Minnesota State University, Mankato SAE Clean Snowmobile Design Using a Semi-Direct Injection Two-Stroke

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ABSTRACT

This paper describes the design strategy of the 2008 Minnesota State University, Mankato Automotive Engineering Technology program's entry into the SAE Clean Snowmobile Challenge (CSC) held in Houghton, MI. The goal for this project is to make a snowmobile more environmentally friendly than production sleds without sacrificing the performance of the vehicle. This involves finely tuning the noise, emissions and ergonomics. Included will be the make and model of snowmobile chosen, the fuel delivery system, changes in the electrical, exhaust, suspension, and emission systems. Also included will be rules in the CSC that we had to work around and compromises we had to make.

INTRODUCTION

The SAE Clean Snowmobile Challenge is an intercollegiate competition for students to redesign an existing snowmobile. Reducing harmful emissions and noise output, while maintaining stock performance, are the main goals of the project. The specific challenge was to reengineer a 2005 Arctic Cat F5 chassis, with a 2004 Arctic Cat Sabercat 500cc engine.

The 2008 Clean Snowmobile Competition is held on March 10-15. The five day competition includes many events such as an emissions test, fuel economy, static display, noise events, as well as many more.

Minnesota State University, Mankato is one of seven state universities in the Minnesota State Colleges and Universities (MnSCU) system. Located in south-central Minnesota, it is attended by over 14,000 students. MSU offers an Automotive Engineering Technology (AET) program as a four-year Baccalaureate degree through the College of Science, Engineering, and Technology. Automotive Engineering Technology is accredited by the Technology Accreditation Commission of the Accreditation Board for Engineering and Technology (TAC-ABET).

ENGINE MODIFICATIONS

Snowmobiles have been known for being inefficient compared to most automobiles. There are 2-stroke and 4-stroke cycle snowmobile engines, but the majority of snowmobile manufacturers have continued with the 2-stroke cycle engine. Due to the anatomy of a 2-stroke engine, they emit more hydrocarbons and carbon monoxide. In addition to the creation of the 4-stroke snowmobile, the semi-direct injection (SDI) 2-stroke snowmobile was created to reduce emissions and improved drivability. When Bombardier introduced the SDI system, it reduced pollutants by 60% when compared to carbureted 2-stroke snowmobiles.

INJECTOR PLACEMENT

In placing the injectors, it was decided to spray them directly through the transfer port and into the cylinder. From previous year's design, the placement of the first injector is at a forty degree angle from the casting line on the cylinder jug, and sitting horizontal. This was only designed for one injector per cylinder. This system had a flaw, which was not having enough fuel to run at a higher rpm.

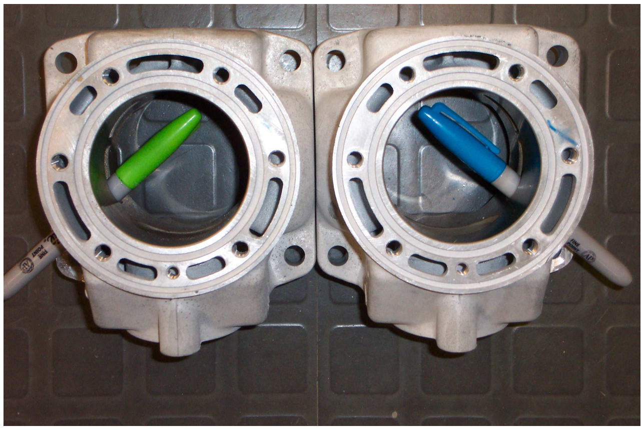

Figure 1: Initial 40 degrees to casting line

If a bigger injector was used, the idle speed would go up because of the turn down ratio of the injector. Two injectors were needed because of this, one injector of low rpm and one for high rpm. A new design was needed to fulfill this need. The first design was to place another injector at the same angle as the first injector, but facing the opposite direction.

