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Utilizing a Kubota Diesel Engine in a Utility Snowmobile Chassis

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Abstract

The University of Wisconsin-Platteville Clean Snowmobile Challenge (CSC) Team's objective was to build a low emission producing, quiet and efficient diesel-powered snowmobile to compete in the 2018 Society of Automotive Engineers (SAE) Clean Snowmobile Challenge. The Diesel Utility Class snowmobile is based on a 2016 Arctic Cat Bearcat 3000 LT utility platform. The UW-Platteville CSC snowmobile is powered by a turbo charged 898cc D902 Kubota diesel engine. Emissions are mitigated with a diesel oxidation catalyst in conjunction with a diesel particulate filter, both are manufactured by Blackthorn. This exhaust system reduces emissions with an emphasis on soot reduction. The particulate filter can be used effectively for up to 8 hours before a passive regeneration is required. Other technologies used to increase fuel economy are a lightweight belt drive system and large rear idler wheels. To reduce noise, an undercoating was applied to the tunnel and custom gearing/clutching was performed. A custom track and anti-stab kit were also implemented for sound reduction. These modifications, along with others, have facilitated the UW-Platteville CSC Team goal of creating a low emission, quiet and efficient diesel snowmobile.

Innovations

The most significant innovation of the UW-Platteville diesel class snowmobile is the exhaust system, which consists of a 26mm turbocharger, DOC and DPF. The DOC and DPF minimize emissions while the turbocharger adds useable horsepower. The overall combination enhances performance and minimizes air pollutants without sacrificing the agility of the Bearcat 3000.

Team Organization and Time Management

This past summer, the UW-Platteville shop was reorganized by faculty resulting in a smaller work space. Coincidentally, shop hours were reduced, and several frequently used manufacturing tools were discarded. This created a greater challenge to the team to design and build in a timely manner. Organization and time management were vital for the team's progress with these new obstacles. With less space, it was important for everyone to keep up to date and understand the work in progress to optimize useable workspace. A project management spreadsheet was created and shared with the team members allowing members to stay up to date on current projects. A continuously updated list of projects with individual responsibilities, tasks, and needed parts/tools were contained in the spreadsheet. A large whiteboard in the work area was also used for brainstorming, expressing ideas, and tracking progress.

Design

Chassis

The Arctic Cat Bearcat 3000 LT chassis was selected for its durability, practicality, and ergonomic features. The Bearcat 3000 LT is a mid-size utility chassis that offers the rider comfort and enjoyment. The Bearcat LT puts the operator in an upright forward position on the sled, but also allows the rider to sit back in a relaxed comfort-oriented position while maintaining full control over the sled. The chassis also features Arctic Cat's slide-action rear suspension system that is proven to decrease rider fatigue by reducing the effect of whoop-de-dos on the trail surfaces by allowing the front of the skid to better bridge gaps between bumps [1]. This, paired with the custom track from Camso, improves traction of the snowmobile by keeping the track in contact with and adhered to the operating surface. The Bearcat 3000 LT also utilizes a 15-inch-wide track, while other utility snowmobiles feature a 20-inch-wide track. The shorter width track improves efficiency by having less rotating mass to keep in motion. The Bearcat LT also has a cargo area on the rear of the snowmobile that can hold 55 lbs making it a convenient location for the large DPF.

Engine

The Kubota D902 diesel engine was chosen for its proven durability, low emission output and compact size. The D902 is a small displacement, naturally aspirated diesel engine. An increase in horse power was added to the engine with the addition of a 26mm turbocharger. The turbocharger uses exhaust gases to compress the air that enters the engine. When implementing the turbocharger, a design consideration taken into account was the size of the compressor and turbine wheel. The 26mm turbocharger was chosen for its rapid response as compared to a turbocharger of larger diameter. The smaller turbocharger decreases the boost lag and provides more operating efficiency. The selection of boost pressure was also an important design consideration. Dyno and emissions data determined that 10 psi of boost best met the design goals of the competition.

Engine speed was another deciding factor in engine selection. With the factory engine speeds set at 3600 rpm, it was decided that an increase of 200 rpm would give a larger window to tune the continuously variable transmission for proper speed and efficiency, while also accounting for boost pressure.

