2014 University of Waterloo Clean Snowmobile

Alec Espie
University of Waterloo Clean Snowmobile Team

ABSTRACT

The University of Waterloo Clean Snowmobile Team is debuting a new platform for the 2014 Clean Snowmobile Challenge. The new design combines a Weber MPE 750 Turbo engine with a Polaris Rush chassis. This continues Waterloo's strategy of combining high-output, small-displacement, four-stroke engines with lightweight chassis. Modifications to this platform include the addition of a three-way catalyst, stoichiometric tuning, an aluminum muffler, and an isobutanol-compatible flex-fuel system.

INTRODUCTION

Background

Snowmobiling is a popular winter recreational activity that has historically received substantial scrutiny for its environmental impact. Prior to the 21st century, snowmobiles were primarily powered by two-stroke engines with very little emissions control. This led to legal action being levied against the National Park Service for failing to uphold environmental regulations governing Yellowstone National Park, among others, due to the pollution caused by recreational use of snowmobiles in the parks. [1] It is from this controversy that the SAE Clean Snowmobile Challenge was conceived.

Undergraduate engineering students from across Canada and the United States compete annually to modify current production snowmobiles to reduce their tailpipe emissions, improve their fuel economy and render them quieter. The Challenge has also evolved to include the use of biofuels to improve the sustainability of snowmobiling as well. Most recently, isobutanol blends have been debuted as the competition fuel for the 2014 competition.

DESIGN

The University of Waterloo Clean Snowmobile Team's strategy for 2014 is to build a platform that combines a small-displacement, turbocharged four-stroke engine with a lightweight, durable rider-forward chassis and implement an isobutanol-compatible flex-fuel system and three-way catalytic converter. This platform is expected to serve the team for the next three years of competition over which some more ambitious modifications will be implemented.

Design Criteria

The design team has agreed on the following design criteria to evaluate design alternatives:

- Maximize trail performance
- Minimize emissions of carbon monoxide, unburned hydrocarbons and oxides of nitrogen
- Minimize noise
- Minimize snowmobile weight
- Minimize overall cost

Design Constraints

For the 2014 UW Clean Snowmobile to be considered successful, the following constraints must be met:

- The safety of the rider must be ensured
- The snowmobile must be able to operate on isobutanol blends up to 32%
- All fuel system components must be compatible with isobutanol
- Noise emissions must not exceed 78dB at a distance of 50ft
- The engine must, after being cold-soaked, start within 20 seconds and be able to travel 100 feet in 120 seconds without stalling

Engine Selection

This year, Waterloo has elected to use the Weber MPE 750 Turbo which has been used in Polaris Industries' FST snowmobiles. This engine is capable of delivering up to 140hp in its original application and thus leaves some allowance to meet the 130hp limit with the added flow restriction from the modified exhaust system.

In previous competitions, Waterloo has used an Arctic Cat T660 Turbo engine. While this engine was moderately lighter and had a smaller displacement, the team was still having difficulty adapting its lubrication system and power takeoff to the tight space of a rider-forward chassis. The switch to the MPE 750 allows the team to focus on competition objectives rather than troubleshooting oil leaks.

Flex Fuel System

Isobutanol blended gasoline is being introduced as the competition fuel for 2014. Given that isobutanol's stoichiometric air/fuel ratio is lower than gasoline's, the base fueling for the engine needs to be adjusted accordingly (Figure 1). Furthermore, because the blend ratio is not fixed, the fueling must also be adjusted dynamically.

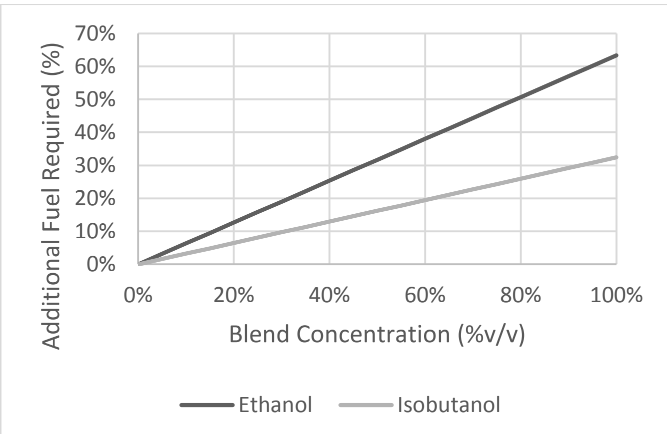

Figure 1. Additional fuel required vs blend concentration for ethanol and isobutanol

Historically, two flex-fuel strategies have been employed by teams: closed loop operation with a wideband oxygen sensor or fuel composition sensing (with or without closed loop feedback). For Waterloo's 2014 snowmobile, as in the past two competitions, the latter is used.

