03/04/05

Minnesota State University, Mankato Clean Snowmobile Challenge 2005

Analysis of an E85 Four-Stroke Cycle Snowmobile

Bradley Bahneman, Timothy Christensen, Andrew Graham, Wade Kahout, Andrew McNair, Kevin Reiss, Erik Shallbetter, Joseph Wrobel,
Senior Team Members

Dr. Bruce Jones
Faculty Advisor

ABSTRACT

Illustrated throughout this paper is Minnesota State University, Mankato's 2005 Clean Snowmobile Challenge entry. To meet the competition's demand for low emissions, the students employed a four-stroke cycle engine modified to operate on a blend of fuel which consists of 85 percent ethanol and 15 percent gas (E85). Due to its low emission characteristics and consistent composition, E85 was selected and was injected on the back side of the intake valves for increased atomization and more complete combustion. An aftermarket ECU was used to optimize the fuel map and a catalytic converter was added to eliminate any unburned hydrocarbons.

To address the concerns for operating noise, a larger expansion type muffler was selected to match the noise characteristics of the engine. Noise dampening material was applied at critical locations and a low velocity air box was selected to reduce noise in the intake. Performance was maintained by using adjustable shocks with digressive valves and a tuned clutching system. In addition stock Polaris parts were used where applicable to reduce added cost and improve reliability.

INTRODUCTION

In 1999 the Society of Automotive Engineers founded the Clean Snowmobile Challenge in response to the negative publicity that snowmobiles had received in environmentally sensitive areas. The main purpose of the competition was to design and build an over-the-snow machine that would have reduced emissions and lower noise pollution than a stock snowmobile. This is done while maintaining or increasing the original performance, engineering technology, and cost efficiency. The competition allows engineering students the opportunity to create and implement ideas on an existing snowmobile that could be realistically applied to the snowmobiling industry, thus promoting a cleaner environment. The contest awards points to teams for their design solutions in the areas of: emissions, operating noise, acceleration, suspension, endurance, static display, and a technical paper.

Concept

To satisfy the goals of the competition, the students decided to develop a four-stroke cycle engine that would operate on E85. The details of this decision are discussed based on design parameters, implementation, testing, and results.

Design Parameters

ENGINE SELECTION

The 2005 clean snowmobile objective was to modify a snowmobile to be quiet and to emit significantly less unburned hydrocarbons and carbon monoxide than current production snowmobiles, without significantly increasing the emission of oxides of nitrogen. With this objective in mind the students decided to use a four-stroke cycle engine rather than the two-stroke cycle engine used in the control sled. The decision was made as a team to continue the development of a Polaris Sportsman 683cc engine based on the success of this four-stroke cycle engine in last year's competition. This engine will allow for quiet operation, low emissions, and excellent fuel efficiency without incurring a large cost or a decrease in reliability.

EMISSIONS

The 2005 MSU clean snowmobile challenge team has decided to continue the use of last year's Polaris 683cc four-stoke cycle engine based on its success in the past. The four-stroke cycle engine was chosen based on its capability of producing significantly lower emissions when compared to a two-stroke cycle engine.

The team selected E85 as the fuel for the competition because it is a renewable, cleaner burning fuel that reduces emissions when compared to regular gasoline. This decision was also influenced by the benefits and attraction of using cleaner snowmobiles in environmentally sensitive areas such as National Parks. These over-the-snow machines would fit within a vehicle fleet application where a central fueling location could be implemented. This would result in a smoother integration of an alternative fuel with limited refueling locations.

In addition to the motor selection, an aftermarket engine management system (EMS) was integrated to control fuel curves. The control of these aspects of the engine parameters enabled the team to further reduce emissions and increase performance. This aftermarket fuel and ignition control system would be replaced with a non-adjustable system once development was completed to reduce cost.

Several commonly used emission control devices were investigated to determine if their application would be beneficial or detrimental to the overall operation, reliability, and cost efficiency of the project. Of the possible systems, a catalytic converter was used to reduce unburned hydrocarbons and excessive NOx. Resistive heaters were used to improve cold starting emissions, and a fuel injection system with injectors directed at the back of the intake valves were used to improve the atomization of the fuel.

Combustion temperatures were not excessive, so utilizing an exhaust gas recirculation system was not appropriate. Also emission testing revealed the presence of a sufficient amount of oxygen in the exhaust even after the catalytic converter. This made the incorporation of an air injection system trivial.

FUEL CHOICE

The team chose to use E85 as its fuel. E85 is a renewable fuel which has many benefits when compared to gasoline and other hydrocarbon fuel emissions. The fuel characteristically demonstrates lower HC, CO, NOx and PM emissions according to the Environmental Protection Agency's website [3].

