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ABSTRACT

Minnesota State University, Mankato's Automotive Engineering Technology program formed a team to enter the Clean Snowmobile Challenge 2001. Selections for the organization's machine included a 2001 Polaris Edge Chassis specially outfitted with a 2000 500 cc two-stroke Polaris engine. Modifications to the snowmobile were made specifically for Clean Snowmobile Challenge 2001 events. Acceleration, emissions, cold start, noise, fuel economy/range, handling/driveability, hill climb, and static display made up the list of events featured in the competition.

MSU Xtreme has modified the snowmobile in every area with special emphasis on emissions and handling. Testing and analysis of the sled's systems brought the team to its resulting design. The technical paper describes the results of those tests, explains the team design procedures, and presents all modifications made to the snowmobile.

INTRODUCTION

The Society of Automotive Engineers (SAE) developed the Clean Snowmobile Challenge 2001 (CSC2001) for engineering and engineering technology students. The competition evolved due to the rising concern of the use of snowmobiles in national parks. Effects of the machine's emission and noise levels were of great concern to environmentalists [11]. CSC2001's main focus was on lowering wildlife threatening exhaust emissions without dampening the sled's performance. For the competition, teams were allowed to use any sled platform they desire with limited engine style and sizes. This greatly improved the team's ability to fully use its member's knowledge and talents to effectively create a snowmobile versatile enough to win this year's competition. This new guideline also made this to be the most competitive Clean Snowmobile Challenge yet. Fourteen North American colleges and universities were approved for competition. Selection of teams was conducted by evaluating each schools design proposals prior to competition. Minnesota State University, Mankato was one of the schools selected to compete (Fig. 1). The competition was held at Flag Ranch, just outside of Yellowstone National Park, Grand Teton National Park, and at Snow King Resort in Jackson Wyoming during the days of March 25 - 30, 2001.

Figure 1: Minnesota State University, Mankato Sled

South central Minnesota houses Minnesota State University, Mankato, (MSU) and its Clean Snowmobile Challenge team. MSU is one of seven state universities in the Minnesota State Colleges and Universities

(MnSCU) system. Over 13,000 students attend the University. Automotive Engineering Technology (AET) is a four-year Bachelor of Science program located within MSU's College of Science, Engineering, and Technology. The AET program is accredited by the Technology Accreditation Commission of the Accreditation Board for Engineering and Technology (TAC-ABET). The AET program at Minnesota State consists of 166 majors with 35 of them graduating during the 2000 – 2001 academic year.

Every student who majors in Automotive Engineering Technology is required to complete a comprehensive senior design project. Nine senior students selected the CSC2001 as their final project. Since the end of last year's Clean Snowmobile Challenge, ideas have flowed into this year's team. With the acceptance of the CSC2001 team proposal, debates on the chassis and engine type were well on their way.

Decisions were made while keeping in mind the rules and regulations developed by SAE. With open communication and strict compliance to CSC2001 rules, a delicate balance between everything from performance, to emission levels, to final cost analysis, was maintained throughout all design decisions. There were three basic groups within the organization. The teams consisted of a chassis group, two-stroke engine group, and four-stroke engine group. Members of these teams included students who either had an elaborate knowledge of the systems they were developing, or found that particular part of the sled interesting.

The chassis team focused on platform selection and design improvements. They made decisions on drivetrain modifications, suspension upgrades, and even worked on color schemes for the sled.

Efforts from the two-stroke group centered on selecting an engine and developing a direct fuel injection system. A thorough investigation on fuel injectors, computer management systems, and cylinder head designs was conducted.

Four-stroke team members ensured that a reliable engine was available in case the two-stroke system did not work or failed to meet time constraints. Four-stroke development concentrated on upgrading the engine to operate at the performance standards of a two-stroke powerplant. The group concentrated on turbocharging systems and weight reduction. All findings and suggestions found in each group were discussed with the entire team during weekly team meetings.

Each of the three specialized groups would discuss their findings and conclusions with the entire MSU Xtreme organization. Selected actions to be taken involving their specialized area were then suggested. The entire CSC2001 team then decided on these actions. It was during those meetings that final decisions on everything from chassis and engine selection, to fundraising were made. This was also the time that questions and deadlines were given to each group to research and conclude for the next week's meeting. It was through this process of meeting and communicating that MSU Xtreme developed successful designs that were completed in a timely manner.