Sensing the fuel composition directly has the advantage of allowing a tighter limit on the amount of long-term compensation the closed loop system is allowed to accumulate, preventing damage in the event of a wideband sensor failure. Moreover, keeping the systems separate allows the aim lambda value to be varied based on the fuel used. This allows, for example, leaner mixtures to be used when the fuel is predicted to have a higher knock index.

Recent developments in fuel sensor technology have made composition sensing substantially more economical. Where the Siemens sensor the team has used in the past cost between CAD$300-600, General Motors part number 1357729 costs approximately CAD$80. This new sensor outputs the same signal as the previous one and thus, with the exception of requiring a different connector, is a drop-in replacement and is well-documented.

Both versions of the sensor are designed for ethanol blends and thus their applicability to butanol blends is untested. The sensor outputs a frequency-based signal based on the capacitance across an annular section of fuel which varies linearly with the composition of the fuel. It thus stands to reason that, if the dielectric constant of isobutanol is between that of gasoline and ethanol, the sensor can still be used. Moreover, if the difference in stoichiometric air fuel ratio is equivalent to the difference in dielectric constant (Table 1), the same fuel compensation table could be used and the snowmobile could run both ethanol and isobutanol blends.

Table 1. Fuel properties

Fuel	Stoichiometric AFR	Dielectric Constant
Gasoline	14.7	2
Ethanol	9	24.55
Isobutanol	11.1	16.68

Based on the relative stoichiometry and dielectric properties of the three fuels and on the sensor output, it is evident that the sensor can be used for isobutanol. It is also evident that the system could only be adequately calibrated for one of ethanol or isobutanol as the difference in compensation becomes pronounced at blends as low as 20% ethanol or 30% isobutanol (Figure 2).

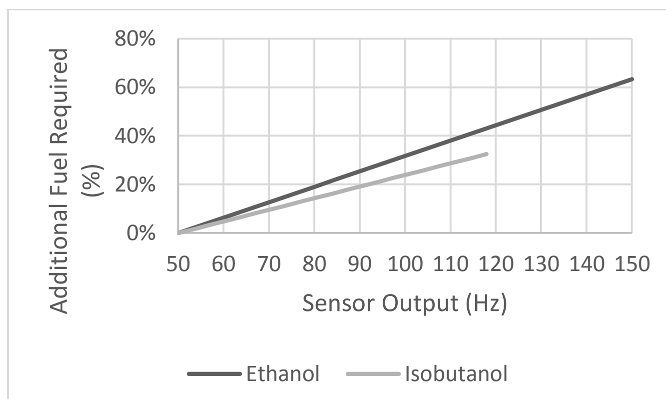

Figure 2. Additional fuel required vs sensor output for ethanol and isobutanol blends

In order to have full control of the fueling strategy, a Motec M400 engine control unit is used. Flex fuel compensations are achieved through a 2D transform table.

Sound Reduction

Turbocharged engines are typically quieter than equivalent normally-aspirated engines, owing to the damping effect the compressor and turbine blades have on intake and exhaust pulses. However, the MPE 750 has an intense exhaust sound due to its large displacement per cylinder and will require diffusion of the exhaust stream to lessen the sound intensity.

The primary mode of exhaust sound attenuation comes from a single-element, double re-entrant diffuser (Figure 4). Because the re-entrant portions are of different lengths, the attenuation profile has two peaks. Ideally, these should occur at the primary frequencies of the cruising engine speed and at the CVT hold speed (that at which the CVT holds the engine during acceleration). The reasoning behind this is that the cruising speed is where a trail sled will operate most of the time and that the CVT hold speed is where the engine is under the most load, displacing the most air and thus producing the most noise.

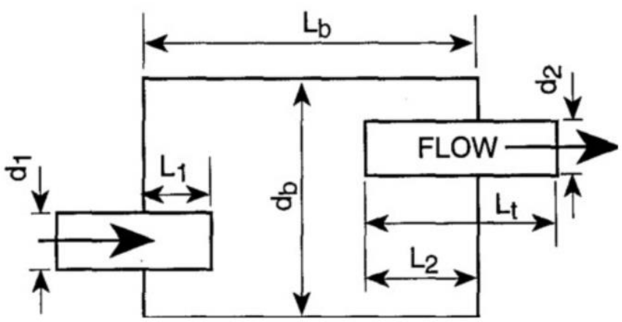

Figure 3. Re-entrant diffusion muffler, Blair [2]

Due to time constraints, the muffler from the Team's previous 3-cylinder snowmobile was used and thus the attenuation peaks occur at much higher engine speeds than the MPE 750 would be able to remain assembled for. However, the muffler should still be able to, in theory, reduce the noise to a passable level assuming the untreated intensity is less than 10dB (Figure 4).

