University of Maine Clean Snowmobile Team Design Paper

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ABSTRACT

For the 2008 SAE Clean Snowmobile Challenge, the University of Maine chose to modify a stock 2007 Yamaha Phazer instead of continuing to refine their previous clean snowmobile, an Artic Cat 660. This paper describes the UMaine team's efforts at converting the new snowmobile to E85, reducing emissions, and dampening noise, all while striving to maintain the Phazer's aggressive styling and performance characteristics.

INTRODUCTION

Snowmobiles produce a significant amount of pollution, considering their small numbers, as compared to cars. This is due to few regulations on snowmobile emissions. They are also responsible for the majority of pollution in many of the nation's natural parks. For example, as of the late nineties, snowmobiles have produced up to 90% of the hydrocarbon emissions in Yellowstone National Park [4]. Because of this, significant reductions in the pollutants and greenhouse gasses emitted per mile of travel from snowmobiles should be a concern for manufacturers.

Some modifications, such as the addition of catalytic converters to all future snowmobiles, are relatively simple and inexpensive to perform, and yield tremendous environmental benefits. Other changes, although more comprehensive, shouldn't be too difficult for large companies with advanced manufacturing facilities to implement. Hopefully by demonstrating the implementation of such technologies, clean snowmobile teams like that of UMaine can bring about change.

Since 2004, UMaine's Clean Snowmobile Team has engineered a snowmobile to compete in the Clean Snowmobile Challenge. The goal of this challenge is to demonstrate how modern engineering principals can be applied to produce a quiet, efficient snowmobile with a smaller emissions footprint than traditional snowmobiles. A new rule for this year's competition is that all snowmobiles with internal combustion engines must run on either E85 or B10. The UMaine team chose E85 as the fuel for the Phazer because of the fuel's growing popularity for use in passenger cars.

In the United States, the majority of ethanol used in formulating E85 fuel comes from corn. When E85 is burned in an internal combustion engine, the carbon dioxide that is released is later absorbed by this corn, which can then be processed into ethanol for more E85. From this perspective, E85 is a clean, 85% carbon neutral fuel. However, when the considerable use of fossil fuels in the production of ethanol is factored in, the environmental benefits of using E85 dwindle [2]. Still, with the development of new farming practices and manufacturing technologies, it may be possible to drastically reduce the amount of fossil fuels used in the production of ethanol, eventually leading to a widely available form of E85 that can be considered truly beneficial to the environment. Because of this potential to reduce our dependence on oil, as well as the fact that E85 vehicles produce less non-methane hydrocarbons and nitrogen oxides than their gas counterparts [1], it is worthwhile to demonstrate the conversion of a snowmobile to run on E85.

UMAINE'S DESIGN APPROACH - The University of Maine's team is subdivided into three groups: engine controls, E85 fuel system, and noise dampening. This provides an organized way to address the three essential areas of work. The goal of the engine controls group was to replace the stock engine control unit with a programmable ECU that could adjust engine parameters to allow E85 operation. Similarly, the fuel system group had the responsibility of replacing the fuel system components with ones that would not be harmed by the ethanol in E85. Another goal of the fuel system group was the constructing a larger fuel tank to maintain the snowmobile's maximum range, as ethanol contains about two-thirds the energy per unit volume as gasoline [1]. The noise, vibration, and harshness group's task was to analyze the acoustic profile of the snowmobile and reduce sources of noise accordingly, as well as to construct the clutch cover and new cowling pieces.

A requirement of next year's CSC is that internal combustion snowmobiles must be "flex-fuel" machines; that is, they must be able to run on any mixture of ethanol and gasoline, up to 85% ethanol. Therefore, instead of focusing purely on E85, the UMaine team incorporated a flex-fuel sensor into the fuel system.

When working on their Yamaha Phazer, the UMaine team made a point to preserve the snowmobile's appearance. To many people, the most appealing aspect of a snowmobile is the "Coolness Factor", and in a world where good looks sell, a snowmobile that is both energy efficient and attractive has a better chance of being noticed by consumers.

RESULTS OF EFFORTS - As of the writing of this paper, the Phazer hasn't been completed. This is due to the scope of work, as the team chose to modify a stock snowmobile instead of continuing work on last year's model. The tank and cowling still need to be finished, the flex-fuel sensor configured (if possible), and the engine tuned for E85. However, concrete results detailing emissions, performance, and noise levels should be achieved within the next week and will hopefully be available at the competition.

THE BASELINE SLED: 2007 YAMAHA PHAZER

Figure 1. 2007 Yamaha Phazer

RELEVANT SPECIFICATIONS -

- 15-18 MPG averaged fuel economy (91 octane gas)
- 8 gallon gas tank
- 85 dB of noise by SAE J192 Noise Test
- 490 Pound Dry Weight
- 80 horsepower, 499cc, 2-cylinder, 4-stroke engine

REASON FOR CHOOSING - The team chose this snowmobile because of its light weight design, its four-stroke engine, and its aggressive looks. The snowmobile's dry weight of about 490 pounds means that its 80 horsepower yields great acceleration. The engine providing the power is a twin cylinder 499cc 4-stroke, which by virtue of its design produces fewer emissions than an equivalent 2-stroke [1].

The engine also has a relatively high compression ratio of 12.4 to 1, meaning it can burn the high octane E85 fuel with greater efficiency than a lower compression engine could [1].

Overall, the snowmobile's considerable performance, combined with its dirt bike-inspired looks, makes it an appealing model for the majority of snowmobile riders. This model provided the UMaine team with a way to demonstrate a product that appeals to the environmental fan base while still retaining the "Coolness Factor" that inspirers snowmobile lovers and performance enthusiasts to visit the showrooms.

DESIGN

This section provides details the steps taken in the design and build process.

Figure 2. The Phazer in the middle of the design process.

