École de technologie supérieure's High Pressure Direct Injection Two-Stroke Flex Fuel Snowmobile

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ABSTRACT

The École de technologie supérieure's participation to the 2012 Clean Snowmobile Challenge (CSC) was powered a high pressure direct injection (HPDI) snowmobile capable of running on various types of fuel and ethanol mixtures. The HPDI engine was designed to help raise fuel economy and lower exhaust emission while sacrificing a minimum of the engine power output. With our new compact exhaust design with integrated catalyst, Team Quiets snowmobile has now better lab emissions results with lower HC, NOx and CO levels and is confident that our new exhaust system will be reaching an estimated and targeted decibel sound level of 68dB.

INTRODUCTION

In a time where the reduction of greenhouse gases matter, the contribution of a handful of engineering student to Team Quiets' student club show the determination and care of the new generation of engineers on the verge of entering the market. This competitions gives us the chance prove and show global manufacturers that current environmental standards do not limit design and innovation, and that it is possible to surpass them without destroying what really makes this winter sport enjoyable. This competition does not only put our name and our school at stake but also the reputation of the future generation of engineers entering the market to take over environmental problems. With that said, Team Quiets is setting the bar a level up with new objectives such as lower fuel and oil consumption, reduced harmful exhaust emissions and reduced decibel levels to obtain the best and most environmentally friendly snowmobile. Our ultimate goal is to change the criticizing image given by the consumers towards the 2 stroke engines, bringing them back in style by proving and demonstrating that the 2 stroke can be less polluting and that they can have a better fuel economy with the proper modern modifications. We hope that our efforts in the reduction of emissions will reverse the stigma amongst consumers that 2-stroke engines are "dirty".

ÉTS SNOWMOBILE MODIFICATIONS AND SELECTION

SNOWMOBILE SELECTION

For third consecutive year, the snowmobile choice for Team Quiets will be the 2009 MXZ TNT from BRP equipped with a modified 2 stroke E-tech engine. Not only is this sled an optimum choice because of its excellent handling, light weight engine and chassis, but it is the perfect solution to accommodate our HPDI system. On a more personal note, being one of the only teams from the Quebec region of Canada, the selection of homemade product is a way to show our support towards Canadian recreational products.

ENGINE CALIBRATION

The original control module from the stock snowmobile was removed and replaced with a MotoHawk® ECU555-80 controller. The ECU555-80 is a purpose-built ECU based around the Freescale (Motorola) MPC555 processor running at 40MHz. It designed to withstand engine vibration, electromagnetic interference, submersion in water, and is able to function within a large range of temperatures (-40ºC to 105ºC). In addition to being robust, the ECU555-80 also comes with a full development and calibration suite.

We believe that the reduced downtime during development and experimentation by choosing a purpose-built ECU over a generic or homebrew solution more than justifies the additional cost. We have been progressively improving our embedded software over the years by both restoring old functionality such as the dashboard warnings, and adding new features such as a Flex-Fuel sensor.

OIL INJECTION

One of our major setbacks in 2011 was poor emissions performance, which we largely attributed to the injection of too much oil. The inherent risk of engine failure from under-lubrication, along with the highly proprietary nature of oil injection data has presented a major hurdle in our attempts to calibrate the oil injection map. However, our recent success in tuning the overall engine has allowed us to focus our efforts on adjusting the oil calibration. The amount of oil to inject is now based on the amount of fuel flowing into the engine, instead of an arbitrary amount based solely on throttle position and revolutions per minute. We believe that this will remove a significant amount of guesswork from the calibration process.

