École de technologie supérieure (ÉTS)

Direct Injected Two-Stroke Snowmobile

Clean Snowmobile Challenge 2010 Design Report

Abstract

Team Quiets is very proud to take part in the 2010 Clean Snowmobile Challenge hosted by Michigan Tech University. The team uses the same sled as last year. A 2009 TNT, Direct Injection, 2 strokes 600cc from BRP. The engine is fuelled by E20 up to E29 as per the CSC 2010 rules. The engine has been fitted with a Mototron controller from Woodward Inc. that allows a full engine calibration. This year the squish velocity and compression ratio combustion chamber are stock. We are using an E-TEC cylinder head. Since the team has learned a lot on the competition last year, we are eager of seeing how well our sled competes against other teams this year. In the present technical paper, you will see the modifications done and the different reasons that motivated our decisions.

Introduction

Since the creation of the snowmobile in 1960 by J-Armand Bombardier in Québec, Canada, this product has known a great popularity throughout the country and North America. With an annual average sale of more than 57 000 snowmobiles in Canada, for the past twelve years, this winter sport has an important economic impact. In Canada only, it's a business that generates over $6 billion CAD annually. This situation is proportionally the same in the province of Quebec. Each year about 800 000 people practice snowmobiling throughout the province. It's also an appreciated activity by tourists that generates a direct economic profit of around 752 M$.

However, this circulation involves significant consequences. Since December 1st 2004, the court of Quebec ordered a judgment prohibiting the use of snowmobiles on approximately thirty eight kilometers (km) in the Mont-Tremblant area on the linear park of "Le Petit Train du Nord". Also there is another 120 km near the region of Lachute that has been prohibited. This legislation originated from complaints of owners, living a few hundred meters away from the path. They considered unacceptabl the noises emitted by the snowmobiles [1]. This new rule had huge consequences on the snowmobile tourism industry and several jobs were endangered.

To resolve this situation and to assure the survival of the region winter tourism, new technological solutions must be proposed and used. Those solutions must give the same good performances while being environmentally friendly.

Since 1998, the Society of Automotive Engineers helps to improve and find innovative ideas for the snowmobile world by hosting each year, the Clean Snowmobile Challenge (CSC). This competition is opened to colleges and universities in North America. The goal is to modify an existing standard snowmobile and make it more ecological. Mainly by reducing its fuel consumption, the levels of pollutants and the noise emitted by the sled. The students must also ensure good performances to keep a certain appeal for consumers. For this year, the CSC 2010 will be held in Michigan's Keweenaw Peninsula from March 15th to March 20th. Representing the province of Québec, QUIETS, from the "École de Technologie Supérieure" in Montreal, Canada will be participating for its seventh year at the challenge.

Participating to the project as volunteers, the team members do not receive any credits for this project. To realize their achievements, each member worked on building sponsorships by developing a technological partnership with different companies.

The following paper describes in details the modifications made to the sled and their specific reasons. The first section describes how the team was able to keep a maximum performance while making important changes in order to reduce fuel consumption and pollutant emissions. The second section treats of the noise reduction and the different systems used to achieve our goals. Finally, we have included a small analysis summarizing the overall modifications costs. In the end, the sled proposed by team QUIETS is economical, reliable, powerful, environmentally friendly and is a good contender in the 2010 CSC.

ETS – CSC SNOWMOBILE DESIGN

CHASSIS SELECTION – Quiets ETS team selected a 2009 BRP Ski-Doo XP TNT chassis. This chassis offers lightweight, excellent handling and good modification opportunities, while reflecting the newest technology available on the market.

CALIBRATION - There is relatively no calibration freedom due to the nature of the CVT transmission, typically peaky nature of high specific power two-stroke engines and the slightly variable resonant frequency of the tuned pipe. Due to the large sudden load changes typical of snowmobile operation, we steered to a calibration focused on part load efficiency. This means that the time the engine is run under high engine load but low or mid engine speed will occur only in the transient state, we chose to put our efforts in the partial throttle engine operation calibration. Angle of injection is retarded in order to minimize the amount of unburned fuel that will be lost in the tuned pipe and the associated unburned hydrocarbon emissions and fuel consumption

INJECTION SYSTEM OVERVIEW - It is almost impossible for a SDI two-stroke engine to have an emission level that complies with new EPA laws and regulations based on average serial-produced engines emission results. The E-TEC system is considered similar to the FDI injection and since BRP's E-TEC injection system is compliant with the new EPA regulations, a decision was taken to proceed with the development of the DI prototype.