NOISE

One of the MSU students' most important goals was to reduce the noise produced by a stock snowmobile. The students discovered from previous competitions the two major noise factors were the air intake and the track. With this in mind the students looked into different air box designs that were proven suitable for their engine. An air box of this type reduces noise by decreasing the velocity of the intake air. An extreme-temperature sound absorbing foam with a noise reduction coefficient of .52 (NRC) was used on the belly pan and hood to absorb engine noise [2]. The higher the NRC value, the more efficiently the material absorbs sound. A material with an NRC of 1 is the most sound-absorbing material available. To go along with Arctic Cat's Quiet Track (an OEM track specifically designed to reduce noise) which was used in previous competitions, the drive wheels were modified and a skirt was designed to act as a sound absorber hung around the rear of the track. The absorbent material for this skirt has an NRC rating of .50 and is also water resistant.

PERFORMANCE

The focus of Minnesota State University's Clean Snowmobile Team was to complete the competition and do as well as possible. Performance had become secondary to noise and emissions, the most important areas of the CSC. Due to the nature of the CSC performance was addressed after these critical areas. The students had adequate performance for any conditions that may be present while riding in America's National Parks and wildlife areas.

SUSPENSION/HANDLING

While the stock Fox racing shocks provide adequate all around performance, the students felt that a more tunable suspension was necessary for the competition. The Fox shocks were a rebuildable shock, but the tuning options were limited. After considerable searching, it was discovered that QA1 had a rebuildable, sport-touring shock with the desired digressive valve curve and 12 separate exterior settings for compression and rebound. This, combined with the proper spring rates, provided a much more tunable, better handling suspension.

DURABILITY/FEASIBILITY

Due to the vast research and testing behind the stock Polaris parts and their proven durability, the students tried to retain as many stock parts as possible. There were some areas where stock parts were simply unusable and therefore certain parts had to be designed, fabricated, and tested for their desired application. Also, a four-stroke cycle engine typically runs at a lower RPM range, thus usually having a longer running life, and longer service intervals.

COLD START

Since the students chose to use E85 a cold start mechanism was required. The Reid Vapor Pressure of E85 was considerably less than that of regular gasoline. According to the EPA [3] and the Department of Energy [4], gasoline RVP is commonly between 7.0 and 9.0 compared to E85 at 2.3 The decision was made to run an “injector bypass” pressure regulator system, placing a two port regulator ahead of a single fuel rail type fitting on each injector. The injector fitting also houses a resistive heater which warms the fuel to the target temperature of 100ºF. This system allows the fuel to be heated before cranking and remain static without loosing any heat through the pressure regulator return. The higher temperature fuel will atomize more efficiently as it is injected into the cold intake air.

COST

The overall cost of snowmobile modifications was also very crucial. Snowmobile retailers would struggle to sell a clean snowmobile unless the price was competitive with other conventional snowmobiles. When a consumer is considering the purchase of a new snowmobile they are often looking for the snowmobile with the most options for the least amount of money. The overall durability of the four-stroke cycle engine will also be less expensive over time since four-stroke cycle engines operate at a lower engine RPM and therefore run cooler resulting in less engine wear. Since the engine does not operate at as high an RPM as a two-stroke, a four-stroke engine will also have an increased fuel economy. The Total Incurred Cost Analysis (TICA) of the modifications to the student’s snowmobile could not exceed $1500 for this reason. A quiet, low emission snowmobile would have a marketing disadvantage if there were other conventional, higher performance snowmobiles on the market for a more reasonable price. The students kept the TICA as low as possible while still obtaining low emissions, quiet operation, and adequate performance. Consumers would be more willing to purchase a clean snowmobile if the cost is competitive with that of conventional snowmobiles. Not only would low cost benefit consumers, but it would also help retailers receive increased sales and everyone would enjoy a cleaner environment to ride in.

Implementation

EMISSIONS

Based on the fact that a majority of the points for the competition are related to noise and emissions, this year the students chose to use an E85 four-stroke cycle engine. Thus the students found that the Polaris 683cc engine would fit without major modifications to the snowmobile. In a study by SouthWest Research Institution it was shown that the use of E85 as a fuel could greatly reduce the amount of overall emissions produced by a four-stroke cycle engine [5]. The addition of a reduction type catalyst to the system will also greatly reduce the amount of total emissions produced by the engine. In the presence of oxygen, any unburned hydrocarbons will be oxidized and oxides of nitrogen will be reduced.