	0.00	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00
0.00	200.00	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.00
500.00	200.00	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.00
1000.00	200.00	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.00
1500.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00	85.00
2000.00	81.67	81.67	81.67	81.67	81.67	81.67	81.67	81.67	81.67	81.67	81.67
2500.00	78.33	78.33	78.33	78.33	78.33	78.33	78.33	78.33	78.33	78.33	78.33
3000.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
3500.00	71.67	71.67	71.67	71.67	71.67	71.67	71.67	71.67	71.67	71.67	71.67
4000.00	68.33	68.33	68.33	68.33	68.33	68.33	68.33	68.33	68.33	68.33	68.33
4500.00	65.00	65.00	65.00	65.00	65.00	65.00	65.00	65.00	65.00	65.00	65.00
5000.00	61.67	61.67	61.67	61.67	61.67	61.67	61.67	61.67	61.67	61.67	61.67
5500.00	58.33	58.33	58.33	58.33	58.33	58.33	58.33	58.33	58.33	58.33	58.33
6000.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00	55.00
6500.00	51.67	51.67	51.67	51.67	51.67	51.67	51.67	51.67	51.67	51.67	51.67
7000.00	48.33	48.33	48.33	48.33	48.33	48.33	48.33	48.33	48.33	48.33	48.33
7500.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
8000.00	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67
8500.00	38.33	38.33	38.33	38.33	38.33	38.33	38.33	38.33	38.33	38.33	38.33
9000.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00

Figure 1- Oil calibration map filled with fuel:oil ratios (these values are for demonstration purposes only).

Despite these advancements, we will still be running our oil injection on the conservative side, as we would rather have a slightly “dirtier” engine than no engine at all!

FLEX-FUEL

With oil becoming scarcer and the burning of fossil fuels taking its toll on the environment, there has been an increasing demand for cleaner, more sustainable fuels such as ethanol. The Clean Snowmobile Challenge has been encouraging the use of ethanol/gasoline blend fuels by making it a requirement that all participants in the internal combustion category are capable of running their snowmobiles on Flex-Fuel. Ethanol contains less energy by volume than gasoline, which means that more must be injected into the combustion chamber to compensate. In order to determine how much extra must be injected, we have employed a Siemens Flex-Fuel sensor from a GM series vehicle. The Flex-Fuel sensor generates a frequency that varies depending on the quantity of ethanol passing through it, allowing the ECU to determine exactly how much ethanol is being used and compensate the injection time accordingly.

Figure 2- The output of the Flex-Fuel sensor shown on an oscilloscope.

As an added feature, the Flex-Fuel sensor also varies the pulse-width as a function of the fuel temperature. This is beneficial to our research, as our high-pressure fuel system is likely to heat the fuel by a certain amount. With the sensor, we will be able to tell by exactly how much it is being heated, and whether it is a cause for concern. Sadly, although we were able to implement the Flex-Fuel sensor, we did not have enough time to build the compensation map for the different levels of ethanol. Therefore, we have decided not to employ the Flex-Fuel sensor in this year's competition, but we expect to have it operational soon afterwards since all that is left to do is the calibration.

DASHBOARD

After having replaced the stock ECU, we largely neglected the various dashboard indicators. This year, we made a point of re-integrating some of the more critical dashboard warnings, such as engine and exhaust temperature. We also repurposed the invalid DESS key warning to report any significant drops in fuel pressure. This not only provides the obvious advantage of being able to preempt any catastrophic engine failure, but also provides insight into the conditions of the engine during "real world" testing as well as on the test bench.

ACOUSTICS

The modifications made for the 2012 competition towards acoustic improvement and performance were concentrated towards the design of a new custom exhaust system and the insulation of the engine cabin. After evaluating sound emissions and they're origins, we determined that the use of a modified exhaust system took care of tailpipe sound emissions but left the out engine vibrations and knocking from the tune pipe. Being restricted by space in the 600cc model, the decision was took to convert the skidoo with the cabs from the 1200cc model, giving us on average more than an inch all over the cab volume. With this extra space, our limitation to the exhaust design and cab insulation had been eliminated.