ENGINE CHOICES AND DEVELOPMENT

One of the most important choices to be made centered on what kind of engine to use. Either a 2000 500cc Polaris two-stroke (2000TS) or 2001 500cc Polaris four-stroke (2001FS) engine was to power the chassis. The challenge of selecting either engine lay within their differences and what was required for the competition.

TW0-STROKE VS. FOUR-STROKE

While looking at powerplants, both powertrain teams presented the pluses of their design while digging up every minus of the other. Many issues were discussed as MSU Xtreme drew closer to its engine selection. The major controversies surrounded emission levels, performance characteristics, weight and packaging, cost of production, and noise.

Emissions

Hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) were the three exhaust emissions researched by the team. It was found that a two-stroke engine was capable of putting out ten times more HC levels than a four-stroke model [10]. There were two main reasons behind this. One was because a great majority of two-stroke engines used a carburetor rather than a fuel injection system. Carburetors ran a rich mixture of fuel to ensure the engine did not develop a lean misfire causing a lack of power. The extra HC in this charge was not burned during the combustion process and was released out the exhaust port. The other problem was with the scavenging effect found in all two-stroke engines. Scavenging will be explained later but basically resulted in some of the fresh air/fuel charge being pushed out the exhaust port before combustion took place. These two factors alone resulted in the higher levels of HC. Efforts were concentrated on lowering HC emissions on the 2000TS powerplant. The best solution was to design a direct fuel injection system for the engine. Both the carburetor and scavenging effect could be eliminated using this system while maintaining its dominance of power over the four-stroke. Four-stroke engines did not have these problems because there was no scavenging of gases and most incorporated fuel injection systems. CO and NOx emissions could be controlled in both engines by using catalysts and air injection units in the exhaust system [1,8]. This showed that for the emission-testing portion of the competition, the four-stroke engine would be more favorable unless the direct injection system worked on the two-stroke model.

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Performance Characteristics

More defined power bands could be found in two-stroke engines when compared to four-stroke motors. Also, two-stroke engines produced twice the number of power strokes that a four-stroke did and therefore, had better power to weight ratios. This made for better performance in the acceleration and hill climb events of the competition. So whatever points could have been gained in emissions by the use of a four-stroke engine would have been lost during performance tests in competition. More power could be produced in a four-stroke engine with the addition of a turbocharger, but, this would increase the weight more remained a problem.

Weight and Packaging

For best performance, it was better to make the snowmobile as light as possible. Two-stroke motors dominated in this category. Due to the fact that four-stroke engines utilized more parts to create equal power levels of a two-stroke, they were significantly heavier. This made the two-stroke the better choice. Its small size was also better for packaging and weight distribution. There were many problems in this area for the 2001FS that were not faced with the use of the 2000TS. First, modified mounting plates needed to be designed and manufactured to accommodate the unique 45-degree position the 2001FS required. Additional specialized plates were needed for various sensors that ran the fuel injection system. Also, the position in which the four-stroke cycle engine was mounted in the chassis shifted the majority of its weight to one side making the snowmobile as a whole unstable. There were also problems with aligning the clutch assembly with the engine. All of these situations caused difficulty in incorporating the four-stroke model and added to the cost.

Cost of Production

Production costs for the four-stroke engine ran between 15% and 25% higher than those of the two-stroke. Also, with additional money needed for specialized brackets and turbochargers for the four-stroke, the cost ran up to 70% higher [2]. Even though mass production techniques would lower price ranges, dollar amounts for the four-stroke still remained larger.

Noise

Two-stroke engines produced higher noise levels. This was due to the fact that they were more sensitive to increased backpressure [10]. But modifications to two-stroke exhaust and intake systems, along with the addition of sound deadening materials, lowered the decibel reading to that of the four-stroke.

Final Decision

The DFI equipped two-stroke cycle engine was the power plant of choice in the end. Several reasons backed up this decision. By this time many hours had been spent in the design process of the systems needed to run the DFI engine. In addition, it was strongly felt that this engine, even not running completely perfect would out perform the four-stroke cycle engine in horsepower, and maintained considerable advantages concerning weight distribution. The team considered this engine, with the modifications made, to fit the scope of the competition perfectly. The design aspect was also a huge technical accomplishment in comparison to adapting the four-stroke engine.

