmobile naturally aspirated as to allow for a stronger focus on other aspects of the snowmobile.

MODIFICATIONS

PERFORMANCE

ECU Modification

Equipment Added/Used

- Performance Electronics PE3 ECU
- Performance Electronics PE Wide-Band Lambda Sensor
- General Motors Flex Fuel Sensor
- Performance Electronics peMonitor Software (v3.04.18)
- Cisco Linksys Router E800
- Land and Sea Dynomite Dynamometer

Procedure

A standalone ECU was decided on early in the fall. The standalone ECU was used to increase flexibility in tuning and add the capability to install additional sensors needed for running the snowmobile on the iso-butanol/petroleum fuel mix. Performance Electronics was decided upon due to the fact of their known product quality and helpfulness. A wide-band lambda sensor was also ordered through Performance Electronics for reading the air fuel ratio. A General Motors flex fuel sensor was decided upon to read the percentage of iso-butanol in the petroleum. This sensor was donated by Kolar, a car dealership in Hermantown MN. To make tuning the snowmobile a comfortable feat, a Cisco Linksys Router was purchased. This router was used to transfer the signal from the ECU to a laptop while tuning. The software used for tuning was a free download off of Performance Electronics website. The Mechanical Engineering Department at the University of Minnesota Duluth acquired the Land and Sea Dynomite Dynamometer this last fall, which was used to tune the engine.

The stock wiring harness of the snowmobile was not setup to hook up to the ECU. In wiring a new harness, a relay was added to the fuse box while two other relays were removed that were used for reverse. The fuse box was completely rewired to add the new relay and to get rid of extra wires that were used for the reverse relays. To help in wiring, Performance Electronics and Arctic Cat provided wiring diagrams of their systems. A mixture of both wiring diagrams was used. The ECU wiring harnesses had extra analog and digital inputs and outputs to give freedom of adding extra sensors. All the wiring for the seat heater and the reverse was removed. Once the initial wiring of the engine was done the wide-band lambda sensor and flex fuel sensors were wired in. The wide-band lambda sensor has its own controller that converts the lambda signal into a 0-5v signal. Also, in the creation of the new wiring harness the seat heater switch was converted to add the option of switching lambda tables on the go. The two different lambda tables are changed from a lambda table for optimum performance to a lambda table for maximum fuel economy. This gives flexibility in riding the sled in many different applications. The option of switching lambda tables was declined due to time constraints on testing.

Once wired up getting the C-Tec 4 Arctic Cat engine to start was the next goal. The engine took a while to get running but after many phone calls with Brian Lewis at Performance Electronics, an updated firmware was made for our engine to correctly read the trigger signals. The engine was started after getting an updated copy of the ECU software. The engine then ran and tuning commenced.

In tuning the engine the dynamometer was used to control engine load and a stiff throttle setup was used to hold the engine at a constant throttle position.

DRIVELINE EFFICIENCY

In the decision to put effort into improving driveline efficiency, a way to measure improvements was developed.

Figure 1: The Chassis Dyno

At first, a motor-less treadmill was decided on to simulate the conditions of the track being flat on the ground. A 3.5hp 3-phase electric motor with a variable pitch pulley was used to drive the track at 15 mph. The amperage was then measured and averaged for each test. The noise output was also recorded. After a few tests, the treadmill was removed due to excessive heat build up from the extra weight and speed of the track and due to overloading the motor. An equation was formulated to convert the amperage to power consumption.

Drive Sprocket Modification

Equipment Added/Swapped Out

- OEM 2.86” Arctic Cat Drive Sprocket
- Custom 6061-T6 Aluminum Roller Drive Sprocket
- 88 - 0.625” OD, 0.25”ID Ball Bearings
- 22 - 0.25” Cap Socket Bolts

Procedure

To aid in the performance of the snowmobile, it was chosen to swap out the OEM Arctic Cat drive sprocket with a custom fabricated 6061-T6 Aluminum roller drive sprocket. The custom roller drive was used to decrease the amount of rolling resistance between where the track and the drive sprocket engage and disengage.