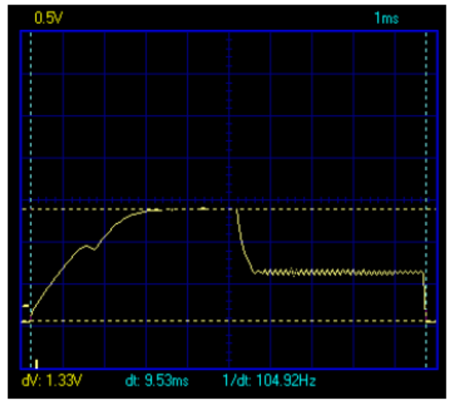
We decided to do a High Pressure Direct Injection System, using standard, off-the-shelf Gasoline Direct Injection (GDI) components that are already produced on large scale in the automotive industry. During stratified injection, crankshaft rotation available for mixture preparation before TDC is limited, thus this system must have a high flow rate and very fine fuel atomization in order to rapidly prepare the mixture and to have better control of short circuited fresh-charge during the transfer part of the engine cycle.

Normalized emission levels

	HC	CO	NOx
Rotax 593 E-TEC	100%	62,5%	100%
Rotax 593 SDI	87,3%	100%	42,4%

Table 1

INJECTORS - We chose high pressure fuel injectors operated at a nominal pressure of 100 Bars with a static flow of 15, 0 cm3/s (615g/min) to match the requirements of the engine. These injectors can be operated at a pressure of up to 125 bars. Those injectors are meant to be used with "peak-and-hold'' electrical injector power stage circuitry, which is handling by our ECU. The ECU first slowly increases current in the injector without reaching the level required to open it, then rapidly increases current obtained with a momentary voltage of around 90V up to a peak value of 15A and finally reduces the current to successively lower levels to limit the energy consumption. This results in more precise flow control and reduced injection time/flow rate ratio.



FUEL PUMP - The pump used for the injection system is a mechanically driven high pressure normally used in four-stroke engine. We decided to drive the pump with an electrical motor, whose speed can be set by the ECU. This has both simplified the assembly and avoided all potential mechanical and thermal problems associated with a pump that would be driven by the engine itself.

FUEL INJECTION SCHEMATIC - The fuel pressure is set to the target level with a Pulse Width Modulation (PWM)-controlled regulator and a mechanical check-valve. PID control is implemented with help of the pressure sensor and the electrical pressure regulator. Regulator return line is routed back to the tank.

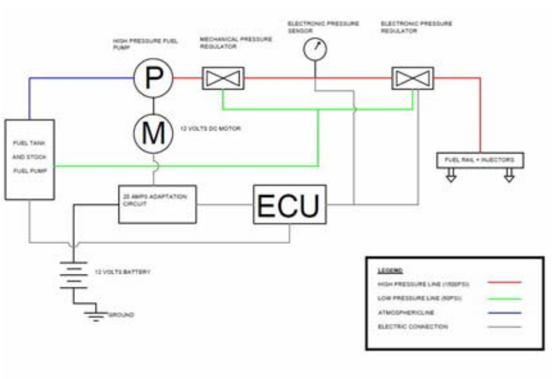
Modifications

FUEL CONSUMPTION & EMISSION CONTROL – Last year's research convinced the team that new combustion chamber geometry had to be modified in order to use maximal fuel efficiency with 85 % ethanol content. This year, the low content of 20% to 29% of ethanol in the fuel was not considered sufficient for redesigning a new combustion chamber.

IGNITION – This year, the Quiets team doesn't equip the engine with dual spark plug cylinder configuration. The new 2010 competition ethanol content does not require any modification. The only design that we made as to make an ignition module because our ECU doesn't have these component embedded. The solution was simple; we used the same components as original ECU. The missing components are IGBT MOSFET. We packaged the components in a small metallic box.

RAVE CONTROL – Since our engine is equipped with a 3D RAVE valve (Rotax Adjustable Variable Exhaust) system, which modifies the exhaust ports using crankcase positive pressurization. This technology permits control of the closing/opening exhaust ports by the ECU using a solenoid. This allows higher torque in low RPM range while allowing higher power readings at high RPM - [2].

FUEL COOLING EFFECT ON PISTON- It is important to keep in mind that, ethanol has a higher octane level than ordinary fuel. It also produces less vapor emanations than regular gas at low temperature because of its low flash point (Approximately 286.15 K for ethanol versus 230 K for gasoline). Ethanol does not releases as much energy as regular gasoline because of its lower heat of combustion, the calorific value of E85 is 22790 KJ / L versus 31800 KJ / L for regular



petroleum fuels. To keep the same power out of the engine we would need to inject about 40 % more fuel in the engine. The more gas injected in the cylinder the more the piston is cooled. Higher ethanol content results in higher piston cooling.

