Cost Effective Solutions to Snowmobile Emissions Concerns

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Montana Tech Clean Snowmobile Design Team

PROBLEM

Snowmobiles today are creating a controversy among environmentalists, snowmobile enthusiasts, and business owners as they become a more popular form of recreation. Environmental groups want to ban snowmobiles from national parks because of their emissions and loud noises that distract the wildlife. In response to this controversy, the Society of Automotive Engineers (SAE) in 2000 started the Clean Snowmobile Challenge (CSC). The CSC challenges college students to modify an existing snowmobile to be clean, quiet, and produce desirable performance characteristics.

By 2006, the Environmental Protection Agency (EPA) will require manufacturers to achieve 30% reduction in both carbon monoxide (CO) and unburned hydrocarbon emissions (UHC) in half of their production models. In 2007, all models must meet the requirement. This 30% reduction means that manufacturers must achieve emissions levels of 275 grams/kilowatt-hour for CO and 100 grams/kilowatt-hour for UHC. These levels were established based on an industry wide average of 400 grams/kilowatt-hour for CO and 150 grams/kilowatt-hour for UHC [9]. To achieve these emission standards, the Montana Tech Society of Automotive Engineers (MTSAE) will engineer reliable, low-cost, add on modifications for a snowmobile similar to those that established the industry wide baseline emissions average.

NEED

Snowmobile enthusiasts do not want to see snowmobile use banned in national parks. Yellowstone Park in particular, offers winter scenery that can only be appreciated on a snowmobile. For snowmobiles to be allowed in the national parks, emissions and noise must be drastically reduced.

The snowmobile industry contributes $26 billion to the worldwide economy each year. This contribution comes from expenditures aspects of snowmobiling such as clothing, travel/trip expenses, and equipment [10]. West Yellowstone alone has had business hurt by up to 60% in the recent years [11].

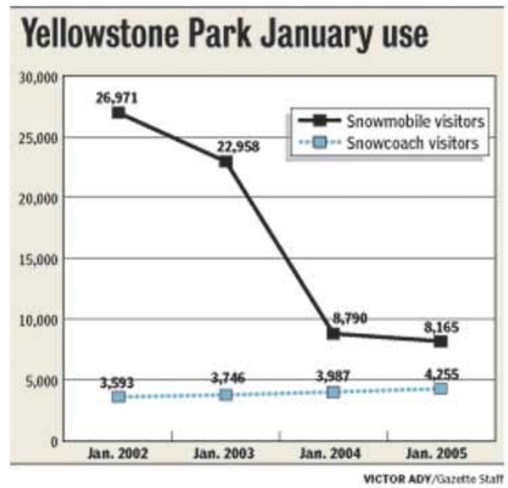

Figure 1. Yellowstone Park Use [12]

As Figure 1 suggests, snowmobile use has declined drastically in the recent years since the controversy has begun. This decline directly reflects the economic impact on West Yellowstone businesses as cited previously.

MTSAE has set goals to re-engineer an existing snowmobile to improve emissions and reduce noise while maintaining the overall performance of the original snowmobile to make it acceptable for National Park use. The modified snowmobile also must be cost-effective and a marketable product.

The snowmobile was re-engineered by:

- adding a catalytic converter;
- designing a pre-combustion chamber;
- designing a 2-stage exhaust silencer;
- designing an intake silencer;
- using sound dampening materials; and
- selecting a fuel to reduce emissions and maximize performance.

In entering the CSC, MTSAE also has a secondary goal to reduce the overall weight of the snowmobile; thus, MTSAE will reduce the static and rotating mass of the snowmobile.

PERFORMANCE AND EMISSION CONTROL

MTSAE chose to use relatively simple, bolt-on modifications for two reasons:

- the cost of the snowmobile would not increase; and
- the everyday snowmobile user can make these modifications themselves.

To maintain the highest performance, MTSAE chose to use a two-stroke engine, engineer a pre-combustion chamber, apply a catalytic converter to the system, and select the proper oil to promote catalyst life. The use of all four of these components together will produce a system that will maintain the performance of the snowmobile and decrease emissions.

TWO-STROKE ENGINE - Two-stroke engines have three important advantages over four-stroke engines:

- Two-stroke engines have fewer moving parts, which greatly simplifies their construction and operation;
- Two-stroke engines produce a power stroke on every stroke. This gives the two-stroke engine a significant power advantage over the four-stroke engine; and
- Two-stroke engines can work in any orientation. A four-stroke will have problems with oil flow unless it is upright.

MTSAE chose to use a two-stroke engine because it is lighter, simpler, and less expensive to manufacture than a four-stroke engine.

