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Re-Engineering a previously flex-fuel modified 2007 Yamaha Phazer to accommodate a turbocharging system, for the 2012 SAE Clean Snowmobile Challenge

Abstract

The 2012 University of Alaska Fairbanks Clean Snowmobile Team has entered in Society of Automotive Engineer's Clean Snowmobile Challenge with a 2007 Yamaha Phazer inherited from last years team. The snow machine will be modified to run on an ethanol blend ranging from E20 to E29. SAE will test the teams and their modified snow machines in 12 categories, including EPA 2012 emission standards, with the main goal to reduce the environmental impact in rural or sensitive environments.

Addition of a turbocharger to the Phazer will boost power while decreasing emissions. Straight from the factory, the four stroke Phazer makes around 80 horsepower. With a turbocharger we have the potential to reach the competition's maximum power limit of 130 horsepower. Once at the competition, the Phazer will have an advantage over other naturally aspirated machines in the fuel economy, acceleration, and emission events.

Previously, this particular Phazer snow machine had run on an ethanol fuel mixture at the 2011 CSC. This required fuel mapping adjustments via an aftermarket Power Commander computer control module. Once the turbocharger was installed, fuel mapping had to be readjusted for proper performance.

Installing our turbocharger was not easy, as it involved many modifications to systems like the exhaust and intake. Parts for adaptation were machined and additional parts like a second oil tank and pump were added. Positioning these in an already tight engine compartment proved to be a challenge. Time was extremely short before the competition, due to inherited equipment difficulties, and as a result our schedule was very packed in an attempt to make a competitive vehicle for this year's event.

Introduction

Snow machines are very popular for recreational activities as well as transportation in the far northern or southern parts of the globe. By reducing the damage on the planet and leaving a smaller carbon footprint; this should help people enjoy outdoor activities more, with less concern about environmental impact.

The University of Alaska Fairbanks is competing in the 2012 SAE Clean Snowmobile competition in both the internal combustion and zero emissions classes. This is the design paper for the snowmobile currently being built to compete in the internal combustion class. The snowmobile is a 2007 Yamaha Phazer Mountain Lite with a 499 cubic centimeter displacement four stroke motor. New in 2007, it was reasonably priced with a MSRP of $7,199. As of February 2012, the most current 2012 Yamaha Phazer base MSRP is $8,599. When purchasing a new machine it is common to spend $5,000 to $14,000. The Yamaha Phazer was a well priced, low power, efficient snowmobile with models aimed towards trail and mountain riders. Our machine came with a long track for good floatation in the deep snow and we switched it for a short track for better performance in the CSC. After this modification, it is very comparable to the Phazer FX model. To be competitive, we added a turbocharger to increase power and performance, while turning the machine in such a manner to attempt to decrease emissions.

The turbocharger acquired was not an easy bolt on performance specific kit. We have the snow machine and a garret GT12 turbocharger to adapt to it. Many aftermarket performance companies like BoonDocker Performance, Aerocharger LLC, and Push Turbo offer these complete kits in the 3000 to 5000 dollar range. These kits are for pure performance, not necessarily for less emissions. Our goal, however, was to decrease emissions while increasing power and performance. In conjunction with the fuel mapping components both new and previously installed on the snowmobile, our goal was to be able to tune for our ideal parameters with the performance brought about by the turbocharger to increase the efficiency of the vehicle.

Flexible Fuel Delivery System

There was a flexible fuel system installed on the snowmachine for last year’s CSC. This system included components that were put in place to analyze the fuel mixture for fuel to air ratio adjustment. For this our team left in place the existing Dynojet Power Commander III USB and a corresponding ignition module. The Power Commander module allows for the fuel injection to be adjusted as much as 100%. The ignition module allows for the adjustment of the engine timing to compensate for the difference in injection and fuel used.

