Clarkson University's Efficient Snowmobile Turbo Implementation

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Abstract

For 2015 the Clarkson University SAE Clean Snowmobile Team's objective is to improve upon our 2011 Ski-Doo MXZ Sport 600 ACE design. The Rotax 600 ACE (Advanced Combustion Engine) is a 600 cubic centimeter, two cylinder four stroke motor. And for the 2015 competition we have designed and implemented a custom turbo induction system to increase the motor's overall efficiency and fun-factor.

The implementation of a custom stand-alone ECU unit enabled the team to tune for the increased boost of the turbo. It also allowed us to pair it with a GM/Delphi oxygenate sensor in order to create a closed-loop fuel system that would meet competition rules of running the flex-fuel of bio-isobutanol ranging from 16-32% and gasoline. Because the percent mixture of the flex-fuel will be unknown to us, the closed loop system has been adjusted to deal with the changes in percentages on the fly. The new standalone ECU also allows us to tune for the implementation of a 3-way gas catalytic converter, which drastically reduces the emissions of the snowmobile.

One of the major areas of focus, past the implementation of turbo induction, for the team this year is in the area of noise reduction from the snowmobile. Noise pollution is the number one cause of trail closure in the U.S. and the Clarkson Clean Snowmobile team decided to tackle this issue in a practical and effective manner.

Introduction

Snowmobiling is a sport enjoyed by millions a winter enthusiasts all around the world. Although it is loved by many people, there is much opposition because of the fact that throughout snowmobile history the machines have been noisy and have produced high emission levels. It was from this pressure that made the design and development of clean and quiet snowmobiles a necessity in order to keep the sport alive. The Society of Automotive Engineers (SAE) Clean Snowmobile Competition (CSC) is designed to promote the further development of the technologies sold by manufacturers through innovation from collegiate engineers at universities from all over the snow belt of North America.

The CSC design competition is based on a series of tests that analyze the snowmobile's fuel economy, emissions, noise level, practicality of design, endurance, performance, and handling. For this year's competition a new flex fuel has been introduced to the teams, a blend from a range of 16-32% bio-isobutanol and gasoline mixture. The exact level is unknown at the time of competition, so a fuel system must be developed in order to adjust for this on the fly. Along with this the entire snowmobile must be further developed in order to successfully meet the objectives of the tests outlined by the 2014 SAE CSC. This report will show how the Clarkson University Winter Knights further developed our 2011 Ski-Doo MXZ 600 ACE in order to meet these objectives.

Snowmobile Selection

For the 2015 CSC, the Clarkson Winter Knights have decided to further the

development of our 2011 Ski-Doo MXZ 600 ACE. Although the snowmobile is now 4 model years old we feel it still represents the BAT of the industry as it is similar in base design to what is on the market today. Ski-Doo has been a leader in the power sports industry for many years, they have achieved this with products that stress power, fuel economy, low emissions, exceptional riding quality, and strong handling characteristics. The MXZ being Ski-Doo's flagship model, embodies all of these characteristics making it the obvious choice for a day on the trails or in an advanced engineering competition such as the SAE CSC. The engine of choice for the Clarkson University Winter Knights is the Rotax 600 ACE.. The ACE is a four stroke engine that is extremely efficient and makes adequate power for an engine of its size. The engine specifications are shown below in table 1.

Table 1. 600 ACE Engine Specifications

Displacement	**602 cm3**
Configuration	**Inline 180 Deg. Two Cylinder**
Compression ratio	**12:01**
valves per cylinder	**4; 2 intake & 2 exhaust**
Maximum Power	**56 hp**
Maximum Torque	**42 ft*lb**
Maximum power speed	**7250 RPM**

Powertrain Modifications

The 600 ACE is a very advanced engine that is very efficient and smooth operating. In order to make the ACE more fuel efficient and cleaner several modifications were made. In order to utilize the engines wasted heat energy a forced induction system was implemented in the form of a turbocharger. Turbocharging was chosen because it is powered by the exhausts wasted energy to force air into the engine at pressures above atmospheric, this added pressure is known as boost. For the ACE to handle the added pressure from the turbocharger custom pistons were designed by the Winter Knights with the help of Wiseco to lower the compression ratio from 12:1 down to 10:1 to avoid detonation. The pistons were designed to fit into the stock engine bore and stroke size to allow for minimal necessary cylinder modifications for the custom piston to be integrated. The lower compression was accomplished by "dishing" the top of the pistons. The turbocharger used for the 600 ACE is a Garrett GT1241 fixed vane turbocharger with oil journal bearing and liquid cooling. The GT1241 was chosen based on the Garrett's "Boost Advisor" and Garrett's professional opinion. Our maximum boost pressure is set at 8 psi which is accomplished using the turbochargers internal waste gate as well as an external blow-off valve. To achieve greater efficiency with the turbocharger an air/air intercooler was designed by the winter knights to cool the air before it passes through the throttle body. The air/air design was chosen because snowmobiles are typically run in sub-freezing temperatures which makes this style of intercooler extremely effective at cooling the intake charge.