FUEL INJECTION SYSTEMS

Fuel injection was far superior to carburetors because it utilized a feedback system, through the use of many sensors, to control air/fuel ratios. By controlling these ratios, less unburned hydrocarbons would leave the exhaust pipe. CO emissions were also significantly lowered with the use of this feedback system. Each of the two engines used a different style of fuel injection. Indirect fuel injection was designed for the four-stroke, and direct fuel injection was developed for the two-stroke.

INDIRECT FUEL INJECTION

To improve emissions on the existing normally aspirated four-stroke engine, a more efficient method of controlling air/fuel ratios had to be developed. A fairly simple yet highly effective solution to this problem was to incorporate a fuel injection system into the stock intake. Utilizing a throttle body style fuel delivery system performed this function.

Throttle Body Unit

Many throttle body set-ups were researched for use on the 2000FS engine. A final decision was made to use a fuel delivery system from GP Engineering, (Fig. 2). There were several advantages to this. One was that the throttle body itself utilized a standard Bosch injector. This was important in that Bosch fuel injectors were available in many different flow rates. The unit itself was convenient in that no modifications had to be made to fit it into the stock intake.

Figure 2: Throttle Body Assembly

Injectors

Fuel injectors by Bosch were used because the throttle body was designed to utilize this style of injector. Because of the many different flow rates available, Bosch injectors worked well for tuning the four-stroke powerplant. The consistency and reliability of the injectors offered the perfect option for meeting the challenges of the competition while keeping the production costs at a minimum.

Turbocharging System

The major addition to the four-stroke engine consisted of an Aerocharger turbo system (Fig. 3). This system used a variable vane turbo design eliminating the need for a wastegate. Its self-contained lubrication system eliminated oil and coolant lines, keeping maintenance at a minimum. Low friction ball bearings quickened throttle response. Also, increased torque at lower engine speeds improved performance and fuel economy. This well designed system was perfect for boosting horsepower needed to compete in this year's competition.

Figure 3: Turbocharger

Fuel Pump

MSD Ignition, also a supplier of fuel management components, furnished an electric fuel pump (PN 2225) for this year's system. Flow rates needed to run this year's system were met with its 163L/hr capacity. Metering of the incoming fuel was accomplished with a Mallory adjustable fuel pressure regulator (PN 4310) that could run anywhere from 21-448 kPa. This regulator also aided in determining the optimum fuel pressure needed to run the injectors.

Electronic Control Unit

The same ECU was to be used on both engines. A versatile and flexible MoTeC M48 electronic control unit was selected (Fig. 4). The basis for this decision was that the MoTeC had very high performance abilities and that it was the same system used on last year's sled. Because of its versatility, the team was able to select which sensors it wanted to use to most efficiently control the engine. These sensors included the following:

- Throttle position
- Wide Band Lambda
- Coolant Temperature
- Manifold Absolute Pressure
- Ambient Air Temperature
- Crankshaft Position
- Camshaft Position

For proper firing of the injectors, a trigger wheel was mounted on the crankshaft in place of the starter recoil. 35 teeth separated ten degrees from each other lined the wheel. An open space between two of the teeth allowed for twenty degrees of separation. This separation was what commanded the MoTeC to turn on the injector.

Figure 4: MoTeC M48 Electronic Control Unit

DIRECT FUEL INJECTION

Being the superior fuel system, much effort was given to successfully developing and completing the DFI design. Combining a direct injection system and a two-stroke engine made for more power with fewer emissions [2,3,4,6]. To reach this goal, an entirely new system had

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to be planned. This did not come without its difficulties. Engineering and developing a cylinder head for the two-stroke was the biggest complication to the team. First, everything from the combustion chamber design to manufacturing the head had to be completed. Secondly, a design to deliver the fuel at extremely high fuel pressures needed to be achieved. This high pressure needed to be maintained so fuel entering the combustion chamber could overcome pressure created by the upwardly moving piston. Another advantage of the high fuel pressure was that it helped atomize the fuel. Mixing air and fuel normally occurred in the intake stream. But because the intake system was bypassed with direct fuel injection, mixing time was drastically shortened. The whole reason for getting this design to work was to eliminate the scavenging effect of the two-stroke engine. Ideally, the fresh air/fuel charge would completely displace the burned gases, but in reality there was always some mixing. With both intake and exhaust ports being open at the same time, either too much air entered the cylinder and fuel was pushed through releasing unburned HC in the exhaust, or not enough was forced through trapping unusable gases in front of the exhaust exit. This was how scavenging affected the two-stroke powerplant.