ENGINE MANAGEMENT

A MoTeC M48 engine management system was chosen to more accurately tune the engine. The data gathered from the sensors is used by the ECU to control the fuel injection system. The seven sensors incorporated into the engine include:

- Coolant Temperature
- Intake Air Temperature
- Barometric Pressure (MAP)
- Camshaft Position
- Throttle Position
- Crankshaft Position
- Wide Lambda Sensor

By using the Horiba, an air/fuel ratio meter, oxygen levels could be monitored outside of the engine management system. This allowed for more precise control of the combustion mixture and enabled the students to tune the engine to a stoichiometric air/fuel ratio.

A heated wide band lambda sensor was used in conjunction with the ECU. The wide band lambda sensor sends the air/fuel ratio to the ECU thus allowing it to correct the mixture as needed. With built in heaters, the wide band lambda sensor heats up much sooner than a conventional oxygen sensor. This results in the engine running closed loop in a shorter period of time. With the values set to stoichiometric, the emission levels are lowered as much as possible obtaining peak efficiency as shown in Figure 1.

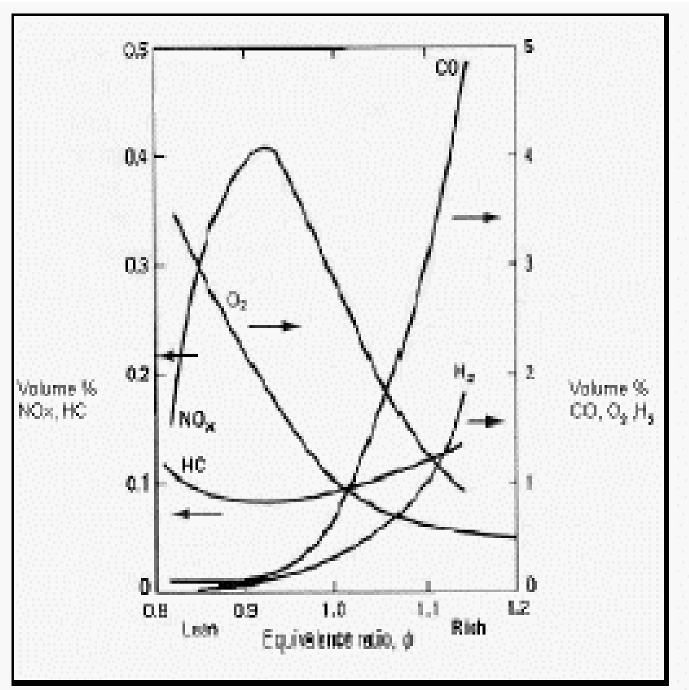

Figure 1. Equivalence Ratio and Emission Level Relationships

The engine was mapped by holding throttle position in increments of 10% for each 500-RPM level. At each increment, the injector pulse width is adjusted to provide maximum torque. The fuel map is adjusted until the engine was operating close to the lean end of a stoichiometric air/fuel ratio.

The last step in fine tuning the fuel map was to measure emission levels with an exhaust gas analyzer. With finite adjustments of the map it was possible to richen or lean the engine for optimal emission levels and performance.

FUEL

As previously mentioned, the snowmobile uses E85, which consists of 85% ethanol and 15% gasoline. Not only is E85 a renewable resource, but it is also known to improve emissions by 25% according to the U.S. Department of Energy [1]. Part of the reason it is a cleaner fuel is due to its higher oxygen content. E85 is considered to be a more chemically consistent fuel when compared to gasoline, which can vary from one season to another. This allows for a more consistent fuel map when dealing with ethanol. Due to a lower BTU content, a larger volume, and therefore greater weight, more E85 would be required per mile compared to gasoline. However the benefits of this fuel far outweigh this single drawback.

OCTANE

E85's increase in octane (100 to 105 vs. 87 to 93) over common gasoline has allowed the students to create more power from the 683cc Polaris engine. E85 also has a significant cooling affect aiding in component longevity and reduction of NOx.

REID VAPOR PRESSURE

One of the major disadvantages of this fuel is that it has a very low Reid Vapor Pressure. To combat the negative effects, the students installed inline electric fuel heaters which raise the fuel temperature and allow for easier cold starting.

ENERGY DENSITY

Another aspect the students took into consideration was the lower energy density of E85. The students selected fuel injectors that would be capable of the higher rate of fuel flow and had a 20° spray pattern to aid in fuel atomization and protect against wetting of the intake port walls. Additionally, the students determined the minimum size fuel tank required for the endurance part of competition and built a tank accordingly.

CATALYST

The students selected a catalyst developed by Engine Control Systems (ECS). The catalyst was constructed of 400 cells per inch with a modest loading of Platinum and Rhodium. The catalyst consists of a reduction section (Rhodium) and an oxidation chamber (Platinum). The reduction bed converts the NOx that exits the exhaust into nitrogen and oxygen.