Figure 2: Redesigned Drive Sprocket

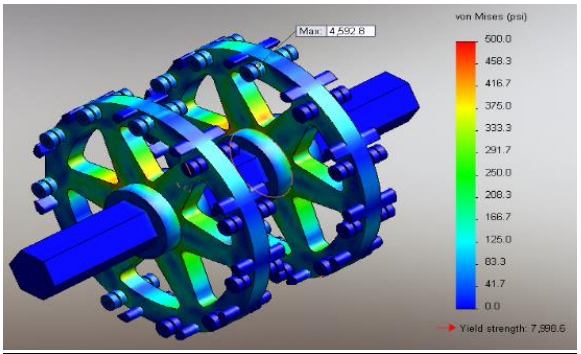

Figure 3: Von Mises Plot in Acceleration

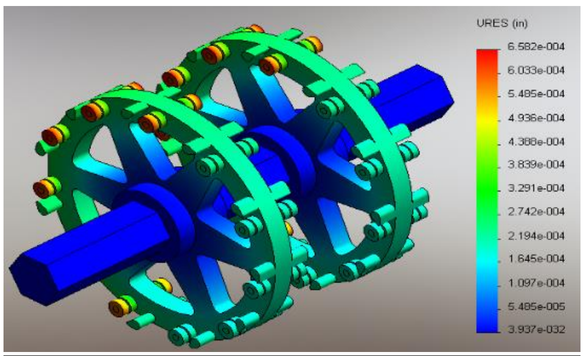

Figure 4: Deformation Plot in Acceleration

There are a few differences between the OEM drive sprocket and the custom roller drive sprocket that are worth noting. The custom roller drive sprocket has a total of 88 ball bearings and 22 socket head cap screws. There are also cogs machined into the drive sprocket that will absorb the braking force that the snowmobile generates. Figure 2 shows the custom roller drive sprocket used. The original drive sprocket has a 2.86" drive pitch and the custom roller drive sprocket is a 2.52" drive pitch. The reason behind the change in drive pitch was not needing a bigger lug distance to grab powder and the understanding that the smaller the pitch, the less rolling resistance there would be. The assumption made with deciding the pitch was that the competition would be on a lightly rough to smooth trails. With the change in drive pitch, it was also decided as a team to change the number of cogs provided on the drive. A stock 2.52" drive sprocket on similar models has ten cogs while the new custom drive sprocket has 11 cogs. The decision of more cogs comes from wanting more of the drive sprocket to be engaged with the track at a given moment and the reduced rolling resistance from the track bending at a larger radius.

With the assistance of MasterCAM software, the g-code was generated to machine the drive sprocket. After generating the g-code, it was able to enter into the University of Minnesota Duluth's 3-axis CNC VMC. The outer circumference, hexagon, and the weight reduction holes were cut out using the University of Minnesota Duluth's water jet cutter.

Results/Data

To analyze the roller drive sprocket, Finite Element Analysis (FEA) was performed using SolidWorks. The force values that were used to analyze the stresses and deformation of the drive sprocket on the snowmobile were found from research of snowmobiles similar to the Arctic Cat ZR7000 LXR.

The force of the track acting in the forward operation on the drive sprocket was assumed at 20lbf. The torque that was is

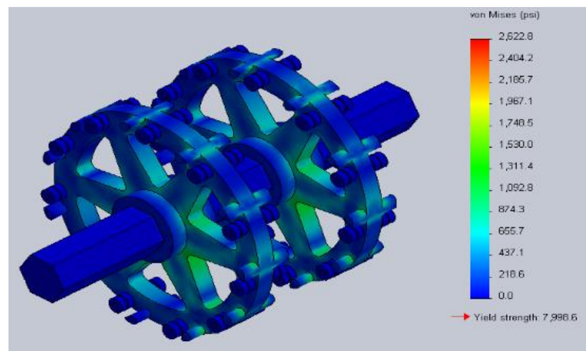

Figure 5: Von Mises Plot in Braking

being transferred to the drive sprocket was found to be 144lbf*ft. With entering these values in the FEA model, it was found that the max stress acting on the drive sprocket is 4,592psi, as shown in Figure 3, which is shown in the socket head cap screws. The max deformation that is being generated from the forces is 0.0006582in or approximately 7 ten thousandths of an inch, as shown in Figure 4.

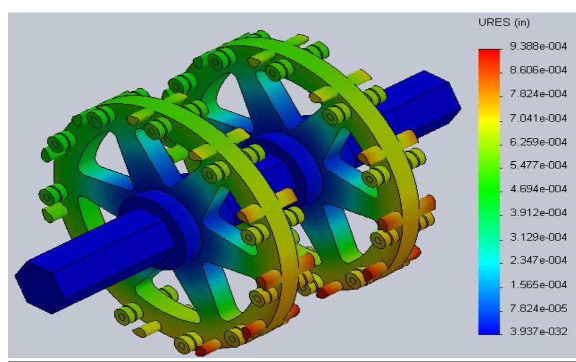

Figure 6: Deformation Plot in Braking

Next the data was analyzed when the brakes were applied to the snowmobile. The assumption was made that there was a total of 1,000lbf acting on the drive sprocket and the integrated cogs. The same 20lbf is, that was acting in forward operation, is acting on the drive sprocket from the tension of the track. The max Von Mises stress acting cogs is 2,622psi, as shown in Figure 5. The max deformation that was produced was 0.0009388in or approximately 9 ten thousandths of an inch as shown in Figure 6.