ENVIRONMENTAL MODIFICATIONS - In order to cut down on emissions, the team needed a way to adjust the snowmobile's engine parameters for economy. In addition, the engine control unit needed to be flexible enough in its adjustment range to allow for the use of E85 fuel. Since ethanol is corrosive to many rubber and aluminum parts, the fuel system had to be analyzed and components replaced as necessary.

The MegaSquirt Programmable ECU - To achieve the goal of running the Phazer on E85 and future ethanol fuel mixes, a software platform with many user-selectable parameters was required. The team determined that the MegaSquirt engine control unit by Bowling and Grippo was a suitable platform.

Other controllers were considered, but they were simple plug and play models that offered less in the way of engineering challenges and customization. In addition to being able to interface with the majority of existing hardware on the Phazer, MegaSquirt has tunable volumetric, air-fuel, and spark advance tables. Its code is open source, meaning the only thing needed to access the controller's programming is a PC. When compared to other solutions on the market, this means that the MegaSquirt has a broader range of adaptability to specific applications. Also, the fact that MegaSquirt has a large fan base and plenty of online forum support was a factor in its selection.

MegaSquirt is controller that anyone can build from inexpensive, readily available parts. However, the team chose to purchase the unit preassembled, since it was inexpensive and would likely be more reliable this way. The tuning and data logging software, MegaTune, is available by free download from the MegaSquirt website.

The MegaSquirt connected to most of the hardware already present on the Phazer through the included DB37 wiring harness, a diagram of which is included in the appendix. However, a flex-fuel sensor had to be added to the sled's fuel system to make use of the controller's flex-fuel capabilities. To this end, some circuitry had to be added to controller itself.

Figure 3. MegaSquirt ECU

Trigger Wheel - A stock Yamaha Phazer ECU computes engine RPMs off of a crankshaft position signal from the A/C magneto. This technology is not compatible with the MegaSquirt due to the electrical noise caused by electricity generation and trigger tooth spacing. The team's solution was to install a crankshaft position sensor (variable reluctance sensor) and 36-1 trigger wheel to generate an accurate crankshaft position signal. The trigger wheel was mounted to the crankshaft instead of the clutch, because the Phazer has approximately a 3:2 reduction gear after the crankshaft. The sled needs this reduction due to the high speed that the engine operates at (up to 11500 rpm).

Although necessary for the sled's drivetrain, the gearing makes obtaining accurate signals from the clutch side of the motor difficult.

The Phazer had a preexisting hole in the crankcase cover on the A/C magneto side of the engine. This provided a suitable mounting location for a shaft, which would transfer crankshaft rotation outside of the crankcase. A company which fits superchargers to the Phazer offers an extension kit that can be mounted without having to modify the crankcase cover. This kit was chosen because it also includes a fitting to mount an oil seal where a plug used to be.

One of the design goals for the trigger wheel's hub was to keep it as close to the crankcase as possible, thus ensuring clearance between the frame and oil reservoir. Weight was an additional concern, because rotational mass on the crankshaft takes power away from propelling the sled. The hub also needed to be well balanced so as to prevent destructive engine vibrations. To fine tune the ignition timing, notches were incorporated into the hub face. After selecting an optimal position, the wheel was welded to the hub to minimize play between the two components. Nylon locking bolts were used to fasten the trigger wheel to the hub and provide an extra safety margin.

Figure 4. Trigger wheel

Bracket - Once the trigger wheel was in its final position, a bracket was designed to locate the crank position sensor above and perpendicular to a tangent to the wheel.

The sensor was spaced 0.030 inches from the wheel, because this is a good gap for both sensor strength and reliability. The RPM signal strength improves with decreasing sensor to wheel gap, but a gap that is too small could result in the trigger wheel striking the sensor if there was any non-uniformity in the sensor or wheel face. The sensor was connected to the MegaSquirt with the DB37 wiring harness.

Ford EDIS - MegaSquirt was designed to control ignition via an electronic distributor, but the Phazer's ignition system uses a coil-on-plug system, where each of the snowmobile's two cylinders has its own ignition coil. Since MegaSquirt only has one ignition output, a system was needed to adapt the coil-on-plug system to operate with the controller's single ignition signal. The Ford Electronic Distributorless Ignition System (EDIS) was chosen for this task, because it only requires a crankshaft position sensor to operate. Other solutions required a camshaft position sensor, and thus extensive modification to the Phazer's engine.

The EDIS receives the sinusoidal signal from the crankshaft position sensor on the trigger wheel. A missing tooth on the wheel creates a gap in the signal, which allows the system to locate engine position. The trigger wheel was timed so that the missing tooth is nine teeth ahead of the crankshaft position sensor, as per information about EDIS on the MegaSquirt website. This configuration aligns the gap in the sensor signal to the time when piston number one is ninety degrees before top dead center. The EDIS interprets this calibrated signal and sends a twelve volt square wave Profile Ignition Pick-up (PIP) signal to MegaSquirt, which the controller uses to calculate engine RPMs and ignition timing.

The EDIS then receives a Spark Angle Word (SAW) signal from the MegaSquirt. It uses this signal to control the firing of the coils. Since the EDIS came from a four cylinder engine, some modifications were necessary to ensure proper operation. The team connected the two signal wires (intended by Ford to alternate the ignition between a pair of cylinders via a 2 x 2 coil pack) to the Phazer's two individual coils (one wire per coil). This configuration means that the 4-cylinder EDIS sends out two sparks to each coil for every 720 degrees of crankshaft rotation. One spark is for actual ignition and one spark is wasted. For each cylinder, the waste spark occurs when the piston is at top dead center in-between exhaust and intake stroke. The EDIS was connected to the MegaSquirt with the DB37 wiring harness.