Another element that makes the D902 engine a suitable choice is the Kubota E-TVCS (Three Combustion System). This technology facilitates reduced exhaust emissions, engine noise, and increased performance. The system uses an optimum stoichiometric ratio by creating three vortexes inside of the spherical-combustion chamber

(Swirl Chamber) as shown in *Figure 1*. With a redefined concave recessed piston, it forces compressed air into the swirl chamber, achieving an ideal air/fuel mixture and smooth combustion gas exhaust. Throttle nozzle injectors are utilized to control the injection quality at the start of combustion, helping to reduce the known diesel knocking noise which is a result of excessive fuel injection. The half floating valve cover design helps to isolate engine vibrations and reduce the noises that resonate in the crankcase. It is also improved by using rubber ring seals incorporated into the engine valve cover.

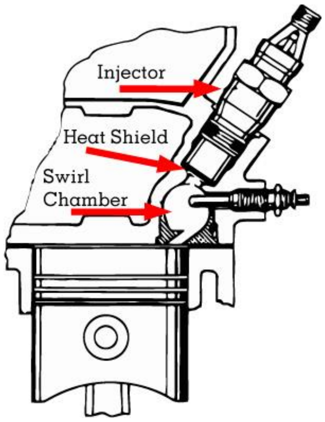

Figure 1, Swirl Chamber [2]

The D902 is versatile for many applications due to its dimensional size and weight. The difference in motor weight between the OEM Bearcat engine and the D902 is a mere 43lbs. The weight increase of the snowmobile associated with the D902 is significantly less than the typical small diesel engine that could be implemented. Weight is a concern when choosing engines because of fuel efficiency, stability, and ride quality.

With the addition of the turbo, it was necessary to retune the engine to accommodate the additional air flow. The fuel delivery blocks were opened to max delivery and the timing was advanced to see what the maximum power the engine could produce was. Along with this, an emissions analyzer was utilized to collect data that could be used later on to determine the most efficient engine calibration. Various timings were chosen with a set fuel delivery and the engine was ran through a ramped modal dyno session to collect data. The final determination was to reduce the engine delivery blocks to midrange to give us a manageable power range to be able to justify the use of the turbo with the given fuel supply. This addition increased the horsepower to 27 compared to the stock 23. The maximum output for this engine with a turbo is 35 horsepower.

Track

The track was chosen to accommodate the sound constraints that were given. The track, specially designed by Camso, features clips in every other lug. The track has weight saving features such as being single-ply and ported, seen in *Figure 2*. The new track for this year weighs 40.8 lbs compared to the old 42.3 lbs. In addition to the quietness of the track and it being lightweight, there are other special design techniques used. The basic track design is an imitation of the ripsaw with a 2.8 pitch. Another aspect of what makes this track special is the in lug studs which provide increased traction while also reducing weight.

Figure 2. Camso track

Muffler

The stock muffler was removed due to the fact that the DPF system is doubling as the muffler.

Catalytic Converter

The catalytic converter utilized this year was selected to match the performance of the engine and the DPF system.

Skis

The snowmobile is equipped with Arctic Cat OEM trail skis from rather than the OEM utility skis. The reasoning is that most of the riding is done on packed snow or trails verses deep powder that you would encounter in the back terrain.

Other Modifications

Driveline & Suspension

Hyfax slides with graphite inserts were chosen over the standard polymer hyfax due to their lower coefficient of friction, lower operating temperatures, and increased durability. These advantages increase fuel economy and driveline efficiency. The graphite composition in the slides withstand higher temperatures, which decreases the tendency for the slides to melt to the track clips.

A C3 Powersports Syncro Drive system was implemented in the chassis due to a maximum engine speed of 3800 RPM. The gear ratio was decreased to 1.56 to better transfer the power from the engine to the driveline. The belt drive system increased efficiency, alleviated friction, and reduced mass. The belt drive reduces rotating mass by 8 pounds along with an additional 3 pound reduction from unused components from the factory chain-drive system. The belt drive has no need for oil, therefore, it is more environmentally friendly and requires less maintenance.