Engineering a New Head

Complete mixing of air and fuel along with equalizing temperatures and pressures across the piston crown, were the major influences on the design. The first development consideration was contouring and placing the combustion chamber (Fig. 5). Since a new cylinder head was going to be made, it was considered to be the perfect time to raise the compression ratio to gain more power. However, when raising the compression ratio of an engine, its tendency to knock was also increased. So it was a challenge to the team to design a head that worked efficiently while raising the compression ratio and preventing knock. The secret to getting these results lay in the placement of the combustion chamber with respect to the cylinder. The chamber itself was drawn offset to the intake port side. This aided in distributing piston top temperatures. Due to the more evenly distributed combustion heat, a high compression ratio could be achieved without increasing the risk of engine knock. Therefore, the compression ratio was raised to gain 10% trapping pressure. This gain reduced brake specific fuel consumption by 10% while lowering HC emissions. It also increases the thermal efficiency of the fuel/air mixture entering the chamber, which created more power. After decisions on combustion chamber placement were made, the squish band was examined.

Figure 5: Machining of the Combustion Chamber

Squish Area

An increase in squish velocity was required for efficient running of the engine. Enlarging the squish area ratio (SAR) would accomplish this. However, increasing this ratio would also create higher HC emissions. To increase squish velocity, some modification had to be made. Once again, the offset style of the combustion chamber increased the velocity. As a result, the SAR was left at stock. The squish clearance was lowered to 1.27mm from the stock 1.52mm. This was where the increased compression ratio was derived, which in turn gave the opportunity for more horsepower. This was advantageous, except that when maneuvering the head closer to the piston, the risk of contact between the piston and head increased. MSU Xtreme calculated that 1.27mm would give a slight increase in power without jeopardizing contact.

Figure 6: Squish Area and Combustion Dome Orientation

With the completion of the squish area and combustion chamber design (Fig. 6), location of fuel injectors and spark plugs was addressed.

Injector and Spark Plug Placement

An injector was placed in the center of each of the cylinders. This was done to minimize the washing of oil from the cylinder wall, which would increase friction and possibly cause engine seizure. It also allowed for the favorable uniform discharge of fuel in the cylinder for more efficient burning. Next came spark plug location. The center of the combustion chamber would normally be the best spot. However, the injector already occupied this space. It was decided to put the spark plug closer to the intake side, which consequently was very close to the combustion chamber center, because it was slightly offset. The plug was angled 30 degrees from vertical and 30 degrees from the axis that runs through the intake and exhaust ports. Head bolt clearance was the main reason for the side offset. With this arrangement set (Fig. 7), the remainder of development focused on fitting the head to the existing block.

Figure 7: New Head, Spark Plugs, and Fuel Injectors

Because space was so limited, the team also chose to use a smaller spark plug, 10mm versus the stock 14mm plug (Fig. 8).

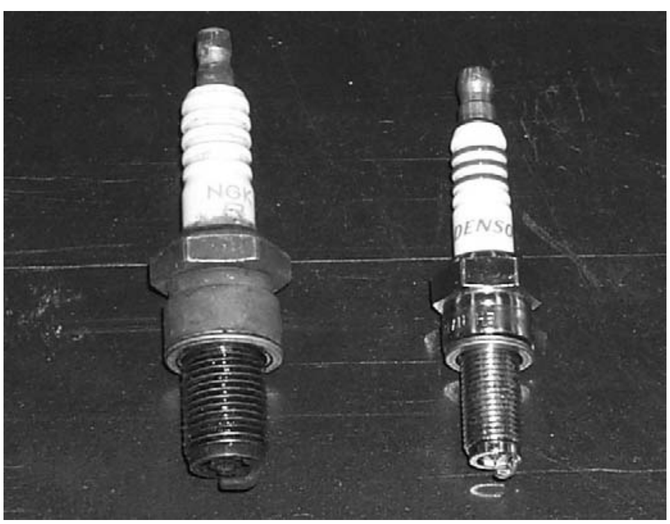

Figure 8: 14mm Spark Plug (left) and 10mm Spark Plug (right)

With the cylinder head design complete, the next task was to create high enough fuel pressure for the DFI to become possible.

