Modifications to a 2002 Polaris Pro-X 600 to Compete in the Clean Snowmobile Challenge 2005

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ABSTRACT

A 2002 Polaris Pro-X 600 was redesigned to compete in the 2005 Clean Snowmobile Challenge. The objectives were to engineer a quiet, clean, high performance snowmobile. Along with these important features the group also wanted to design a snowmobile that was rider, manufacturer, and environmentally friendly. While meeting these objectives, the performance characteristics that consumers have come to expect needed to be maintained or improved. To achieve these objectives, the team replaced the Polaris carbureted two stroke engine with a Rotax semi-direct injected, two-stroke engine. A catalytic converter and secondary air injection pump were added into the exhaust system to reduce the emissions. The University of Wisconsin-Platteville (UW-P) team also added an automotive style muffler to the exhaust system to reduce the noise associated with the exhaust process. The modifications on the snowmobile achieved UW-P's goals in a cost-effective manner, while maintaining reliability.

INTRODUCTION

The Clean Snowmobile Challenge 2005 is an engineering design competition for college and university student members of the Society of Automotive Engineers (SAE), organized and administered by the SAE, and the Keweenaw Research Center (KRC).

The challenge is to modify a stock snowmobile to improve emissions, reduce noise, while maintaining or improving the performance characteristics of the snowmobile. The modified snowmobile competes in the Clean Snowmobile Challenge starting March 15, 2005 in Houghton, MI. The competition consists of events including cold start, fuel economy, acceleration, handling, rider comfort, emissions, noise, and design. These events are spread over a six-day period [1].

The University of Wisconsin-Platteville SAE Clean Snowmobile team's overall objectives for the competition are to modify a snowmobile that:

1) Meets noise and emission requirements
2) Maintains or exceeds stock performance characteristics
3) Will win the Clean Snowmobile Challenge 2005

TEAM BACKGROUND

The Clean Snowmobile Team (Figure 1) is one of several student design and competition teams within the SAE student chapter at UW-P. The project is managed and directed by the students, with the assistance of an advisor and the Department of Mechanical Engineering. The team is funded through the Segregated University Fee Allocation Commission, team fundraising, and commercial sponsors.

Figure 1: 2005 Clean Snowmobile Team

DESIGN STRATEGY

The UW-P Clean Snowmobile Team's intent was to modify a snowmobile to provide a successful entry in the 2005 Clean Snowmobile Challenge. The team has set out to meet the competition requirements for sound and emissions as well as maintaining the qualities desired in a production snowmobile by today's consumers.

Design constraints and criteria relevant to the modifications made to the snowmobile are outlined in the report to follow. A complete set of the constraints and criteria are provided in the Clean Snowmobile Challenge competition rules [1].

DESIGN CONSTRAINTS [1]

- Modifications to the engine, including substitution of a different engine is allowed. Two-stroke, four-stroke, and rotary engines are allowed. Engine displacement is limited to 600 cc or less for two-stroke and rotary engines, 960 cc or less for four-stroke engines.
- Snowmobiles must be fueled with a blend of 10% ethanol and 90% premium gasoline, 85% ethanol and 15% premium gasoline, or electricity. Fuel additives (with the exception of commercial two-stroke oil) are not permitted

- The snowmobile must be propelled with a variable ratio belt transmission.
- The modified snowmobile must also meet or exceed all applicable safety standards
- The snowmobile's track may be replaced with a different track. The track must be a commercially available, one piece, molded rubber snowmobile track and cannot be modified.
- Ski and ski suspension may be modified. However the snowmobile must remain ski steered, have at least six inches of suspension travel
- The use of traction control devices such as studs, ice grousers, or paddles is not allowed

The team's first major decision was the use of a two-stroke engine because of the existing consumer confidence and the performance qualities of this engine. This engine selection meets all design criteria and goals. Strategy then focused on increasing the efficiency and power of the engine. Careful consideration was given to assure that these modifications did not exceed limitations set for emissions, noise, reliability and safety.

DRIVELINE IMPROVEMENTS

The main improvement to the driveline of the snowmobile was the installation of the Radical Machines Incorporated (RMI) direct-drive system (Figure 2). The direct-drive system relocated the driven clutch to a direct-drive gearbox near the drive shaft, thereby eliminating the jackshaft and chain case. By removing the jackshaft, rotating mass was reduced. Removal of the chain case reduced the overall mass of the snowmobile, lowered the number of wearable parts, and eliminated the need for the inefficient chain drive. This delivers the power to the track through a fewer number of components thereby increasing overall driveline efficiency. Also by removing these components and installing the direct drive system, the center of gravity of the snowmobile was lowered.