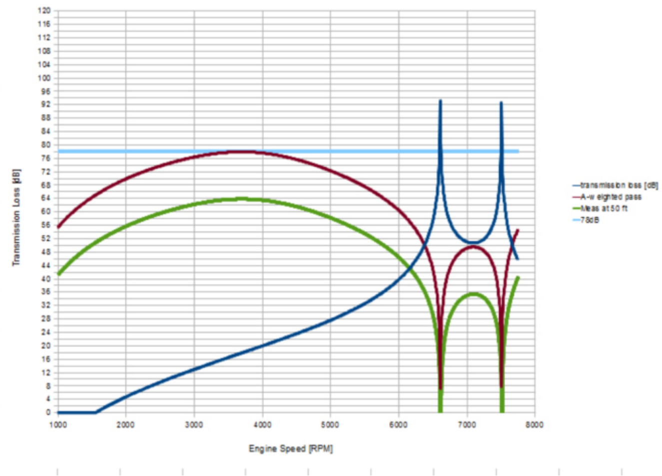

Figure 4. Attenuation profile for muffler on a 3-cylinder engine assuming 100dB untreated noise emissions

Drivetrain and Chassis

A large amount of energy loss on a snowmobile comes from the drivetrain and chassis. Mitigating these losses is a very important part of reducing the snowmobile's fuel usage and therefore its overall emissions.

Idler Wheels

Typical track idler wheels are required to rotate at considerably high speeds whenever the track is spinning. Frictional losses in bearings, assuming a constant coefficient of kinetic friction at trail speeds, are proportional to the angular speed of the idler wheel which is, in turn, inversely proportional to the diameter of the wheel. The rear idler wheels are constantly subject to force applied by track tension, the weight of the snowmobile, and by transient force from acceleration. As such, the bearings of these rear wheels present the highest potential for loss-reduction. Furthermore, the track is constantly deformed as it passes over the rear wheels. Energy is converted to heat as a result of the bending strain imposed on the track. Assuming the losses are roughly proportional to the curvature (inverse of radius) of the track passing over the rear wheels, an increase in rear wheel diameter will reduce such losses. The stock rear wheel diameter is 180mm (7.125 inches). A modified diameter of 8 inches would be easily accommodated by an offset axle without requiring a longer track or any modification of the skid frame. Using the theoretical loss relations assumed above, the reduction of steady-state losses at the rear idler wheel (neglecting inertial effects) is as follows:

$$\%reduction \sim 100 - 100\left(\frac{D_{old}}{D_{new}}\right) \qquad (1)$$

Using the above formula, the percent reduction in frictional losses and bending losses for substituting 8 inch rear wheels is approximately 10.9%. The aluminum extrusion used for the

Rush's slide rails is tall enough to accommodate a taller rear wheel section (the front arm mounting section is much taller). The only foreseeable added cost would be for larger rear wheels.

Figure 5. Offset axle and 8-inch rear idlers

Track

Under slippery conditions, energy can be lost to slippage of the track. The UW Clean Snowmobile Team has elected to use a factory pre-studded track with studs moulded into the lugs to increase traction with a reduced impact on rolling resistance versus traditional studs. By doing so, more of the power delivered to the track is converted into forward motion. The added rear traction also benefits cornering performance, reducing oversteer and thus allowing the rider to maintain a consistent speed through cornering, reducing the need to accelerate when exiting a curve.

Battery

A lithium iron phosphate battery has been chosen to reduce the weight of the electric start system required by a four-stroke engine. This battery weighs less than three pounds and is substantially smaller than the absorbent glass mat battery it replaces. This reduced the snowmobile's weight by approximately 10 pounds while still providing 360 cold cranking amps for cold starting.

SUMMARY/CONCLUSIONS

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CONTACT INFORMATION

Alec Espie
Author
waespie@uwaterloo.ca

Nick Mulder
Team Lead
nmulder@uwaterloo.ca

Kristen Sperduti
Team Lead
kasperdu@uwaterloo.ca

Peter Teertstra
Faculty Advisor
Department of Mechanical Engineering
Peter.teertstra@uwaterloo.ca

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