Oxidation catalysts do not start working until a temperature of between 500°F and 600°F is reached. Efficiency of the catalyst increases until it reaches its maximum operating temperature of 1200°F. Upon reaching this critical temp, the catalyst achieves peak effectiveness as shown in Figure 2 [6].

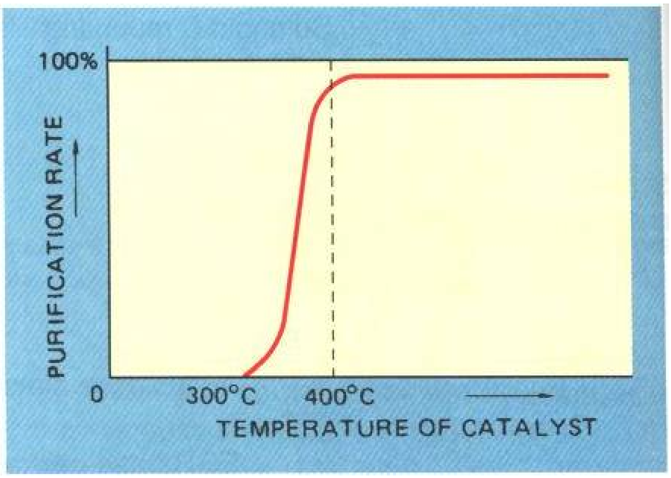

Figure 2. Purification vs. Temperature for Catalyst

MAP

The fuel map of a fuel injected engine is important for achieving good performance and fuel economy. To improve fuel economy, the map provides proper calibration based on engine as well as air temperature, and altitude. A wide band lambda sensor was used to measure the air/fuel ratio at all rpm and throttle position points. These parameters set the tables (engine temp correction factor) for the proper values in order to keep it in the correct operating range. The lambda for best fuel economy, under part throttle operation, is around 1.0-1.2. [7]. During partial throttle operation, a lean lambda is obtainable since the load on the engine is lower and the demand for horsepower is reduced. While testing the engine with a water brake, the students optimized fuel injection timing for the best Brake Specific Fuel Consumption. By having a low BSFC, a lower amount of fuel is required to produce an equal amount of horsepower.

NOISE

To improve the noise emitted by the MSU students' snowmobile, the team chose to concentrate on the parts of the snowmobile that emit the most noise. These areas included: the exhaust system, under hood mechanical noise, and rear suspension and track noise.

EXHAUST

To allow sufficient room under the hood for a catalytic converter and proper heat dissipation, it was decided to route the exhaust along side the fuel tank and under the seat. This routing also allowed for a larger, quieter muffler and enhanced noise reduction by directing the exiting exhaust to the underbody of the sled at the rear of the track. A skirt was used to contain noise not eliminated by the muffler, allowing it to be absorbed by noise dampening material.

Table 1. Experimental Correlation Calculations for a Conical and Expansion Type Muffler

	1	**2**	**3**	**4**
Critical Frequencies (Hz)	21	34	41	56
Exhaust Temperature (°F)	867.02			
Diameter of Exhaust (in)	2.125			
Cross Section of Exhaust (in^2)	3.55			
	Length	**Width**	**Height**	
Space Constraints (in)	15	12	6	
Conical Connector				
Maximum Cross-Sectional Area (in^2)	28.27			
Dimensionless "m"	8			
	1	**2**	**3**	**4**
Wavelength (ft)	85.15	52.59	43.61	31.93
Ls,min (ft)	0.161			
Ls,max (ft)	0.646			
Dimensionless [Ls,min (ft)/Wavelength (ft)]	0.002	0.003	0.004	0.005
Dimensionless [Ls,max (ft)/Wavelength (ft)]	0.008	0.012	0.015	0.020
TL maximum	4 dB @ maximum cross section and any Ls			
Expansion Chamber				
Maximum Cross-Sectional Area (in^2)	56.55			
Dimensionless "m"	16			
	L1	**L2**	**L3**	**L4**
Optimum Length (ft)	21.7	13.4	11.1	8.1
Critical Frequencies (Hz)	21	34	41	56
Dimensionless "kl" for Length = Lmax	1.11	1.79	2.16	2.95
Dimensionless "kl" for Length = L2	0.99	1.60	1.93	2.64
Dimensionless "kl" for Length = L3	0.82	1.33	1.60	2.19
Dimensionless "kl" for Length = L4	0.60	0.97	1.17	1.60
TL maximum	18 dB @ kl = 1.6			