Figure 2: Direct Drive Installation

A large factor in driveline efficiency with a variable ratio belt transmission is the clutch tuning to transmit maximum power to the track. The effect of clutch tuning can be seen in the horsepower graphs, Figure 4 and Figure 5. The ideally tuned clutch set up should follow a path similar to that shown in Figure 3. [6]

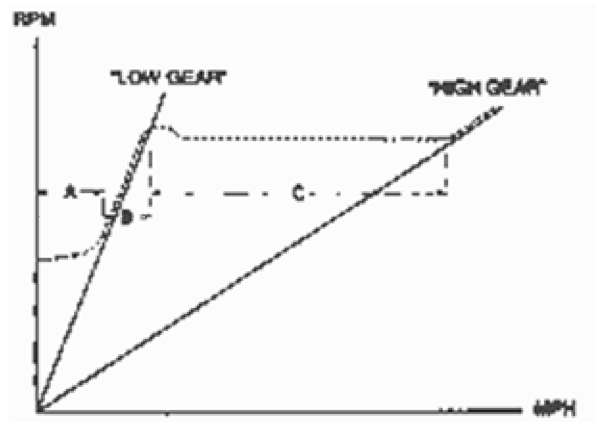

Figure 3: Properly Tuned Clutches (MPH vs RPM)

The first thing that must be considered in clutch tuning is the engagement speed shown as segment A in Figure 3. The engagement speed should at the lowest speed possible without creating engine bog. If the engagement speed is set too high damage to drive components can occur. Segment B in Figure 3 is the low gear acceleration, and segment C is the up shifting acceleration. These two segments must be set properly in order to achieve the quickest acceleration.

The most important aspect of clutch tuning is controlling the maximum engine speed so that it coincides with the rpm, at which the engine creates the highest horsepower. With a two-stroke engine, this maximum horsepower occurs over a very short range of rpms. In order for the engine to remain running in this range, the weights and springs on the primary clutch must be adjusted. Along with adjusting the primary clutch, the spring and cam angle on the secondary clutch must also be adjusted to keep the engine operating at its maximum power through the entire acceleration run. [6]

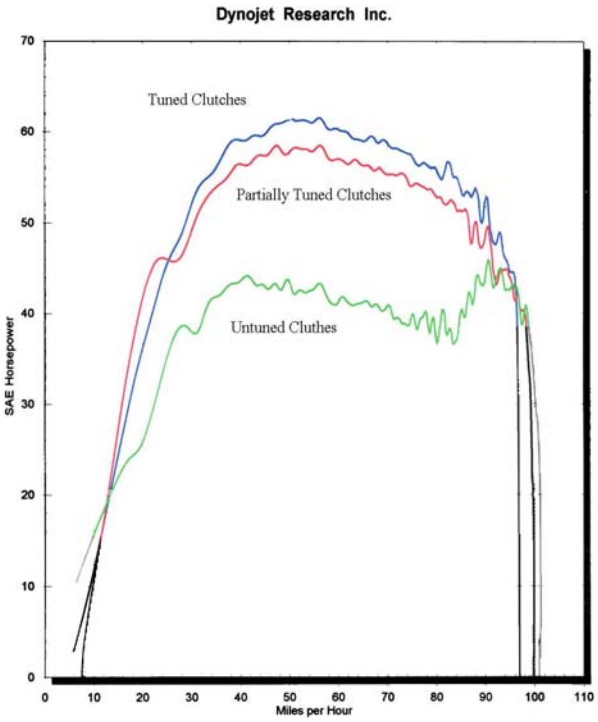

Figure 4: Track Horsepower

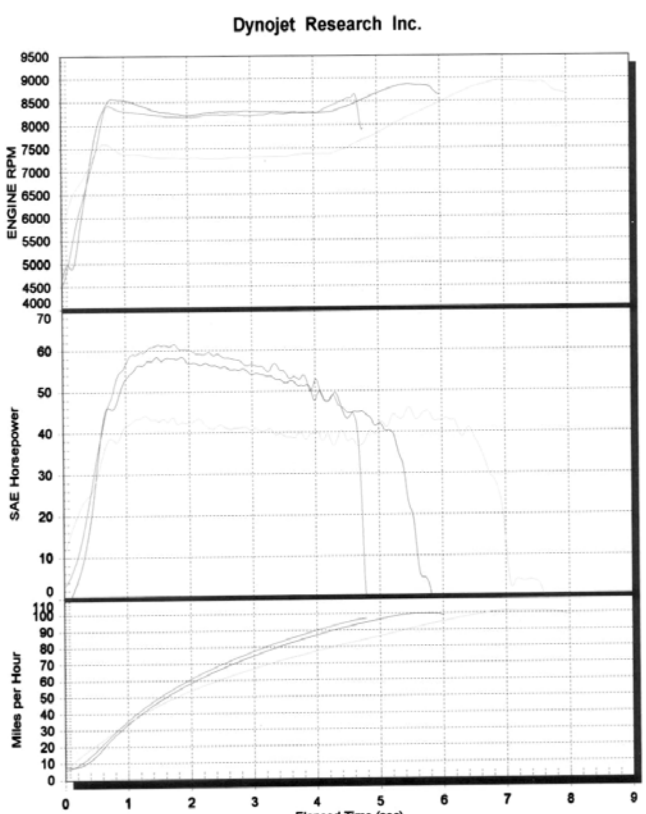

Figure 5: Dynamometer Results

The Polaris Pro-X suspension features the use of aftermarket slides. These Hiperfax slides utilize Teflon inserts that improve performance by reducing friction between the rails of the skid frame and the track. As the snowmobile is driven, the Teflon coating is spread onto the track clips in order to create a Teflon-to-Teflon contact area. While most slides have a melting point near 300°F, Hiperfax slides have a melting point close to 700°F. By increasing the melting point of the slides, the chance of the slides approaching these temperatures under normal trail conditions is greatly reduced. If the slides approach their melting temperature they can start to wear much faster, shortening the life of the slides. Gains in fuel economy of three to four gallons per mile have been seen with the use of Hiperfax slides. These gains in fuel economy are due to the decreased friction in the track-slide interface. [7]

The RMI direct-drive, Hiperfax slides and properly tuned clutches have helped in achieving the goal of increasing driveline efficiency.

