Clarkson Winter Knights Methods in Efficiency and Noise Reduction of a Combustion Snowmobile

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Abstract

Clarkson University's SAE Clean Snowmobile team is aimed at reducing friction and noise for the 2016 SAE Clean Snowmobile Challenge. Continuing with the previous success of the 2011 Ski-Doo TNT chassis powered by the 600 ACE (Advanced Combustion Efficiency), Clarkson returns to the competition with a similar 2016 Ski-Doo TNT. A new lower cost GM/Continental flex fuel sensor was integrated with the existing Power Commander V to give the ability to run up to E85 blended fuels while still maintaining excellent fuel mileage, emissions, and power characteristics. REM Surface Engineering has partnered with Clarkson University to produce internal engine and driveline components with drastically decreased surface roughness in which to increase overall efficiency. Reducing sound is via a new 2 into 1 exhaust system as well as tunnel and body panel coating with an acrylic insulation emulsion. These adaptations make an already BAT (Best Available Technology) snowmobile even more favorable to the green trend of reducing environmental impact.

Introduction

The purpose of the SAE Clean Snowmobile Challenge (CSC) is to raise awareness of the growing needs of having cleaner vehicles within the recreational off highway industry in order to ensure a sustainable future for all stakeholders. The competition takes form as a collegiate design competition utilizing base snowmobiles from one of the four major manufacturers in the industry, designing and implementing changes to make these snowmobiles cleaner in terms of emissions, reduce noise harshness, and increase the fuel economy using a flex-fuel source. An important aspect to keep in mind throughout the process is the consumer appeal and feasibility of mass production for the prototypes developed, after all if the consumer does not want to, or is unable to purchase the technology, then there is not much of a point of developing it.

For the 2016 CSC the Clarkson Winter Knights have chosen to start with a base model snowmobile from Ski-Doo, the current market share leader within the industry, with their 2016 MXZ Sport 600 ACE model. From this base snowmobile we have focused our efforts in developing practical and cost effective solutions to fit the specifications of the competition. Development of fuel management, custom exhaust system, and general improvements to the drivetrain of the snowmobile have all been incorporated into the competition snowmobile.

Base Snowmobile Selection

As previously mentioned we have chosen to further the design of our 2016 Ski-Doo MXZ Sport 600 ACE. This model was selected after much deliberation and analysis through the development of a design matrix, and was determined to be the best starting platform based on the specifications of the competition, after all the 600 ACE in some form has won the competition for the last five years. Our design matrix was developed in order to compare snowmobiles from each of the manufacturers and assigning them a weighted numerical value based on the point breakdown of the CSC events, the clear winner of this was the 2016 Ski-Doo MXZ 600 ACE. This was due to the fact that it is one of three engine options from all major manufacturers for model year 2016 that is

BAT(Best Available Technology) certified based on its low emissions and noise levels. Furthermore, the chassis is well known in the industry for being lightweight with great riding characteristics.

Engine Modifications

Internal Engine

For the 600 ACE this year we have decided to focus on reducing friction in order to gain efficiency. Our team has partnered with REM Surface Engineering which offers an isotropic superfinishing service on most any metal surface. Starting with a completely stock engine, we've had most of the internal engine components processed with the isotropic superfinish including the crankshaft, connecting rods, wrist pins, camshafts, valves, lifters, timing chain and pto roller bearing. The ISF process is not a coating or plating, but a friction reducing surface finish that reduces overall Ra or average surface roughness. REM uses a stylus type measuring device which can measure the depth and height of a surface to as little as 0.01µin. Below is **Figure B** showing the driven gear from the chain drive system BP, before processing. Ra measures 22.58µin.