<u>DFI Fuel Delivery System</u>

In order for the gasoline to burn completely it needed to be atomized. In the conventional gasoline engine, this happened as the fuel traveled with air through the air intake. In the DFI system the fuel was injected directly into the combustion chamber, and had very little time to atomize. In order for this system to be efficient, the fuel needed to be injected at extremely high pressure so it could be atomized instantaneously. In the system chosen by MSU Xtreme, the high fuel pressure was delivered to the injector. This differed from last year's Ficht DFI system in which the injector itself created the high pressure. The pressure used in MSU Xtreme's selected system originated at a mechanical fuel pump that was chain driven off the crankshaft on the magneto side of the engine (Fig. 9).

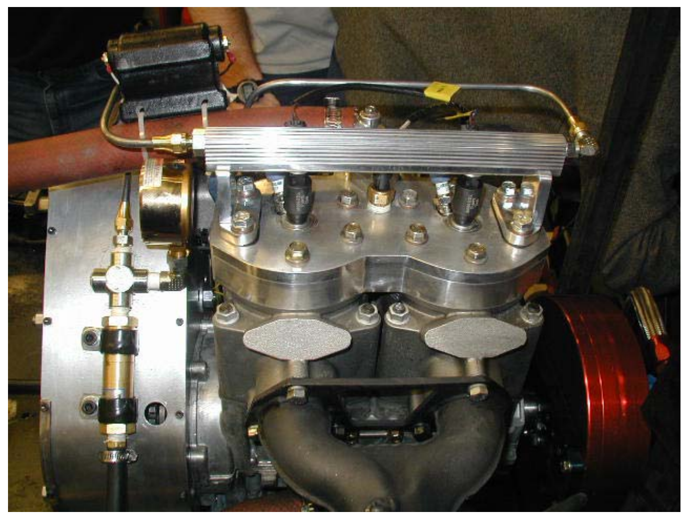

Figure 9: DFI Engine with Fuel Pump Drive on Left

This pump was a positive displacement piston pump that delivered 0.6cc per revolution. The pressure was regulated to approximately 7,580 kPa by using a pressure relief valve. This design was common to many hydraulic systems that ran such pressures. The initial design of the pump drive system was to use a V-belt to transfer power to the pump. Due to heat accumulation and belt slippage this design was rendered unusable. Phase two of the belt drive incorporated a cogged belt drive. In both designs the pump was geared at one half of the crankshaft speed in an attempt to lessen wear and minimize power losses. Because of time constraints, a chain drive was quickly installed on the engine, but to be used temporarily. It was considered to be a more dangerous method of driving the pump with the risk of the chain coming apart, however shielding was used to deflect debris during such an event. Because of its reliability the chain drive remained on the engine. The main drawback of the placement of the chain drive however, was that it eliminated the recoil assembly. This

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left the rider with having to use a strap around the clutch as a back-up alternative to the electric starter.

OTHER ENGINE MODIFICATIONS

THERMAL COATING

Coating the piston tops and combustion chambers with a thermal coating allowed the engine to be operated with a slightly leaner air/fuel ratio. It also prevented heat from being lost through the piston and cylinder head making the engine more thermally efficient. Rather than being lost to the atmosphere, the heat was turned into power. Coatings also reduced heat transfer through the piston keeping the incoming charge cooler and denser. A friction reducing coating was applied to the piston skirts to reduce engine friction (Fig. 10). Oil consumption was reduced as well with better sealing of parts preventing blowby and decreasing HC emissions.

Figure 10: Friction/Thermal Coated Piston (left) and Non-Thermal Coated Piston (right)

IGNITION MANAGEMENT SYSTEM

The same MoteC ECM was selected as the ignition management system for the 2000 two-stroke cycle engine. Along with reading the many sensors used for the injection system, (such as crank position, engine coolant temperature, intake air temperature, throttle position, and wide band lambda sensor), the Motec was used to command ignition timing. With the engine running on MSU's Land and Sea dynamometer, an ignition-timing map was calibrated to meet the engine's needs.

SECONDARY IGNITION

The electronic ignition chosen was a system by Jacobs Electronics. The module is called the Jacobs "i.C.E. PAK" (Fig. 11). The chosen coil was a dual ended Jacobs motorcycle coil. Selection on the module was based on its high speed switching capabilities needed for a two-cycle engine. This system could create over 1380 MJ and 65,000 volts at the spark plugs and could handle up to 20,000 RPM. In testing it was evident that the hot sparks given from this system helped reduce carbon build up on the spark plug ground electrode which could be have a problem with the direct injection.

