North Dakota State University
Diesel Powered Clean Snowmobile

Ross Larson, Justin Omdalen, Joe Borden, Justin Carlson

Abstract

To be competitive in this year's Clean Snowmobile Challenge the NDSU team will be utilizing a 2011 Polaris Pro-R chassis and a diesel engine. The engine that will be used is a 903cc Yanmar diesel engine. The engine is naturally aspirated, so in order to obtain more power the engine will have to be turbocharged. The addition of a turbocharger will also bring into account the addition of an intercooler to cool the air from the turbo going into the engine. Although this engine already meets Tier-4 emissions standards, the goal is to create an even cleaner engine. To do this, a diesel particulate filter (DPF) and a catalyst will be added to the exhaust system of the snowmobile. The addition of these elements will enable it to produce cleaner emissions while the addition of the turbocharger will make the snowmobile run more efficiently.

Modifications to the chassis and running gear will be very limited. The Pro-R chassis is already a very light weight design so there is no need to take measures to lighten the snowmobile. The suspension will not be redesigned but the steering system and upper chassis will need to be positioned higher to accommodate the larger motor. A very crucial redesign that will occur is the redesign of the clutching and gearing system. The clutch and gearing in the snowmobile were originally designed for a high rpm gas motor. A lower rpm diesel engine will need a new clutching and gearing ratio in order to run at its peak efficiency.

Introduction

In today's society pollution and efficiency have become a very prominent aspect of almost every application of engineering. Today's engineers are looking for more efficient and cleaner ways to solve problems that society is in desperate need of. A big division of engineering that is feverishly working to increase efficiency is the automotive field. With the cost of fuel increasing at a rapid rate and global warming being a high concern, consumers are looking to purchase the most fuel efficient and environmentally friendly vehicles possible. Therefore, engineers will need to continue to work at creating more efficient means of travel. The Clean Snowmobile Challenge held by the Society of Automotive Engineers is a contest to instill "energy awareness" into future engineers. The challenge is to design and build a snowmobile that is cleaner and more efficient than the snowmobiles on the market today. Each team will build a snowmobile that will go through a series of events which will test the efficiency, emission, handling, and acceleration of the vehicle. The winning snowmobile needs to perform well in all of these areas while also being an affordable option for consumers.

DESIGN

Engine Selection

The objective of the snowmobile design is to reduce the emissions while increasing the efficiency. It is also important to maintain the performance of the snowmobile to attract the consumers. In the automotive industry many different systems are being utilized to bring a more efficient, but yet high power output vehicle to the consumer. A system that has seen a lot more attention in the automotive industry is the diesel engine. Utilizing a diesel reduces emissions while maximizing performance, therefore, it was decided to implement a diesel engine into a snowmobile chassis. Diesel engines have a higher thermal efficiency due to their high compression ratio. A higher thermal efficiency translates to a more fuel efficient engine.

Diesel engines have a stigma that they are dirty burning engines. This is actually not the case. With the utilization of ultra low sulfur diesel fuel and particulate filters, diesel exhaust can be cleaned to meet the strictest of government standards. The design of the snowmobile exhaust system will be explained later on in the report.

The engine that was chosen for the snowmobile application was a 903 cc Yanmar diesel engine (3TNM72). This engine is rated at 23.6 HP and has a maximum torque of 40.9 ft-lbs. The engine can be seen in Figure 1. The reason this engine was chosen compared to other small diesel engines was that this engine was more compact in size yet produced the same amount of power. This engine stock also meets Tier-4 emissions standards which is the most up-to-date standard in the powersports industry. The engine is mechanically injected which makes fuel adjustments more difficult, but if set properly for the application will make the entire system much simpler. If the engine was left unmodified for the snowmobile application it would be a very efficient and clean engine, but it would lack the power needed to keep up with today's fuel injected two-stroke engines. Therefore, modifications will need to be made.