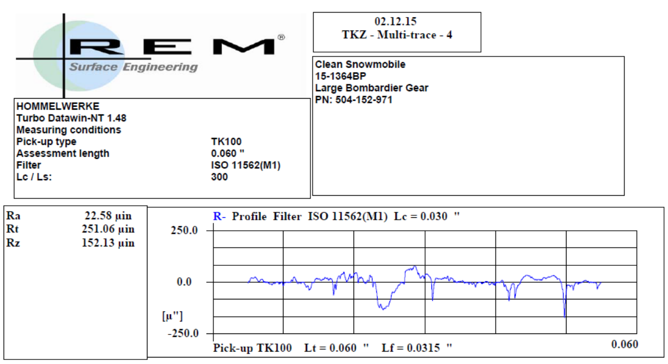

Figure B

Next is a plot of AP, **Figure A**, after processing. Ra measures 8.58µin, a reduction of 62% of average surface roughness. With a super finished surface, less friction is created between metal on metal surfaces. Because of this, we can use a less viscous oil (from 5w30 to 0w20) which uses less force to pump through the engine and therefore increase overall efficiency of the engine. Also, less surface roughness increases the life of the parts processed as well as the parts they are in contact with. This engine should have a lifetime much greater than one without processing. We have begun to prove this theory by evaluating the engine oil and filter as the engine is used. After an initial break in and approximately 75 miles of riding, the filter remains clean with no metallic particles while still retaining the original oil from the initial break in.

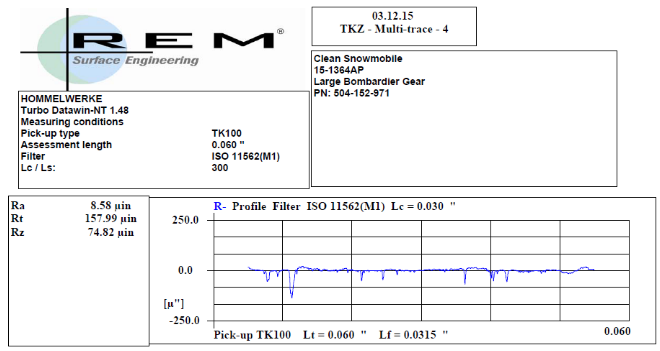

Figure A

Engine Management

To aid our engine in achieving the most efficiency and giving us the ability to control the system, we have chosen to use the DynoJet Power Commander V. The PCV is a 'piggyback' support engine control unit (ECU) which changes engine output signals to injectors and coils rather than creating an entirely new engine map. The PCV simply jumps connections between the coils and injectors to the stock ECU without the ECU acknowledging there is a change, and without changing stock ECU features. We have also fitted the PCV with two Wideband 2 controllers from DynoJet with Bosch wideband oxygen sensors for each cylinder. The decision to run individual oxygen sensors was based on examination of spark plugs even before the PVC was installed on the stock engine. It was determined that the 600 ACE engine runs lean on the magneto side cylinder which causes uneven cylinder pressures and therefore uneven power distribution from each cylinder.

Using two wideband oxygen sensors allows us to run "live" real-time fuel trim maps for individual cylinders with the PCV which can run closed loop and alter fuel trims to achieve targeted AFR table values. To do this, the PCV runs stock trims from a table of zeros in an open loop until a set time of 30 seconds after engine startup, in which the PCV begins to use the Wideband signals to create live fuel trim maps in a closed loop system. For 2016, the Ski Doo Sport TNT 600 ACE comes equipped with an electronically actuated throttle body. This has allowed Ski Doo to develop 3 different modes for riding: Sport, Standard, and Eco. Sport mode is an all-out, full power setting. Standard mode sets a good linear response of the throttle for most riders. Eco mode drastically limits the engine output by slowing the throttle response and limiting the top speed to 45mpg. This allows the 600 ACE to achieve exceptional fuel economy but giving any performance a back seat. It was chosen to use the Standard mode due to the limitation of the Eco mode to 45mph since the endurance portion of the competition states that all competitors must maintain speeds up to 45mph. This was too close of a margin to risk for the reward.

Fuel System

For 2016, the competition will offer fuel in the form of 0-85% ethanol content. Because of this, our system must measure ethanol content of the fuel and change fuel trims accordingly. To do this, we have fitted a flow through GM Flex Fuel sensor, made by Continental. This sensor was chosen to replace our larger flex fuel sensor because of its compact size, but also its cost was much less than the previous. Under normal conditions, this sensor sends out a 50-150Hz signal which is read by a Zeitronix Ethanol Content Analyzer. The ECA then changes this signal into a 0-5v signal on a linear scale of 0 to 100% ethanol. This analog signal is then received by the Power Commander V as an analog temperature signal. As a temperature signal, the power commander uses a scaling table to match the voltage input from the ECA to ethanol content percentage and then trims the fuel accordingly.