In order to comply with CSC 2005 rules, MTSAE researched many 600 cc two-stroke engines [13]. To satisfy both rule requirements and our design considerations, MTSAE chose an Arctic Cat ZR/ZL 600cc electronic fuel injected 2-stroke engine to use as our base engine. This engine was chosen for four reasons:

- Our existing chassis was an Arctic Cat and engine mounts could be bought to make the engine swap easier.
- The engine was of twin-cylinder design. This would benefit the cooling for our pre-combustion chamber design.
- The engine was electronic fuel injected. This would help for tuning changes because of elevation. The elevation in Butte, MT is 5780 feet while the elevation in Houghton, MI is 1093 feet. The fuel injection makes fuel changes in the computer instead of making carburetor jetting changes.
- The engine comes from the factory with a variable exhaust system. Variable exhaust timing has been shown to reduce hydrocarbon emissions by as much as 40% [1].

PRE-COMBUSTION CHAMBER - The pre-combustion chamber maximizes the speed of the flame propagation during the power stroke. In normal 2-stroke operation, all energy must be converted from chemical energy to mechanical energy within approximately 80 degrees of crankshaft rotation. This assumption is based upon the exhaust port timing on typical 2-stroke engines. When the piston uncovers the exhaust port, cylinder pressure drops dramatically; therefore, no energy can be used to push the piston down. [4]

Under high revolutions per minute (RPM) engine operation, there is little time for complete combustion of the fuel/air mixture. The fuel that is not burned from the spark plug ignition gets released through the exhaust in forms of unburned hydrocarbons (UHC), carbon monoxide (CO), and other chemicals. There are many chemicals that are by-products of running a snowmobile, but the EPA focuses primarily on CO and UHC. To combat this problem, MTSAE chose to further pursue the use of a pre-combustion technique.

The pre-combustion chamber works to burn the existing fuel/air mixture much faster than normal spark ignition operation. The pre-combustion chamber is also designed such that the flame propagation is distributed much more evenly than in normal spark ignition operation.

Figure 2. Early Ignition

As can be seen in Figure 2, the ground electrode creates a “shadow” in the initial flame kernel. As the kernel expands, it must propagate around the ground electrode to fully develop. We believe this shadow creates incomplete combustion near the spark plug and at the cylinder walls where temperatures are lower. This incomplete combustion leads to higher CO and UHC emissions. The pre-combustion chamber eliminates this shadow.

The pre-combustion chamber has four holes on the bottom that are angled such that the resulting flame will follow the contour of the cylinder head dome. (See Figure 3.) Fuel/air mixture flows through these holes during the compression stroke. The mixture is then ignited within the pre-combustion chamber with the factory ignition system.

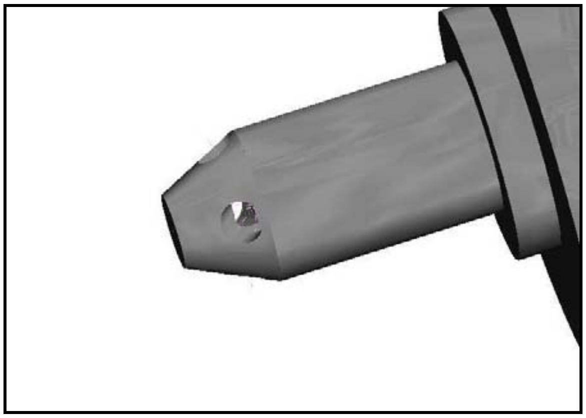

Figure 3. Pre-combustion chamber tip

Due to the high pressure created by the initial ignition event in the limited space available, the burning gases leave the pre-combustion chamber at a very high velocity. Since the pressure rises within the pre-combustion chamber so rapidly upon ignition, unburned fuel/air mixture is displaced from the pre-combustion chamber prior to being burned. This results in a fuel/air stream traveling through the fuel/air mixture within the engine’s combustion chamber. (See Figure 4.)

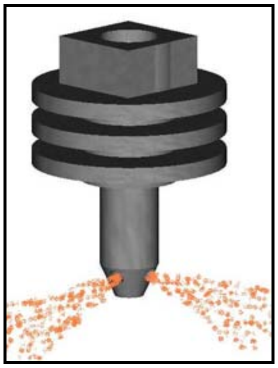

Figure 4. Pre-Combustion Chamber Operation

The air/fuel stream’s high velocity creates a high amount of turbulence in the path of this stream. High turbulence in a fuel/air mixture results in faster flame speed [1]. This increase in flame speed allows the flame to initially propagate along the stream towards the outside of the engine’s combustion chamber. Since the four holes in the pre-combustion chamber are spaced equally around the tip of the pre-combustion chamber, the engine combustion chamber’s flame front is allowed to travel through all 360 degrees towards the piston and cylinder walls.

A much larger portion of the fuel/air mixture is in contact with flame when initial ignition begins within the combustion chamber. This new ignition process allows for a very fast and efficient combustion process. Faster flame travel will benefit the 2-stroke engine by burning the fuel/air mixture prior to exhaust port opening.

Figure 5. Pre-Combustion Chamber

The pre-combustion chamber was re-designed based on issues encountered last year. During CSC 2004, the center pre-combustion chamber in our Arctic Cat 660 4-stroke engine failed due to retained heat. (See Figure 6.)

