University of Alberta Cylinder Injection MXZ-X Conversion

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University of Alberta Clean Snowmobile Challenge Team

ABSTRACT

The University of Alberta Clean Snowmobile Challenge team is using a modified 2001 Ski-Doo MXZ-X for the 2005 Clean Snowmobile Challenge (CSC). We have added our own billet aluminum cylinders and combustion chambers as well as a custom built cylinder fuel injection system and a supercharger to the sled. A custom built single pipe and catalyst system were also added. This design will aim to produce far less hydrocarbon emissions while at the same time, improving the performance of the snowmobile.

INTRODUCTION

The Society of Automotive Engineers (SAE) organizes the Clean Snowmobile Challenge intercollegiate design competition. The main goals of the CSC are for the teams to re-engineer a snowmobile with reduced exhaust and noise emissions while maintaining or improving the performance of the snowmobile. The snowmobiles compete in numerous events such as emissions testing, acceleration, braking, handling, endurance, cold start, noise measurement, and oral/written design.

The competition was started in 2000 by Bill Paddleford and Dr. Lori Fussell. From 2000 to 2002, the competition was located in the community of Jackson Hole, Wyoming and the surrounding Teton County. Since then the competition has been moved to Houghton, Michigan at the Michigan Technological University. Jay Meldrum is the present organizer for this competition.

This paper will outline the procedures employed by the University of Alberta Clean Snowmobile Challenge Team (UACSC) to redesign a snowmobile for improved emissions and noise while improving all performance aspects of the snowmobile.

TEAM BACKGROUND

The UACSC is organized through the local University SAE chapter. The UACSC is housed in the Mechanical Engineering Department and is managed by students. The club has attracted a wide range of talented individuals with skills in engine building, machining, fabrication, and design. Our program is not limited only to Mechanical stream students. Students of many backgrounds and engineering faculties are involved. Students have designed all modifications to the snowmobile and have a very hands-on approach to building the snowmobile. The skills of the team coupled with their enthusiasm and drive will lead us to a successful year.

Figure 1: UACSC Team

The UACSC team has set the following goals for the end resultant snowmobile:

1. Design the snowmobile to exceed emissions and noise requirements set by the competition

2. Enhance the acceleration and ride of the snowmobile to truly offer a high performance

cleaner alternative that any buyer would consider as a viable alternative.

3. Make the snowmobile a user friendly, fuel efficient, “pull and go” sled while maintaining a reasonable overall weight.

4. Place in the top 3 in the overall standings.

DESIGN STRATEGY

DESIGN OVERVIEW

The UACSC chose a two-stroke platform due to the two-stroke’s natural higher power to weight ratio and compact size. The team decided to use a Polaris 600 VES engine for a base. This engine has a reliable and proven crankcase that will allow us a strong foundation for our modifications.

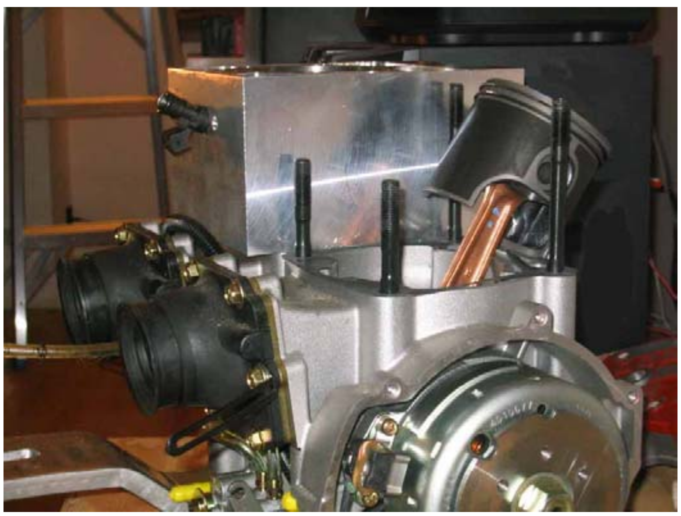

Figure 2: VES 600 crankcase and prototype cylinder

To achieve the desired power, emissions and noise of our snowmobile, 4 main modifications were made:

1. Design and construction of our own cylinders with matching combustion chambers.

2. Forced aspiration via a belt-driven supercharger which increases overall power output, throttle response and to supplies sufficient airflow to the catalytic converters.

3. Custom fabricated expansion chamber exhaust system tuned to compliment the cylinder geometry, maximize fuel-scavenging and to allowing sufficient room for the noise-reducing mufflers in the engine bay.

4. Development of a computer-controlled engine management system with in-cylinder fuel delivery.

CYLINDER AND COMBUSTION CHAMBER DESIGN

To comply with competition rules, the stock bore size of 77.12mm was used to limit the displacement to 600cc. The cylinders were machined from billet aluminum entirely by UACSC team members. Cast cylinder liners were chosen since this a prototype engine.