The second system installed on the snowmachine, was the Dynojet Wideband Commander, used for measuring the ethanol content in the fuel being used at any particular time. This component does this via an oxygen sensor that was previously placed in the exhaust pipe. This component, after the turbocharger was installed, is now located after the turbocharger in the exhaust system.

The final piece of the fuel mapping system is a Boondocker EFI controller. It intercepts the signal sent to the fuel injectors and can adjust fuel injection up or down depending on RPM, load, and boost pressure.

The difference in energy densities between ethanol blends and pure gasoline requires a higher fuel delivery rate to compensate for the deficiency in energy per volume. As seen in figure 1, the energy density of the highest possible ethanol percentage is roughly 90% of pure gasoline. The maximum amount of additional work required should only be approximately 10% over stock requirements, so there was an assumption made that the stock fuel injectors could handle this relatively small requirement. After the addition of a turbocharger to the snowmachine, it was still assumed that the current fuel delivery system could be used with just the addition of the Boondocker EFI controller.

Fuel Type		Fuel Energy Densities	
		(Btu/gal)	
Ethanol		76,000	
Gasoline		115,000	
E20		107,200	
E21		106,810	
E22		106,420	

E23		106,030	
E24		105,640	
E25		105,250	
E26		104,860	
E27		104,470	
E28		104,080	
E29		103,690	

Figure 1. Calculated Fuel Energy Densities

Baseline, Stock Data

As a control, for the sake of tracking improvements and modifications made to the snowmobile, baseline data was measured.

Baseline Data				
RPMs	HC(ppm)	CO (%)	CO2 (%)	O2 (%)
5000	126	0.8	3.8	14.85
6000	51	1.05	3.9	14.95
7000	53	1.8	4.5	13.2
8000	75	2.7	7.9	8.5
12500	500	5.15	3.2	20

Figure 2. Baseline Emissions Testing

Scope of the Project

SAE publishes rules for each years competition. They specify what snow machines are eligible to be used, modifications that are allowed, modifications that are necessary to compete and how the snow machines will be judged.

The minimum performance expectations for a trail IC snowmobile are set by these rules as a sled that by design will go 100 miles without refueling and can attain a trail speed of 45 miles per hour on a smooth trail. Additionally, they should be able to traverse 500 feet in 12 seconds or less. Designs that do not have a reasonable expectation of achieving these requirements will be allowed to compete only on an "Exhibition" basis.[1]

Turbocharging the Yamaha Phazer was the main scope of the project. An issue that had to be mitigated was an overproduction of power. The specifications of this competition state that a machine may not use over 130 horsepower. By installing the turbo charger it might create too much horsepower for the snow machine to compete. Secondly, we can't afford to buy the turbo charger from Boondocker Performance because it will cost us around $4,500. It would be difficult to acquire that much funding, and the competition suggests that we come up with an innovative idea and discourages spending a lot of money. One event of the competition is based on MSRP of the machine. Spending $4,500 on a turbocharger would most definitely put the team at last place in the MSRP event. Instead we adapted the Garrett turbocharger to fit by ourselves with the help of Eric Johansen from the CEM machine shop.

Initial State of the Snowmobile

The snowmobile's condition when it was received by this year's team was non-operational. During the previous year's competitions and testing, the machine made attempts at utilizing external combustion principles on multiple occasions, causing damage to fragile electronic wiring and components inside of the engine compartment. As a result there was a need for a replacement wiring harness to be installed before any improvements or modifications could be completed on the vehicle. The logistics for locating the proper wiring harness proved to be difficult, as the only one that could be located was a used unit, and when it was finally received it

[1] SAE Collegiate Design Series: Clean Snowmobile Challenge: About Clean Snowmobile Challenge, http://students.sae.org/competitions/snowmobile/about.htm

was discovered to be a harness designed to work on a non-reverse model. The funds from the return were required to purchase another one on order through a factory dealer.