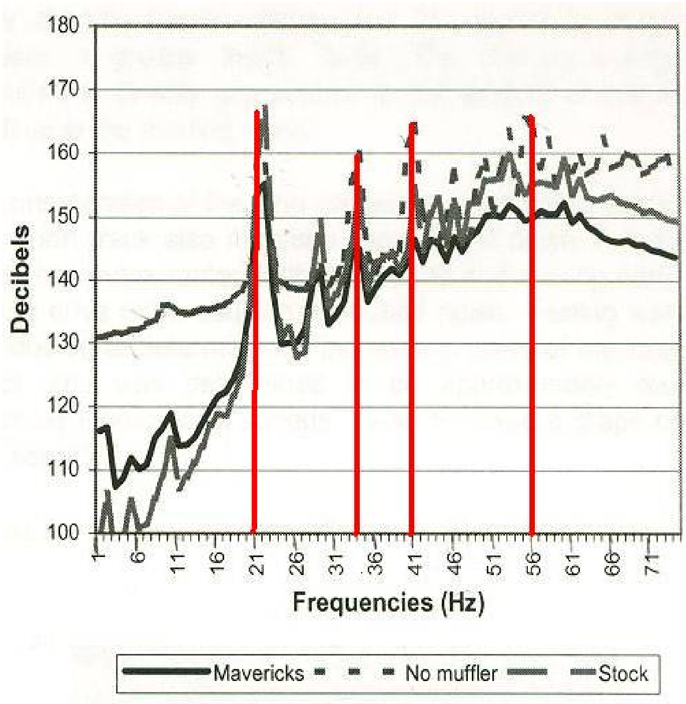

Figure 3. Sound Map for a 683cc Polaris Four-stroke Cycle Engine

When selecting a muffler spatial restrictions were the primary concern. The maximum dimensions for an under-seat muffler were measured as a starting point and were determined to be 12, 6, and 15 inches for the width, height, and length respectively. Next, a sound map of the exhaust noise was consulted to determine which frequencies produced the highest decibels. These critical frequencies were highlighted to optimize noise reduction and can be seen in Figure 3.

A reactive type muffler, using an expansion to cancel pressure reverberations, was selected over an absorptive type because of its ability to dampen higher decibels over a wider range of frequencies. Two styles of reactive mufflers were assessed to determine which could dampen more noise at the determined critical frequencies.

Experimental correlations published by Beranek [8] were consulted to determine what shape and size of muffler would be suitable. These correlations can be seen below in Figures 4 & 5. From the trends of these correlations, it was immediately evident that the larger the area of the expansion the more effective it would be. Sample calculations for each type were performed and it was discovered that the maximum size conical section muffler could cancel a maximum of 4 decibels and that the expansion type could cancel between 15 and 18 decibels over the entire range of frequencies. A muffler could not be found that exactly matched the desired dimensions, but a Walker Quiet-Flow muffler was found that matched them closely. The dimensions of this muffler were 11, 5.5, and 15 inches for the width, height, and length respectively.