Gages - The Phazer came with a fully electronic gauge package. This compact display of important parameters, such as fuel, speed, and RPM, was tied in with the factory ECU and was difficult to modify. MegaTune can display many operational parameters in the form of gages, and up to eight gages can be viewed at one time. So, instead of finding physical gages for things such as the tachometer, speedometer, coolant temperature, and oil pressure, the decision was made to add an onboard Windows computer and LCD screen to the Phazer. This solution saved the team the trouble of trying to fit a large cluster of gages in the small space below the Phazer's handlebars.

The computer, a Hercules EBX, runs MegaTune in real time as the sled runs, displaying the results on the VarTech 8.4 inch outdoor LCD screen.

Since the MegaSquirt supports flex fuel monitoring, a percent gage should also be available for incorporation into the digital display as well.

Tuning - Engineering is about optimization. It can be optimization of a system, a process, or a design. For example, an internal combustion can be modeled well via the use of computers, however not everything can be accounted for accurately. This is why testing of the system is done to further optimize desired results. For the UMaine team, Emissions and performance are the results of interest, so a dynamometer and five gas analyzer are the tools central to the tuning process.

Once hardware modifications were complete, the team began tuning the MegaSquirt to minimize harmful emissions under all operating conditions. This was done by monitoring emissions with a five gas analyzer and air fuel ratios from the oxygen sensor. UMaine's five gas analyzer can display real time data in addition to recording data, making the comparison of results easy.

UMaine's tuning strategy is to treat the process like a controlled lab experiment. One parameter, for example the air-fuel ratio, will be adjusted while other user-selectable parameters like timing are held constant. An analysis of the emissions results then leads to conclusions about the air-fuel ratio; specifically, what kind of changes to the air-fuel ratio cause negative or positive emissions changes.

Tuning began with the volumetric efficiency tables. With the engine running, MegaTune analyzed the oxygen sensor input to determine the composition of the exhaust gas. If there was a lack of oxygen in the exhaust, the engine was running rich. Conversely, if there was excess oxygen in the exhaust, the engine was running lean. By monitoring the oxygen sensor and applying different amounts of load, the team was able to optimize the engine's operation with ideal air-fuel ratios for different RPM and loading situations. More extensive tuning will follow.

<u>E85 fuel system</u> - From a durability standpoint, the use of E85 in an engine poses some problems. The ethanol in E85 is an electrical conductor, whereas gasoline is an insulator. Thus, using E85 fuel can lead to galvanic corrosion of fuel system parts. Ethanol also absorbs water. If enough water is present in the fuel, many materials in the fuel system will corrode. In order to ensure compatibility with E85, all metallic fuel system components must be anodized aluminum, stainless steel, or nickel-plated. Standard grades of steel, aluminum, brass, and zinc will not last, and the corrosion of these materials may lead to engine damage. Because ethanol affects various rubbers differently, fuel system parts such as hoses and O-rings must be certified for use with E85 or tested for compatibility via immersion [5].

Many vehicle manufacturers have modified the designs of their products to be ethanol compatible since the introduction of gasohol fuel, which contains ten percent ethanol and ninety percent gasoline. However, snowmobiles are not a mainstream form of transportation, and the UMaine team found that many of the Phazer's components needed to be replaced.

Fuel Pump - The stock Yamaha fuel pump was located inside the fuel tank. Its internals were contained inside a plastic shell, which had a mesh fuel filter attached to the underside. No data was available on the pump's resistance to ethanol, so the team replaced it with an inline EFI pump from Edelbrock. This pump, model # 3594, was certified by Edelbrock as being compatible with methanol and ethanol.

The fuel flow rate to the engine also had to be calculated, because E85 contains less energy per unit volume than gasoline. After determining the energy density of E85, an energy balance calculation was performed using a target engine power output of 80 hp (59.7 kW) and an estimation of engine efficiency of 25%. It was found that the new fuel pump needed to deliver 60.3 liters of fuel per hour. Since the Edelbrock pump is rated at 215 liters per hour, it is more than capable of meeting the Phazer's needs. The fuel flow calculation is included in the appendix.

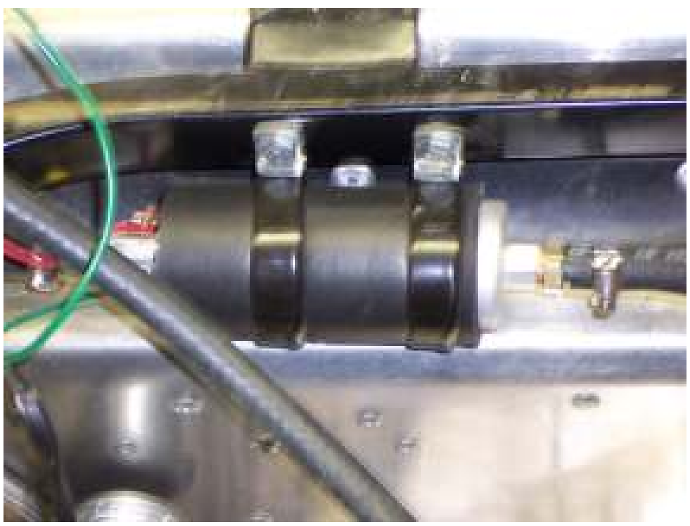

Figure 5. Edelbrock Fuel Pump

Fuel Pressure Regulator - The team decided to raise the fuel system pressure to 62 psi (up from 40 psi) in order to maximize fuel flow through the stock injectors. The stock fuel pressure regulator was not capable of this change in pressure, and no documentation existed regarding the regulator's compatibility with ethanol. Therefore, the team replaced it with an ethanol certified adjustable regulator from Edelbrock, model # 1728. When combined with an inline fuel pressure transducer from Cyberdyne, this regulator allowed for the easy adjustment of fuel system pressure with the turn of a wrench. Further fine tuning of the fuel system pressure may occur once the snowmobile is operational.

Figure 6. Edelbrock Fuel Regulator

Fuel Filter - The requirements for the fuel filter were that it be able to support a system flow rate of at least 215 liters per hour at 65 psi while being ethanol compatible. The JEGS model 15040 inline filter met all requirements and was installed.