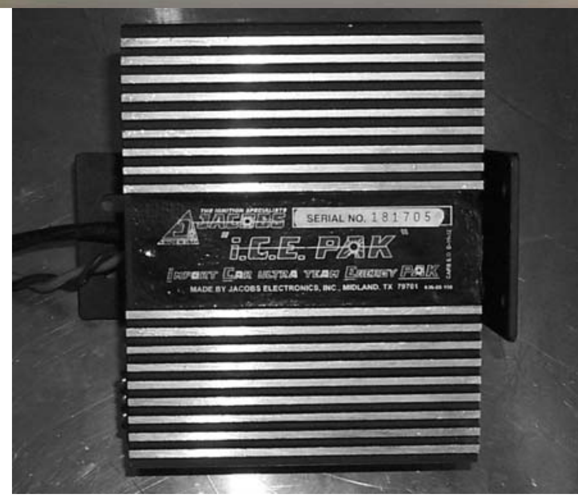

Figure 11: Jacobs's i.C.E PAK

EMISSIONS AND NOISE REDUCTION

For the two-stroke cycle engine, the stock silencer was used with a few modifications. To accommodate noise and emissions reduction, a catalytic converter was incorporated into the silencer. The catalyst was of the metal substrate type. The precious metals used were oriented in a corrugated fashion within layers of thin steel and rolled into a cylindrical unit. The catalyst had 200 cells per square inch, and a 5:1 platinum to rhodium ratio. The platinum aided the oxidation of HC and CO emissions while the rhodium caused reduction in NOx emissions. This type of design offered high flow characteristics and low specific heat capacity, which aided in shortening the catalyst warm up period. This catalyst arrangement was used in the 1980's on rotary type engines used by Mazda, which were similar to two-stroke engines in having high contents of unburned fuel exiting the engine.

CHASSIS DEVELOPMENT

For the chassis, two prospective sled platforms were considered. A 1998 Polaris Generation II was readily available. However, an opportunity arose for the team to receive a drastically superior 2001 Polaris EDGE chassis. A decision was made on the basis that if MSU Xtreme had not received the EDGE chassis by Christmas break, arrangements were to be made to obtain the Generation II chassis for immediate modifications. After a substantial waiting time, word came to the team that the Polaris EDGE chassis would show up on time at absolutely no cost. This meant that money planned for purchasing a chassis could be directed to the depleted funds available for modifications. Elated, MSU Xtreme promptly redirected its limited funds to developing improvements on the EDGE platform.

FRONT SUSPENSION

OEM skis were stripped from the sled and replaced with C & A skis. They offered excellent control, superior handling, great durability, and fantastic stability. Other reasons for the addition of these skis was that unsprung weight was reduced and the risk of getting stuck in existing ski ruts was lowered.

REAR SUSPENSION

Modifications made to the rear suspension of the sled included track replacement and the addition of rail and tunnel extensions. All alterations were made to improve chassis performance without jeopardizing rider comfort.

<u>Track</u>

A much longer, 366 cm track with 3.175 cm lugs was installed (Fig. 12). This allowed for use of bigger rear wheels without having to change the rear suspension geometry. Larger wheels decreased rolling resistance of the track and at the same time increased horsepower supplied to the ground. The larger track surface area, which contacted the ground, increased stability and traction while reducing slippage. A more comfortable ride was also achieved with the addition of a longer track.

Figure 12: Rear Suspension with 366 cm Track

<u>Extensions</u>

Custom made rail and tunnel extensions were added to accommodate the larger wheels and longer track. This also simplified serviceability by increasing the area in which engine management components could be stored. Parts such as the battery box and other electrical components could be placed in strategic locations on the extensions to help evenly distribute the total sled weight.

<u>Wheels</u>

Larger rear idler wheels were installed to decrease track angle in the rear. 20.32 cm wheels replaced the stock 15.24 cm wheels (Fig. 13). These wheels increased

efficiency by not forcing the track to bend as sharply as it did with the OEM wheels.

Figure 13: Original Idler Wheel (left) New Idler Wheel (right)

ERGONOMICS AND SAFETY

Edge pegs were added to increase driver safety by allowing better foot grip, decreasing the likelihood of foot and leg injuries. Reinforcement of the running boards was achieved by installing fishbone style tunnel braces. And a soft mountain bar was used to increase handlebar grip. This handle bar was safer to the driver than a hard one in the case of a collision with a barrier or another sled.