Reverse Removal Modification

Equipment Removed

- Reverse gears
- Reverse chain
- Reverse shifting fork
- Electronic reverse actuator
- Reverse Relays

Procedure

In order to make the driveline quieter and more efficient, it was determined that the mechanical reverse needed to be removed. The Arctic Cat ProCross Chassis used an electronically actuated shifting fork along with a complete reverse chain to shift into reverse. The magnesium chain case cover was removed along with all of the gears followed by the jackshaft. Multiple snap rings and lock rings had to be removed before pounding the jackshaft out the left side of the chassis. Three unnecessary reverse gears were then permanently removed to reduce the rotating mass along with the second chain. Noise output of the chain case was also a factor that was planned on being reduced. Less moving parts meant less vibration and noise. In order to make the jackshaft be in direct drive, a new snap ring groove had to be machined into the shaft end to hold the top gear in place. This was accomplished by turning down the end of the shaft on a lathe until a standard snap ring would fit. Sufficient room was left between the groove and the front face of the bearing so the top gear could be properly aligned.

Results/Data

Before any reverse modification was made, the torque need was 2.319 hp in our controlled environment. After removal of the reverse components, testing in the same controlled environment, the torque was 2.288 hp.

Exhaust Modification

Equipment Added

- Resonators
- Absorption Muffler
- Reflective Chambers
- Three-Way Catalyst
- High Temperature Fiberglass Insulation

Procedure

A modification to the exhaust system was necessary to aid in the emissions control and the overall noise reduction of the snowmobile. To develop an understanding of how the current exhaust system was operating, the stock muffler was modeled in SolidWorks and analyzed using the Flow Simulation Add-In. Equation 1, a calculation of the theoretical mass flow rate, was utilized to properly define the inlet boundary condition.

$$\dot{m} = \rho * \eta * \frac{RPM}{n} * d$$

m' = Mass Flow Rate
ρ = Density of Exhaust (Air)
RPM = Engine Speed
n = 2 (Four-Stroke Engine)
d = Displacement

Equation 1: Mass Flow Rate Theoretical Calculation

Once the stock muffler was completely analyzed it was determined that there was room for improvements. Using the data that was obtained, the new designs were developed. Equation 2 was used to assist in developing the length of resonators for frequency canceling applications. These resonating tubes at a calculated length of 1.343 in., were placed within the new design in reflection chambers where

$$f = RPM * Cy * \frac{1min}{60sec}$$

$$\lambda = \frac{c}{4f}$$

λ = Resonator Length
f = Theoretical Frequency
RPM = Engine Speed
Cy = Number of Cylinders
C = Speed of Sound

Equation 2: Theoretical Resonator Length opposite wavelengths will cancel, reducing unwanted frequencies.

An additional component was added to further the noise reduction efforts in the exhaust. At the outlet of the muffler an absorption muffler was added to dampen the highest frequencies outputted in the exhaust that were not canceled by the previous resonators. The absorption muffler is a 12" long perforated tube incased in another fiberglass insulation packed cylinder. The absorption muffler will assist in the noise reduction efforts without increasing the backpressure of the exhaust.

A significant portion of this competition is devoted to bettering the environmental impact snowmobiles generate. The total emissions output of the stock snowmobile had to be improved by adding an emissions control device. The most significant pollutants that were needed to be improved include Total hydrocarbons (THC), Carbon Monoxide (CO), and Nitrogen Oxides (NOx). Thus, it was determined that a three-way catalyst would be implemented to significantly reduce those pollutants. To consolidate on space and maintain a factory look, the catalyst was staged inside the inlet of the muffler.

Results/Data

Figure 8 displays the velocity trajectory plot of the stock muffler simulation. This muffler produced a backpressure of roughly 2 psi, simulating with the calculated mass flow rate of 0.2826 lb/s at 8000 RPM. The new muffler design was analyzed in flow simulation without a catalyst to run correlating experiments with the stock muffler as there would be a definite increase in backpressure associated with the catalyst.

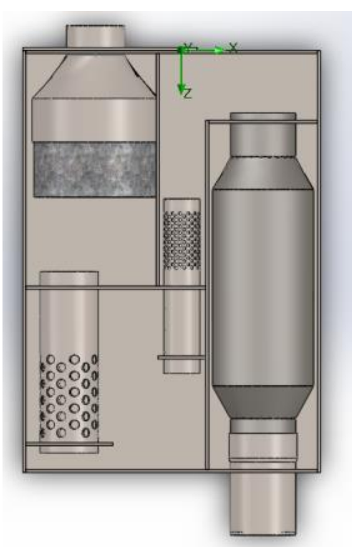

Figure 7: New Muffler Design

With the same mass flow rate, the new muffler produced a slightly larger backpressure of 2.5 psi. However, Figure 9 shows a larger vortex region in the second chamber of the muffler. This signifies more wavelength interferences, thus more frequency cancelations within this resonating chamber. Official decibel readings were scheduled to be conducted for comparison of the noise output of both mufflers however due to time constraints on the paper submittal date; data was not compiled in time for the new design.