Fuel Lines - The fuel pump, regulator, and filter required 3/8 inch fuel hose. Hypalon EFI hose from Goodyear was selected because it can handle pressures well above the Phazer's 62 psi. The Hypalon material also has excellent permeation resistance against ethanol [7].

Compatibility Tests - In order to verify compatibility with E85, any components that are made of an unidentifiable material must be tested in ethanol. Figure 7 shows an immersion test of the plastic fuel rail and an accompanying O-ring in denatured alcohol (90% ethanol, 10% methanol). In the test, the parts were submerged for three days. No noticeable swelling of the O-ring or softening of the fuel rail occurred. Since most materials that are affected by ethanol show signs of swelling or softening after a day of immersion, it was determined that the O-ring and fuel rail were ethanol compatible.

Figure 7. Ethanol Compatibility Test

Fuel Rail Modifications - The new fuel pressure regulator from Edelbrock was designed to be placed in the fuel path before the fuel rail. This arrangement means that excess fuel bypasses the fuel rail and flows from the regulator back to the tank. However, the stock fuel pressure regulator bolted to the end of the fuel rail. Excess fuel flowed through the rail, through the regulator, and back to the tank. Once the old regulator was removed and the new one installed, the open end of the stock fuel rail needed to be plugged.

This was accomplished by machining a plug out of stainless steel, shown in figure 8. This plug uses the stock Yamaha O-ring from the old pressure regulator attachment to create a seal inside the fuel rail. Fuel system schematics are included in the appendix.

Figure 8. Plug for fuel rail

Flex-Fuel - Many new cars and trucks that are sold today are advertised as being “flex-fuel” vehicles. These vehicles can run on any mixture of E85 and gasoline. This works because a sensor in the fuel system tells the ECU the percentage of ethanol in the fuel. The ECU then uses this signal to adjust the timing and other parameters to yield efficient combustion of the particular fuel mix.

The ability to operate a vehicle on any mixture of gas and ethanol is appealing to consumers. For example, if a snowmobile rider’s fuel tank is half-full of E85, but they happen to be at a location that only sells gasoline, it is not a problem to fill the tank the rest of the way with gas. Since flex-fuel is as great marketing strategy (as well as a requirement of next year’s competition), the UMaine team obtained and installed a General Motors flex-fuel sensor, shown in figure 9.

Figure 9. General Motors Flex Fuel Sensor

Exhaust - A catalytic converter is a required piece of hardware for all of today’s cars. They are designed to reduce the emission levels of the three main toxic pollutants that internal combustion engines produce: carbon monoxide, hydrocarbons, and nitrogen oxides [1]. However, although the EPA requires catalytic converters on cars, there is no such regulation for snowmobiles.

Adding a catalytic converter is simply a matter of welding the unit into a vehicle’s exhaust path. This was one of the first things the UMaine team did. They have learned from past experience that catalytic converters on snowmobiles can reduce emissions considerably (hydrocarbon emissions on their 2003 Artic Cat 660 decreased from roughly 130 parts per million to 20). A wide-band oxygen sensor was also added in order to monitor air-fuel ratios and to ensure the proper engine conditions for optimal catalytic converter operation.

Figure 10. Catalytic Converter welded before muffler

NOISE MODIFICATIONS - Snowmobiles frequent areas of natural beauty, and often receive complaints from local inhabitants and park visitors for being loud. Noise can be considered pollution, so it makes sense to engineer a clean snowmobile to be quiet as well. Conversely, many potential snowmobile buyers are interested in the throaty roar that powerful sleds make during acceleration. This is mirrored in the automotive world, where companies develop tuned exhaust systems to bolster the exhaust notes of street vehicles. In order to satisfy both groups, the UMaine solution was to mute mechanical noise as much as possible while reducing but not eliminating the exhaust note.

Noise tests on the snowmobile are conducted via the procedure outlined by the SAE J192 specification. Here, the snowmobile is driven for 150 feet in a direction perpendicular to a sound meter located fifty feet away from the sled. To pass the test, the snowmobile's noise level must be lower than 78 dB at full throttle. In its stock configuration, a Yamaha Phazer produces 85 dB in this test.

Sound Dampening Material - Testing showed that the peak frequency of emitted noise was 1000 Hz. To quiet the snowmobile, thin mass-loaded sound dampening material was chosen because, according to manufacturer data [6], it performs the best at absorbing this frequency. The specific material that was ordered is called Vcomp. Made by B-Quiet, Vcomp consists of open cell foam bonded to dense vinyl. When sound energy passes through this material, it is attenuated by the material's structure [6].

Figure 11. Vcomp soundproofing material by B-Quiet

Cowling Pieces - The stock shroud of a Yamaha Phazer consists of eight small plastic panels. The team decided to replace these with three larger panels that could be sealed easier and lined with sound absorbing material.

By soundproofing the cowling, unwanted mechanical noise from the engine and clutch can be suppressed, resulting in an acoustic profile that comes mostly from the exhaust. For time and visual considerations, the new shroud was made by modifying the coverings of a Yamaha Venture Lite.

Exhaust - The original exhaust, while having a pleasing tone, was louder than necessary. As depicted in figure 12, the muffler was cut open and modified with fiberglass packing and additional muffling, all while keeping back pressure to a minimum. The exhaust outlet will be directed downwards and fed into the tunnel in order to reduce the amount of noise allowed into the environment and to provide an appropriate mounting location of the emissions testing equipment.