Sensors for the ACE that come fitted as part of the stock engine configuration include sensors such as crankshaft position, throttle position sensor and manifold absolute pressure sensors. The stock ACE is controlled by a Bosch ME17.8.5 ECU which is sealed and cannot be altered by anyone. By virtue of this fact an aftermarket ECU called the Megasquirt 3 (MS3) by DIY Autotune was implemented to allow for the necessary control of the engine to make it

flex fuel capable as well as making it possible for the engine to be turbocharged. With the implementation of a new ECU there were engine functions that needed to be monitored and calculated that are not used for the stock ECU. Cam shaft position was not monitored with the stock ECU so custom cams were integrated that allowed the cam position to be monitored. Another engine parameter that is monitored by the MS3 is crank shaft position. The ACE comes with a missing tooth wheel on the crankshaft to monitor position, however the MS3 could not recognize the tooth pattern so a custom 36 tooth wheel was designed and created to allow the MS3 to know the position of the crankshaft. These engine functions are used to adjust timing of the engine and allow the engine to be tuned for additional fuel loads due to running on flex fuels.

With the engine producing roughly 95 horse power with the addition of the turbocharger the clutching needed to be adjusted to account for the increase in power and torque. The stock 600 ACE uses the E-Drive cvt clutch to translate the engine power to the track. The E-Drive 2 clutch, which uses the same housing and spring as the E-Drive was selected due to the heavier weights internally. The E-Drive uses six 32 gram weights while the E-Drive 2 uses six 40 gram weights. The 40 gram weights are used for an engine that produces nearly 130 horse power and proved to be too heavy for the amount of power being produced by the ACE. In order to adjust for the power made by the turbocharged 600 ACE three of the six weights in the E-Drive 2 were swapped with weights the weigh 36.4 grams each. This reduction in weight allows the snowmobile to accelerate smoothly and be very responsive to the drivers input.

Fuel System & Emissions Reduction

The fuel system being used for our 600 ACE is controlled by a DIY Autotune MS3 ECU. The use of a GM/Delphi oxygenate sensor, identical to what is found in current GM flex-fuel vehicles allows the ECU to calibrate for varying blends of isobutanol and gasoline mixtures. This sensor outputs a square wave signal from zero to five volts which is read by the ECU to allow for the proper fuel maps to be used. The created fuel maps are aimed at “target” air fuel ratios across four dimensions: RPM, throttle position, isobutanol percentage and manifold absolute pressure which is the equivalent of boost.

For moderate cruising speeds the throttle position is in the mid-range of the engines running RPMs, it is at these speeds that the target AFR is slightly leaner than the stoichiometric ratio for reduced emissions. At wide open throttle the target AFR is slightly richer than stoichiometric to provide additional cooling for the pistons when the engine loads it at a maximum. With the addition of a Dynojet Wideband 0_2 sensor the system becomes closed loop and requires zero user input. A closed loop system is ideal for consumer snowmobiles because it requires no knowledge of internal combustion engines from the user to get the best possible emissions.

In an effort to use the wasted heat energy from the engine the Garett GT1241 turbocharger is implemented into the 600 ACE system. For an engine with forced induction the need for additional fuel is increased. Injector size is increased from the stock injectors which are 211 cc/min each to 333 cc/min for each cylinder. For low RPM’s the injector pulse widths needed to be decreased by roughly 35% and this is

accomplished in the MS3 programming. To further reduce the emissions from the 600 ACE a three way catalyst from Emitec is used to treat the exhaust gasses after they have passed through the turbocharger. The three way catalyst causes a reaction which reduces unburned hydrocarbons (HC), Nitrous Oxides (NO_x) and Carbon Monoxide (CO) in the engines exhaust. The catalyst reduces the nitrous oxides into N_2 and O_2, and it uses free oxygen in the exhaust flow to oxidize carbon monoxide into carbon dioxide. The following chemical balances show the reaction of the nitrous oxides within the catalyst.

$2NO_x \rightarrow xO_2 + N_2$

$2CO + O_2 \rightarrow 2CO_2$

$C_xH_{2x+2} + (3x+ ½)O_2 \rightarrow xCO_2 + (x+1)H_2O$

The substrate was chosen with the help of Emitec based on the exhaust mass flow rate as well as the measure power and torque of the engine. The recommended catalyst is 75mm in length and 110mm in width with a substrate density of 300 cells per inch to minimize any added back pressure from the catalyst.

Noise Reduction

In effort to reduce noise pollution of the 600 Ace motor, fire retardant foam was placed in areas where space permitted. This sound absorbing foam reduces noise level by 85% if the engine bay were to be completely lined with it. With limited space due to a turbo system and ventilation needs, this was not the case and only certain areas were able to be lined with the noise reducing foam.

At speed, one of the largest sources of noise came from the turbo intake. In an effort to reduce this noise, an air box was created in the front of sled. This box creates smoother air flow to the intake, helping to cut down on the sound of forced air induction. Also, an air filter was placed inside of the box. This acts as both a particle filter and noise filter, muffling the noise of the turbine spooling.