NOISE REDUCTION

With noise pollution issues being one of the main focuses of the competition, noise was a primary concern for this year's snowmobile. Many sources that contribute to noise levels from snowmobiles were investigated. These sources included the engine and drive train. To reduce the total amount of noise emitted each source of noise was individually evaluated and the best solution was determined for each case.

ENGINE NOISE REDUCTION

Some of the significant sources of noise on a stock snowmobile are the exhaust and intake systems. Pressure pulses through the air-box create intake noise. The noise from the intake process was dealt with through sound absorbing materials.

Exhaust noise is created from the pressure pulses exiting from the exhaust ports and resonating through the exhaust system. Because of the high velocity and flow rate of air through the exhaust system it is a large source of noise. Thus the exhaust system received a great deal of attention for noise reduction resulting in considerable modification.

To maintain performance of the engine the expansion chamber was not changed. Beyond the stock Rotax expansion chamber, the entire exhaust system was modified. From the expansion chamber, the exhaust system continues around the modified gas tank to an automotive type muffler located under the seat of the snowmobile. The automotive muffler does a much more efficient job of canceling out these sound waves and maintaining the flow rates required. After the exhaust gases leave the muffler they go directly into a catalytic converter. Beyond the catalyst, the exhaust exits the snowmobile directly out the end of the tunnel. Sound testing was done with various modifications and the results can be seen in Figure 8. These experimental tests were performed at a constant speed pass of 35 mph with measurements taken at a distance of 50 ft.

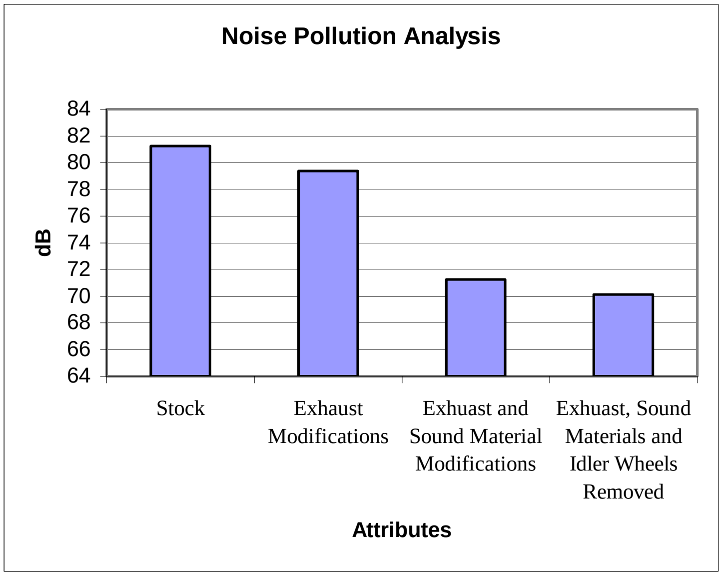

Figure 6: Noise Pollution Analysis

DRIVETRAIN NOISE REDUCTION

In the drive train, the main producers of noise were the chain case, track, idler wheels, and the continual variable transmission clutches. The chain case creates a high frequency noise due to unavoidable imperfections in the gears and chain. By replacing the jackshaft and chain case with a RMI direct-drive system, noise output was reduced. While the RMI direct-drive does remove the chain case and related noise, it does create some noise of its own. The gears in the direct drive create a high frequency noise when the snowmobile is under hard acceleration. In order to reduce the amount of noise emitted by the gearbox the gears were lapped to improve the surface finish. A heavier weight oil and vibration damping material were also added to aid in reducing the gearbox noise.

Another source of noise is the interaction of the idler wheels and the track. As the snowmobile moves, the idler wheels found on the skid frame roll over the inner surface of the track. On a conventional snowmobile track, idler wheels receive an impact load from the lugs and fiberglass reinforcing rods molded in the track. This loading scenario creates a distinctive sound frequency that can be reduced / removed by removing excess idler wheels. A tradeoff to removing idler wheels is increased wear on the slides when encountering marginal snow conditions. To meet a compromise, some idler wheels were removed and the Arctic Cat "bump track" from Camoplast has been incorporated to our snowmobile.

As seen in Figure 7 the track incorporates wedges on the track in the path of the idler wheels between the lugs and reinforcing rods to create a "smooth" path for the idlers to roll on when under load. This track has been known to decrease sound levels and increase the overall efficiency of the driveline.

Figure 7: Bump Track

Because a variable ratio belt transmission was required by competition rules, noise emitted from the clutches created a unique problem. As the clutch engages and disengages the driveline creates high frequency noises. Air disturbance caused by the high RPM of the clutches is a major cause of noise emissions. Since the use of a variable ratio belt transmission could not be avoided the noise it creates must be absorbed.

Another source of noise that was addressed was the noise created by the CVT clutches. It was found that the primary clutch makes a large amount of noise when running at a steady low speed. In order to limit this noise shims were added to the weights to reduce the amount of vibration in the clutch.