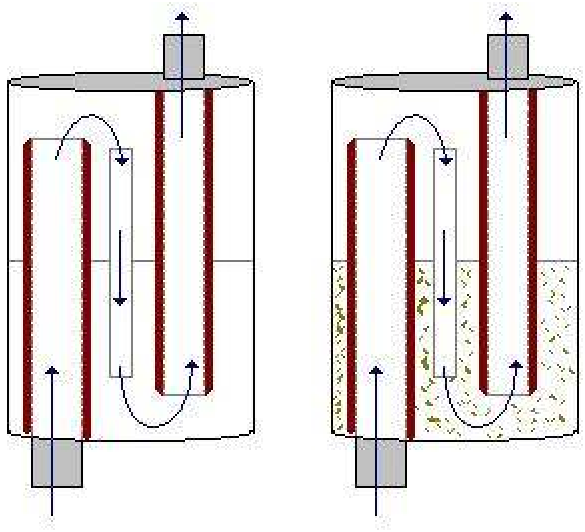

Figure 12. Muffler diagram, before and after packing

PERFORMANCE - The team plans to tune the snowmobile to make at least the same amount of horsepower as it did stock (80 hp) without sacrificing good emissions. In addition, the following problems were addressed.

Fuel Tank - It was expected that the Phazer's fuel economy would decrease by about thirty to forty percent while running on E85 because ethanol has roughly two-thirds the energy density as gasoline [1]. This means that the sled could expect to average around twelve miles per gallon instead of eighteen. With the stock eight gallon fuel tank, the machine's maximum range would be about ninety-six miles.

Many of the UMaine team members are snowmobile enthusiasts, and they all agree that maximum range is a huge concern for snowmobiles. Fueling stations are scarce when riding in the wilderness, and one of the worst things that can happen to a snowmobile rider is becoming stranded without any fuel.

With fuel capacity in mind, the team decided to make a new fuel tank out of composites. Their goal was to increase the tank's volume by at least two gallons while maintaining the Phazer's sleek, aggressive looks. The two gallon increase will extend the snowmobile's range to 120 miles, which is enough to complete the CSC's endurance run.

The team started by making a plug out of body filler, foam, and a spare eight gallon Phazer tank. Chunks of foam were added to the tank to take up approximately two gallons worth of volume. Then, body filler was applied to fill in the gaps and create a pleasing, contoured look. The plug was sanded smooth, painted, and waxed, so that a mold could be lifted from it without sticking.

Figure 13. Stock tank with added foam

Figure 14. Final plug (unfinished surface)

Once the plug was finished, it was sprayed with PVA release agent and laid up with fiberglass. A fiberglass mold was made from it in two halves.

The first layer of fiberglass was very thin and fine woven, so it followed the contours of the plug and made for a smooth inner mold surface. The outer layers were composed of thicker boat glass.

Figure 15. Finished plug with mold halves

The two tank halves were then laid up inside the mold halves and vacuum bagged to withdraw excess resin and reduce weight. The tank halves were made mostly of fiberglass to maintain a reasonable MSRP. The top half of the tank was covered in visible areas with carbon fiber, which will look attractive when finished. The fiberglass parts of the finished tank will be covered with a thin layer of body filler and then sprayed to match the sled with Yamaha Blue paint.

Figure 16. Lower mold half, laid up with fiber

The tank halves are currently in the process of being plumbed and combined for the fuel system. All fittings are either anodized aluminum, stainless steel, or nickel-plated. Since ethanol is harmful to standard epoxies, like the West System epoxy used to make the tank, the inside of the tank will be coated by an ethanol-proof Novolac epoxy resin.

Figure 17. Final tank, in two halves

Figure 18. Tank Size Comparison

Battery - The stock Yamaha battery only provided 200 cold cranking amps and twelve amp-hours of capacity. This was fine for the engine running off of gasoline, but because ethanol-based fuels have a lower vapor pressure, cold starting the engine with E85 will take more cranking of the starter. To compensate, a larger battery with 350 cold cranking amps and twenty-one amp-hours of capacity was purchased. This was the most powerful battery available locally that had the same slim profile as the stock battery. This profile will allow the new cowling to stay as close to the sled as possible, thus preserving the Phazer's profile. The new battery is a sealed AGM type, meaning no battery acid can escape.

OTHER MODIFICATIONS - The following modifications were performed to ensure the Phazer's design follows the rules of the competition.

Cooling System Modifications - In the 2008 CSC rules, section 9.6.2.4 states that "Liquid-cooled sleds are to be configured with cooling systems supply and return lines for connection to the external system."

The Phazer's cooling system was configured to comply with this rule. After testing, it was determined that the specified connectors to be used caused a build-up of backpressure in the cooling system under normal operating conditions. This caused the cooling system's cap to pop, spilling coolant on to the ground. This could result in engine damage if excessive overheating were to occur.

In order to fix this problem, a system was designed to bypass the connectors and reduce backpressure in the cooling system under normal operation. Using a parallel, unobstructed line as a bypass, a system of two ball valves was introduced to control the coolant path. For normal operation, one valve is shut, blocking flow through the connectors. The other valve, being open, allows flow without obstruction. During the Emissions Event, the bypass valve will be closed and the other valve opened to allow flow through the connectors to and from the external engine cooling system.

Clutch Cover - The team constructed a clutch cover out of .090 inch aluminum as specified in the CSC rules. Although Kevlar was first used as reinforcement, the team added Nylon after learning that Kevlar was no longer allowed. Sound proofing material will be added to the inside of the clutch cover to reduce clutch noise.

Figure 19. Clutch Cover

Battery Box - A sealed and vented battery box was created by modifying a plastic battery box. The plastic box was cut down in order to better fit the aftermarket battery and reinforced with fiberglass.

Brake Rotor Cover - As per the CSC 2008 rules, the team constructed a brake rotor cover to shield the rider and bystanders from an accidental explosion of the rotor. A kinetic energy ballistics analysis was performed, in which the brake rotor's maximum energy was found and compared to experimental results for projectile penetration of thin aluminum plates [3].