OIL SYSTEM - The engine RAVE system and engine are lubricated by an electrical oil injection system. A solenoid activated oil pump normally used in outboard engines was chosen to channel oil to the engine according to the oil flow calculated by the ECU. Variable engine lubrification is achieved according to engine operation parameters. Normal lubricant oil system on a two- stroke engine is total-loss oil system compare to recalculated oil system in four-stroke engines.

This system was adapted on our modified SDI engine. This system eliminates premixing and lubricates specific parts of the engines by oil injectors. On DI engines this technology reduces up to 50% the oil consumption [9]. Using this technology oil is normally mixed in the fuel tank or mixed in the inlet-air stream like the olds carburetor and SDI technologies on our SDI engine will bring the same reduction of oil consumption.

Additionally, when ethanol is used as fuel in a two-stroke engine, it obligates us to find the perfect oil/fuel mix. We have done some research on the different types of oil. We found out that the perfect oil that mixes well with alcohol is beaver oil. Other oils had tendency to separate with alcohol. After an elaborate research on which company makes that kind of oil, we found out that the only one is a company named Klotz oil. By talking with technical advisors, they helped us find the best oil for our project. Our choice was stopped on Super Techniplate KL-100 [7].

EMISSION - At the time of writing this paper, the possibility of putting a catalyst in the tune-pipe is being analyzed. Knowing that this technology needs high temperature to ensure good results, team Quiets is trying to figure out a way of fitting the catalyst inside the tune-pipe without changing the pipe tuning. This catalyst position has been chosen to use the high temperature that occurs by proximity of the exhaust ports.

NOISE REDUCTION - In order to reduce the noise emitted by our snowmobile, the different sources had to be assessed. Therefore a noise analysis was made on our snowmobile. The main sources could then be determined and solutions could be developed. The results of our analysis showed that the primary sources of noise were, in no particulate order: the muffler, tune-pipe, engine, drive-train, track, rails and wheels, as shown in figure 5.

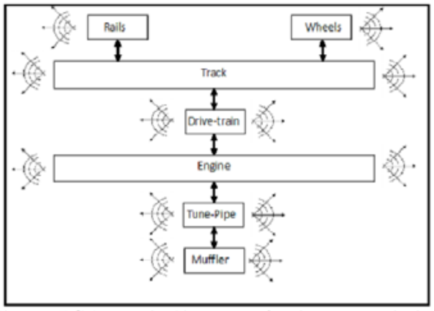


Figure 5 Schematic diagram of noise transmission

In this diagram, force transmission between the parts and acoustic dispersion of the parts themselves are represented. Since every noise emitting part does so in a particular way, each part had to be studied individually. Consequently, a unique solution was implemented for every source. Since this sled is the same as the one used during the 2009 Clean Snowmobile Challenge, our goal this year was to improve on last year's results. So our baseline for this year was 72 dB (A). Since it's not practical to accurately measure the overall noise emitted by a snowmobile, we decided to make improvements based on our research and then to get an accurate measurement at the 2010 competition. Some tests where made prior to the 2009 CSC to determine stock numbers but deemed inaccurate due to the results of the 2009 competition. The stock numbers then obtained at the 2009 CSC is presented in table 3.

Table 3 SAE-192 results for stock sled

Frequency	125	250	500	1k	2k
dB(lin)	64.9	66.7	66.7	59.5	59.9

In this section are explained the modifications made to every major sound emitting part.

CHASSIS - The material of which the chassis is made easily propagates vibrations. Sounds produced under the cab are then transmitted throughout the chassis to every other component. To counter this, the frame was covered with a high strength resistive material on the outside to act as a sound barrier and a damping material on the inner side tunnel to work as an absorber. These modifications were made to absorb the vibrations emitted through the frame in order to limit the effects of sound transmission. The material added to the inside tunnel also absorbed the noise created by the snow hitting it while the sled was in operation.

ENGINE - The engine, a two-stroke, is the major sound-emitting part in a snowmobile. To be precise, this is primarily due to the transmission effect, though the intake and exhaust. Since it's the most prominent, we decided to firstly address the exhaust noise. By design, a two-stroke exhaust system is calibrated to a specific engine. Since the engine used in our sled is very sensitive to variation in backpressure, a system that does not disturb the flow of exhaust gases had to be used. By analyzing the stock tune-pipe, it was determined that it could easily be modified to become a Helmholtz resonator by adding a small pipe at its end. Figure 6 represents a schematic drawing of the modification made to the tune-pipe.