The engine cylinders were designed chiefly to facilitate the installation of fuel injectors in the cylinder walls. The complex water channels in cast aluminum cylinders leave no room to install injectors. Injecting fuel directly into the combustion chamber drastically reduces fuel loss out the exhaust port. By injecting the fuel directly into the cylinders on the compression stroke, there is no fuel added into the crankcase. Thus, on the exhaust stroke of the engine when the transfer ports are uncovered, only fresh air enters from the crankcase. By delaying the addition of fuel as late as possible, the majority of the fluid losses into the exhaust pipe are simply fresh air. Fuel is not injected into the cylinder until the exhaust pipe pressure reverses and begins scavenging material back into the cylinder through the exhaust port.

Porting Design

The main deviation made from the stock port map on the VES 600 was to significantly reduce the exhaust duration of the engine. Large exhaust ports generate high peak power since they allow high fluid flow and have a longer open duration which allows greater fluid scavenging from the exhaust. The problem with larger exhaust ports is that they allow more unburned fuel into the exhaust, the majority of which is not scavenged and escapes unburned.

Figure 3: Exhaust Port

The UACSC port design focuses on a single polished exhaust port with decreased duration to replace the triple exhaust port in the stock cylinder. The port smoothly mates with the cylinder liner and Y-pipe exit flange to reduce carbon buildup. The smaller single port also lends well to extended piston ring life as the ring is supported better throughout the piston stroke and is less likely to snag. This increase in piston ring support allows the exhaust port to be more oblong in shape, which expels exhaust gases more quickly than a more circular port shape. Further, a flatter leading edge on the exhaust port sends a higher peak pressure pulse to the exhaust pipe which helps generate larger scavenging pressure waves.

To accommodate the lowered exhaust ports, the transfer ports were also lowered to maintain enough engine ‘blow-down’ time. Blow-down refers to the crank angle duration during which the exhaust port has opened but the transfer ports remain closed. The transfer port wall angles were modified to direct incoming air/oil mixture toward the back wall of the cylinder and away from the exhaust port. The port sidewalls also were reshaped to converge upon the cylinder entrance, increasing the velocity and turbulence of the incoming air. To maintain high power output, the transfer port roof angles were flattened slightly.

Figure 4: Main Transfer Ports

Cylinder Head Design

Running forced induction on a stock two-stroke engine with pump fuel (E10) is not recommended as detonation will likely occur. The UACSC designed combustion chambers are built to allow the safe use of up to 10psi of boost on E10 fuel. This is done by increasing the cooling capacity of the head, decreasing the compression ratio and reshaping the combustion chambers. The inside of the combustion chamber was also textured to promote turbulence.

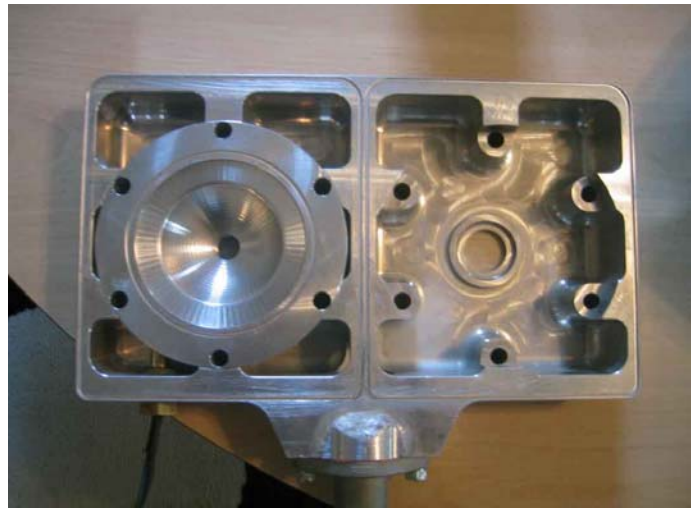

Figure 5: Cylinder Head Assembly

SUPERCHARGER LAYOUT

Early on in the development of this snowmobile, testing of our injectors indicated erratic behavior at levels above 7300 RPM due to high duty cycles. At this point it was decided that the engine should be built with a maximum operating RPM of 7000 to avoid these injector problems. It was then decided that the desired power level could not reliably be achieved at this operating speed on a naturally aspirated power plant.

Both exhaust-driven and engine-driven air chargers were considered. Due to the fact that this vehicle needed to be easy to ride and have smooth power delivery, a supercharger application was chosen. A centrifugal supercharger was selected for high efficiency and availability.