The stock 600 ACE injectors are rated at 211 cc/min and as tested in previous years by Clarkson, use an 86% duty cycle for E40 fuel. For this year's competition with fuel levels up to 85% ethanol, we must again use 1200 ACE injectors which allow 333cc/min of flow. Because of the higher flow rate, the temperature input scaling must decrease fuel trims. This is simply done by inputting negative values in the temperature input tables. For 0% ethanol, the 1200 injectors, pulse width is decreased by 36.4% to reduce their flow to approximately 211cc/min, or stock flow rate. **Table 1** shows the relationships between ethanol content, 211cc/min and 333cc/min injectors.

***Table 1-** Fuel Trim Requirements for Specific Ethanol Contents – Naturally Aspirated, Stock Compression Ratio*

Fuel E%	Stock Injectors Duty Cycle Change	1200 Injectors Duty Cycle Change
0%	0.0%	-36.4%
10%	4.0%	-34.1%
20%	8.4%	-31.5%
30%	13.1%	-28.8%
40%	18.3%	-25.7%
50%	24.0%	-22.4%
60%	30.2%	-18.8%
70%	37.2%	-14.7%
80%	44.9%	-10.2%
85%	49.0%	-7.8%
90%	53.5%	-5.2%
100%	63.2%	0.5%

As calculated in previous competition years, stoichiometric ratios were used to create the trim levels in which to use the 1200cc/min injectors. **Equation 1** uses 30% ethanol gasoline in relation to pure gasoline to find a stoichiometric AFR.

$$[Eth_{\%} * Eth_{Stoich} + (1 - Eth_{\%}) * Gasoline_{Stoich} \ ] = Exx_{Stoich}$$

$$[0.30 * 9.01 + (1 - 0.30) * 14.7 \ ] = E30_{Stoich}$$

$$Stoichiometric\ AFR\ for\ E30 = 12.993{:}\,1\ (By\ Mass)$$

Equation 1

Equation 2 shows how the mass of ethanol in E30 fuel is calculated. Using these results, **Equation 3** calculates the percent change in fuel which is required for the 30% ethanol content.

$$\frac{AIR_{grams}}{Fuel_{grams}} = E30_{Stoich} \quad \rightarrow \quad Fuel_{grams} = \frac{AIR_{grams}}{E30_{Stoich}}$$

$$Fuel_{grams} = \frac{14.7}{12.993} = 1.13138\ grams\ of\ E30$$

Equation 2

$$\frac{|Grams\ of\ Gasoline\ Fuel\ Req - Grams\ of\ E30\ Fuel\ Req|}{Grams\ of\ Gasoline\ Fuel\ Req} * 100 = \%\ Change\ in\ Fuel\ Req$$

$$\frac{|1.00 - 1.13138|}{1.00} * 100 = +13.138\ \%$$

Equation 3

Exhaust System

For the 2015-2016 Clean Snowmobile Competition, the exhaust team has the focus on two main categories, emissions and sound. The system is designed and is to be comprised of three main distinct features; A resonator, catalyst and a muffler.

Before introducing the main features, the focus will be on the custom headers designed for the Rotax 600 ACE. The headers consist of a 30mm pipe at each port, bent to safely miss the steering post. Each header length is set equal and then converge into a y-pipe with a 1 ¾" diameter output. Equal header length ensures that the exhaust scavenges efficiently throughout the primaries. In every exhaust stroke there is a positive pressure wave that propagates and travels down the exhaust pipe. The effect of this is the creation of a negative pressure wave behind the leading edge of the positive region. With equal length headers this waves' negative pressure zone is entering the y-pipe just before the other cylinders positive wave reaches the y-pipe, effectively pulling the other cylinders exhaust, increasing efficiency. After these equal length headers, the first distinct feature appears.

The first of which is a custom resonator to assist in the reduction of noise from the engine. The resonator, or passive inline muffler, is made up of a 1 ¾" diameter steel exhaust tubing that has been perforated with 60-⅜" holes evenly spaced in an offset pattern throughout the 5 ⅜" length of the pipe. This is surrounded by a 3" section of 2 ¼" exhaust tubing. The two layers are connected with a 1" long cone on each side to create the resonance effect and to seal the two layers. The cavity between the two layers is filled with fiberglass packing. The exhaust gas flows into the main tube and escapes through the perforations in the tube into the surrounding packing material. This material works to absorb sound by dissipating the energy of the gasses. The perforations in the tube act to split up the gasses and bounce them against each other to further reduce the sound.