MATERIALS USED FOR NOISE REDUCTION

For effective noise control both a damper and an absorber must be used. Individually they do not result in optimal noise reduction. The ability of a material to damp structure-born sound is measured as the acoustic loss factor "n." The acoustic loss factor quantifies the vibrational energy that is converted to heat rather than sound. An undamped, 1mm thick steel panel has an acoustic loss factor of roughly 0.001 at 200 Hz. Dynamat Xtreme® applied to a 1mm thick steel panel increases the loss factor to .417 at 20°C and 200 Hz. Dynamat Xtreme® was used as a sound barrier and vibration damper. Dynamat Xtreme® was placed as a base layer throughout the hood, belly pan, and the tunnel. Dynamat Xtreme® is a lightweight, elastromeric, butyl and aluminum constrained-layer vibrational damper. [2]

For the absorbent layer, one inch Polydamp® Melamine foam with adhesive backing was used. Polydamp® Melamine foam is an extremely lightweight, open-cell material that exhibits exceptional resistance to heat, low flame propagation and smoke. The Polydamp Melamine® foam was more economical, durable, and easier to work with than fiberglass based sound absorbing materials. The effectiveness of acoustical foam is dependent on the foams ability to convert sound waves into heat energy. The affects of the sound absorbent material can be seen in Figure 8. The 0.002" aluminum skin on the Polydamp® gives it outstanding fire resistance capable of withstanding temperatures up to 425 ºF, which protects the hood and other components from excessive heat. [3]

The effectiveness of acoustical foam is dependent on the foams ability to convert sound waves into heat energy. Polydamp® Melamine foam's open cell structure has the ability to dissipate sound waves. The affects of the sound absorbent material can be seen in Figure 8. With Polydamp's® aluminized facing, it as has to ability to reflect nearly 97% of radiation heat, which protects the hood and other components from excessive heat. [2]

Another reason for using the Dynamat and Polydamp products for noise reduction was the weight. Weight is a factor when making almost all decisions for a vehicle such as this snowmobile. The Dynamat Xtreme has a weight of .45 pounds/ square foot, and the Polydamp Melamine Foam has a weight of .05 pounds/ square foot, which is less then half the weight of the materials that have been used in the past.

To effectively reduce the amount of noise emitted from the engine compartment of the snowmobile, a combination of both Dynamat Xtreme and Polydamp Melamine Foam was used. This combination of sound absorbing material and vibration dampening material produces optimal sound reduction. These materials were applied to all inner surfaces of the hood and belly pan.

To reduce the vibrations transferred through the tunnel, Dynamat Xtreme was applied to these surfaces. Polydamp could not be used in this location due to the limited space and exposure to snow and dirt.

Sound Level Testing

Two different sound level tests were performed on the snowmobile. The first test performed was the static sound level test with the snowmobile engine at idle. Four measurements were taken from different locations on the snowmobile as shown in figure XX. The second test performed was a wide open throttle pass by. Three passes were made for each test condition. Results can be found in tables 1 and 2.

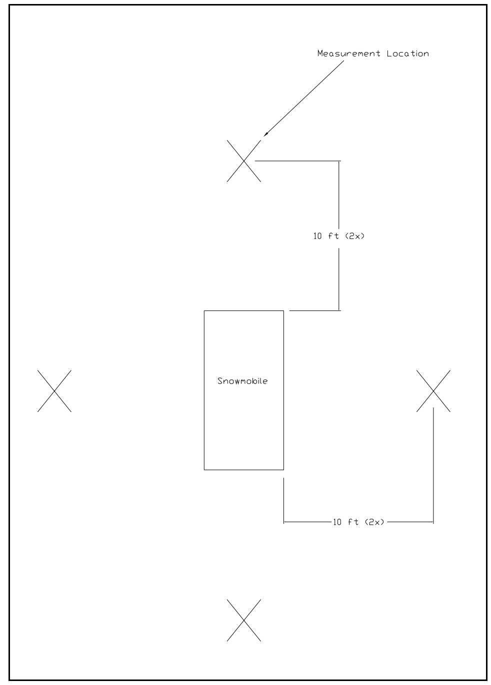

Figure 8: Static Sound Level Test Setup

Static Reading						
	Hood Off Catalyst Off		Hood On Catalyst Off		Hood On Catalyst On	
Front	74.5	dBa	72	dBa	72	dBa
Left	82.5	dBa	80.6	dBa	75.5	dBa
Right	81.4	dBa	79.3	dBa	75.5	dBa
Rear	83.5	dBa	79.5	dBa	75.9	dBa

Table 1

Wide Open Throttle Pass By						
Conditions:	Hard Packed Snow and Ice					
	Hood Off Catalyst Off		Hood On Catalyst Off		Hood On Catalyst On	
Pass 1	100.4	dBa	98.6	dBa	89.2	dBa
Pass 2	98.3	dBa	99.6	dBa	88.6	dBa
Pass 3	98.8	dBa	97.4	dBa	88.9	dBa

Table 2

APPROACH AND ENGINE SELECTION

Choice of engine plays a large role in the design strategy. Both the two-stroke engine and the use of a four-stroke engine were considered. For many the four-stroke engine is the first choice in reducing emissions. This is a common reaction because the four-stroke cycle controls the exhausting of combustion gases and the induction of the fresh air/fuel charge much better than that of the two-stroke. However, the four-stroke engine has a lower power to weight ratio when compared to a two-stroke. For comparison between two and four stroke outputs, it would take an 800cc four-stroke engine to provide the equal horsepower as a 550cc two-stroke. [9]

A two-stroke semi-direct injected (SDI) engine was chosen over an ordinary carbureted two stroke engine because of its low emissions, performance, fuel economy, and reliability. Semi-direct injected engines are the future of the snowmobile industry by merging the characteristics of two strokes and four stroke engines. A SDI engine unifies the low emissions and fuel economy of four stroke engines with the lightweight and high performance of two stroke engines. Along with these qualities and the proven reliability of Rotax's 2-Tec SDI 600cc engine, this engine proved to be our 2005 competition engine of choice.