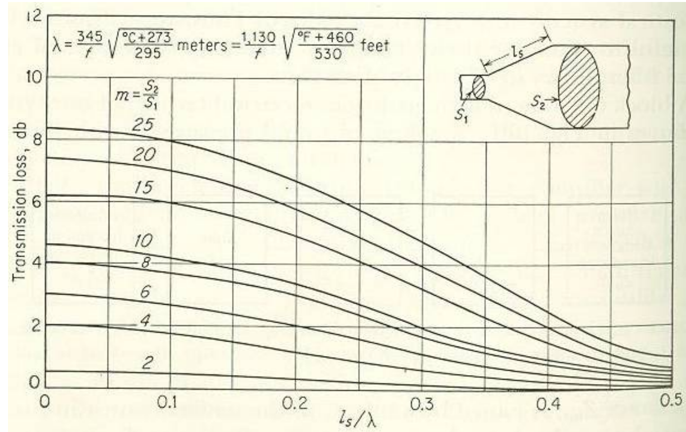

Figure 4. Experimental Correlations for a Conical Section Muffler

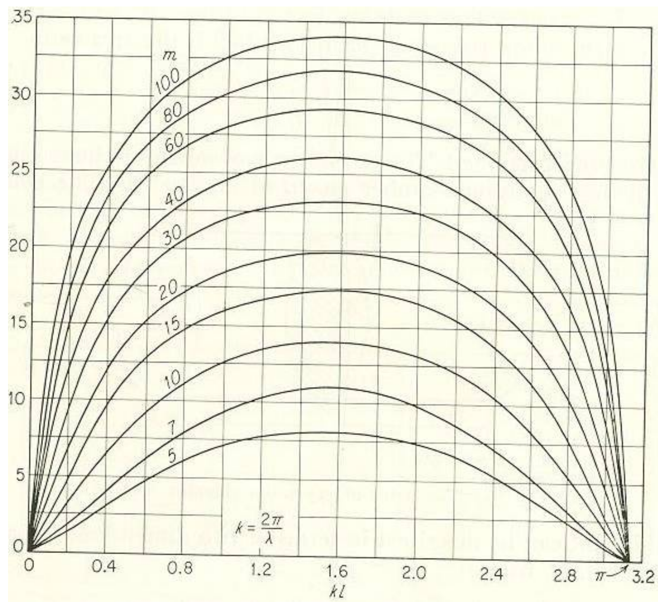

Figure 5. Experimental Correlations for an Expansion Type Muffler

QUIET TRACK

One of the main sources of noise on a snowmobile is the track traveling around the rear suspension skid. Again this year the students have decided to run Arctic Cat's Quiet Track. The track is specifically designed to lower the amount of noise that is produced by the rotation of the track around the skid of the rear suspension. The track offers a new lamination process that eliminates the ridges in the track. With this design the track is able to glide over the slides and bogie wheels without causing the track to vibrate. By eliminating this vibration the track, produces less noise.

AIR BOX

Intake manifold noise is a prevailing negative aspect in four-stroke cycle engines. To combat this dilemma, an Artic Cat air box was chosen because of its intake noise deadening capabilities. This air box in combination with the filter cancels out the critical audible frequencies from intake manifold without compromising intake air flow to the engine. The new air induction system is also designed for optimal air scavenging from the atmosphere while filtering out excess water vapor.

PERFORMANCE

While establishing low emission levels and quiet engine operation, it was realized that a certain level of performance needed to be maintained in order to be competitive with current production snowmobiles. After reviewing the criteria for the 2005 competition it was decided that the students would devote a majority of their efforts into implementing technology that will allow the snowmobile to run cleaner, quieter and produce lower emissions. However, this can not be accomplished without sacrificing some performance. The team did what was possible to maintain performance, but not at the expense of emissions and noise.

CYLINDER HEAD

The stock Polaris head was flowed and it was determined that the flow in the exhaust valve was low. With a larger valve or porting, there would be increased exhaust flow exiting the engine.

After porting the stock head, the gains were very minimal. It was different that there was not enough material on the stock head to use a bigger exhaust valve, so the use of an alternate head was necessary. The head from a 2004 Polaris Frontier 780 was obtained because it was virtually the same as stock, except that it has a 28mm exhaust valve instead of the stock 26mm valve.

The 780 head was flowed and then compared with the stock head. Although both intake valves flow nearly the same in both heads, the significant exhaust flow advantage of the frontier head made it a great replacement for the stock head.

CAMSHAFT

To avoid intake charge short circuiting careful camshaft selection is important to a naturally aspirated engine. In order to decrease the overlap, the lobe separation angle must be increased.

The stock Polaris camshaft was ground to a lobe separation angle of 105.6 degrees. The new camshaft was modified to have a lobe separation angle of 115.3 degrees. Having a larger lobe separation angle decreases the time that the intake valve and exhaust valve will be open simultaneously, thus resulting in less air/fuel charge that will exit the exhaust. This will result in lower HC and CO emissions. Increasing the lobe separation angle will result in less duration. In order to compensate for this, increased lift will be necessary to obtain the same area under the curve.

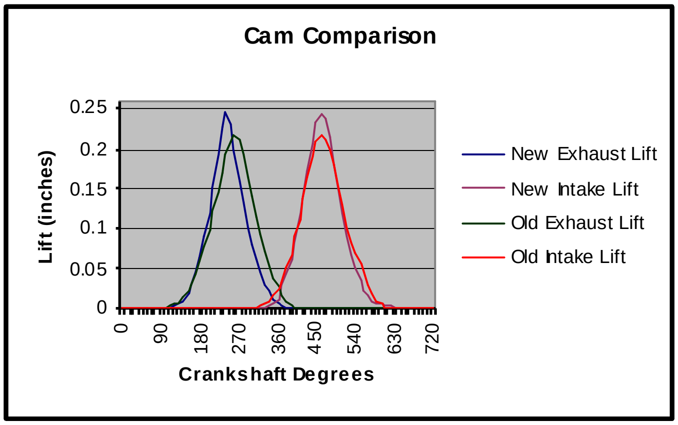

Figure 6. Camshaft Comparison

EXHAUST HEADER DESIGN

It was determined that in order to position the air box in the desired location, a new header design had to be incorporated. The design also had to facilitate the new exhaust routing which was designed to exit under the seat. The dimension had to be determined to relate the mounting planes. Once they were dimensioned, PRO/E was used to determine the smoothest possible sweep between the two planes, and a scale drawing was developed. All bends in the manifold were made in only two dimensions to allow for easier construction.