Figure 6. 2004 Pre-Combustion Chamber Failure

The primary problem governing this issue was the recessed spark plug location. Because of this engine design, forced convection heat transfer was not allowed to occur. As can be seen from Figure 5, cooling fins were machined into the pre-combustion body to increase surface area. In addition to better convective heat transfer, conductive heat transfer is also much improved over last year's design [3]. Since the cooling passages in the triple cylinder engine do not allow for as efficient heat dissipation as do those in a twin cylinder engine, more heat created in the pre-combustion chamber can be removed through the engine's liquid cooling system.

In order to allow our engine to run properly with the pre-combustion chambers installed, one modification must be made. Since the pre-combustion chamber moves the ignition source away from where it would normally start, there is a delay in when the actual ignition event begins. Therefore, the timing must be adjusted to compensate for this delay. Since we chose to use the stock ECU, we do not have actual control over timing; therefore, adjustments had to be made to the ignition timing sensor. We were able to accomplish this timing advance by removing the crankshaft's woodruff key and rotating the flywheel on the crankshaft. Though this technique would seem like a great risk of flywheel movement is possible, it is a common practice in two-stroke racing. Valve grinding paste provides a high-friction mating surface between the crankshaft and the flywheel. This is due to the press-fit between the two surfaces. [5]

The pre-combustion chamber was produced at Montana Tech's Creativity Forge using Haas CNC machining tools. The estimated cost per unit on a 5000 unit basis is $30.

CATALYTIC CONVERTER - The catalytic converter reduces emissions by removing polluting chemicals before they leave the snowmobile. The three main regulated emissions are carbon monoxide, hydrocarbons, and nitrogen oxides. Carbon monoxide is colorless, odorless, and poisonous gas. Hydrocarbons are produced from unburned fuel that evaporates. Sunlight breaks these hydrocarbons down to form oxidants that react with oxides of nitrogen to produce a major component of smog called ground level ozone (O_3). Nitrogen oxides contribute to the smog and acid rain; also, nitrogen oxides cause irritation to human mucus membranes. Catalytic converters are designed to reduce all three of these emissions.

A major problem with the use of catalytic converters on two-stroke engines is the amount of UHC emitted from the engine. Generally, two problems occur from this UHC release: chemical and thermal deactivation [2]. Chemical deactivation occurs when substances come in contact with the catalyst that will not oxidize. These chemicals then occupy reaction locations needed for UHC and CO oxidation. Thermal deactivation occurs when the catalyst bed becomes too hot and the bond between the catalyst bed and the washcoat is broken. According to our catalytic converter supplier, thermal deactivation is the primary issue concerning the use of catalytic converters on a two-stroke engine.

In order to combat this issue, we worked closely with a catalytic converter company to come up with a catalyst bed and washcoat combination that would be able to withstand the high temperatures created during the UHC oxidation. Ceramic substrate was chosen as the catalyst bed since it has better high temperature durability than metallic substrates. A 3-way (platinum, palladium, and rhodium) washcoat was then used to provide the catalyst for the oxidation reactions. According to vConverter Corporation, rhodium provides the most efficient conversion efficiency for CO and UHC oxidation and NOx reduction. Therefore, we chose to have the catalyst bed heavily loaded with rhodium to best complete the UHC oxidation reaction.

Also, in order to complete the CO and UHC conversion, additional oxygen had to be added to the exhaust system. This oxygen addition was accomplished with a small 12-volt air pump. It was very important for us to find a pump with minimal current draw since the factory electrical system only produces 175 watts. The pump we chose only draws approximately 48 watts. A nozzle was constructed and added to the exhaust piping between the expansion chamber and the catalytic converter. We chose this location as it provides the adequate distance for good mixing of the incoming excess oxygen with the exhaust gases. This location provides approximately ten pipe diameters for the gases to mix. According to vConverter's past experience with catalytic converters on other CSC teams' two stroke engines, localized thermal deactivation was a problem due to inadequate mixing.

To further protect the catalytic converter from getting too hot, it was placed as far as possible downstream in the exhaust. This location worked out to be deep in the bellypan where little air movement takes place to provide convective heat transfer. Therefore, we removed a section of the plastic bellypan and replaced it with a louvered section of 22-gauge sheet metal.

TABLE I. EMISSIONS DATA

	Stock Setup		Modified Setup	
	HC ppm	CO ppm	HC ppm	CO ppm
Idle	12720	2.81	9693	2.21
5000RPM	12402	1.27	15948	3.27
7000RPM	8819	3.9	8906	3.18

Table I shows a sample of an emissions test we performed on our snowmobile before and after we made our modifications. This data suggests that we improved emissions at idle; but not at the other two RPM settings we were able to get. This data also suggests that CO was reduced at both idle and at 7000 RPM. We feel that this data is not an accurate representation of the successfulness of our modifications for several reasons. First, we do not have access to a proper method of loading the engine while running the emissions test. This problem does not allow our exhaust gas temperatures to reach adequate temperatures to allow the catalytic converter to light off. A second problem with our testing method is that the emissions analyzer we used is not set up for two-stroke engines. It was designed for emissions inspections to be run at idle and off-idle RPM settings. We recognize that our emissions testing method is inaccurate, but must report it since it is the best data we can gather with the resources we have and the equipment available in our area.