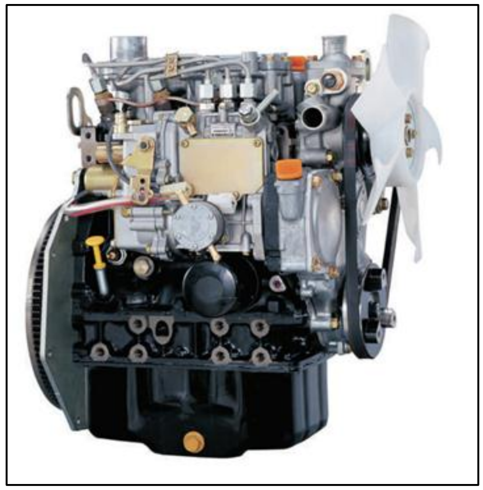

Figure 1 Courtesy of Yanmar

Engine Modifications

Like mentioned above, modifications were made to the Yanmar diesel engine to ensure that it has enough power to maintain the necessary speed for competition. To gain extra power the engine was turbo-charged (explained later in the Forced Induction section). The stock engine was not reliable under the extra pressure created by the turbo. The extra boost pressure created need for some engine modifications. The first modification that was made was a gapless ring system. The gapless ring system will eliminate blow-by and allow sufficient boost pressures to produce the power desired while maintaining reliability. A picture of a gapless ring system can be seen in Figure 2. Without a gapless ring the excessive boost pressure would blow by the piston and possibly blow oil out of our system.

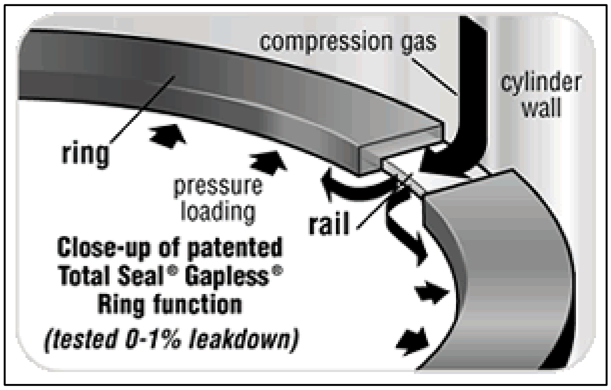

Figure 2 Courtesy of Total Seal

Another effect that the turbo has is that it forces more air into the cylinder creating a higher than normal pressure. This may create a phenomenon known as diesel knock. Diesel knock occurs when the air fuel mixture ignites while the piston is still moving upwards. This is very harmful to the engine. To combat this the compression ratio of the engine was lowered by milling the top of the pistons to create more volume when the piston is at the top of its stroke.

Having more air in the cylinders requires more fuel as well. The fuel injection system was modified to create the optimal air to fuel ratio. The injectors were bored out to allow 300% more fuel to flow into the cylinder. Having the correct air to fuel ratio will create the most power. The actual injection pump was not modified due to the fact that the amount of fuel supplied can be adjusted by the simple turn of a valve.

Drivetrain Modifications

With the implementation of a diesel engine into a snowmobile designed for a regular gas engine requires a lot of modifications to the drive train. The modifications that needed to be made included the drive shaft from the motor to primary clutch, the clutch weights, and the chain case.

A drive shaft to transfer power from a Yanmar diesel engine to a snowmobile primary clutch does not exist so one needed to be designed and fabricated. The shaft was made of stainless steel so it would be able to handle the large amount of torque applied to it. The FEA analysis of the shaft can be seen in Figure 3. It is expected that the engine will be outputting a minimum of 60 horsepower. Since diesel engines typically have a 2:1 ratio of torque to horsepower, it is expected a minimum of 120 foot pounds of torque will be subjected to the shaft. For extra assurance, 160 foot pounds of torque was applied to the shaft. After analysis was completed it can be seen that the shaft has a factor of safety of 1.36. Since the torque applied will be much less than supplied, the part should be more than adequate to sustain long periods of use. Also fatigue analysis was done on the part and was found since it had a high enough factor of safety, fatigue should not be an issue.