Being a relatively quiet snowmobile to begin with, it was easy to hear the track spinning at trail speeds. To hinder this noise a SilentDrive track and drivers were added to the snowmobile. Ski Doo's SilentDrive design strategically placed sixteen smaller internal lugs in the tracks center area. This allowed a reduction in track vibration as much as 70% at trail speeds and led to 5dB reduction in track noise.

Handling

In order to improve upon the handling abilities of what is already considered to be a decent handling snowmobile, the Winter Knights focused on the the area of improving traction and the geometry of the front suspension. We felt that these were the areas that would do the most to improve the handling characteristics while keeping cost to a minimum.

With the help from a great sponsor and industry leader in snowmobile traction, Woody’s traction provided us with 48 signature 1.075” studs and their signature Dooly 6” carbide runners. We chose to only use 48 studs instead of what is traditional for the 137” track which is to use 96. We did this in order to reduce the rotational mass of the track, which saves approximately 4.5 pounds. We also felt that because we are only around the 100 horsepower number we do not need to have and overly aggressive amount of rear traction because it is unlikely with the 48 studs and longer track that the track will suffer from spinning during acceleration. It is also important to note that during on snow testing the rider felt more confident and safer because of the fact that

the snowmobile was much less likely to lose traction in a corner due to iciness.

In order to gain traction in the front of the snowmobile we chose not to change the stock skis due to cost, rather we chose to change the stock 4" carbide runner to Woody's 6" dooly carbide runner. We chose this runner for its anti-darting characteristics, meaning that the snowmobile is less nervous feeling and tracks straighter on the trail. And with the increased amount of carbide tip on each runner there is naturally more turning grip, so the rider can corner faster and more confidently.

One of the shortcomings of the Ski-Doo XP chassis has been the front-end geometry; it has a nervous feeling nature and a tendency to be unstable in its tracking pattern through larger bumps. Ski-Doo has released their solution to this problem in model year 2015 with the all new RAS2 front suspension. Ski-Doo claims that the new geometry, taller spindle and longer lower a-arm with shorter upper a-arm, lightens the steering and allows the snowmobile to track straighter through bigger bumps, as well as reduce the nervous tendencies that the snowmobile encounters. They accomplished this by reducing the camber change of the front suspension through its stroke when hitting a bump. These claims were backed up by a Winter Knights team member, who has this new front-end geometry on his personal snowmobile. However, it was clear that from riding their personal snowmobile that there was still room for improvement. After a little bit of research on how to improve the geometry passed what Ski-Doo had done, we discovered the Hygear Slicast system, which allows the user to not only mimic both the stock XP geometry as well as the RAS 2 geometry, it allows users to adjust its settings in a way that matches both the snowmobile and the riders riding style.

Once the new slicast system was installed and dialed into the needs of the snowmobile and the rider style of our test riders it was clear how much of an improvement that this product made. Anyone of our riders that drove the snowmobile before the modification immediately notice how much straighter the snowmobile tracked through bumps and how much easier the steering input needed to be in order to corner. The most important characteristic that was changed was the nervous feeling and tendency for the snowmobile to dart, with the new slicast kit and Woody's dooly runners, the snowmobile was much more stable and predictable in its movements, giving the rider a more confident and enjoyable riding experience.

Ride Quality

In order to further enhance the consumer appeal of the snowmobile, the Winter Knights focused on two primary areas. First we addressed the front suspension, with the basic economy style shocks that come standard on the snowmobile, the suspension experiences fade when the snowmobile is ridden hard through bumps, causing the ride to suffer. In order to combat this, we have switched to HPG(high pressure gas) shocks that allow for increased adjustability and reduced shock fade when ridden on rough trails at speed.

The other area we focused on was the rear suspension, the regular 120" inch SC-5 rear skid frame offers good riding and handling characteristics. However we felt that the ride quality could be enhanced by extending the rear skid frame to a 137". With a longer skid frame and track, the snowmobile can now effectively bridge bumps better. This leads to a less harsh ride through sections of rough

trail because the suspension is able to stay within its stroke causing less harsh movements of the suspension, as it does not need to fully decompress and compress again.

Summary

The Winter Knights focused on modifying our Ski-Doo MXZ 600 ACE in a way that would not only be more environmentally friendly, quieter, and fuel efficient, we wanted to ensure that it was still a fun snowmobile to drive. After all the snowmobiling sport is a sport of recreation, meaning that it is for fun. Through the custom turbo induction, we were able to efficiently and effectively increase the power of the snowmobile with little sacrifice in terms of the overall objectives of the competition.

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Abbreviations

SAE- Society of Automotive Engineers
CSC- Clean Snowmobile Challenge
ACE- Advanced Combustion Engine
ECU- Engine Control Unit
BAT- Best Available Technology
RAS- Response Angle Suspension
MS3- MegaSquirt3