FUEL CHOICE

The team decided to use fuel with a blend of ten percent ethanol and ninety percent premium gasoline (E10). E10 fuel was chosen because of its compatibility with this engine as well as its performance qualities and wide availability for consumers trailside. Using a blend of 85% ethanol and 15% premium gasoline was also considered but decided against due to its lower heating value as well as the inherit problems with cold start situations.

INDUCTION

One of the goals was to limit the cost of modification of the two stroke engine, while maximizing performance and efficiency. The use of a DFI system would be the first choice for control of fuel delivery. The DFI system is probably the best induction system for a two-stroke engine if implemented correctly. This is because the engine is clean air scavenged and fuel is introduced directly into the combustion chamber late in the compression stroke in most cases after the exhaust port is closed by injectors positioned in the cylinder head. This drastically reduces the short scavenging problem of the conventional two stroke engine. However, DFI is a very delicate, sensitive system that requires large amounts of calibration and numerous components including a costly high pressure fuel pump. The presence of high pressure fuel in close proximity to the rider raises safety concerns in the event of a collision. The complexity of implementing a DFI system prevents this system from being a safe, cost effective, reliable option. Additionally, the use of a direct fuel injection system would require contracting an outside company to help with development, an option much too costly for the given budget. Also, the time and cost involved in implementing the system did not appear practical. The option of using a DFI system was eliminated.

An option that offered many of the same advantages as the DFI, the semi-direct injection system (SDI) was chosen. The SDI system placed two automotive style injectors in the transfer ports of each cylinder. The system also uses a clean air charge from the crankcase to scavenge the cylinder similar to a DFI system. However, late in the scavenging process fuel is injected into the transfer ports. This drastically reduces the short scavenging problem of the conventional two stroke engine at low rpm levels. The system maintains a low injection pressure of 399kPa (58psi) which is much safer than the costly high pressure DFI alternative. The fueling demands are controlled by an electronic control module (ecm) which receives input from several sensors monitoring intake air pressure, air temperature, rpm, throttle position, detonation, coolant temperature and exhaust gas temperature. The onboard ecm provides reliable fueling to the engine automatically compensating for variations in temperature and elevation.

THE ENGINE

Our Rotax 2-Tec Semi Direct Injected engine choice, figure 10, utilizes a 72mm bore and a 73mm stroke with 46mm throttle bodies to provide optimum performance within the 600cc displacement limit for 2-strokes. The Rotax 2-Tec SDI engine excels in many areas of the 2005 CSC competition. The SDI engine provides the same horsepower as traditional carbureted engines. The SDI engine delivers a 50% decrease in emissions and a 25% increase fuel efficiency compared to a carbureted two stroke engine. The 594.4cc motor uses two injectors in each of the two cylinders to deliver the right amount of fuel into the transfer ports. The SDI engine can reduce emissions by ~50% by only operating one injector at idle or low speeds. When the snowmobile is running at high speed the electronic control unit activates the second injector. Along with controlling the injectors, the electronic central monitor (ECM) examines the incoming data from the crank position, atmospheric pressure, throttle position, ambient temperature, knock from the engine, engine temperature, and uses this information to adjust timing, injection, and exhaust valve movement. All of this information is computed by the ECM to provide response to driver input and better fuel economy. [10]

Figure 10: Rotax 2-Tec SDI 600 engine

Another area of the engine that was investigated was the lubrication of the engine. Power loss due to friction in the bearings and the piston rings and skirt is one of the largest factors in reducing the engine's overall efficiency. Through research it was determined to use Blue Marble® oil, which contains the additive Phosfamid™. Phosfamid is an additive that makes it possible to reduce friction in internal combustion engines by up to 88%. This reduces the amount of oil needed. Phosfamid also improves the emissivity of the combustion chamber walls. By improving the emissivity of the walls, the walls cause more heat to be reflected back into the combustion chamber instead of being transferred through the walls. This allows for a more efficient and cleaner burn in the cylinder. The more efficient burn results in lower emissions and improved fuel mileage. Phosfamid also reduces the coefficient of friction between moving components as can be seen in Figure 9. [5]