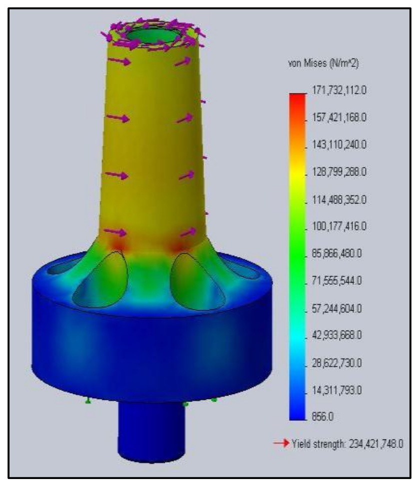

Figure 3 Drive Shaft FEA

A spacer was designed in order to mate the differing bolt holes of the flywheel and the output shaft. After analysis was completed with the same amount of force applied it was found that the factor of safety was 29.25. This is an extremely high factor of safety but since the part is so small weight is not an issue so the same type of material as the output shaft was made was applied to this part. Also with such a high factor of safety, fatigue will not be an issue. The figure can be seen in Figure 4 below.

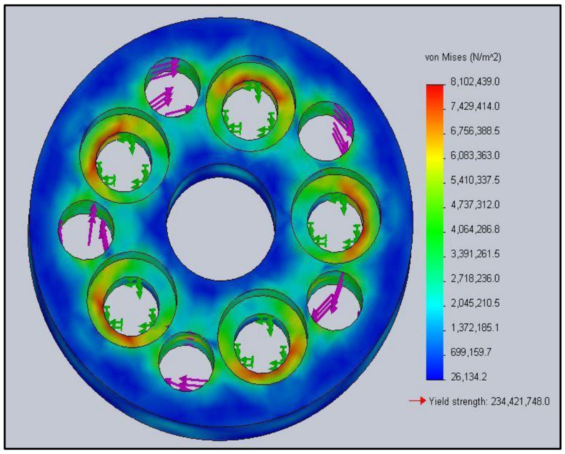

Figure 4 Spacer FEA

The clutch weights also need to be altered in order to accommodate the much lower RPM range of the diesel engine compared to the gas engine. Changing the weights combined with the changing of the gear ratio in the chain case optimized the power produced by the 900cc diesel engine.

Force Induction and Intercooler

Like mention before the choice was made to turbo-charge the Yanmar diesel engine. There are many advantages to turboing a diesel engine. Like mentioned before, an engine produces more power when it is turbo-charged. This is due to the fact that more air is forced into the cylinders before combustion. This fact is also the reason why turbos make engines more efficient. An IHI RHF3 turbocharger was selected for the Yanmar diesel engine. This turbo was chosen because the manufacturer states that this turbo is ideal for engines with a displacement of around 900cc. This turbo is also small enough that is was easy to fit in the Pro-R chassis. The turbocharger is lubricated straight from the engine's oil reservoir and a return line was drilled into the oil pan. The turbocharger does create a lot of friction heat, so it was placed near the front of the chassis where it will have the maximum air flow around it.

The ambient air that is sucked into the turbo is compressed before it is forced into the cylinders. As a result of the compression the air is heated. This compressed air now needs to be cooled before it enters the combustion chamber. The reason for the cooling is to increase the amount of power that can be extracted from the air. Cooler air is much denser than hot air, so colder the air is in the cylinders means more air molecules, and more air molecules means more power generated from combustion. The hot compressed air from the turbo will be run through an intercooler to reduce the temperature. The intercooler was place where the original headlight assembly once was. This position will allow for the most possible air flow which results in the most cooling power. Figure 5 below shows a schematic of the turbo and intercooler system.

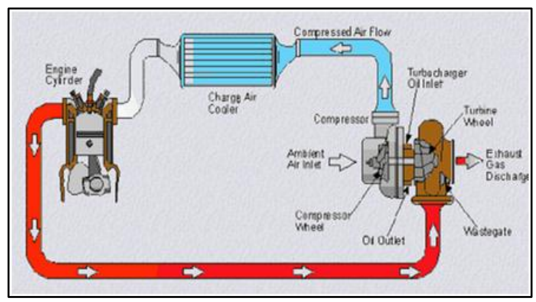

Figure 5 Photo Courtesy of How Stuff Works

Emissions

Emissions control is a very important part of this competition and also out in industry. The diesel engine used in this snowmobile application has the ability to run very clean. Many steps were taken to ensure that the diesel engine ran clean. The first step that was taken was to make sure that the right amount of fuel was being delivered to the system after the introduction of the turbocharger. It was important to make sure that all of the fuel in the combustion chamber was burnt and was not being expelled out through the exhaust system. The most important steps though included implementing a catalyst and a diesel particulate filter. During the combustion stage of a diesel engine many by-products are produced. The most harmful by-products include carbon monoxide, nitrous oxides, and diesel particulates. If untreated diesel exhaust is very harmful to one's health, but the implementation of a catalyst and diesel particulate filter greatly reduce the negative effects.