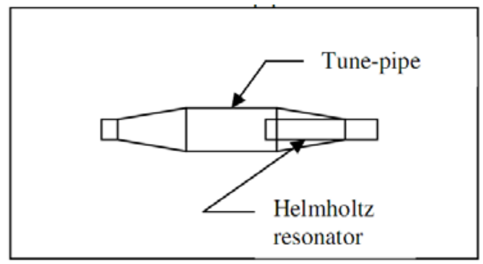


Figure 6 Schematic tune-pipe Helmholtz resonator

Then, to further reduce the noise level coming out of the stock muffler, a sound absorbing active muffler was designed and added at its end. This muffler is located below the foot rest, out of the driver's way. This added muffler is built using the sound cancelling properties of a Helmholtz resonator. The figures below present the theoretical noise cancelling properties of a standard size resonator depending on the frequency it's being used at.

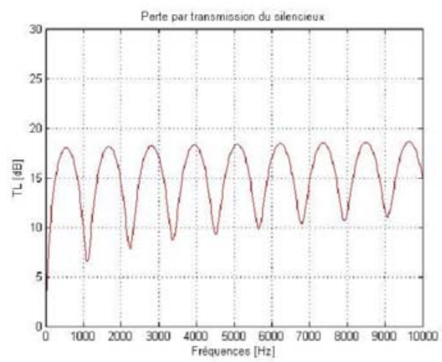


Figure 7 Empty expansion chamber

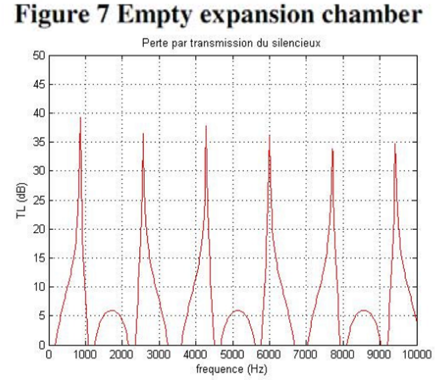


Figure 8 Helmholtz resonator

Since the speed at which the measurements are taken during the competition is around 70km/h (or around 100 Hz in our case) we decided to focus on that frequency. A model was built using the MatLab software and different dimensions where tested in order to maximize the effects of the muffler around 100 Hz. Below is a drawing of the final design of our muffler.

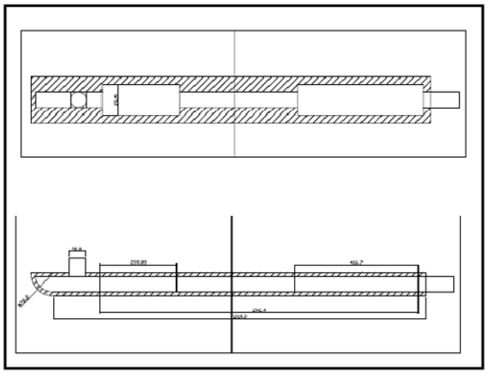
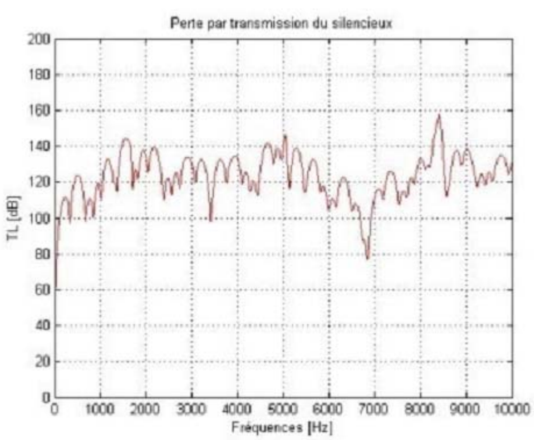
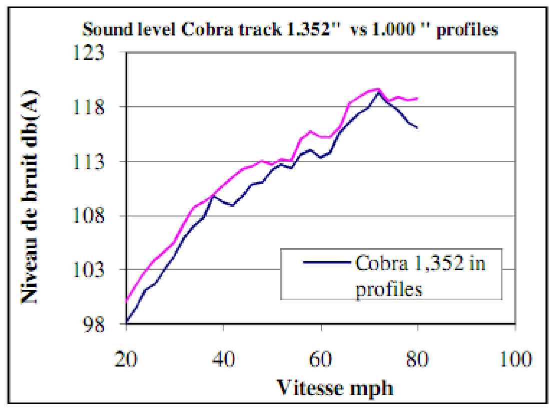