The catalytic converter was produced by V-Converter for MTSAE as a donation. The quote from V-Converter for a 5000 unit production run is $70.

OIL SELECTION - Proper oil selection was also a factor in improving overall performance and reducing emissions. The oil chosen for this year's CSC is Blue Marble® 2-stroke oil manufactured by EnviroFuels. The Blue Marble oil improves engine performance by reducing metal-to-metal friction. Unlike most oils that concentrate on the molecules between metal surfaces to reduce friction, Blue Marble oil focuses on the metal in contact with the oil. Blue Marble oil is able to reduce dry metal to dry metal friction coefficients by over 85% without any surface lubrication [6].

As mentioned in the "Catalytic Converter" section, chemical deactivation is a problem with catalytic converters. To account for this issue, significant time was spent reviewing all available two-stroke oil Material Safety Data Sheets (MSDS). Lead (Pb), sulfur (S), phosphorus (P), zinc (Zn), calcium (Ca), and magnesium (Mg) are known catalytic converter poisons [2]. Each oil's composition was carefully reviewed to determine if any of these substances were present in any of the components of the oil. As it turns out, Blue Marble's chemical composition is primarily mineral based (approximately 70%); therefore, chemical deactivation has a much lower chance of happening [7].

The combination of a two-stroke engine, pre-combustion chambers, a catalytic converter, and the use of Blue Marble oil all help to reduce emissions and maintain performance.

NOISE REDUCTION

Another reason that snowmobiles are being threatened to be banned in national parks, is the noises they produce. The four main sources of noise are the exhaust, the intake, the track, and the suspension. Noise reduction comes primarily from tuning the exhaust to attenuate certain frequencies. The challenge comes from trying to maintain maximum flow out of a silencer while lowering the sound level it outputs. MTSAE chose to reduce noise by designing a muffler that will enhance performance while reducing noise, installing an intake-silencer, and applying sound-dampening material on the snowmobile.

EXHAUST SILENCER DESIGN – The overall shape was the most important aspect of muffler design, as it would dictate if it would fit under our hood. An exhaust noise silencer was designed based on sound testing. A diffuser and absorption silencer was fabricated to aid in noise reduction.

Sound data from the engine was taken at idle and at 7000 RPM. The data was analyzed using a Fast Fourier Transform (FFT) program called Sample Champion. The FFT program changes the sound file from the time domain to a frequency domain. These frequency spectrum graphs show which frequencies have the highest amplitudes and therefore are most dominating. (See Figure 7 and Figure 8.)

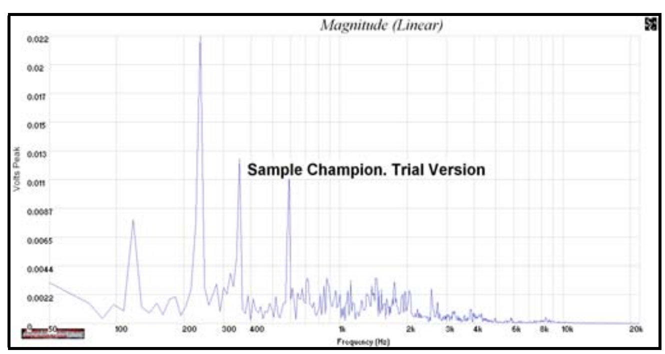

Figure 7. Frequency Spectrum Idle

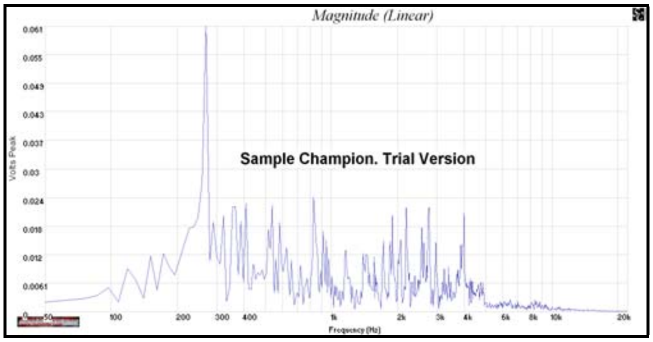

Figure 8. Frequency Spectrum 7000 RPM

The data collected shows that there is almost no data beyond 5000Hz and it is primarily concentrated between 0 and 2000Hz. The large spike in the data that occur at 275 Hz is caused either by the microphone resonance or another external source; thus, this large spike of data will be thrown out and not designed for. A specific silencer could then be designed based on the data collected.