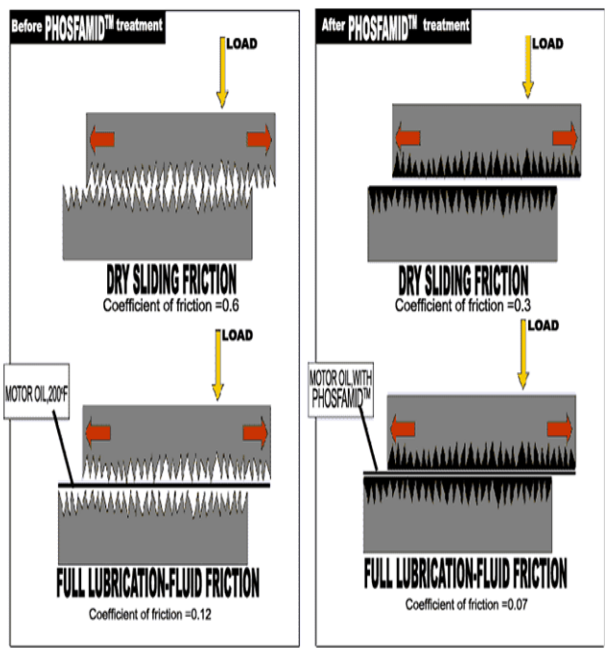

Figure 9:Effect of Phosfamid on Sliding Friction

THE EXHAUST

One main area of concern in preparing for the 2005 Clean Snowmobile Challenge was the exhaust system. This system has a huge effect on both the noise level of the snowmobile as well as the emissions. Since these two criteria are weighted the heaviest at competition, the exhaust system was given special attention. The final configuration consisted of three distinct components; expansion chamber, muffler and catalytic converter.

The decision was made to continue to use the stock single expansion chamber to control weight, under hood heat, and overall noise. The use of twin pipes would not only increase all of the aspects listed above, but also the total cost of the snowmobile since there would be two pipes to manufacture instead of one. Cost is one of the variables important to the possible consumer who will be purchasing the environmentally friendly snowmobile. The stock expansion chamber was not modified due to the fact that it was designed and built to exact manufacturer specifications in order to optimize the efficiency and performance of the engine. Within the expansion chamber pressure waves from the exhaust process bounce back and forth these waves can have a great deal of effect on the performance of the engine. A slightly negative pressure is desirable at the time of exhaust port opening to aid in the blowdown process. A positive pressure is desired during the crank angle between the close of the intake ports and the closing of the exhaust ports. This positive pressure ensures that the fresh charge stays in the cylinder for combustion. With these desired pressure effects and the natural complexity of controlling pressure waves it was decided not to make any changes to the expansion chamber. [8].

Beyond the initial expansion chamber the exhaust systems goes immediately out from under the hood to an automotive style muffler located under the seat. By having the hot exhaust gases under the hood for the minimum amount of time the under hood temperatures are lowered. Under hood temperatures were also a focus point for the team this year due to the complications created by extremely high under hood temperatures at previous competitions. The muffler that was to be used in this system had to have the ability to handle the large flow rates associated with the high rpms of the two-stroke engine. It also had to provide minimal restriction and still do a great deal of silencing. The layout of the exhaust can be seen in Figure 10.

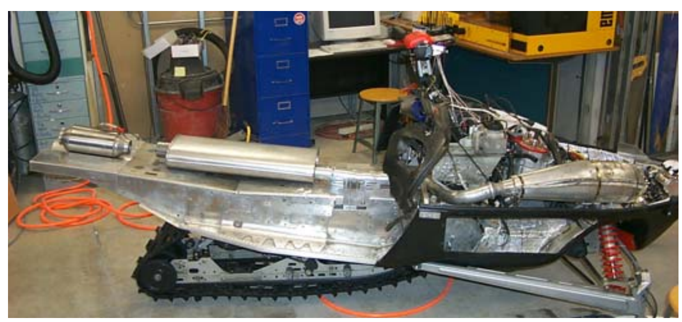

Figure 10: Pro-X with Modified Exhaust System

Directly behind the muffler is the catalytic converter. The catalyst was placed at the end of the exhaust system in order to alleviate the problems associated with the high temperature exhaust gas beyond the catalysts. This adversely affects the light off time of the catalyst. However, cold start emissions are not measured in competition so this was not a primary concern. Light off of the catalyst is still achieved in this configuration as proven through testing.

The purpose of the catalyst is to convert hydrocarbons, carbon monoxide, and nitrogen oxide into water, carbon dioxide and hydrogen. This process involves chemical reactions between the catalyst material and the exhaust entering the catalyst. The material on the surface that makes these conversions possible are: alumina oxide, cerium oxide, rare earth metal stabilizers, and the precious metals platinum, palladium and rhodium. [3]

4.66-inch diameter catalyst with a cell density of 200 cells per inch was selected for use. This design was used in order to meet the required flow rates and allow for enough surface area to complete the reactions. The catalyst uses a ceramic substrate, this allows for higher temperatures in the catalyst without the substrate failing.

With the use of the ceramic substrate there has to be an isolation layer between that and any metallic housing. This is necessary due to the fact that the steel housing and the ceramic substrate have different coefficients of thermal expansion. As the temperatures in the catalyst increase the steel expands at a quicker rate then the ceramic substrate. If these two were directly connected the stresses from this expansion could cause the substrate to crack.