The catalytic converter that was utilized is almost identical to a converter that can be found on a diesel truck, just a lot smaller. The catalyst is a tube with a ceramic webbing inside that is coated with catalysts. The catalytic converter takes the harmful hydrocarbons, carbon monoxides, and nitrogen oxides and converts them into water, carbon, and dioxides.

The diesel particulate filter filters out all of the diesel particulates in the exhaust gas and burns them off. A partial diesel particulate filter was utilized due to the fact that partial diesel particulate filters can regenerate (burn off the particles) without the use of any additives. The partial filters use the heat generated from the engine along with the precious metals in the filter to burn the particles. A picture of a partial diesel particulate filter can be seen in figure 6

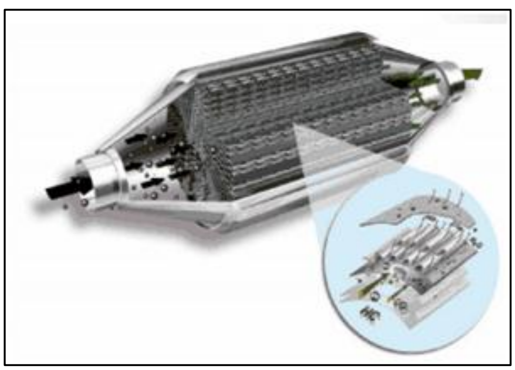

Figure 6 Photo Courtesy of Emitec

<u>Chassis Modification</u>

In order to implement the 904cc diesel engine into the Pro-R chassis a fair amount of modifications had to be made to the chassis. The modifications included engine mounts, upper chassis, and the steering system.

Engine Mounts

Engine mounts were designed to accommodate the new Yanmar engine. The design of the engine mounts utilized multiple parts and plates to help engine integrate easily into the existing chassis. The new Yanmar engine has much higher mounting points than the stock engine, so the original mounting points could not be used. A plate was attached to the chassis behind the engine to attach the mounts as opposed to welding the mounts to the intercooler behind the engine. The intercooler behind the engine is made of aluminum and may be difficult to weld to. The complete engine mount setup can be seen in Figure 7 below.

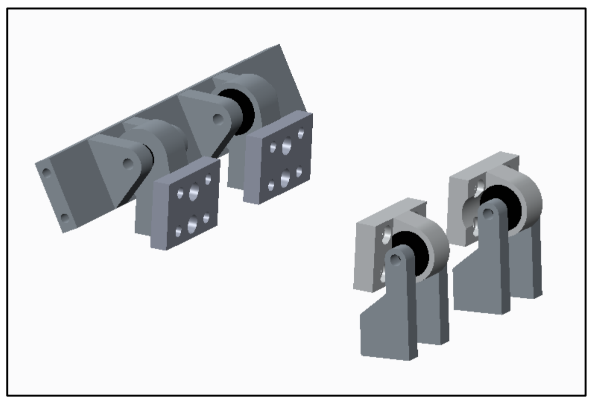

Figure 7 Motor Mounts

Analysis was done on the mounts to ensure that 6061 Aluminum would be a sufficient material to machine the mounts from. Figure 8 shows analysis of the bracket used to attach the engine mounts to the front and rear plates. As can be seen in Figure 9 the maximum von Mises stress in the part is considerably less than yield stress for the 321 Stainless Steel that was chosen. Even though the yield strength is much higher than the applied stress, the 321 Stainless Steel was still chosen due to the fact that a bolt will be riding in the hole in the part and the 321 Stainless Steel will resist wear better than an aluminum alloy.

The front and rear motor mounts were analyzed as well to ensure that a proper material would be used to machine them.