BRAKES

Original brake pads and rotors were replaced with a superior Starting Line Products brake assembly. This system decreased rotating mass by 1.4 lbs. and in turn increased drivetrain efficiency and horsepower delivered to the ground. Their unique wave design offered better brake cooling and stopping power while at the same time minimized brake fade.

FRICTION MODIFIERS

A non-paraffin based friction reducer from Militech was added to the chain case and bearings. This served several functions in that it increased drive-train efficiency and component life. It also reduced heat producing friction and drive train noise. Because it was not paraffin based, no waxy deposits accumulated.

ADDITIONAL MODIFICATIONS

Major thought was given to reducing the net noise level of the sled. To reduce decibel readings, Koolmat noise reduction material was added to various sections of the under body to reduce exterior sound levels. This material also aided in the protection of components from excessive heat. Covers were added to help lower noise escaping through the vents. And medium height windshield was installed to relieve drivers from wind harshness.

One more detail lay within the color scheme of the snowmobile. A purple and yellow color combination was designed to coincide with school colors. Even though aesthetic modifications did not affect the performance of the chassis, it did increase points gained for the static display portion of the competition by making it more appealing.

TESTING PROCEDURES

The Minnesota Center for Automotive Research at MSU was the location for all testing and research done on MSU Xtreme's sled. Many engine dynamometers and emission test equipment were available for use by all team members. Acceptable accuracy for test results was obtained by using standard correction factors set by the Society of Automotive Engineers.

ENGINE PERFORMANCE TESTING

A water brake dynamometer from Land & Sea measured horsepower and torque data for the engines. All performance comparisons from the stock to the modified engine were made using this data. Another valuable contribution of the dyno was in the aiding of all finite motor adjustments made to maximize the horsepower output of the engine.

EMISSION EVALUATIONS

AN OTC 5-gas exhaust analyzer provided almost real-time measurements of gases found in the exhaust of the two-stroke and four-stroke engines. The analyzer was utilized to aid in mapping ignition timing and fuel injection timing. The engine was initially tuned according to carbon monoxide levels combined with exhaust temperatures, however no accurate emissions data could be recorded without standardized model testing. This 5 mode testing occurred at the CSC2001 competition.

COST OF PRODUCTION

Much thought was given to manufacturing and assembly costs of MSU Xtremes snowmobile. Caution was exercised to use parts that were readily available at low prices. Specialized parts were kept at a minimum to decrease production expenses. The group used components that were easily accessible to customers so downtime of the vehicle would be minimized. This meant that efficient and timely repairs could be made so more use of the sled was available. POWERPLANT

MSU Xtreme's engine platform was chosen to minimize production costs while remaining in compliance with CSC2001 rules. Two-stroke motors had been widely accepted as standard by the snowmobile market. Selection of the motor was made, keeping in mind the fact that two-strokes dominate the small engine market and were significantly cheaper to produce (two-stroke vs. four stroke section of this paper). However, there were concerns over the cost of producing the direct fuel injection system used on this motor.

<u>Direct Fuel Injection</u>

Fuel injection had started to overtake carburetors in the snowmobile industry. Injecting fuel directly into the cylinder had been proven in the automotive field for years. It was this reliability, and conversion to fuel injection, that makes up the basis for using such a system. Even though direct injection on two-strokes was still in its infant stages of development, some day it will be standard equipment and mass-produced at low costs. This will be better for the industry because of its versatility to work in different climatic weather without need for manual adjustment.

<u>Emissions</u>

Primary emission control came from the use of fuel injection. The addition of the catalytic converter to help clean up emissions did add to the cost of the exhaust system, but the catalytic converter was designed to last the life of the snowmobile. Durability, and low cost if mass-produced, made the catalyst a definite advantage for controlling emissions.

CHASSIS

Even though direct fuel injection raised the cost of motor production, the use of already mass-produced parts on the chassis justified the slight increase by minimizing chassis costs. All parts on the chassis were readily available at most local sled shops.

<u>Ergonomics and Safety</u>

The addition of the soft handle bar and edge pegs could be easily installed on a production line. They increased the cost a little, but they helped to show customers that the sled was built keeping their personal safety in mind. This may help in sales by showing people that team Xtreme's snowmobile may be safer than others. Increased automobile sales due to improved safety features such as air bags and side impact beams have already been proven.

Friction modifiers

All parts with friction reducing agents could be coated before installation on a production line. Production speeds would not be harmed while forming a superior sled. These modifiers could also be purchased in bulk containers keeping prices to a minimum.