For this layer a catalytic converter insulation material was used. This mat is especially designed to have optimal mid to high temperature operation. Its purpose is to isolate the substrate from the housing and serve as an insulation to keep the housing temperatures lower. The housing was assembled using a tourniquet style wrap. This is one of the latest advancements in catalyst assembly technology. It assembles the housing and mat to a given pressure, which automatically makes up for any variations in the substrate and the mat material. This is all accomplished by closing to the housing to given pressure instead of a set dimension as with most catalyst assembly practices. This type of assembly allows the converter to withstand accelerations up to 75g for the entire life of the vehicle. The catalyst housing is made of stainless steel, 409 on the conical sections, and 441 for the remainder. The catalyst and housing can be seen in Figure 11 [9]

The catalyst used on the Pro-X is divided into two separate substrate bricks, with secondary air injection between the two bricks. The first brick has a three-metal washcoat: platinum, rhodium, and palladium. This brick is designed to be an extremely effective at reducing NO_x as well as beginning the conversion of the other exhaust gases that are present. The second brick has a palladium and rhodium washcoat. This is used to clean up the emissions, effective on HC and CO emissions as well as finishing the NO_x conversion. Rhodium is the best of the precious metals to help in the conversion of all three major raw exhaust gases; therefore the second brick has an especially high concentration of rhodium. Rhodium is also the least costly of the precious metals used in catalytic converters. The basic layout and workings of the catalytic converter can be seen in Figure 12. [9]

Figure 11: Catalytic Converter

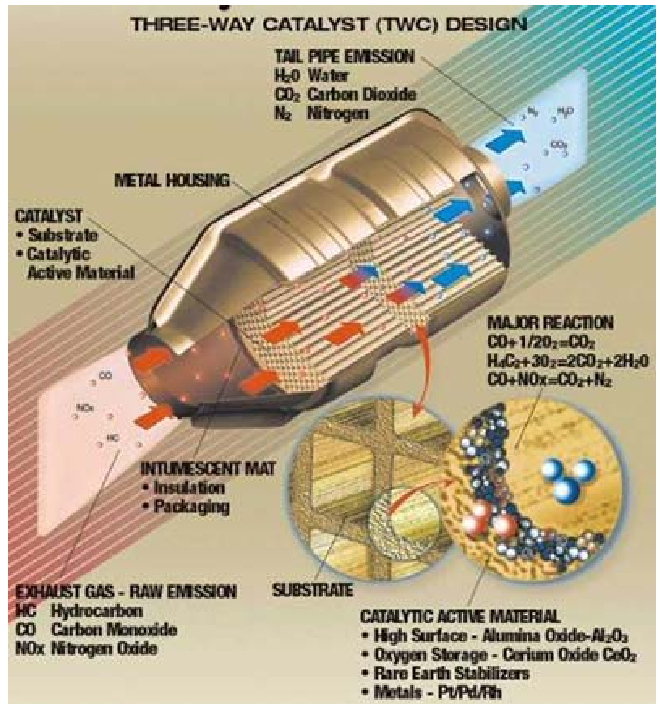

Figure 12: Structure and Function of a Catalytic Converter

To increase the effectiveness of the catalyst a secondary air injection system was installed (Figure 13). The secondary air injection had a large effect on both the unburned hydrocarbon and carbon monoxide emissions as can be seen in Figure 15 and Figure 16. This data was collected using a three-gas analyzer with the snowmobile running at idle, 2000 rpm, with no load. This system consists of an air pump driven by the magneto side of the engine and a valve to regulate the amount of air that flows into the exhaust system. Oxygen is needed in the chemical reaction that takes place in the catalyst (Figure 14). When the exhaust exits the cylinder after the combustion process there is little oxygen left for the reaction in the catalyst. Additional oxygen is needed to turn carbon monoxide into carbon dioxide and finish the combustion of the hydrocarbons as seen in figures 17 and 18. The secondary air injection system increases the amount of oxygen available for the conversions in the catalytic converter by injecting fresh air. The effects are most apparent when looking at the carbon monoxide emissions levels (figure 18).

Figure 13: Secondary Air Injection Pump

$$CO + \frac{1}{2}O_2 \longrightarrow CO_2$$

$$H_4C_2 + 3O_2 \longrightarrow 2CO_2 + 2H_2O$$

$$CO + NOx \longrightarrow N_2 + CO_2$$

Figure 14: Typical Chemical Reactions in a Catalytic Converter

Once the gases have gone through the catalyst they are immediately exhausted out the rear of the snowmobile. This configuration helps to eliminate many of the problems associated with the high temperature exhaust gases.