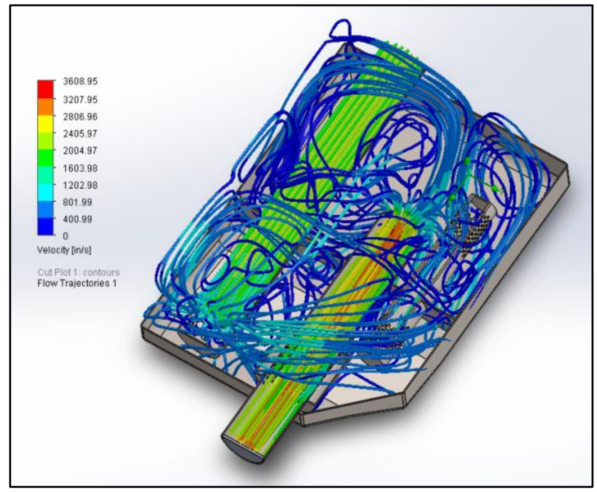

Figure 8: Stock Muffler Velocity

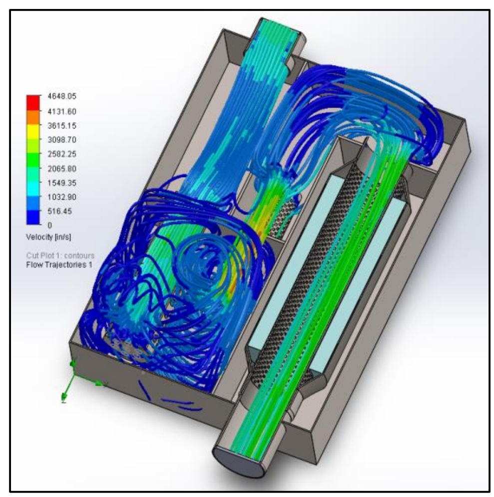

Figure 9: Re-designed Muffler Velocity Plot

The resulting catalyst implemented in the muffler is a 3-way Heraeus catalyst utilizing their HeraPur coating over honeycomb fins. This coating consists of precious metals platinum, palladium, and rhodium over an oxide coating alumina. This coating initializes the chemical reactions with the pollutants THC, CO, and NOx along with heat to convert it to a cleaner output of Carbon Dioxide (CO_2), Water (H_2O),

Figure 10: Re-designed Muffler

and Nitrogen (N_2). (1) The final catalyst contains a 105 mm diameter core, 74.5 mm in length. Figure 9 shows the internal components of the new muffler (without the catalyst which is installed in the first empty chamber).

Track Modification

Equipment Added/Swapped Out

- Removed Camoplast 129" x 15" x 1.25" Cobra standard track 2.86 pitch
- Installed Camoplast 128" x 14" x 1.00" Hacksaw quiet drive track 2.52 pitch

Procedure

The track was swapped out to get better traction on the trails, increase drivetrain efficiency, and reduce noise output of the track. Arctic Cat fit this sled from the factory with a standard Camoplast 129" x 15" x 1.25" Cobra track with 2.86 pitch. The chain case was split along with the clutch side bearing to extract the stock drive sprockets. After removing the driveshaft, the new track was installed with the new drive sprocket. The new track was a Camoplast 128" x 14" x 1.00" Hacksaw quiet track with 2.52 pitch. In order to drive the new track without binding, 2.52 pitch drive sprockets were installed to accommodate it.

Results/Data

With the stock set-up, the track put out 96.6 dB of noise at 15 mph in a controlled environment. After installing the new track along with the accommodating 2.52 drive sprockets the track put out 92.3 dB of noise and 1.806 hp.

CONCLUSIONS AND RECOMMENDATIONS

The University of Minnesota Duluth's Snowdawg's 2014 Arctic Cat ZR 7000 LXR Snowmobile will reduce emissions and improve fuel economy while still performing market standards. While using the chassis dyno the replacement of the track, and removal of the reverse system reduced noise and improved efficiency. Due to time constraints on tuning the snowmobile, the drive sprocket and the official 5-mode EPA test with the three-way catalyst was not completed at the time this paper was written. Also, any fuel economy tests were not permitted due to the same time constraints. For the next year, more time will be set aside for testing and tuning.

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DEFINITIONS/ABBREVIATIONS

CO-Carbon Monoxide
CO2-Carbon Dioxide
ECU- Engine Control Unit
EPA-Environmental Protection Agency
FEA-Finite Element Analysis
H2O-Water
NOx-Nitrogen Oxides
N2-Nitrogen
THC-Total Hydrocarbons

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