Emissions Results

Due to electronic complications the direct injection fuel system had to be removed prior to logging emissions data. However, this was not before the system was proven to perform. During calibration MSU Xtreme was able to log over 260 miles of "on trail" testing.

For the reason stated above emissions were tested with stock carburetors jetted to achieve exhaust gas temperatures in the 1200-degree range combined with the catalytic converter. Hydrocarbon emissions were reduced to 35.4 g/kW-hr, an 80% reduction from the control sled. Carbon monoxide was cut to 387 g/kW-hr, a 75% reduction, and oxides of Nitrogen were lowered to 2.16 g/kW-hr, only a 6.9% reduction. In addition to these reductions the snowmobile was still able to achieve a maximum power of 34.8 kW at 7500 rpm at the track.

COMPETITION RESULTS

Minnesota State Xtreme accomplished 4^{th} place overall in CSC2001. MSU was able to achieve 1^{st} place in the handling event with 50 points. MSU Xtreme placed 2^{nd} in the hill climb with a time of 56.78 seconds from a standing start. Only four of fifteen teams were able to make it up the hill. The team placed 4^{th} in the acceleration event with a time of 7.52 seconds. The noise event was held during the acceleration event. MSU Xtreme did not pass. The low limit was 74 dBA, MSU Xtreme only lowered the noise level to 74.7 dBA. In the Fuel Economy event MSU placed 3^{rd} increasing the sled's mileage 15.7% to 17.4 MPG. Finally, in the emissions event, MSU placed 4^{th} with 387 g/KW-hr of carbon monoxide, 2.16 g/KW-hr of NOx emissions, and 35.4 g/KW-hr of unburned hydrocarbons.

CONCLUSION

Minnesota State University, Mankato Team Xtreme was a great example on how teamwork, paralleled with a well-structured design process, could complete a project in a timely fashion with significantly positive results. All members agreed that this project taught the importance of completing individual jobs to benefit an entire organization, and that no contribution goes unnoticed. Without the dedication of all team members, completion of large projects such as this would not be possible. As individuals help a team, individual teams can benefit an entire society. The Clean Snowmobile Challenge has shown that student organizations all over North America can be a valuable resource for technological development. All concerned groups need to know that engineers are not trying to disrupt the delicate balance of nature. Sometimes problems do arise from new technologies whose effects have not yet been explored. However, it is technological advances and organizations such as SAE that help correct such problems. Also, it is projects like CSC2001 that help develop the minds of those who are going to solve real world problems in the future. It is for these reasons that Team Xtreme is proud to be a part of this years Clean Snowmobile Challenge.

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REFERENCES

1. Stone, Richard; "Introduction to Internal Combustion Engines", Society of Automotive Engineers, 1993, ISBN 1-56091-390-8

2. "Controlling Two-Stroke Engine Emissions" Automotive Engineering International, Vol. 108, February, 2000

3. Badami, M.; Marzano, M. R.; Millo, F.; Nuccio, P.; "Comparison Between Direct and Indirect Fuel Injection in a S.I. Two-Stroke Engine", SAE paper 938066

4. Katsuo; "Combustion Control Technologies of Mitsubishi Direct S.I. Engine", SAE paper 960600

5. Sonquin, Wang; Jingsheng, Bai; Xin, Liu; Xiuwu, Sui; Manqun, Lin; Lidi, Zhao; "The Study of Chinese Motorcycle Emissions and a Study of Application of Catalytic Converter on two-stroke scooter" SAE paper 938039

6. Kuwahara, K.; "Control Strategy for Engine Performance Improvement in a gasoline Direct Injection Engine", SAE paper 980158

7. Wright, Christopher W.; White Jeff J.; "Development and Validation of a Snowmobile Engine Emission Test Procedure", SAE paper 982017

8. Riley, Robert Q.; "Alternative Cars in the 21st Century", Society of Automotive Engineers, 1994, ISBN 1-56091-519-6

9. Jennings, Gordon; "Two-Stroke Tuner's Handbook" H.P. Books, 1973

10. Lloyd, Ronald; Toro Engineering, Bloomington, MN

11. Bishop, Gary A.; Hektner, Mary; Ray, John D.; Stedman, Donald H.; "An In-Use Snowmobile Emission Survey in Yellowstone National Park", Environmental Science and Technology, Vol. 33, November 1, 1999