After the proper wiring harness had been located, and installed, three weeks before competition, there were still more error codes displayed on the on-board computer that had not been fixed by the replacement wiring. As a result of all the damage, the snowmobile had developed an issue within the drive/reverse system, and was being governed at approximately 1500-2000 rpm. This engine speed barely engaged the clutch system, and needed immediate correction. Research into this problem showed that other Phazer owners had similar problems, and had to modify a sensor location within the gearbox assembly.

After a tear-down of the drive system, and relocation of the sensor, the problem had not been fixed. Eventually, due to project time constraints, a bypass of the sensor and the reverse system was performed which allowed the snowmobile to become drivable, with only about two weeks until the snowmobile shipping date.

Turbocharger Feasibility

We utilized the feasibility study, from last year's UAF CSC team, for a turbocharger to be used in our particular application. In theory, a turbocharger can be used to increase efficiency, since it is a system which recycles heat, pressure, and non-combusted fuel. Honeywell, also know as Garrett turbochargers, has a program that allowed us to acquire a turbocharger unit at no cost, through a selection process performed by their company. Garrett offers two types of turbocharging compressor for our size of application, the GT12 and the GT15. The GT12 is a wastegated style, while the GT15 is a variable nozzle style. In figure 3 is the assumed and interpolated values used in interpolating the values in the compressor and turbine charts for the GT12 and GT15 models. When these values were analyzed, the GT12 was an obvious choice. Although there are many advantages that a variable nozzle would bring, the GT15 was seen to be too big for our application. The curve of our data sits too close to the surge line on the GT15 compressor map, and there would be too large a possibility of damage to the engine and components. Also, large amounts of power production is not our main goal, so the GT12, being the smaller and less powerful of the two models ended up being chosen. In figure 4, it is shown that the compressor increases the air intake, giving us a better fuel-air ratio, increasing the efficiency.

The decision was also made not to include an intercooler in the system. Given the frigid temperature at which the machine would operate, the assumption was made that an intercooler would only provide marginal improvement of results, and would increase the cost and complexity of the system.

	Actual	**Pressure**	**Discharge**	**Pressure**
	Airflow	Required	Pressure	Ratio
Target HP Gain	(lb/min)	(psia)	(P2c)	
20	2.42	13.07	15.07	1.1
30	3.64	16.34	18.34	1.34
40	4.85	18.68	20.68	1.51
50	6.06	20.43	22.43	1.64
60	7.37	21.79	23.79	1.74
80	9.69	26.15	28.15	2.05
100	12.12	29.71	21.71	2.31
120	14.54	32.68	34.68	2.53

Engine Displacement in^3
30.451
Estimated Volumetric Efficiency
0.95
Air Fuel Ratio A/F for E25
13.2186
Approximate BSFC lb/HP*hr
0.55
Approximate Intake Manifold Temp (F)

150
Compressor Inlet Pressure PSIA
13.7

Figure 3. Assumed and interpolated values used in calculations.

				Turbocharged	
	Naturally Aspirated			Airflow Rate	
RPM	Airflow Rate CFM		20hp	30hp	50hp
5000	41.85		46.035	56.079	63.1935
6000	50.22		55.242	67.2948	75.8322
7000	58.59		64.449	78.5106	88.4709
8000	66.96		73.656	89.7264	101.1096
9000	75.33		82.863	100.9422	113.7483
10000	83.71		92.081	112.1714	126.4021
11000	92.08		101.288	123.3872	139.0408
12000	100.45		110.495	134.603	151.6795

Figure 4. Calculated airflow rates in naturally aspirated, and turbocharged states, at differing levels of boost.

Project Feasibility

Addition of a turbocharger to a four stroke snow machine is very feasible. Doing such in three weeks will be tough, as many long hours will be spent working to machine parts, install the turbocharger and redesign the fuel mapping. With money from TAB grants and some out of our pockets, funding will not be an issue. Until this year there has been no indoor facility open to housing the snow machine, thus all work in previous years has been outdoors. With no facility to physically work on the snowmobile on campus, it was moved to a team members private garage. Work was done in the evenings and on the weekends when classes are not in session. This means that the machine shop is not available while we work on the snowmobile. Tools were limited and many work sessions were cut short due to inadequate materials and machinery.