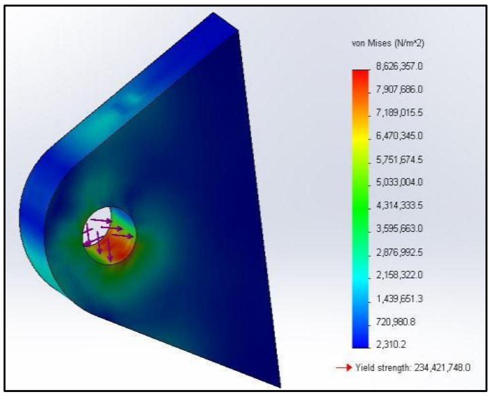

Figure 8

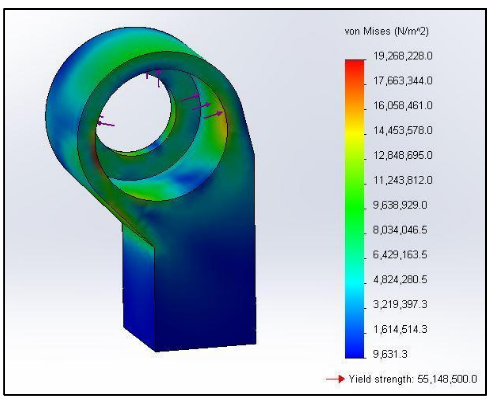

Figure 9

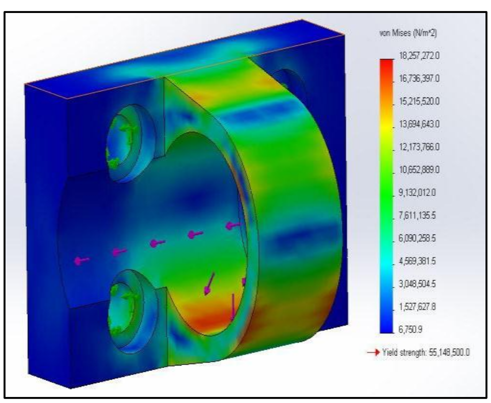

Figure 10

Upper Chassis Modification

The diesel engine's overall dimensions are much larger than the dimensions of the stock Pro-R engine. The main dimension that needed to be designed around was the height dimension. The Yanmar diesel engine's height was too tall so it would interfere with the upper chassis frame. It can be seen in the models below (Figure 11 and 12) that the upper frame was raised up three inches to accommodate the height of the engine. After analysis was completed on the upper bar it can be seen that the factor of safety is 1.46 after 500 lbs was applied to it. Since the snowmobile is projected to weigh approximately 550 lbs and no high impact jumping will be done to the chassis, it was determined that this member will suffice. Modification to the middle member also had to be done to accommodate the exhaust manifold. After analysis had been conducted it was found that it has a factor of safety of approximately 2 after 1500 lbs was applied in the axial direction. This part can be seen in figure 12. All parts are made of alloy steel with a yield strength of 620 MPa.

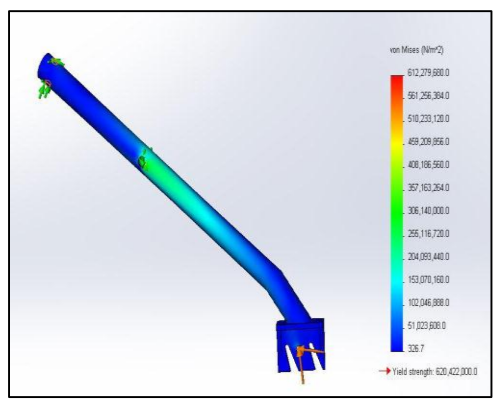

Figure 11

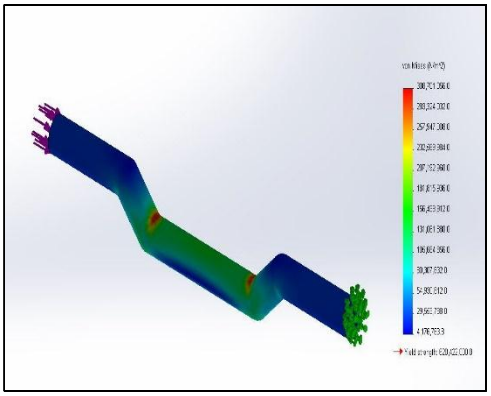

Figure 12

Steering Modification

The original steering setup utilized a push bar that traveled just over the top of the original motor. The stock position of the steering push bar was too low and created interference with the Yanmar diesel engine. To create clearance the entire steering system was raised up three inches. The handlebar assembly was raised three inches by utilizing an aluminum bracket that can be seen below in Figure 14.