The supercharger assembly was rigidly mounted onto the engine using an aluminum bracket. This mounting bracket was attached to the recoil side of the crankcase.

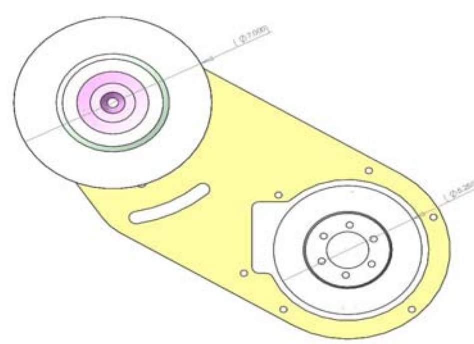

Figure 6: Supercharger mount design

TUNED EXHAUST

Two cycle engine performance is greatly improved by properly-tuned expansion chamber exhaust systems. Because the UACSC engine is extensively modified, a custom exhaust system was designed and fabricated. A mass-produced pipe would not work properly with our new porting specifications. The pipe was also to be positioned in such a way to leave a large volume available for silencer and catalytic converter placement.

There are many different available programs and equations on which to base tuned exhausts for a two-cycle engine. All are based around resonance. The diverging cones at the front of the exhaust serve to cool the exhaust and provide a vacuum to the exhaust port on the exhaust portion of the engine's cycle, which help purge spent gasses. The rear converging cone is used to reflect the pressure pulse back to the exhaust port and help pressurize the cylinder as the exhaust port is closing. This return wave also scavenges unburned fuel which is lost to the pipe during the intake process. Properly tuned exhaust is a crucial element to achieving both higher power and cleaner emissions in a two-cycle engine. The UACSC worked with Neil's Power Pipes, a custom two-cycle exhaust builder in Edmonton to develop our expansion chamber exhaust system.

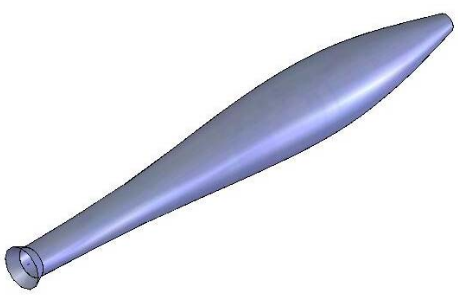

Figure 7: SolidWorks Modeling of Expansion Chamber

ENGINE MANAGEMENT SYSTEM

A Motec ECU was chosen for this snowmobile. This system allows closed-loop fuel mapping, sequential fuel injection, and full control over ignition mapping. An adjustable fuel pressure regulator was used to investigate the effect of fuel pressure on exhaust emissions. The sequential injection capability of the Motec ECU allows fuel injection at any crankshaft angle.

ACOUSTICAL ANALYSIS

To obtain the broadband noise level of the sled, sound pressure levels (SPLs) were recorded with various exhaust setups. SPLs were measured at 7m and 15m both at engine idle and at 4000RPM. The SPL approximately dropped by 6dB at a doubling of the measurement distance (15m), and hence the sled could be considered a point source.

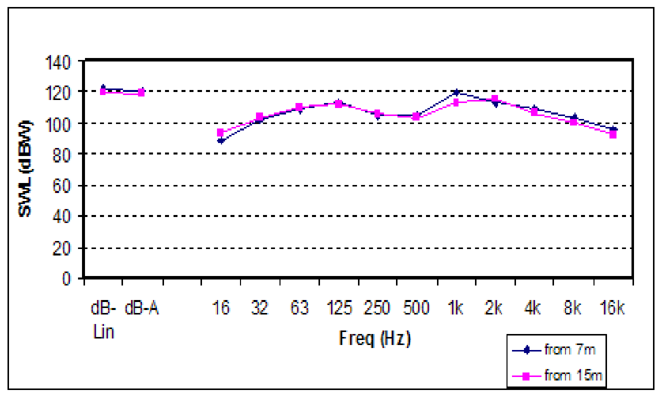

Figure 8: Octave Band noise levels of sled with no reduction system

From the acoustical results shown in Figure 8, the sled noise output was broadband in nature, and hence, the focus of our noise reduction strategy was to reduce broadband noise. To reduce this broadband noise, absorptive silencing methods were applied in three major areas; intake flow noise, mechanical noise, and exhaust/combustion noise.