Header material selection was considered to minimize failure due to the thermal shock experienced by exhaust headers. Mild steal was used on the flanges because of its low rate of thermal expansion. A 321 stainless steel alloy was used since it is common in applications with large temperature changes.

DRIVE TRAIN

The drive train of the MSU Clean Snowmobile was modified for emission sensitive areas, the chain case which is normally filled with thick oil and prone to leakage, has been replaced by a belt drive system.

Incorporating this option eliminates cost of chain case oil and the possibility of spills in environmentally sensitive areas. The noise created by the chain drive was reduced by the belt drive system. The chainless drive also reduces rotating mass of internal components inside the snowmobile.

Clutching for the MSU snowmobile has been based on the stock clutching of the Polaris Frontier. Because of the smaller displacement of the MSU engine, heavier weights in the primary clutch were necessary for optimal drive train efficiency.

SUSPENSION

It was determined that for this years competition a tunable, rebuildable shock would be the ideal set up. The factory Fox Racing shocks were tested on a Roehrig shock dynamometer and were determined to have a linear valve curve.

The students also decided that it would be beneficial for slow speed stability and high speed performance to run a shock absorber with a digressive valve. Since the pistons in the factory shocks have no digressive replacement, it was decided that the students would run QA1's PromaStar single adjustable shock absorber. These come equipped with the digressive curve desired, and have 12 external rebound and 12 compression settings to control the slope of the curve shown in Figure 7. Springs were ordered that closely match those of the stock sled, and using an accelerometer the Mavericks were able to fine tune the shock settings for the smoothest ride possible.

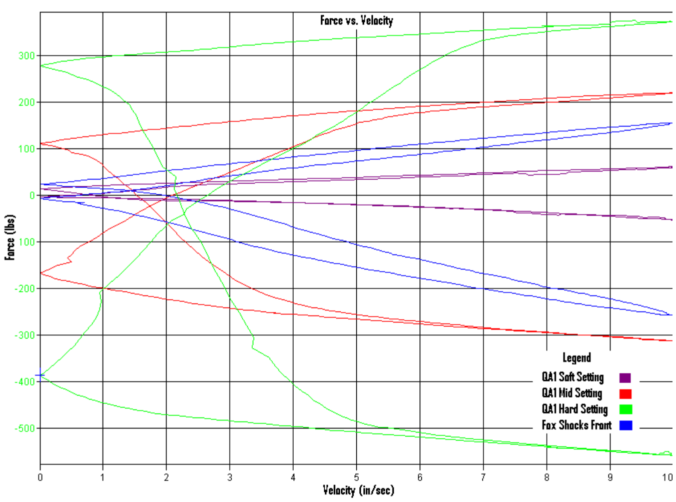

Figure 7. Valve Curves for Shock Comparison

DURABILITY/PRACTICALITY

The students' goal was to ensure that the solution they designed was robust enough to last for years with nothing more than routine maintenance. The four-stroke cycle engine used will run at a lower RPM range than the stock two-stroke. This increases the life of the motor and the time between service intervals. Stock parts were used where applicable so that finding replacement parts would not pose a problem. The students tried to limit major modifications to the snowmobile that would compromise the performance and durability. The engine was tested on a dynamometer and field testing was performed.

COLD START

In general E85 does not exhibit good cold weather starting characteristics. E85 needs to absorb heat to be effectively vaporized for use in an engine. Once an engine has reached operating temp, this vaporization occurs as required. However, there are performance issues with cold weather starting, usually shown in either excessive cranking or a no start condition. Gasoline engines retrofitted for E85 require additional modifications to reliably start in cold weather. The vaporization was increased through the use of fuel rail heaters.

Additionally, to help cold weather starting of the engine, MoTeCs stopped fuel injection was enabled to provide a priming function. When the engine is off and the throttle is pushed to WOT, MoTeC opens the fuel injectors and injects additional fuel to aid in start up. After priming the engine 2-3 times the engine starts more readily.

FUEL HEATERS

To counteract these negative traits, the students have decided to implement a fuel heating system which utilizes two NGK Y-701R glow plugs housed in separate fuel rails.

This year attention was given to the idea of limiting the amount of fuel which would need to be heated prior to and during start up of the engine. To do so the students are using what is called an "injector bypass" type of fuel pressure regulator. Rather than controlling fuel pressure at the injector by placing it at the end of the fuel rail and wasting heat by returning that fuel to the tank, this system allows the fuel to be at operating pressure while remaining static in the area of the heater and injector, thus more efficiently heating the fuel.

The heating element shown in Figure 8 is controlled with a passive system which cycles on and off to result in a controlled increase in the static fuel temperature. During cranking the heaters are at full amperage. This heating of the fuel assists in cold starting applications.