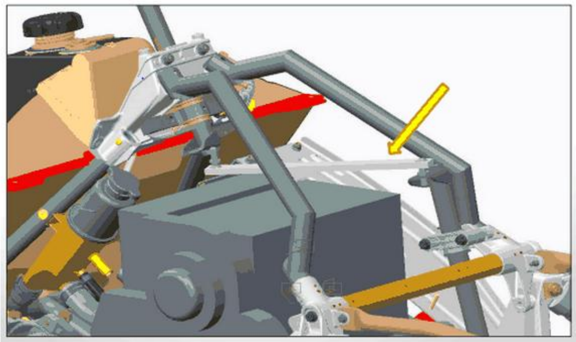

Figure 13

In order to maintain the same quality of handling the original geometry of the steering system had to be kept intact. Because the handlebar assembly was raised three inches the rest of the steering system needed to be raised the same height. It can be seen in Figure 13 that the steering post was extended three inches to maintain the steering geometry. By doing these two steps the clearance for the new motor was obtained while preserving the original steering geometry.

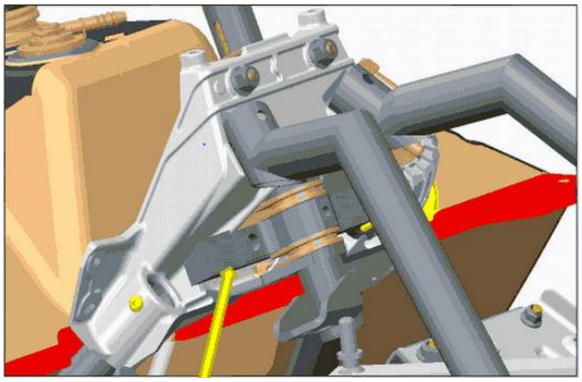

Figure 14

Electrical System

It was decided to entirely redo the electrical system. The stock wiring harness was removed along with the CPU and factory headlight assembly. This was done because nearly all systems are different with the diesel engine with the exception of basic items like the taillight and kill switch. This has proven to be a good decision as the system has been reliable thus far and is easy to troubleshoot as it was entirely designed by the team. Most of the system is made using fourteen gauge wire as its twenty amp capacity is more than sufficient for most systems. The glow plugs were supplied using ten gauge wire because of their high current requirement. Two relays were employed in the electrical system as well. One relay was used to provide power to the rest of the snowmobile from the main battery cable and was controlled by the handlebar mounted kill switch and the tether kill switch. This is required as the rules dictate the kill switches are required to stop power to all systems. The relay was used because it was determined that the kill switches were not able to withstand the high current needed. The second relay was used to provide power to the glow plugs and is controlled by a dash mounted push button switch.

Because of the switch to diesel power an electric start system had to be incorporated. The first battery chosen was lithium ion because it was extremely lightweight. Even though the battery met the specified cold cranking amperage it proved to be insufficient in the cold. The lithium ion battery was replaced with a lead acid which performed much better. The rules dictate a fuse be incorporated into the system before the power is distributed. The fuse is located inside the battery box. Power is distributed using barrier strips. Three barrier strips are located on the clutch cover providing power for the chassis and engine. Two more are located in the hood powering the gauges, GPS, headlight, ignition, and glow plug switch. A wiring diagram can be seen in Appendix 1.

CONCLUSION

All of the designs and modifications made to the snowmobile went through a design process. The process included a design review that comprised of the entire snowmobile design team. The design reviews would assure that the design in question would be suitable for the application. It is believed that the snowmobile is designed to perform well at competition

Appendix 1

Wiring Diagram