MTSAE looked at three different types of muffler elements for our design: side-resonant, diffuser, and absorption. A side-resonant silencer works on the theory that waves will vibrate with infinite amplitude when they are the same frequency as that of the chamber through which they have passed. This creates very high attenuation at the natural frequency of the chamber [1]. The side-resonant design is used mostly for applications where one frequency is very dominant or one frequency needs to be nearly eliminated. The diffuser silencer works by "bouncing" waves around in an open chamber. Waves of certain frequencies cancel each other out and create attenuations. The attenuation curve of a diffuser silencer is based on a sinusoidal shape [1]. These are used for a large amount of attenuation over a wide range of frequencies. The absorption silencer absorbs the energy of sound waves with a dampening material such as fiberglass. This method attenuates nearly all frequencies the same amount [1]. These are the most common type of silencers and are used for a fairly low level of attenuation over a very broad spectrum of frequencies.

With the chassis space available, MTSAE designed an exhaust silencer with a single diffuser section and an absorption element. The silencer was designed using a silencer-modeling program designed from equations found in Design and Simulation of Two-Stroke Engines by Gordon P. Blair. The program produced designs for the three different types of silencers: side-resonant, diffuser, and absorption. The program inputs geometric dimensions of the silencer section and outputs a graph of Attenuation vs. Frequency. Using our frequency spectrum graphs from the sound data that were plotted in a frequency domain, we matched our attenuation curves to attenuate the most dominant frequencies. Using inductive reasoning, the dimensions of different silencer profiles were input to produce attenuation curves that correspond to frequency curves. The silencer itself had pre-defined dimension as it had to fit into a predefined section under the hood. A similar program was found online and was used to check our results.

The silencer that was decided on consisted of a diffuser and absorption element. The diffuser has dimensions of 7.87" long and 7.87" in diameter. The inlet pipe of the diffuser has dimensions of 4" long and 1.625" in diameter. The outlet pipe of the diffuser has dimensions of 3" long and 1.625" in diameter. (See Figure 9.)

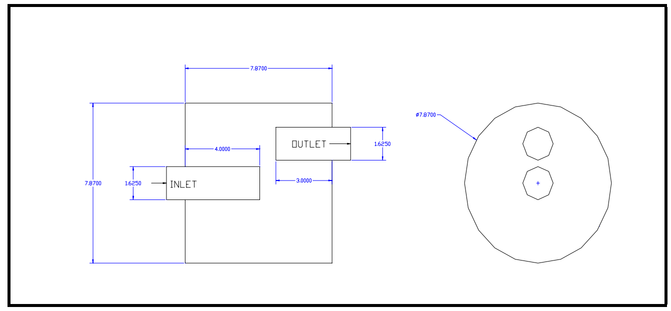

Figure 9. Diffuser Dimensions

The theoretical attenuation of the Diffuser element is seen in Figure 10.

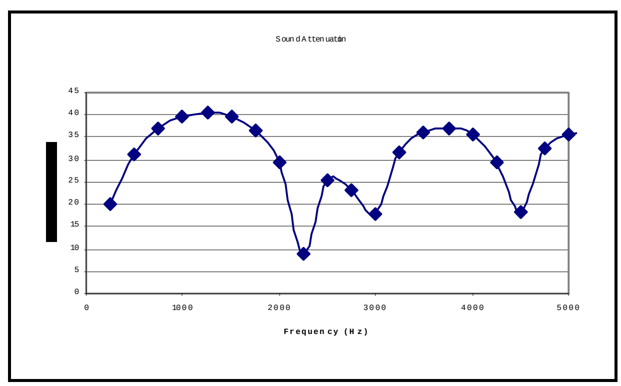

Figure 10. Diffuser Attenuation

The absorption element attenuates all frequencies the same amount, this theoretical value is 10 –15 dB. It is packed with loose fiberglass packing and the perforated pipe is wrapped with a fiberglass sheet. The absorption silencer dimensions are seen in figure 11.

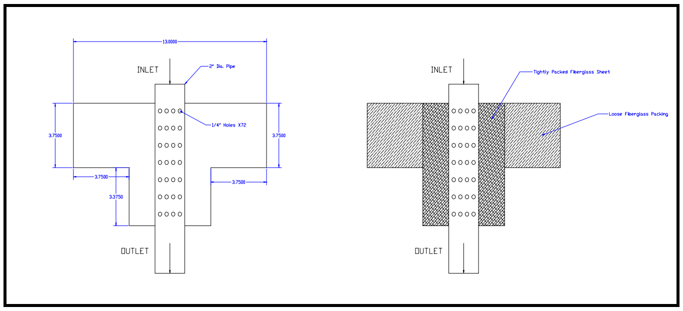

Figure 11. Absorption Dimensions

The theoretical total attenuation of the silencer is seen in Figure 12.