The second feature in the exhaust targets both the noise and hydrocarbon pollution of the 600 ACE Engine. In regards to lowering emissions Clarkson University worked with Continental-Emitec Inc. to receive a catalyst to lower hydrocarbon emissions. The catalyst substrate is specifically engineered to be more effective in a combustion engine that is fueled with ethanol-content gasoline. Another important aspect is the cell density of the substrate, measured in cells per square inch. With engine out mass flow and estimated power output the specific density was chosen to allow for maximum mass transfer to the substrate with minimal increase to backpressure. Incorporating the catalyst into the exhaust system introduced a diverging-converging setup, which is dual purpose. In one aspect the divergence slows the fluid flow over the substrates in the catalyst which increases mass transfer to effectively lower emissions. The other factor is that it acts as a resonator in the converging portion of the nozzle by reflecting sound frequencies back towards the exhaust ports and canceling with oncoming sound waves.

The third feature in the exhaust system is the muffler. The muffler used in this system uses a combination of reflection and absorption to quiet the system. These two methods of absorption and reflection rely on two different principles to achieve the same goal. The absorption occurs by using low density materials such as fiberglass packing for the exhaust gasses to flow through, during which, energy is drawn out of the flow. The reflection occurs when the wave of gasses hits an object which bounces the gasses back and then is routed through a series of chambers with a series of reflections happening along the way. These reflections all change the frequency and speed of the wave of exhaust gas. This in effect reduces and changes the noise made by these exhaust gasses. Combining these two principles in the muffler uses a small amount of space already allocated to the muffler in a stock Ski-doo.

The last segment of the system is an attachment that redirects the position in which the exhaust gases enter the atmosphere. Utilizing a v-band clamp this extension clamps on in seconds to deliver an instant drop in the decibel level of the snowmobile. This is done by aiming the exit point of the exhaust towards the front of the track. This allows for the sound to be absorbed by the rubber track more so than off of ice or asphalt.

Drive Line Efficiency

In order to maximize overall efficiency for the snowmobile, attention was focused on improving the efficiency of the of the driveline system. To reduce frictional resistance acting on the chain case components, the gears and chain were sent to REM Surface Engineering where they went through REM's Isotropic Super Finish. This process greatly reduces the surface roughness of the components resulting in a reduction of frictional forces within the driveline. The finishing process also reduces component wear, reduces vibration and noise, and extends part life. The reduction in friction leads to higher fuel economy and creates a more reliable driveline.

To further reduce frictional forces acting within the snowmobile, the skid bearings for each of the bogie wheels were sent to REM Surface Engineering as well. Each ball bearing was subjected to the Isotropic Super Finish. This allowed for better surface finishing on each of the individual balls as well as the track they roll within. As a result of the process, less lubrication is necessary during use, this means that the bearing experiences less resistance caused by bearing grease as well as less frictional resistance for the balls rolling within the bearings. We decided to repack the bearing with a low viscosity grease called Kluber Isoflex Topas NB52, in using this grease there is less rolling resistance which results in greater fuel economy.

Sound Improvements

In order to improve the overall sound level of the snowmobile multiple modifications were made to the drive system as well as the chassis. Improvements that were made were the addition of a SilentDrive track and drivers, custom exhaust system, and Lizard Skin that was applied throughout the chassis.

The SilentDrive system utilizes a different style driver from the stock driver, along with a multi-lug track design which reduces noise up to 65% at the track at cruising speeds. Along with reduced noise, the SilentDrive system reduces vibration for a more comfortable ride.

The custom exhaust system utilizes three major components in order to reduce sound levels; a resonator, catalyst, and a muffler. The custom resonator is used in order to assist in the reduction of noise from the engine. The resonator utilizes a 5 ⅜" long, 1 ¾" diameter pipe which has 60-⅜" holes drilled in it, that is surrounded by a 2 ¼" piece of exhaust tubing. The open space between the two sections of pipes is filled with packing material which absorbs the sound by dissipating the energy of the gasses while further reducing the sound. The catalyst is utilized after the resonator and concentrates on lowering the noise and hydrocarbon pollution from the engine. A more detailed explanation of the catalyst can be found in the Exhaust System section of the paper above. The third feature in the exhaust system is the muffler. The muffler design utilizes a combination of reflection and absorption to quiet the entire system. By combining these two principles in the muffler, a small amount of space is used in order to reduce the noise drastically.