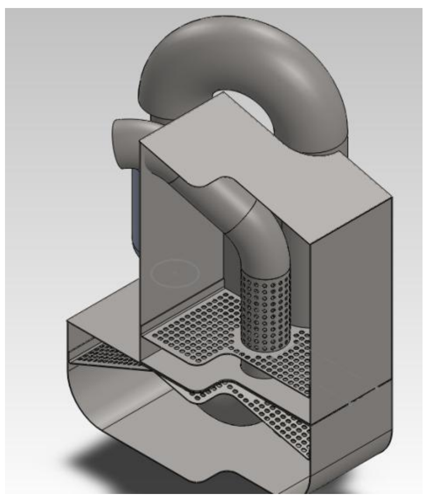


Figure 3 – Team Quiets 2012 exhaust design

The first step in the new exhaust design was to collect sound emissions data from a stock 600cc E-TEC sled. Using SAE J192 procedures, we were able to collect the average decibel levels and frequencies show in red in the graph below. By targeting unwanted frequencies, the proper dimensions for resonators were calculated and applied to the new 2012 exhaust shown above. To achieve our 65 dB goal, the exhaust was designed to make a loop with 6 inches radius elbows limiting exhaust restrictions. The first chamber serves as an absorption chamber and attenuates the sound wave. The first chamber is also combined with a resonator allowing one specific frequency to be eliminated. The second chamber in the 180 degrees elbow contains two resonators allowing two other unwanted frequencies to be eliminated. The targeted frequencies were high frequencies that would sound annoying to the ear. The last loop bringing the exhaust back down serves as an absorption tunnel before allowing exhaust emission to leave the system. Due to a lack of time, the final product for the 2012 CSC was not properly tested therefor no results have been published.

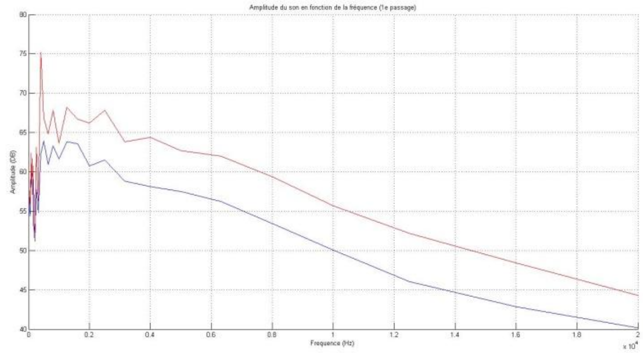


Figure 4 -2009 600cc E-TEC sound emissions

EMISSIONS REDUCTION

In an attempt to optimize the reduction and elimination of harmful gas emission, Team Quiets opted for the integration of a catalytic converter to the exhaust system. An attempt was made at the last competition season but was removed due to unstable results and uncontrolled afterburner effect. With the new exhaust design, the proper catalyst converter had to be selected in order to eliminate the targeted gases. With the help of Aristo and Emitec, Team Quiets was able to obtain a catalyst suited for its 600cc modified E-TEC. The suggested product is a Three-Way formulation catalyst designed for high temperature stability coupled with excellent conversion efficiencies.

CATALYST SPECIFICATIONS AND ISSUES

The Three-Way catalyst substrate is composed of two main areas. The matrix is composed of a stainless steel foil wound which provides 400 cells per square inch. The mantle, also composed of stainless steel, has a 3.5 inch diameter with a total volume of .55L. The washcoat is an alumina-based Three-Way formulation stabilized with Rare Earth Oxides for high temperature durability and good adhesion to the metal foil. A comparison was made with our previous oxide catalyst. As seen in the illustrations below, both catalysts seem to have the same reaction to the stoichiometric mixture of exhaust passing by.