This method showed that a brake rotor shield made from .190 inch thick 6061T6 aluminum should be sufficient to contain the shrapnel from catastrophic rotor failure. Figure 20 is a picture of the brake rotor cover with integrated battery shelf, attached to the sled by aluminum standoffs. The circular cutout in the center was CNC machined to allow access to the dip stick. See the appendix for the experimental results used in the cover design [3].

Figure 20. Brake rotor cover/battery shelf

RESULTS

The team does not have final results for inclusion in this paper because the Phazer hasn't been completed. The team expects to have the snowmobile running on E85 within the week and plans to complete the 5-gas emissions tests, a dynamometer test, and an acoustic analysis. If everything goes as planned, the results from the testing will be written up in a supplementary report and made available for review during competition.

As indicated by figures 25 and 26 in the appendix, the team was successful in reducing the emissions of the Phazer. These figures show initial emissions data of the Phazer running on gasoline at idle. Data was taken from cold start of the snowmobile up to steady state conditions. The baseline Phazer had hydrocarbon emissions of 318.1 parts per million (PPM). After preliminary tuning, the modified Phazer had hydrocarbon emissions of 340.4 PPM. In order to reduce this, further tuning will be performed using the oxygen sensor to get the air-fuel ratio as close to 14.7:1.

Both carbon monoxide and nitrogen oxides were reduced. The testing showed that the levels of carbon monoxide in the exhaust gas was reduced from 2.469 % to 0.5517 %. Nitrogen oxides were reduced from 108.4 PPM to 78.87 PPM.

These preliminary results indicate that the modifications made to the snowmobile will aid in reducing harmful emission. Further testing and tuning with the help of the five gas analyzer will improve emissions and performance.

CONCLUSION

Although the UMaine team is still working to finish their snowmobile, they are confident that their design will be successful in reducing emissions and noise while maintaining the Phazer's performance and attractiveness to buyers. Many of the modifications, such as the sound dampening material and catalytic converter, have proven themselves in the past on the team's previous clean snowmobiles. Once finished, the Phazer should be the ideal machine for snowmobile riders looking for a quiet machine that is both environmentally friendly and exciting.

ACKNOWLEDGMENTS

The University of Maine's clean snowmobile project would not be possible without outside support. We would like to thank our local Yamaha dealer, Friend & Friend of Orono, ME, for lending their support to our project. Thanks also goes to Dutch Chevrolet of Belfast, ME, for helping us reasonably obtain a flex-fuel sensor.

A special thanks goes out to Professor Michael Peterson of the mechanical engineering department, who has been our dedicated faculty advisor, and Professor Murray Callaway of the English department, who was instrumental in the planning and revision of this paper.

Above all, the team would especially like to thank Applied Thermal Sciences of Sanford, ME, for their continued involvement in the clean snowmobile project and their generous aid that went into purchasing the Phazer.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

AGM: Absorbed Glass Mat, a type of battery technology that seals the acid in the battery casing to prevent spills.

CSC: Clean Snowmobile Competition

ECU: Engine Control Unit

EDIS: Electronic Distributorless Ignition System

PVA: Polyvinyl Alcohol, a release agent that aids in composite work.

SAW: Spark Angle Word, a kind of signal used in some ignition systems.

APPENDIX

Fuel Flow Calculations - The following calculation was performed as a check to ensure that the ethanol compatible fuel pump could provide enough fuel flow during E85 operation. It should be noted that the pump will operate successfully on winter blend fuel used at the CSC, because winter blend has a higher energy density than E85, meaning less flow rate is required.

Ethanol Energy Density = 22 $^{MJ}/_{L}$

Gasoline Energy Density = 34.6 $^{MJ}/_{L}$

E85 composition = 85% ethanol and 15% gasoline by volume.

E85 Energy Density =

$$0.85\left(22\frac{MJ}{L}\right)+0.15\left(34.6\frac{MJ}{L}\right)=23.8\frac{MJ}{L}$$

Phazer Target Horsepower = 80 HP

$$80HP=0.06\frac{MJ}{Sec}=288\frac{MJ}{Hr}$$

Assuming a Conservative Engine Efficiency of 20%

$$\frac{288\frac{MJ}{Hr}}{.20}=23.89\frac{MJ}{L}\times FlowRate\frac{L}{Hr}$$

$$FlowRate=60.28\frac{L}{Hr}$$

$$PumpCapacity=215\frac{L}{Hr}$$

Demand on pump = 28% of full capacity.