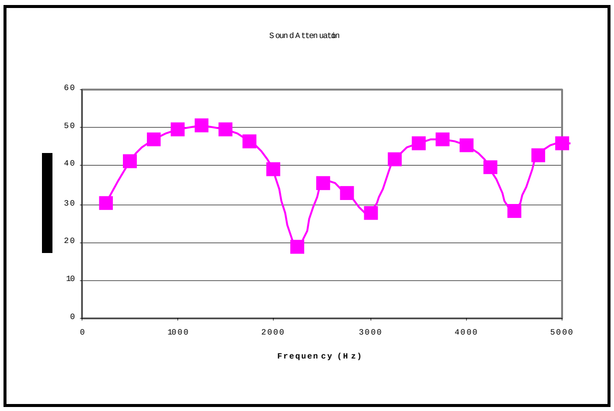

Figure 12. Theoretical Total Attenuation

The silencer system was then fabricated and sound data was then taken from the snowmobile with the silencer system attached. This data was again analyzed with FFT program. The final frequency spectrums are seen in Figure 13 and Figure 14.

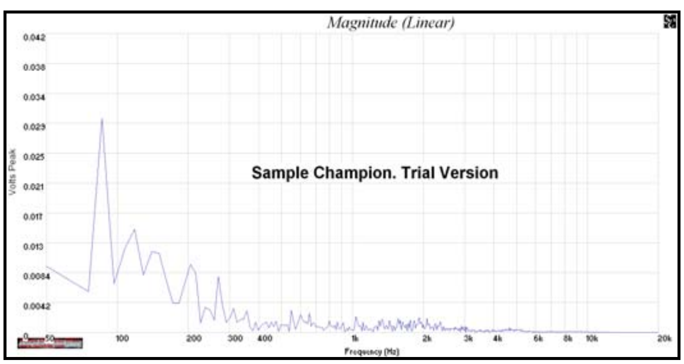

Figure 13. Idle with Exhaust Silencer

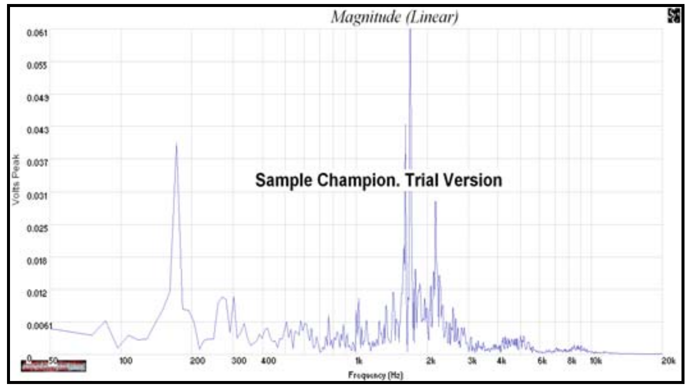

Figure 14. 7000RPM with Exhaust Silencer

From this data, it can be seen that the actual sound attenuation has a very close correspondence to the theoretical approximations. The data shows that the frequencies below about 2000 Hz are significantly reduced. Once again, the peak at 275 Hz is most likely from the microphone resonance or another external source and is therefore ignored concerning actual sound output. The data also shows that the sounds at or above 2000 Hz were virtually unaffected by the exhaust silencer system. As MTSAE predicted, the silencer focuses on frequencies between 0 and 2000 Hz.

The exhaust silencer system was hand manufactured by MTSAE in our shop. MTSAE estimates that to produce 5000 units, it would cost $100 per unit.

INTAKE SILENCER - We chose to design an intake silencer as another part of our overall noise reduction scheme. The type of silencer that we chose to design was a low-pass intake silencer. The theory of operation of a low-pass silencer states that the silencer will only silence noises at frequencies above the silencer's natural frequency; therefore, we calculated the volume and inlet pipe length that would make the silencer effective at the lowest possible engine speeds [1]. The equations used in designing the intake silencer were found in *Design and Simulation of Two Stroke Engines* by Gordon P. Blair.

$$f_i = \left(\frac{a_o}{2\pi}\right)\sqrt{\frac{A_p}{L_{eff}V_b}}$$

The variables in this formula are as follows: f_i is the natural frequency of the intake silencer; a_o is the speed of sound in air; A_p is the area of the pipe; L_{eff} is the effective length of the inlet pipe; and V_b is the volume of the box. The basic shape of the intake silencer is seen in Figure 15.

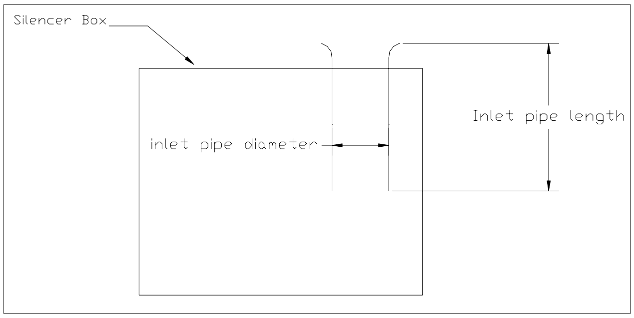

Figure 15. Intake Silencer Diagram

In order to determine the optimum natural frequency of our intake silencer, we plotted the forcing frequency of our engine at different speeds. (See Figure 16.) The plot was based on the following equation.

$$f_e = \frac{N * rpm}{60}$$

The variable f_e is the forcing frequency of our engine and N is the number of cylinders in our engine.