Also, Lizard Skin was applied to various locations on the chassis in order to reduce the amount of sound that is released from the snowmobile. Lizard Skin is an advanced, water based composition of a high-grade acrylic binder that has sound dampening particles integrated into it. The application of the Lizard Skin increased the overall weight of the snowmobile, but we estimated that the benefits from coating various parts of the snowmobile with the product would be effective enough to overcome the extra weight that was added. Lizard Skin was applied throughout the tunnel of the snowmobile in order to absorb some of the track noise which is a large amount of the noise that is heard from the snowmobile. Also the product was applied in the engine bay along with on the side panels of the snowmobile. The idea behind this is that the Lizard Skin will absorb some of the engine noise as well as excess noise from the exhaust system.

Sound testing was performed in order to determine if the modifications that were done to the snowmobile were effective in reducing the overall sound level of the snowmobile. In order to collect sound data our team used a Larson Davis SoundExpert LxT Sound Level Meter. With this sound testing equipment we were able to collect sound levels and create graphs in order to better illustrate the effects of the modifications made to the snowmobile.

The following graph (**Figure 1**), is from testing sound levels from the test procedure J192, during this testing procedure the snowmobile drives at a speed of 15mph for 37.5ft, at this location the snowmobile is accelerated to full throttle for the remaining 112.5ft of the course. During the testing we ran the snowmobile in the three stock modes, eco, normal, and sport mode. The different results for each mode can be found on the graphs in **Figure 1** and **Figure 3.** The testing conditions at the time the data for **Figure 1** was collected were 3-5 inches of mealy snow with a temperature of 25℉. The microphone positioning along with other setup dimensions for the testing procedure can be seen in **Figure 2**. These testing results are from our 2016 Ski Doo Ace with a 137" SilentDrive track and drivers along with an R-Motion suspension system. These results can be compared with **Figure 3.** The testing data that is shown in **Figure 3** is after the modifications have been made to the snowmobile were completed. These modifications include the SilentDrive track and drivers, custom exhaust system, and Lizard Skin applications throughout the chassis of the snowmobile. The testing conditions at the time the data for **Figure 3** was collected were 5-7 inches of snow with a hard packed icy base with a temperature of 25℉. The day before testing rain had fallen and frozen on top of the snow causing for a lot of noise from the skis breaking through the ice in the snow. Although the conditions were not ideal for testing, there is still a noticeable difference in the decibel level of the snowmobile throughout the test.