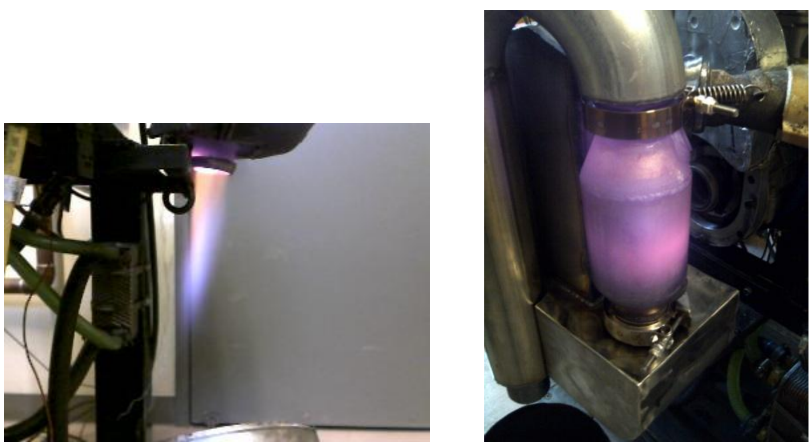
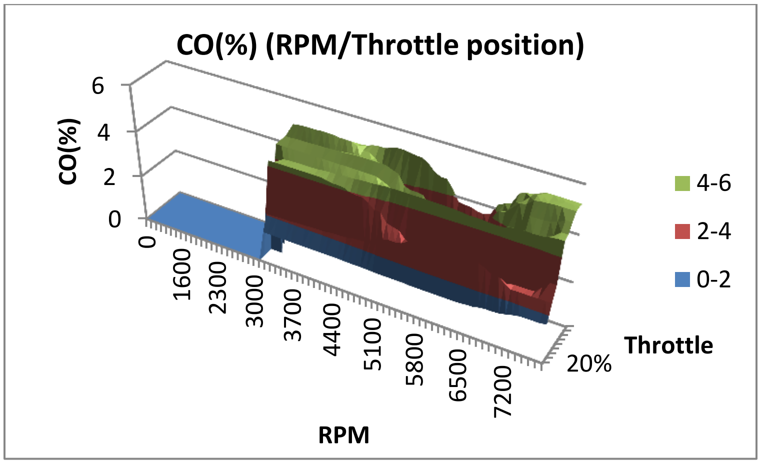


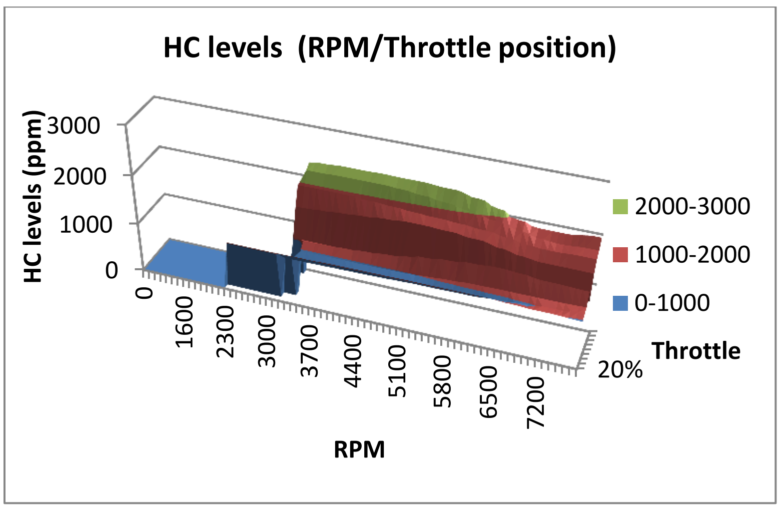
Figure 5 – Three way and oxide catalyst testing

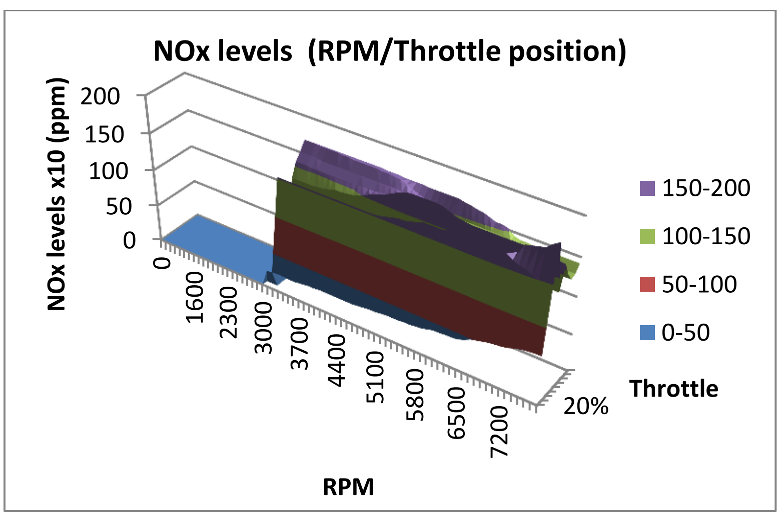
Temperature for both catalysts reached an average of 800 degrees Celsius around 5000 RPM at 70% load. The picture on the left shows the integrated oxide catalyst and the one on the right shows the new 2012 design with three way catalyst. It is believed that this reaction is due to the high level of HC passing through. Possible solutions would be to lean the engine mixture or old back on the ignition angle. The team is still trying to work on reducing the temperature in the catalyst.