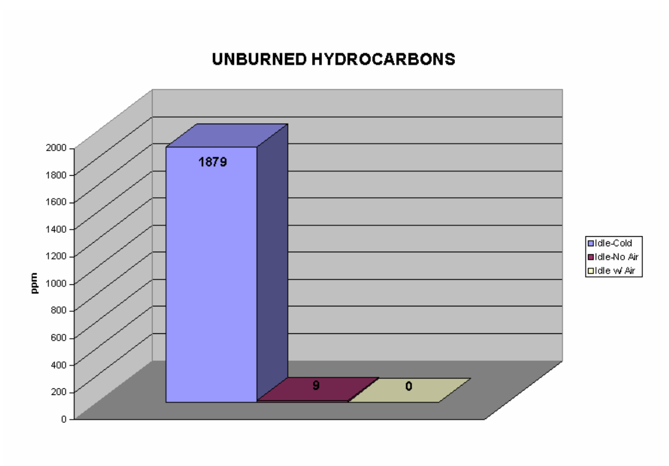

Figure 15: Hydrocarbon Emission Data

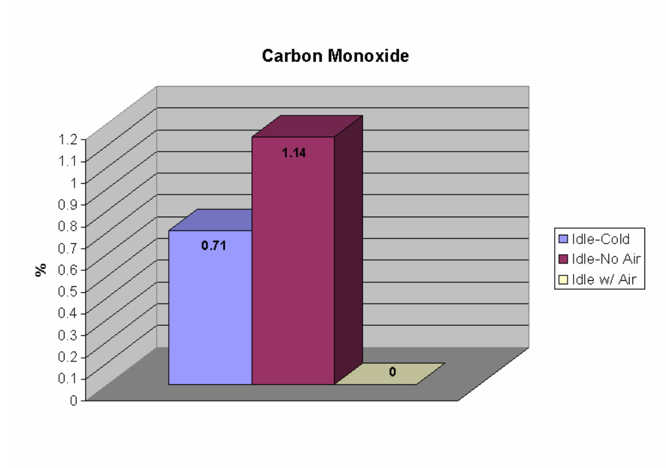

Figure 16: Carbon Monoxide Emission Data

The introduction of secondary air to the catalyst presented some challenges to the team. As seen in figure 19 and 20, the team experienced a local failure of the catalyst in the small oxygen rich environment in the second stage of the catalyst because of the simple method of adding the air. Therefore a diffuser (figure 21) was fabricated with 25 holes on top and bottom to spread the oxygen across the face of the entire substrate, increasing the effectiveness of the second stage of the catalyst. As seen in figure 22, the entire face of the catalyst substrate is still functioning after long-term testing.

Figure 19: Black local section of failed catalyst wash coat

Figure 20: Cut-away section of catalyst housing

Figure 21: Diffuser for secondary air injection

Figure 22: Functioning catalyst with air injection diffuser

RIDER COMFORT

The New Trails X-Flex seat, figure 23, is hollow the length of the seat by utilizing a polymer arch to act as a "spring" between the rider and the tunnel. The engineered spring along with the vertical slots make a structural skeleton to deflect and absorb the blow when the snowmobile runs over uneven terrain (similar to the leaf spring suspension on trucks). The seat can give the rider between five to eight inches of travel depending on terrain. The polymer skeleton is covered with closed cell foam for rider comfort.

Figure 23: NT X-Flex seat

The suspension spring rate and damping was reduced to lower the shock input to the rider over small bumps. The front springs were reduced to an 85 lb/in spring and the damping was reduced to position 1 on the clickers. The front and rear shocks in the rear skid frame were also set for the lowest damping on the clickers. Rear torsion springs were held constant because they were already the same rate as the trail touring suspensions. The front spring however was decreased to a spring with a rate of 120 lb/in.

A computer simulation of the revised spring rates shows the reduced acceleration input as felt by the rider over 3-inch bumps. Our revised suspension calibration is modeled to the left of factory specifications in figure 24.

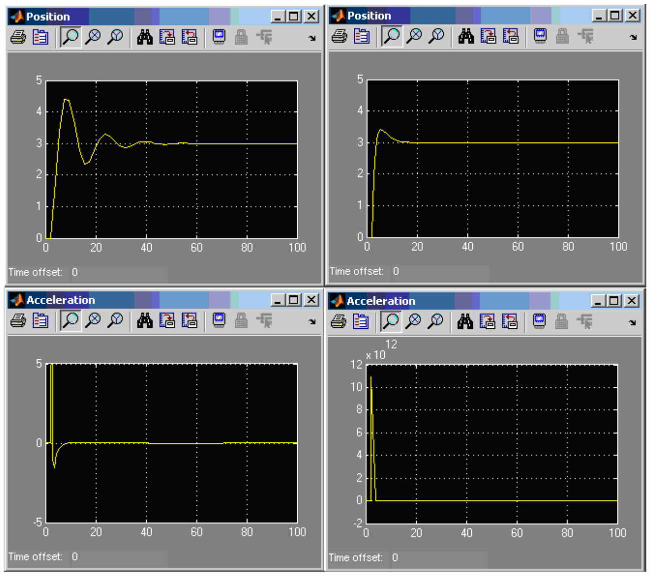

Figure 24: Comparison of damping coefficients

COST ASSESSMENT

The 2005 UW-P Clean Snowmobile team sought to develop a cost effective solution that could easily be implemented into full-scale production. The major modifications to our snowmobile include the addition of sound abatement, an air pump and a catalyst. The total technology implementation cost of our approach was calculated to be $751.50 according to the CSC2005 TICA form [1]. It was the goal of the team to be able to produce a competitive snowmobile that would be available to the consumer at a relatively low cost. If the cost of an environmentally friendly snowmobile is too high consumers will not spend the extra money. The snowmobile industry will not be able to sell environmentally friendly machines if they cannot be achieved at a cost that is reasonable.

CONCLUSION

Modifying a 2002 Polaris Pro-X 600 for the 2005 SAE Clean Snowmobile Challenge presented many challenges to the UW-P team. The goal was to produce a snowmobile that is both rider and environmentally friendly, as well as maintaining or improving performance characteristics. This has been accomplished in a cost effective manner that has not included extravagant new engineering that would lead to increasing manufacturing costs.

Team UW-P is very confident in the design decisions made throughout the modification of the Pro-X. This student team is certain that this snowmobile will meet or exceed all expectations and regulations set by the 2005 SAE Clean Snowmobile Challenge. UW-P believes that the modifications made to this Pro-X are the keys to pleasing the general public by making snowmobiling both an environmentally friendly and exciting sport.

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