FUEL SYSTEM SCHEMATICS -

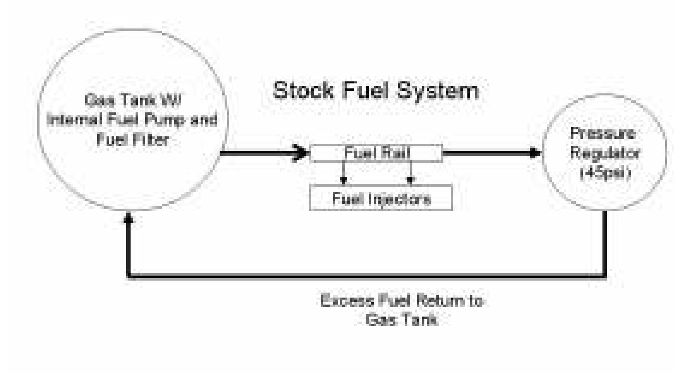

Figure 21. Stock Fuel System

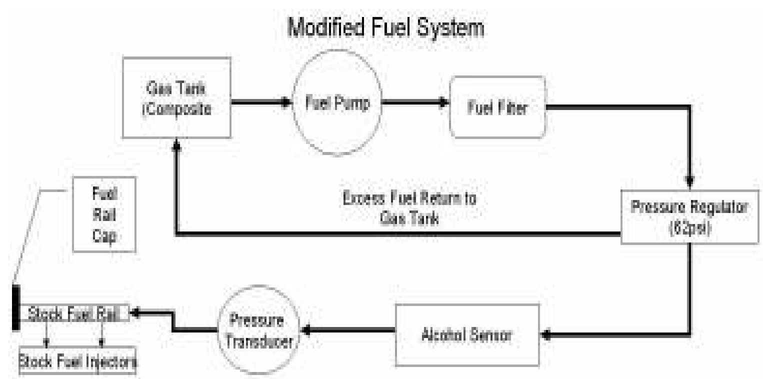

Figure 22. Modified Fuel System

EXPERIMENTAL RESULTS OF BALLISTIC ANALYSIS USED IN BRAKE ROTOR DESIGN [3] -

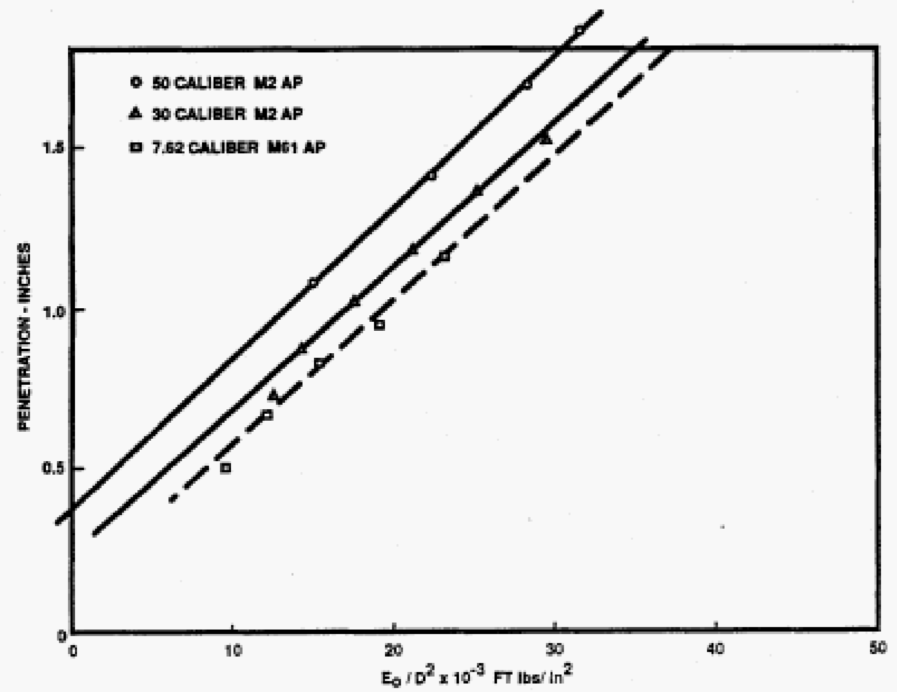

Figure 7. The Experimental Penetration Capability of Various Armor Piercing Bullets Against Aluminum 2024-T4 Armor Plate as a Function of the Areal Kinetic Energy of the Total Projectile

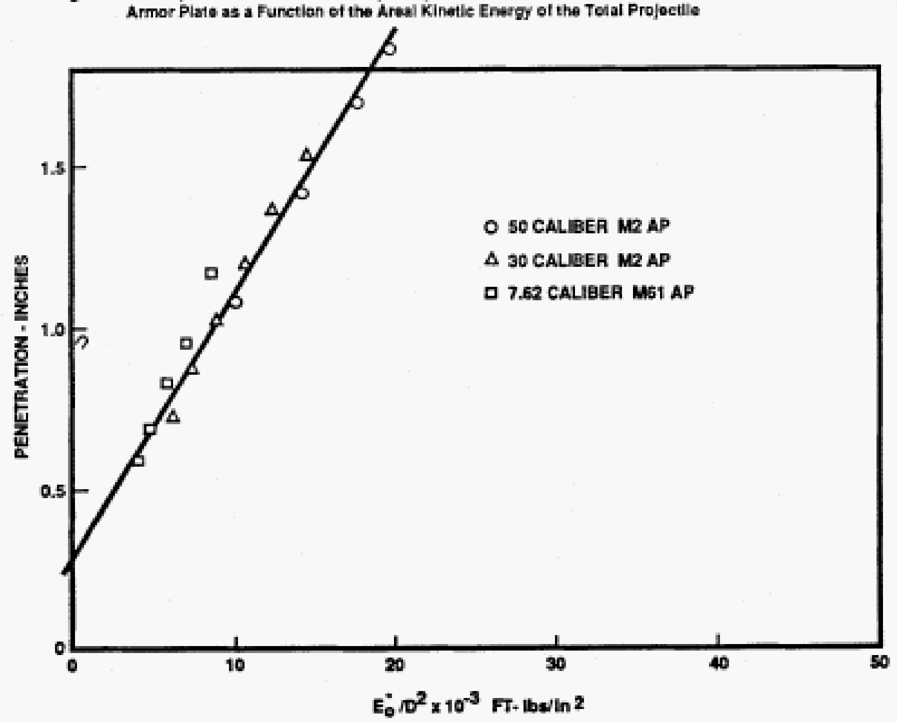

Figure 8. The Experimental Penetration Capability of Various Armor Piercing Bullets Against Aluminum Armor Plate as a Function of the Areal Kinetic Energy of Only the Hardened Projectile Core

Figure 23. Penetration depth of ballistics rounds into aluminum plates as a function of projectile kinetic energy and projectile diameter [3].