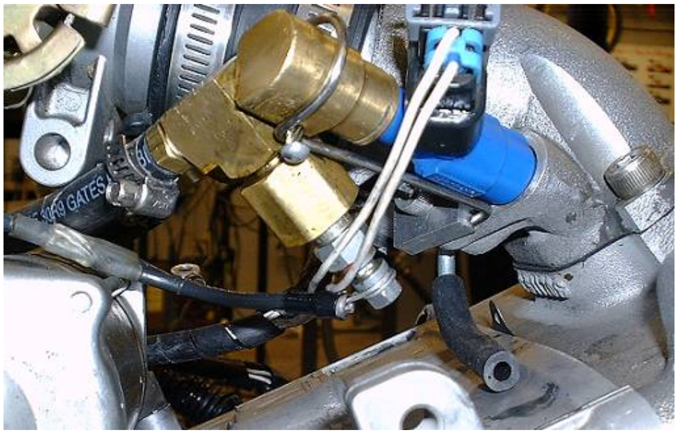

Figure 8. Heating element

COST GOALS

The cost for the students was kept to a minimum by utilizing stock parts whenever possible and keeping modifications minimal. Modification cost will be below $1500 as a result of these minor changes. Therefore, if a 2001 Polaris snowmobile retailed at $4500, the overall cost for our clean snowmobile would be $5771.45

By replacing the stock two-stroke cycle engine with a more fuel efficient and more durable four-stroke cycle engine, consumers will benefit by saving money on fuel and general engine maintenance.

After looking at the performance of a stock 2001 Polaris Edge, it was decided that several of the chassis components would be left as is. Major items include the front suspension control arms, steering, rear skid, belly pan, hood, and tunnel. The students believed that modifying these items would not positively affect the design parameters of the competition and would increase the cost. Custom fabricated parts were used where necessary in order to create an aesthetically pleasing layout. Some improved items are the quiet track, muffler, exhaust, mounts, clutching, and engine control devices.

SPONSORS

MNUSA
Minnesota's Corn Growers Association
Honeywell
OTC
Ross Pistons
Mohawk
Lube-Tech

Acronyms

HC Hydrocarbon

NOx Oxides of Nitrogen

CO Carbon Monoxide

H_2O water

CO_2 Carbon Dioxide

E-85 85% blend of ethanol 15% gas

E-70 70% blend of ethanol 30% gas

MSU- Minnesota State University, Mankato

EMS- Engine Mapping System

WORKS CITED

[1] U.S. Department of Energy. *Alternative Fuels Data Center* (Internet), (Updated February 2005), (Cited June 2003), Available from the World Wide Web: <http://www.eere.energy.gov/>

[2] McMaster-Carr. *Sound Absorbers: page 3271*. (Internet), (cited 1 March 2005), available from the World Wide Web: <http://www.mcmaster.com/>

[3] U.S. Environmental Protection Agency. *Guide on Federal and State Summer RVP Standards for Conventional Gasoline Only*. (Internet), (Updated March 2003), (Cited 15 February 2005), Available from the World Wide Web: <http://www.epa.gov/otaq/regs/fuels/b03002.pdf>

[4] U.S. Department of Energy. *Ethanol Infrastructure Development Resources*. (Internet), (Updated 10 April 2004), (Cited 23 February 2005), Available from the World Wide Web: <http://www.eere.energy.gov/afdc/infrastructure/eth_resources.html>

[5] Bowling, B. and Grippo, A. *Tuning Your Megasquirt*. (Intrernet), (Updated 5 December 2005), (Cited 15 January 2005), Available from the World Wide Web: <http://www.megasquirt.info/manual/mtune.htm>

[6] Gilles T., 1999, *Automotive Service*, Delmar Publishers, Albany.

[7] MoTeC. *Engine Management & Data Acquisition Systems*. (Internet), (Updated May 2004), (Cited 18 January), Available from the World Wide Web: <www.motec.com/support/FSAE04.ppt>

[8] Beranek, L., 1960, "Noise Reduction," McGraw-Hill, New York.

[9] Snow-Tech Magazine, Oct/Nov 2003.

[10] The Soy Daily. *Ethanol 100th E85 Otlet Opens in Minnesota – Can Ethanol, Wind and Biodiesel Reduce Air Pollution? You Betcha!* (Internet), (Updated 7 September 2004), (Cited 21 February 2005), Available from the World Wide Web: http://www.thesoydaily.com/BiodieselBiobased/E85MN09102004.asp

[11] Copyright 2003 SAE International. Paper # 2003-32-0077.
Comparison of an E10 Direct Injection Two-Stroke Cycle Engine, and an E85 Four-Stroke Cycle Engine.