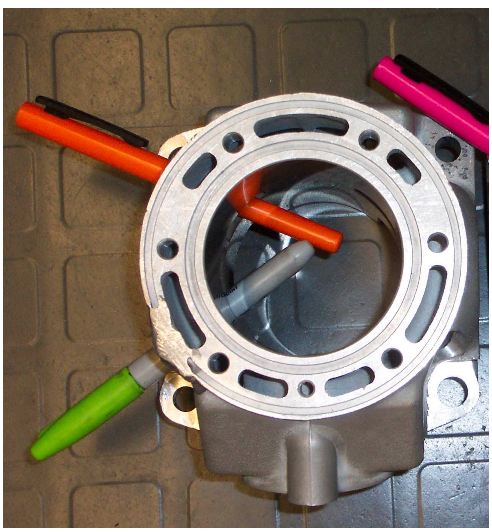

Figure 2: Dual 40 Degree Injector Setup

This proposed a problem. In facing the injector the opposite direction, it sprays raw fuel out the exhaust port. The point of the SDI system is to keep less fuel from escaping out the exhaust port. To remedy the problem, a new system was created. Instead of the rear injector spray towards the exhaust port, the injector was turned to be at a ninety degree angle to the casting line on the cylinder jug. This would spray directing into the air stream coming from the opposing transfer port, thus inducing a homogenous mixture of air and fuel.

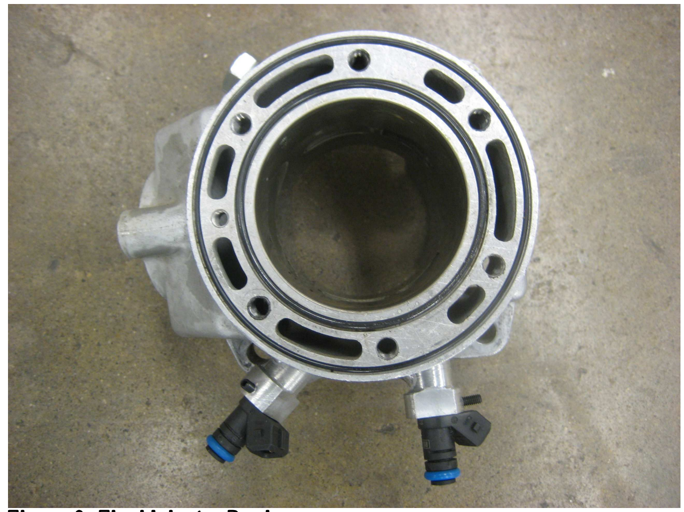

Figure 3: Final Injector Design

After the injector placement was determined, the testing could begin. To test the flow of the injectors in the cylinder along with the air mixture, wet flow testing was used. The setup consisted of the New Age Fuel Injector machine, OTC Fuel Injector Cleaner, Super Flow 1020 Flow bench, Exhaust Barrel, and the test engine.