Approaches

Turbocharging a snowmobile is a common engineering feat that many aftermarket snowmobile accessory companies have and are currently perfecting. Having never modified any engine with a turbocharger before, there will be unforeseen constraints and setbacks that the team will have to face. Once the turbocharger is added, the machine will need to have serious fuel mapping and sensor adjustments. The Dyno-jet Power Commander and Boondocker controller gives the ability to make these modifications with the option of returning all settings back to stock. Not only will programming fuel maps take trial and error, it will be very time consuming. The sooner the turbocharger is installed, the more time there will be before the competition to make adjustments on the machine.

The Phazer has all the plastic cowlings and covers currently removed, providing easy access to work on it. First, the exhaust will be cut, shortened, and modified to fit the turbocharger into it. This includes cutting and welding. Mounts and brackets will be fabricated to hold in place the exhaust pipe and turbocharger. Next, the air intake from the turbocharger to the engine will have to be designed and built. The stock intake and air box will not be used. Depending on the routing of the air intake and the temperature of the air, an inter-cooler may be necessary to provide cooling. Since the turbocharger is always spinning, it needs lubrication. A second oil reservoir and oil pump will be added to the machine. Once this is all installed and in working order, fuel mapping will be the main concern.

After completion of the turbocharger installation and fuel mapping, emissions tests can be done. Also, with the use of a Land and Sea dynamometer, the power curves will be known. The goal is to be 120 to 130 horsepower with cleaner emissions.

Resources

The resources for this project were limited. The University of Alaska Fairbanks does not have any shop facilities where the snow machine can be stored or worked on. The machine is not allowed in the Duckering engineering building because of fire and health hazards due to the gas tank and internal combustion engine. This poses a problem of where to build and test the machine. The machine was being built in a private garage off campus with personal tools and resources.

On the university campus, Eric Johansen in the CEM Machine shop provided helpful advice when building and fabricating parts.

Most snow machine shops in Fairbanks, AK have been very helpful when we have previously needed anything. Usually they offer discounted prices and good advice. Specifically Northern Power Sports has always proven to be a great partner with UAF CEM. In Anchorage, AK Snowmachine Salvage is a source of hard to find parts. Honeywell International Inc. donated the turbocharger for competition purposes.

Conclusions

The increase in performance and efficiency that a is brought by a turbocharger helps to achieve scope and goal of the competition. After implementing this new system, in addition to the components that allowed for flex fuel usage, what we have is a machine that now achieves performance, flexibility, and efficiency. With proper tuning, the potential of this machine in all these aspects has been increased beyond anything that it was ever initially designed to achieve. All this was done, while taking care to keep the design as simple and affordable as possible.

The use of turbocharging systems is something a lot of companies in industry are turning to. These systems are sought after because of their performance capabilities. If more research is done, with regards to the implementation of these systems in not just performance, but also efficiency, it could become an industry standard to use the turbochargers. Aesthetically, to a customer, the allure of owning a turbocharged system could help increase the popularity of more efficient machines being marketable to a wider audience of power-sports enthusiasts, perhaps helping to create a culture that may be more environmentally aware.

References

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- Re-Engineering a 2007 Yamaha Phazer for The Clean Snowmobile Challenge 2010, Northern Illinois University
- University of Maine Clean Snowmobile Challenge Design Report

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-Considerations and Modifications, for the 2011 SAE Clean Snowmobile Challenge, of a 2007 Yamaha Phazer, University of Alaska Fairbanks.

Acknowledgements

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Appendix

-Compression Charts used in the comparison of GT12 and GT15 compressors.