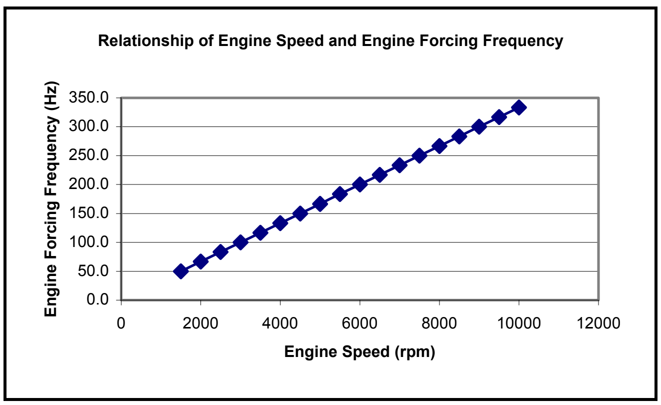

Figure 16. Forcing Frequencies of the Engine

We then studied the effect of different silencer box volumes and inlet pipe lengths had on the natural frequency of our intake silencer. We determined that the larger the silencer box volume the lower the natural frequency of our silencer. (See Figure 17.)

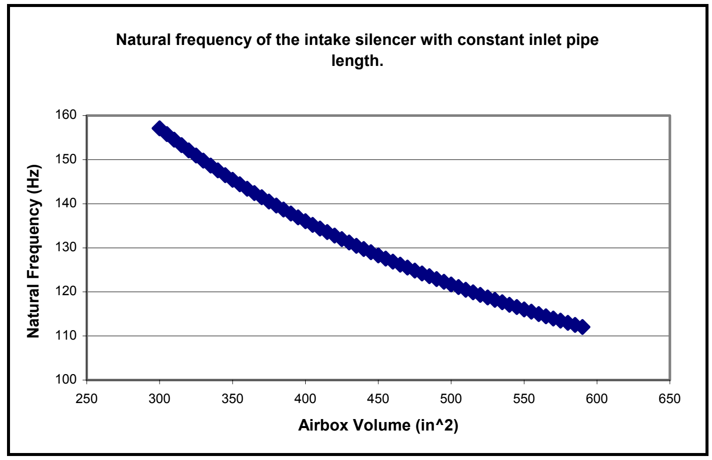

Figure 17. Effect of Different Silencer Volumes

We also determined that the longer the inlet pipe length, the lower the silencer's natural frequency. (See Figure 18.)

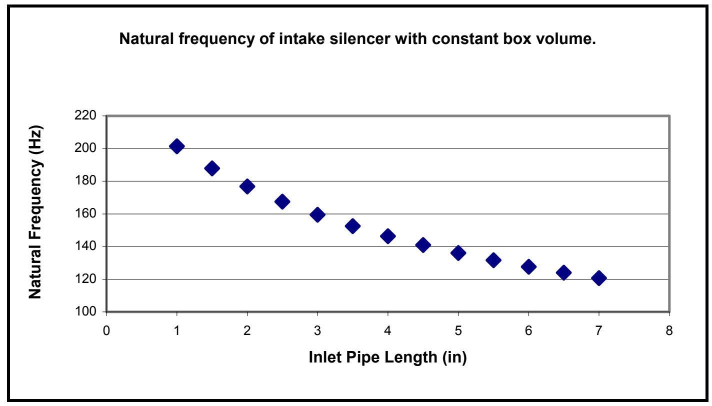

Figure 18. Effect of Different Inlet Pipe Lengths

Because of these relationships, we chose to modify the stock intake silencer to maximize volume and to install the longest possible inlet pipe. Our intake silencer is designed to have a volume of 496 in^3, a 6 in. inlet pipe length, and a natural frequency of 115 Hz successfully reducing noise at engine speeds above 3440 rpm. Although we can hear the difference the intake silencer makes, we cannot quantify the effect of it because other operating noises are relatively much larger.

The intake silencer system was hand manufactured by MTSAE in our shop. MTSAE estimates that to produce 5000 units, it would cost $20 per unit.

SOUND DAMPENING MATERIAL – A large source of noise is the vibration of moving parts on the snowmobile. To reduce external noise, sound-dampening materials were sprayed along the bottom of the tunnel of the snowmobile, on all of the rear suspensions parts of the snowmobile, and under the hood of the snowmobile. The sound dampener used was Quiet Kote® Sound Dampening Spray. The spray is a visco-elastic vibration damper that aids to silence vibration [8]. Foam insulation was also placed under the hood to dampen vibration noise frequencies. This dampening system helps to reduce the total ambient noise level of the snowmobile.