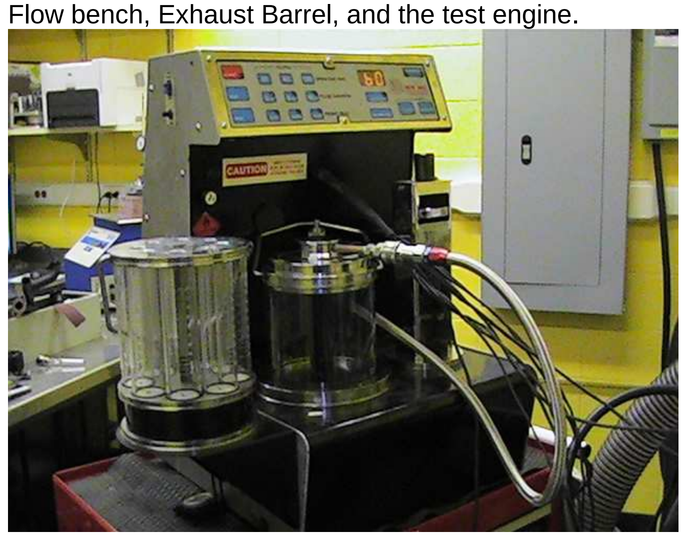

Figure 4: New Age Fuel Injector Machine

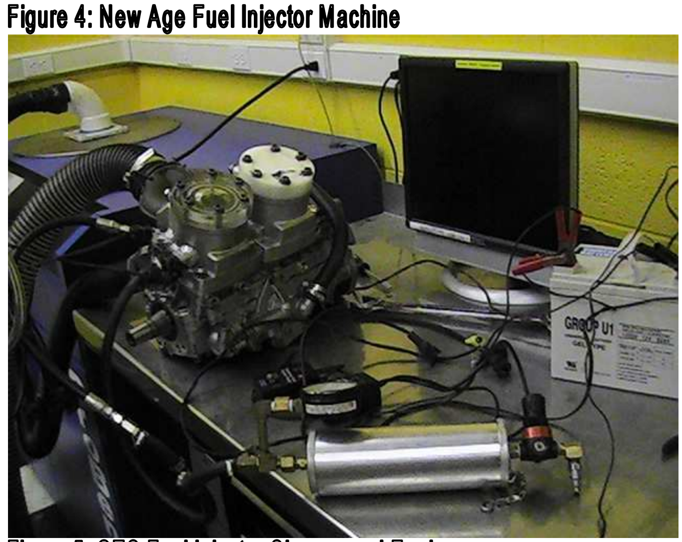

Figure 5: OTC Fuel Injector Cleaner and Engine

During the wet flow testing, the mixture of the injectors showed to be promising. The injector set at 40 degrees was tested alone to show mixture before the second injector was added. The mixture showed to be adequate with favorable results. The fuel was mixing with the air very well, covering about ¾ of the cylinder head with the mixture. When the other injector was added in, the mixture completely filled the cylinder, making a good Air/Fuel mixture.

ENGINE CONTROL UNIT

The engine controller chosen was the Motec M48. The Motec allowed fine tuning of both the ignition and fuel events to precisely manage the combustion process. This should allow the engine to be tuned for the best emissions possible, while maintaining or improving upon the original performance figures.

In order to manage all of these, the Motec utilizes a variety of sensors. The sensors chosen for this setup included:

- 108 kPa Manifold Absolute Pressure (used for barometric pressure)
- Intake air temperature sensor
- Engine temperature sensor
- Hall-effect crank position sensor

The ECU reads the RPM of the engine using the hall-effect sensor and a 24 tooth trigger wheel. The same sensor controls both the speed reading and the sync reading by way of a missing tooth positioned 90° BTDC. When the ECU reads the missing tooth, it knows that 90° following is TDC. The previous design, using a 12 tooth wheel and the OEM crank position sensor, was determined to be unable to keep up with the RPM that the engine would be running. After consulting with Motec USA, they recommended a 24 tooth wheel at minimum, and provided detailed specifications for the sensor being used. These included minimum tooth spacing, tooth size, and wheel thickness.

The ECU was able to read up to 480 samples per second, which allows very fine control over both fuel injection and spark timing. This was critical, as the available window while the ports are open at 8000rpm is only a few milliseconds. This was also the determining factor in choosing a twin-injector SDI setup.

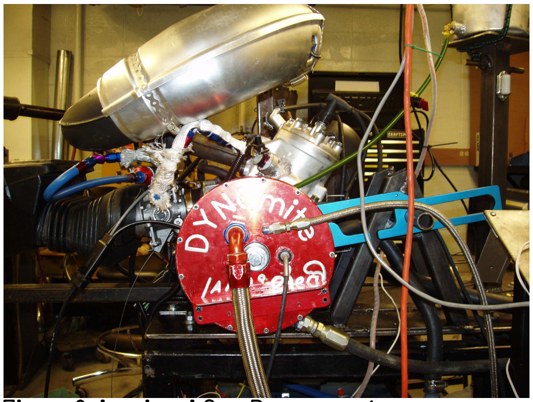

Figure 6: Land and Sea Dynamometer

For fuel and ignition tuning, a 9” Land & Sea water brake dynamometer was used. The dynamometer offered the advantages of being compact, and of being able to tune the engine while it was mounted in the sled, thus saving time removing and reinstalling the motor. It also allowed tuning using all the final components connected as they would be in the final design.

CHASSIS MODIFICATIONS

Maintaining correct ergonomics is a very important aspect while redesigning the snowmobile. Having a well working drive train does not matter if the rider is not comfortable while riding all day long. This year, the decision was made to reinstall the stock seat and gas tank which was engineered for the snowmobile, and will ensure rider comfort and proper ergonomics. The 2005 Arctic Cat F-series chassis has been proven to be a high performance setup for all uses and will fulfill the needs for the Clean Snowmobile Challenge.

The sole modification done to the chassis was the use of a Camoplast Ripsaw track in replacement of the stock Arctic Cat track. The Ripsaw track provides optimum traction on hard pack trails as well as in deep snow.

ELECTRICAL

From research done by the 2007 team the stock stator in the snowmobile does not provide enough power for the added electronics. An upgraded stator was made to try to keep up with power demand but with an output of only 7 amps at idle another source of power is required. Using a 45 amp Denso alternator to supply power solved the electrical problem. The upgraded stator was made by the 2007 team; it has twice the number of windings using 16 gauge wire. In theory it should produce 14.7 volts at 3,000 RPM and support 25 Amps of constant current for 2 minutes. The capabilities of the stator have been proven to be much less. The rectifier bridge from last year’s team will also be used. The bridge uses four 70 amp diodes to convert the AC signal from the stator to a DC current to be used by the electrical system of the sled.