YAMAHA PHAZER WIRING DIAGRAM WITH MEGASQUIRT ECU -

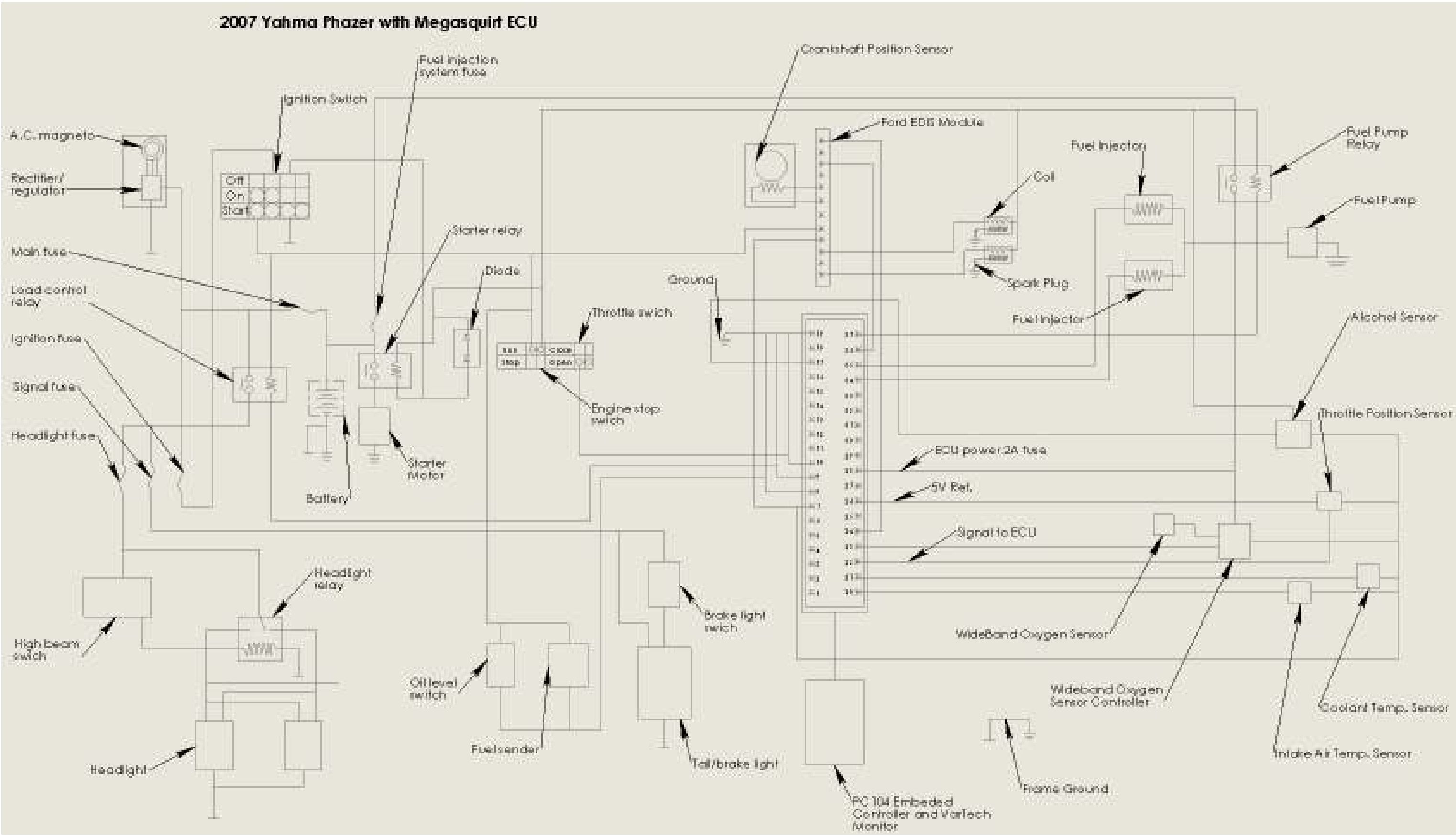

Figure 24. Wiring diagram with new hardware for use of MegaSquirt and modified wiring harness

EMISSIONS DATA -

Figure 25. Emissions of Stock 2007 Phazer

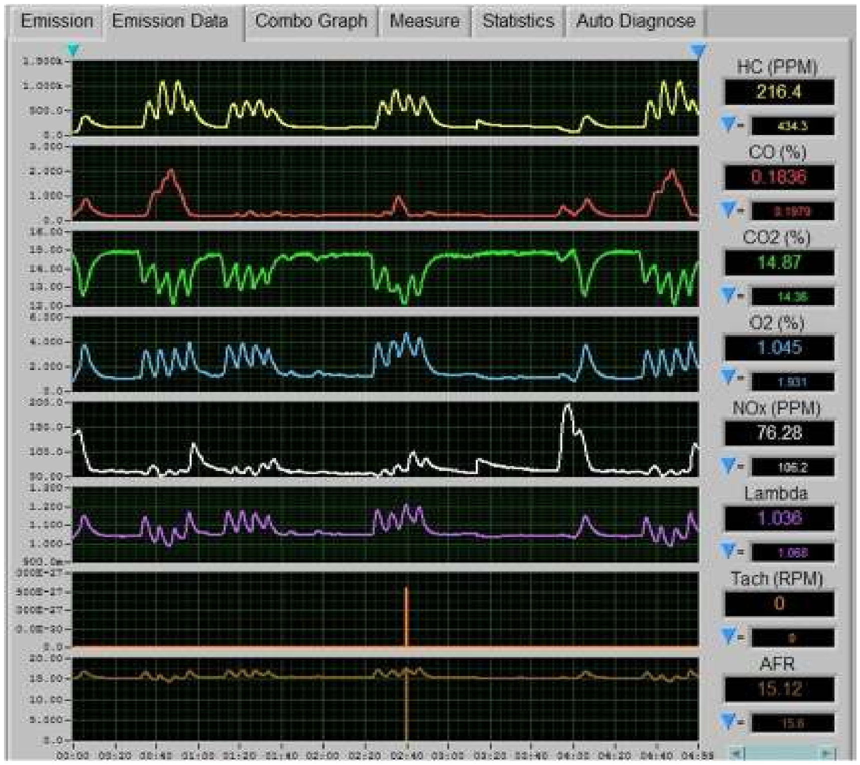

Figure 26. Emissions of UMaine Phazer running with MegaSquirt