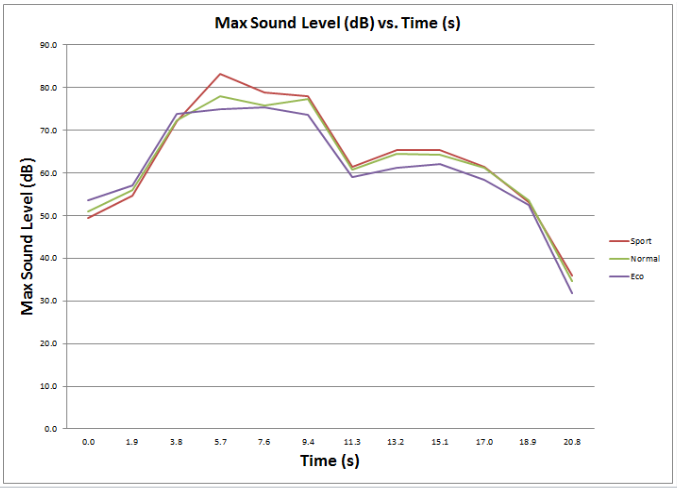

Figure 1

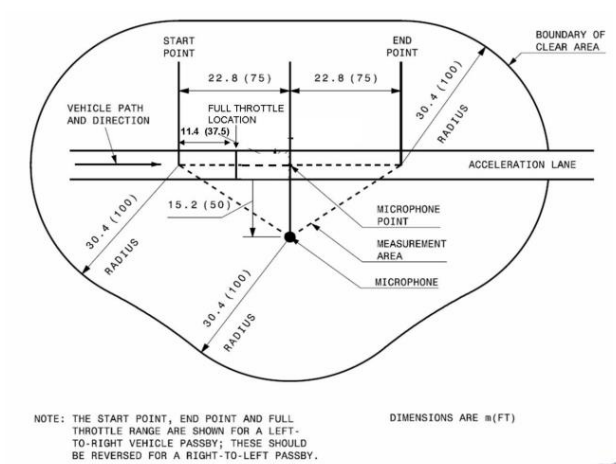

Figure 2

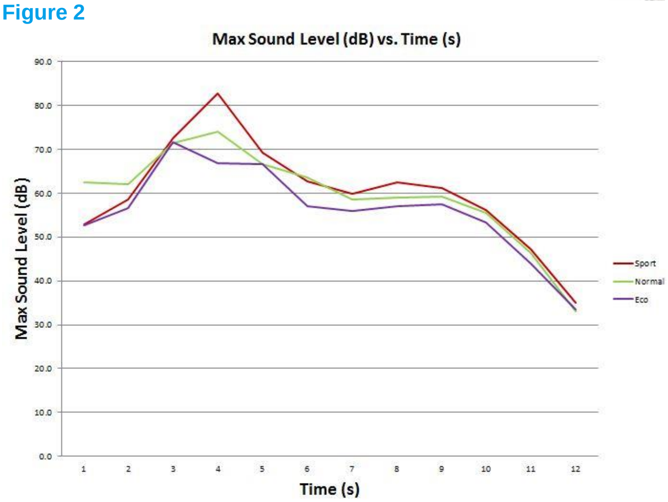

Figure 3

Handling and Ride Quality

As our stock base snowmobile is considered to be an economy package in terms of the features it includes. As a team we focused on improving these features to meet the current higher performance options available from Ski-Doo to further realize the potential of the already capable stock chassis. Firstly, like previously mentioned, we fitted a 137" R-motion skid to the Rev-XS chassis. This skid has a plethora benefits over the stock SC-5 skid we replaced, starting with the progressive rate suspension travel, allowing for better absorption of both small stutter style bumps and larger mogul style bumps. The increased overall track and skid length also allows for the snowmobile to effectively bridge between bumps, providing better ride quality, by keeping the suspension within its stroke allowing it to plane across the bumps. Secondly, the addition of the HPG gas shocks, both front and rear, allow for an increase in performance in terms of the reduction in shock fade in extended time periods of use. These shocks also offer an increased range of adjustability in terms of spring rates and shock dampening, allowing the rider to set the suspension to their preferences.

In terms of the front suspension geometry, the Hygear Slicast a-arm kit was added in an effort to mimic the RAS II Ski-Doo geometry. The reason we chose the Hygear system over the RAS II is due to the ability to further the adjust the caster of the ski. The main advantage of this geometry is that it keeps the pressure level throughout the ski, which helps reduce darting. Another advantage is that the taller spindle allows for the front suspension to travel in a more linear direction during the stroke allowing for the snowmobile to track straighter through rough terrain, giving the rider increased confidence and comfort. In an effort to further reduce the darting of the snowmobile, we fitted Woody's 6" trailblazer carbide runners and pilot ski navigators. These products improve the handling characteristics as the increased carbide length allows for better traction in hard pack conditions and the navigator is designed to better the snow flow through the ski to decrease the darting characteristic. Traction was also addressed in the rear of the snowmobile with the addition of the Camso Ice Ripper XT pre-studded track. This allows the snowmobile to have increased penetration in hard pack conditions over the stock track, and due to the design of the stud being integrated into the lug of the track, the design is lighter than a traditional stud in that it does not need a backing plate and locking nut to hold it in place.

Conclusion

The 2016 Clarkson Winter Knights team has focused its primary efforts into developing practical solutions to further improve our 2016 Ski-Doo MXZ 600 ACE to compete within the SAE Clean Snowmobile Competition. This was accomplished primarily through the development of a custom exhaust system with an integrated catalytic converter, quiet drive implementation, flex-fuel system, and reduction of friction points.

Acknowledgements

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Abbreviations

SAE-Society of Automotive Engineers
CSC-Clean Snowmobile Competition
ACE- Advanced Combustion Efficiency
BAT- Best Available Technology
ISF-Isotropic Superfinish
PCV-Power Commander 5
ECU-Engine Control Unit
HPG-High Pressure Gas