Figure 9 Drawing of the new added muffler

The first section of the muffler is a resonator that helps reduce the noise created by the engine at a frequency of 100Hz. Then, the combination of two empty expansion chambers are used to ensure the best sound absorbing characteristics possible. Additionally, the muffler is placed in a shell made of sheet metal then isolated from the inside with sound absorbing foam. This sound absorbing foam was used in 2009 in the snowmobile engine compartment and has proven itself to be very efficient. This foam resists up to a temperature of 1250 °C, thus preventing it from igniting in operation. Figure 10 represents the sound absorbing properties of the muffler simulated on MatLab.



REAR SUSPENSION - Rear suspension modifications were made in partnership with Camoplast. This partnership helped us in finding the best modifications possible. Past research revealed to Camoplast that the biggest noise source in the rear suspension was the reinforced fiber in the tracks. These fibers hit every time they come in contact with a rear suspension wheel. To prevent this, without taking out the fibers in the tracks, the solution was removing the rear wheels. However, this would eventually lead to heat and friction problems between the rails and the track. To solve that problem, a bolt was placed on each of the front skis, thus creating a snow film that would serve as a lubricant for the rear rails. Furthermore, this snow dust reduces the noise generated by the snowmobile by preventing it from transmitting into the air. To choose the correct track, Camoplast, made a test on two similar tracks: the Cobra 1¼'', and a modified version of the same track. The tread depth was reduced to 1 inch. Figure 11 represents the results of these tests.



These results determined that the Cobra 1¼'' was the track to be used for the CSC 2010 challenge.

SOUNDPROOFING - In addition to the sound coming from the exhaust system and the rear suspension, a lot of noise comes from the motor itself, the various vibrations and the rotating parts, but mainly the pulley and chain transmission. In order to reduce the sound emissions from the motor compartment, we have decided to insulate it completely.

Figure 12 View of the front panel and foam

To start off, we closed all the openings on both side panels and around the chassis. We applied sound-absorbing foam and a sound barrier inside all the panels surrounding the motor and under the hood. The two materials used where Silent Source Hushfoam FireFlex Anechoic wedge HFX-3 and Blachford BaryMat. Each of those foam, have different characteristics and helps in reducing different sound intensity.

The effectiveness level of sound absorption in a snowmobile, vary generally between 15 and 133 Hz for the engine compartment (corresponds to the engine rotation speeds). The foam we chose is efficient in this range of frequencies [6]. The addition of the rubber BaryMat material as mass to soundproofing modifications, we should get improved results at lower frequencies.

At the time of writing this paper the final sound test is not done yet. Consequently, the final results of our modifications will be done at the CSC 2010.

Conclusion

With this year's design, considering the various systems used on the sled, the results with the two-stroke engine technology are coming to a good point. Working with, a new direct injection system and a rear suspension vibration reduction, improved exhaust systems and making a good sound insulation, all the major requirements were achieved to have a truly clean snowmobile. Although, major changes were made on the engine and the look of the snowmobile to keep good performances and an edgy appealing design to snowmobilers. Team QUIETS already await next year's competition in order to develop new and advanced systems.

Acknowledgments

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We would also like to thanks the Clean Snowmobile Challenge organization and Michigan Tech for hosting the event and bringing all the teams together to find new and innovative solutions to boost the overall image and reputation of snowmobiling.

REFERENCE

1. Radio-Canada
http://radio-canada.ca/regions/Montreal/nouvelles/200412/02/004-JUGEMENTMOTONEIGE.shtml

2. Design and Simulation of Two-Stroke Engines, Gordon P. Blair, 1996

3. EPA
http://www.epa.gov/otaq/regs/nonroad/2002/r02022.pdf

4. United States Environmental Protection Agency, September 2002
www.epa.gov/otaj/regs/nonroad/2002/f02040.pdf

5. Econologie.com
http://www.econologie.com/articles.php?lng=&pg=717

6. Silent source
http://www.silentsource.com/afoams-hushfoam.html

7. Klotz
http://www.klotzlube.com/

8. 2010 Clean Snowmobile Challenge Rules

9. http://www.ski-doo.com/brphtml/skidooenginetech/fr/Index.htm