Figure 7: Rewound Stator

Figure 8: Custom Rectifier Bridge

With the increased demands of the EFI system, ECU, fuel pump, and other electrical systems, we want to ensure steady power to all systems. Utilizing an automotive alternator in addition to the rewound OEM stator will give us a maximum 55-60A of power to use.

The battery selected for the sled is an Odyssey PC925 dry cell. The Odyssey has several advantages over a standard lead-acid battery. It can deliver the most power over the widest temperature range, especially at colder temperatures where a standard battery will deliver lower amperage. The sealed dry cell battery can also survive being tilted to odd angles, thus being safer in the event of a rollover or tipping. It is also more compact than a standard battery, allowing us to mount the battery under the seat to conserve space elsewhere.

A complete wiring harness has been made for the snowmobile along with a fuse panel and relay center located high in the rear of the engine bay. This allows quick and easy access to the relays and fuses for diagnostic purposes. The hand and thumb warmers were eliminated by last years team but will be functional this year. They were not used because of the lack of electrical power. The headlights will now function as they were meant to. Last year they were wired in series and had no difference between high and low. With the available electrical power all the standard components and luxury components will be able to function as desired by a snowmobile rider.

EMISSIONS MODIFICATIONS

The engine is a Suzuki 499cc two stroke cycle that's used in the 2004 Arctic Cat Sabercat. The two stroke engine produces more emissions than a four stroke, but is ideal for snowmobiles due to it having a much higher power to weight ratio. Fuel is combusted during every stroke of the two stroke engine, which creates more power, but also creates more emissions. To help reduce these larger emissions from a two stroke engine, a catalyst and secondary air injection system is being used.

The goal is to reduce emission gasses as much as possible and not exceed 90 g/kW-hr of HC and NOx, and 275 g/kW-hr of CO. To do this, Heraeus helped to develop a catalyst that is designed specifically for the Sabercat engine. For the catalyst to work properly it needs to reach a temperature of 600 degrees F.
To help with the efficiency of the catalyst and the reduction of HC and CO, secondary air injection will be used. An automotive-style electric air pump is used to reduce costs and re-engineering. The pump selected can flow a minimum of 25.5kg/hr, or roughly 12.5cfm at standard temperature and pressure (20° C at sea level), more than enough for our purposes.

NOISE REDUCTIONS

A primary consideration of snowmobile use is noise emissions. Reducing noise emissions is another primary consideration of the Clean Snowmobile Challenge, and one that is somewhat difficult to do. An OEM-style silencer from an Arctic Cat F7 is being used, as well as sound dampening materials to line the hood and belly pan. A larger absorption-style muffler and a shrouded track would help to further reduce noise, but would add to the cost and weight of the sled. To determine the style muffler to use that would give the lowest decibel reading, many different muffler styles were tested. Starting with just the engine with no muffler to get a base reading of 105dB, the different muffler styles were added to compare their silencing abilities. Starting with a straight through style gave a reading of 101dB. Then a double chamber style with packing around the inlet pipe gave a reading of 97dB, which then the packing was moved from the inlet pipe to the outlet pipe which gave a reading of 96dB. After these were tested the muffler was changed so the inlet chamber was open, going into the outlet chamber which had a perforated tube with packing around it giving the lowest reading of 93dB. One more style muffler was tested were the baffles were added to the open inlet chamber which gave a reading of 96dB. The stock silencer that came on the snowmobile was dissected to find out that it had the same design that gave the lowest reading during sound testing, so the stock silencer is being used on our snowmobile.

CONCLUSION

With the use of a semi-direct fuel system and three-way catalyst, the main goal of reducing emissions on the two-stroke engine has been maximized. Using a factory silencer helped for packaging in the engine bay and insured that noise levels would be reduced or equal to stock. Retaining the original ergonomics will insure rider comfort and endurance while riding. The original suspension allows for maximum performance and handling characteristics. And finally the addition of an alternator to supply adequate power to the electrical system will allow all standard features and luxury options to be utilized. With all these components combined into one chassis, the F5 will be able to compete at a high level in the SAE Clean Snowmobile Challenge.

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