The spray coating is estimated to cost a manufacturer $3.50 per square foot. Our snowmobile has approximately 16 square feet of spray-on coating, which equals a total cost of $56.

MODIFICATIONS

WEIGHT REDUCTION - Weight is a large factor in determining the overall performance of a snowmobile; hence, MTSAE tried to reduce the dry weight of the snowmobile as much as possible. If the weight of the snowmobile can be reduced, the vehicle can maneuver better, the vehicle could brake and accelerate better, and the vehicle will be more efficient by getting better gas mileage. The two types of weight that can be reduced from the snowmobile are static weight and rotating weight.

Static weight is everything on the snowmobile that is not rotating while the sled is running. Static weight is what makes up the majority of the sled and is what can be most easily reduced. To reduce weight on the snowmobile MTSAE removed unnecessary equipment as well as replaced stock equipment with lightweight parts. The suspension had a few parts, such as bogey wheels, that could be removed without interfering with the performance of the sled. Some other parts of the snowmobile that were removed are: the two-up seat, mirrors, and passenger seat footrests. In addition to removing all of the unnecessary parts of the snowmobile aftermarket parts were also added to the snowmobile.

Aftermarket lightweight A-arms were installed to save a total of six pounds per arm. These A-arms were not compatible with the stock spindles that were on the snowmobile; therefore, spindles from an Arctic Cat ZR style snowmobile were used to mount the new A-arms. These new spindles also reduce the sled weight by six pounds.

ELECTRONICS - When the two-stroke engine was implemented a new wiring harness had to be fabricated to connect the electronic fuel injected engine to the chassis. Another wiring harness was created to attach the gauges to the engine and a Digitron gauge system was installed to the snowmobile. The Digitron system reads exhaust gas temperatures (EGT), cylinder head water temperature, and RPM.

UNDER-HOOD HEAT - When running an exhaust catalyst treatment, a large amount of under-hood heat is generated. MTSAE has attempted to combat this problem by four methods:

- A large metal air duct was placed in the side-panel of the snowmobile next to the catalytic converter.
- The belly pan and side-panels were covered in reflective heat shielding.
- The under-side of the hood was covered in thin, acoustic foam, which has a reflective tape applied to it.
- The air intake feeds cooler air from the surroundings, through the original tachometer gauge hole, to the engine intake.

The hood insulation is estimated to cost a manufacturer $1.50 per square foot. Our snowmobile has approximately 6 square feet of hood insulation, which equals a total cost of $9. The heat shielding is estimated to cost a manufacturer $8.00 per square foot. Our snowmobile has approximately 11.25 square feet of heat shielding which equals a total cost of $90.

HANDLING AND RIDER COMFORT – With the addition of the rider comfort event to CSC 2005, MTSAE has tried to adjust our snowmobile to maximize rider satisfaction. Since our chassis was originally designed as a touring model, the suspension contained “soft-ride” adjustable shocks. In addition to these, MTSAE added lightweight front A-arms and Arctic Cat ZR-style spindles. These weight-reducing parts improve steering response and spring response. MTSAE also tried to adjust the shock absorber to create a soft and comfortable ride. This is a hard value to quantify and is subject to a rider’s personal taste. Testing for these adjustments was very minimal for two reasons:

- Montana Tech does not have portable accelerometers to attach on the snowmobile to measure seat vibration.
- Due to the snow-pack conditions in Montana, finding snow to ride on is a very big problem. Southwestern Montana has only received 34% of normal precipitation for the water year - October 2004 to present. In a normal year, we would be able to build a test track at our shop. However, we did not receive any snow since January and were therefore not able to perform any “controlled environment” testing.

MARKETING

When MTSAE took the challenge to engineer a more efficient snowmobile the cost of producing one was kept in mind. To ensure cost effectiveness, the snowmobile was built using inexpensive parts; these parts are relatively simple bolt-on parts, and can be purchased “off-the-shelf”. This allows the user to purchase the parts and install them on their current snowmobiles instead of purchasing a whole new snowmobile in order to meet compliance regulations.

Each of the modifications done to MTSAE’s snowmobile could be packaged as an aftermarket emissions system.

The total manufacturing price for an aftermarket emissions package is $375 on a 5000 unit basis.

Conclusion

MTSAE took on the CSC with the goal of engineering a snowmobile that reduced emissions and noise without sacrificing performance. Modifications such as the pre-combustion chamber, the silenced intake, the 2-stage exhaust silencer, and catalyst system have proven to be very effective in achieving this goal. Most of the parts used in the design are relatively simple; in fact, the majority of parts used are bolt on.

MTSAE used knowledge from various aspects of engineering to help solve a real world environmental problem that extends much larger than snowmobiles. The CSC has challenged MTSAE to successfully re-engineer a snowmobile to run at its maximum efficiency.

Acknowledgements

Without the support of our sponsors MTSAE could have never made it to the Clean Snowmobile Competition.

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