An anti-stab kit is mounted to the front of the skid and acts as a row of small bogie wheels that prevents the rail tips from catching on the track windows. This helps eliminate vibration caused by the rail tips clicking on track clips as the track rides onto the slide rails [3]. To further increase efficiency in the driveline, it was important to create a smoother transition of the track onto the hyfax and clips. This was accomplished through phased bogie wheels along the front bend of the rails to create a gap between the track and the slides. Advantages of creating a gap include increased skid frame lubrication and reduced energy loss due to friction. The custom designed and fabricated rear idler wheels, shown in *Figure 3*, reduce the torque required by minimizing the angular acceleration of the track due to the larger diameter. By following the enlarged diameter, the amount of track deflection was mitigated, minimizing the energy wasted bending the track. Additionally, the big wheel kit adds aesthetic appeal through incorporating a symbol of UW-Platteville into the design as shown in *Figure 3*.

Figure 3. Custom idler wheels

With testing, on and off the trails, the clutching has been adjusted to compensate for the high torque and low RPM range of the Kubota Diesel engine. In the primary clutch, there are heavier weights and multiple shims to lower the engagement and hit the top end faster. This has been combined with a stiff secondary spring, the secondary spring is also a torsion spring. Utilizing this will help the clutch backshift faster.

Cooling

The factory cooling components of the snowmobile, along with their mounting locations, are utilized with the Kubota diesel engine by rerouting hoses. Testing revealed that this system offered more efficient cooling versus the stock system. The stock thermostat, at high speed operation, remained steady at 155° F. During low speed operation, the temperature reached a maximum of 175° F. These numbers are well within the proper operating conditions.

Undercoating

Resonation was reduced by coating the underside of the tunnel with automotive undercoating. The additional mass mitigates the amplitude of vibration of tunnel connections which results in minimizing sound level.

Exhaust Manifold

The manifold for the diesel snowmobile was redesigned from the factory manifold. The redesign was necessary to incorporate the turbocharger mount into the manifold. The new designed manifold eliminated the need for an adapter to bring the manifold and turbocharger together. This new manifold also provides a smoother flow for the exhaust which will increase the engines overall power. The team is currently in the process of gathering flow analysis data on three different engine manifolds. The results from this data will be presented during the oral presentations at the competition.

ABS Brakes

The handling is aided by the Hayes Trail Trac ABS system. Just as on most modern automobiles, ABS decreases braking distance. This system is critical on a utility snowmobile because the operating conditions are often slippery from ice or loose snow. The Trail Trac system is necessary to ensure that the snowmobile's stopping ability is not overpowered when pulling a load. The Trail Trac system has a crown-like tone wheel that mounts onto the jack shaft. From there, a Hall Effect sensor calculates the speed of the snowmobile. The operating range of the ABS is between 7 mph and greater. Below this speed, ABS is disabled for safety purposes.

Steering

The steering system was modified from the stock Bearcat steering to accommodate the diesel engine. Universal joints and supporting brackets were implemented to clear the engine and keep functionality of the steering system. The lower steering mount was changed so it is no longer a structural part of the chassis. This added rigidity to the chassis. This was done to separate the chassis from the steering so less vibration from the diesel engine was transferred back to the steering. Last year's plastic bushings were replaced with new ball bearing ones to reduce friction for less steering effort. The steering system can be seen in *Figure 4*.

Figure 4. Steering system

Emissions

With a focus on reducing particulate emissions, the UW-Platteville team has deployed a diesel particulate filter downstream from a diesel oxidation catalyst. Both of these products are manufactured by Blackthorn. The goal of the two-module exhaust system is to mitigate the output of hydrocarbons, carbon monoxide, nitrogen oxides, and soot. Testing revealed that the application of the Kubota D902 in a snowmobile produces an average exhaust gas temperature of approximately 260°C (500°F). This temperature is relatively low in comparison to larger diesel engines, making the challenge more difficult to oxidize or burn off emissions. The DOC was sized specifically for the Kubota D902 and consists of a low temperature coating on a metallic monolith substrate. This coating allows for better conversion of hydrocarbons, carbon monoxide, and nitrogen oxide over a wide range of exhaust temperatures. The Blackthorn DOC has a conversion efficiency of 70-90% [4]. *Figure 5* shows the conversion efficiency of the Blackthorn DOC with respect to exhaust gas temperature. The temperature range for maximum conversion efficiency is from around 250°C (480°F) and greater. The DOC was placed near the exhaust manifold and covered in titanium exhaust wrap to ensure high exhaust temperatures. The Blackthorn DPF was also sized in accordance to the output of the Kubota D902. The DPF utilizes ceramic fiber filters that offer a filtering efficiency of 85% [5]. One advantage of the Blackthorn DPF is that it catches soot particles regardless of exhaust temperature, ideal for the diesel snowmobile application. The regeneration process is needed approximately every 8 hours of run time. An electric heating element is used to burn off the soot while the sled is off duty. The heating element is powered by a separate, rechargeable battery pack that plugs into the DPF unit. The DPF system also acts as a muffler for sound attenuation. The Blackthorn DPF can be seen in *Figure 6*.