LAB EMISSIONS RESULT

In an effort to reduce its past high CO, HC and NOx levels from the 2011 CSC, all efforts were concentrated towards the reduction of the custom oil injection mapping. Having been able to get the HPDI technology to work with minimal engine calibration, Team Quiets doubled its effort to optimize the engine calibration for both fuel injection and oil injection timing. The 2011 oil map was designed to help the engine last as long as possible since not enough data was collected on time before the past competition. Now with more knowledge towards cylinder, RAVE lubrication and new sealed base bearings, the oil map was dramatically reduced allowing us to get better lab emissions results as shown below in the three graphs. Fuel injection timing was also reduced to bring the engine to a stoichiometric state.







OTHER MODIFICATIONS

GAS LINE MODIFICATIONS

Having experienced fire hazard problems at the CSC 2011, modification had to be done on the sled to assure such a problem would never occur again. One of the potential problems we experienced was fuel leaks around the engine. The past fuel line setup was composed of flexible hoses fairly large in diameter to sustain the high pressured fuel. These hoses were not organized and would get in the way of accessing the engine bay and components around it. The quick connects and collets would also tend to leak and wear off with time as a result of fuel passage. The solution was to replace the flexible lines with rigid stainless steel line with a smaller diameter, thus reducing the amount of quick connects and collets.

OIL TANK

The previous version of our oil tank caused many problems regarding oil leakage and pump adapter. The solution to that problem was to design a new container with the same volume capacity and adapter for our electric oil pump.

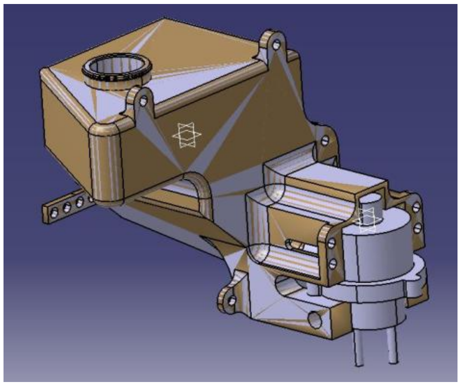


Figure 6 – Team Quiets 2012 oil tank design

As seem in the illustration above, the new oil tank design allowed us not to save on space in the sled, but also to integrate the new electric oil pump, thus reducing the amount of tubes and adapter from the tank to the oil pump.

MSRP

The Manufacturer's Suggested Retail Price (MSRP) for our modified MX-Z 600 E-TEC is estimated at $15,399. The stock new Ski-Doo is $10,199. The donated high pressure fuel pump come to $2000, $400 for the high pressure injectors. The entire exhaust cost around $200 plus an estimated $700 for the catalyst. Electronic control unit comes to $2000.

SUMMARY/CONCLUSIONS

In conclusion to this report, Team Quiets has solved a number of problems on our HPDI projects. Our new exhaust system with integrated catalyst, insulated cabs and optimized HPDI engine oil and fuel mapping were all designed to surpass the environmental standards and set the lead in the snowmobile industry. All though not all aspects of the snowmobile were tested due to a lack of time, we are confident and hope to surpass last year results.

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CONTACT INFORMATION

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DEFINITIONS/ABBREVIATIONS

CSC	Clean Snowmobile Challenge
HPDI	High Pressure Direct Injection
HC	Hydrocarbon
CO	Carbon monoxide
NOx	Nitrous oxide