Intake Noise Reduction

The increased intake air flow generated by a supercharger creates a larger level of noise than a normally-aspirated intake. To combat this, an intake silencer was implemented. To both reduce weight, by over 17lbs, and provide room for such a silencer, a light-weight, carbon fiber hood was provided by Mountain Mod Inc. The team designed an absorptive intake silencer in the cavity normally used for headlights and instruments in a stock hood (the carbon fiber hood has no headlight or instrument display). The silencer uses an 21cm long, aerodynamically-shaped Styrofoam baffle to remove 'line-of-sight' from the supercharger intake to the actual fresh air intake. The 2.5L intake chamber allows for noise reduction without impeding the maximally required 180cfm intake flow rate at 7000RPM. The air intake was routed through a 100cm^2 foam filter, behind the windshield of the hood, to minimize the chance of snow entering the air stream. The intake cavity was lined with 2.5 cm thick fiberglass blanketing to increase the sound absorptive quality of the silencer. Both the Styrofoam baffle and the fiberglass blanketing were covered with a formed plastic shield to stop any particles of foam or glass from entering the intake air stream.

Mechanical Noise Reduction

To maximize mechanical noise reduction, the engine compartment should be airtight and lined with acoustically absorptive material. Such a design was not unfeasible due to the large amount of heat emitted by the catalytic converters. The team compromised, implementing absorptive material on 83% of the hood lining while leaving 17% of the hood area vented to remove heat from the catalytic converters. SUM Canada Enterprises ltd. provided a custom-fitted sound absorbing hood liner for this purpose. This liner is specifically chosen for high noise and heat applications (above 300ºC).

Exhaust and Combustion Noise

The exhaust noise was highly broadband in nature, see Figure 8. Since broadband noise reduction is a thoroughly developed issue in the automotive industry, a commercial solution was deemed more efficient than a student-designed solution. The 2005 UACSC sled chose a stainless steel absorptive muffler for this heat-intensive and corrosive application.

EMISSIONS CONTROL

A major goal in the CSC is the reduction of harmful emissions. The UACSC has chosen the following strategy. The use of a supercharger allows excess air to be added to the engine system. This promotes efficient and complete combustion in both the engine and in the catalytic converters. With the addition of wide band, closed loop fuel injection, the electronic control module continuously compensates for changing altitude and weather conditions, which provides an efficient air to fuel ratio under all operating conditions. The third method of controlling emissions is the use of a catalytic converter. A 2-way catalytic converter is used to reduce carbon monoxide emissions, unburned hydrocarbons, and reduce oxides of nitrogen.

The custom fuel injection controller along with the cylinder-mounted fuel injectors allow for very accurate fuel delivery. The manifold uses a single 58 mm aluminum throttle body and two 88 lb/hr injectors. Fuel injector pulse width and angle of injection are dynamically stored in 512-point maps, based on throttle position and rpm. The controller constantly monitors engine and air temperature and O_2 sensor output, from which it makes fine adjustments to the fuel and ignition maps to maintain a efficient air to fuel ratio.

The exhaust after treatment consists of two, 2-way catalytic converters. The converters were purchased from Engelhard Corporation. Due to the R&D nature of these catalysts, their detailed product information must not be divulged. The converters are high temperature oxidation catalysts, with a cell density of 400cpsi, matrix dimension of 3.36 X 2.36 inches, and a volume of 20.926 $inch^3$. To increase the combustion efficiency in the catalysts, excess oxygen is added through supercharging the engine. A valuable characteristic of the 2004 UACSC team's two-stroke engine design is its ability to flow oxygen through the engine to the exhaust, while still maintaining an efficient air to fuel ratio during combustion.

With 80% of emissions occurring during cold start up it is critical to warm up the catalyst to operating temperature as quickly as possible. The Team's expansion chamber increases the exhaust temperature by forcing air to make an aggressive 90º exit at mid-chamber, instead of flowing smoothly at the end. To ensure quick light-off times, the entire exhaust has been ceramic coated by Perfection Powder Coating. This insulation helps maintain exhaust temperatures for proper catalyst operation.

Initial testing has shown a drastic reduction in emissions from the stock two-stroke snowmobile to the 2004 UACSC supercharged two-stroke platform. Table 3 shows the reduction in carbon monoxide, unburned hydrocarbons, and oxides of nitrogen. Further reductions will be obtained as the engine breaks in and the fuel maps have been optimized.

	CO	UHC	NOx
U of A Snowmobile	160	31	1.21
Stock Snowmobile	2154	386	5.9
Percent Reduction	93%	92%	79%

Table 3: Emissions reduction (ppm)

CONCLUSION

Using a MXZ-X chassis and modified Polaris 600 VES engine, the UACSC team will compete in the 2005 competition. The Polaris engine was outfitted with many features including CNC machined cylinders and heads, a supercharger, custom exhaust and an advanced engine fuel delivery system.

To meet the goals of the UACSC team a low emissions, high performance, quiet snowmobile was built. Extensive testing has proven our design practical and reliable. Through our modifications the UACSC team believes they have met their goal of manufacturing a lightweight, high performance sled that has significantly reduced emissions and noise.

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