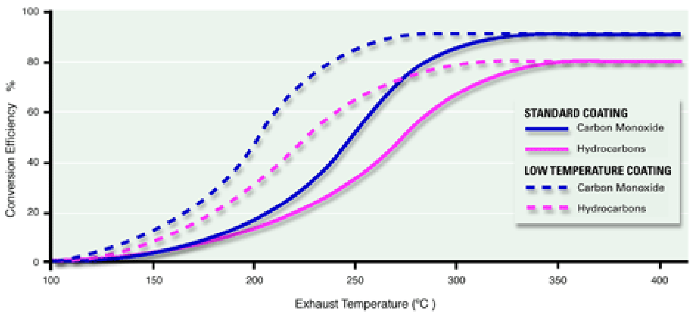

Figure 5. Effect of Temperature on the operation of a diesel oxidation Catalyst [4]

Figure 6. Blackthorn Diesel Particulate Filter

Emissions were monitored using an e-score to verify how well the catalyst was working. The e-score is a rating based on the number of unwanted compounds that leave the exhaust system. The score considers hydrocarbons, carbon monoxide, and nitrogen oxides. *Figure 7* is the equation used to calculate the score. The HC, NOx, and CO values are measured in ppm using an exhaust gas analyzer and then later converted to g/kW-hr based on fuel flow, H/C ratio, and weather data for that day.

$$\boldsymbol{E} = \left[\mathbf{1} - \frac{(\boldsymbol{HC} + \boldsymbol{NO_x}) - \mathbf{15}}{\mathbf{150}}\right] * \mathbf{100} + \left[\mathbf{1} - \left(\frac{\boldsymbol{CO}}{\mathbf{400}}\right)\right] * \mathbf{100}$$

Figure 7. E-score calculation equation

The max E-score that can be attained is 210 and must be 175 to pass in the competition. Also needed to pass is no more than 90 g/kW-hr of HC+NOx and no more than 15 CO g/kW-hr.

Summary

While diesel snowmobiles are currently not in production, teams competing in the CSC are laying the footprint to change that. The CSC continues to play a large role in the improvement of snowmobile design. Implementing a diesel engine into a snowmobile is an example of engineering excellence. With the implementation, the effect on the environment is a huge consideration, promoting better designs each year.

The UW-Platteville CSC Team has successfully designed an environmentally friendly, quiet and efficient snowmobile. The team believes that snowmobile could be marketable snowmobile due to the technology that the diesel engine provides and the future opportunities for advancements; however, its integration into the snowmobile industry is likely to be a time-consuming process.

Through the completion of research and development, the UW-Platteville CSC Team has re-engineered a snowmobile that is performance based but yet environmentally considerate. With the aforementioned modifications, the snowmobile meets and exceeds the required competition standards. The team was able to deliver a snowmobile consisting of adequate power, excellent handling, and increased fuel mileage. The team was able to make these improvements with only an estimated added cost of $4,879.68 over the stock snowmobile MSRP for a total of $15,078.68.

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Definitions

Antilock braking system	ABS
Carbon MonoxideAntilock braking system	ABS
Carbon Monoxide	CO
Clean Snowmobile Challenge	CSC
Diesel Oxidation Catalyst	DOC
Diesel Particulate Filter	DPF
Hydrocarbon	HC
Miles per Hour	mph
Nitrogen Oxide	NOx
Original Equipment Manufacturer	OEM
Revolutions per minute	RPM
Society of Automotive Engineers	SAE
University of Wisconsin	UW