Incorporating Kubota D902 into an Arctic Cat Bearcat 3000 LT

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Abstract

The University of Wisconsin-Platteville Clean Snowmobile Challenge (CSC) Team has successfully developed a quiet, efficient, and environmentally friendly snowmobile. The snowmobile is designed to compete in the 2017 Society of Automotive Engineers (SAE) Clean Snowmobile Challenge, held at the Keweenaw Research Center in Houghton, Michigan, March 6th-11th. The snowmobile for this year's competition is built on the 2017 Arctic Cat Bearcat 3000 LT utility platform. The UW-Platteville CSC utility class snowmobile is home to an 898cc D902 Kubota diesel engine. The sled utilizes a Nett Technologies diesel oxidation catalyst to reduce exhaust emissions such as hydrocarbons, carbon monoxide, particulate matter, and nitrogen oxide emissions. Driveline improvements are as follows, a lightweight belt drive, large diameter rear idler wheels, phasing of the boogie wheels, and an anti-stab kit are also incorporated to increase snowmobile efficiency, fuel economy, and sound by decreasing engine load. One of the biggest challenges to overcome in the diesel utility category is satisfying the speed requirements. This year our team made modifications to the clutching, both primary and secondary, and also adjusted the gear ratio to meet our goal of a cruising speed of 45 miles per hour. Our team has achieved this cruising speed with only using our engines mid-range RPM. These modifications, along with many others, have aided the UW-Platteville CSC Team in achieving our goal of producing a quiet, efficient, and environmentally friendly snowmobile.

Introduction

The snowmobiling industry is continuously met with pressure from the Environmental Protection Agency (EPA) to reduce environmental impact. The main concerns are broken into categories including carbon footprint, noise pollution, and fuel efficiency. As a result, environmental regulations have been enacted, including the Yellowstone National Park's ban of snowmobiles in the year 2000.

In an effort to diminish negative environmental impacts caused by the snowmobile industry, SAE teamed up with Teton County, Wyoming Commissioner Bill Paddleford, along with environmental engineer Lori Fussell, to start working on an innovative solution. Their combined efforts resulted in the first SAE Clean Snowmobile Challenge [1]. The CSC continues to be an international collegiate event aimed at improving the designs of current snowmobiles with the best available technology. After a year of hard work, teams gather in Houghton, MI to showcase their efforts. The CSC competition standards are more stringent than those currently set by the EPA, the National Parks Service (NPS), and the Department of Energy.

For 2017 the CSC will use a blend of 0-9% bio diesel (B002-B9) as fuel.

The CSC is grooming the way for future snowmobiles with the implementation of new flex-fuel systems and efficient design strategies. After the efforts to lessen environmental impact, Yellowstone National Park has implemented a new management approach, which began with the 2014-2015 winter season, changing from the fixed maximum number of snowmobiles per day to a more flexible system based on transportation events [2]. The following paper outlines the UW- Platteville CSC Team's motivations:

1. Chassis selection
2. Engine selection
3. Emissions control
4. Modifications
5. Suspension and driveline
6. Sound control
7. Cost analysis

Chassis Selection

Arctic Cat is an innovator in the snowmobile industry that has a legacy of top performing and durable snowmobiles. The chassis selection was determined by the practicality and ergonomic features of the Bearcat 3000 LT, making it fit for the Clean Snowmobile Challenge. The Bearcat 3000 LT is a mid-size utility chassis from Arctic Cat. Another consideration was the riders comfort and enjoyment. The Bearcat chassis puts the operator in an aggressive forward position on the sled. This allows them to be comfortable while maintaining full control over the sled. The chassis also features Arctic Cat’s slide-action rear suspension system. This is proven to decrease rider fatigue by reducing the effect of rough riding conditions. The Bearcat comes with a 146in length track. This assists with suspension efficiency, and increases traction at all times. Another advantage of the Bearcat is, its 15in wide track. While most utility sleds offer a 20in wide track, the advantage of the narrow track is the reduction of friction and rotating mass to improve efficiency. Apart from the track length and width, the Bearcat comes stock with Arctic Cat's quiet ramp technology. This design improves track efficiency, increasing fuel mileage and lowers noise generated from the driveline. The Bearcat 3000 LT comes with wide skis and A-arms. These features create a stance that allows for greater stability and floatation on deep, ungroomed snow.

Engine Selection

Table 1, Engine Specs

Model	Kubota Super Mini Series D902-EB4
Engine Type	3 Cylinder
Horsepower/ Torque	24.8Hp/ 41 lb ft
Displacement	54.8 cu.in
Combustion Ratio	24:1
Bore X Stroke	2.83 X 2.90
Weight	158.8 lbs

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. The Kubota D902 meets the current Tier 4 emission standards providing an excellent starting point to reduce exhaust pollutants. Table A1 outlines the base emissions for the 24.8 horsepower Kubota.

Engine speed was another deciding factor in engine selection. The D902 redlines at 3600 RPM, which is higher than other engines in its class. The Kubota’s RPM range provides a larger window to tune the continuously variable transmission for proper speed and efficiency.

Another element that makes the D902 engine a suitable choice is the E-TVCS (Three Combustion System). This technology facilitates reduced exhaust emissions, engine noise, and increased performance. The E-TVCS utilizes the 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 compression air into the swirl chamber, to achieve an ideal air/fuel mixture and also smooth combustion gas exhaust [3].

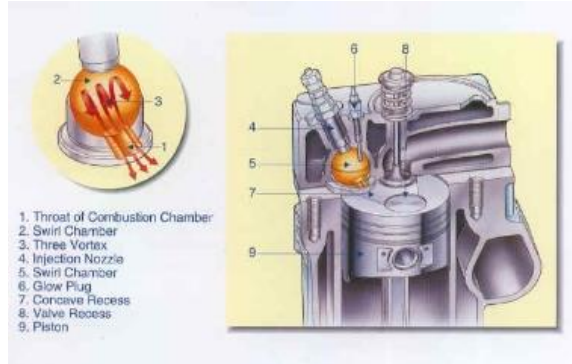

Figure 1 E-TVCS or Three Combustion System

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 are caught in the crankcase. This is achieved by using rubber ring seals incorporated into the engine valve cover.

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 43lbs. The weight increase associated with the D902 is significantly less than the typical small diesel engine. Weight is a concern when choosing engines because of fuel efficiency, stability, and ride quality.

Emissions

With the intent to mitigate exhaust pollutants from the Kubota D902, the UW-Platteville team is utilizing an M-Series® diesel oxidation catalyst manufactured by Nett Technologies [4]. While the Kubota D902 meets Tier 4 standards, the team recognizes the importance of further reducing emissions. With a focus on moderating hydrocarbons, carbon dioxide, particulate matter, and nitrogen oxide emissions, the DOC was strategically placed before the muffler to diminish the targeted air contaminants. Figure *2* outlines expected emission reductions from the Nett Technologies catalyst.

This DOC was sized specifically for the Kubota D902 by determining the flow rate from engine speed and displacement. The catalyst makes use of a metallic

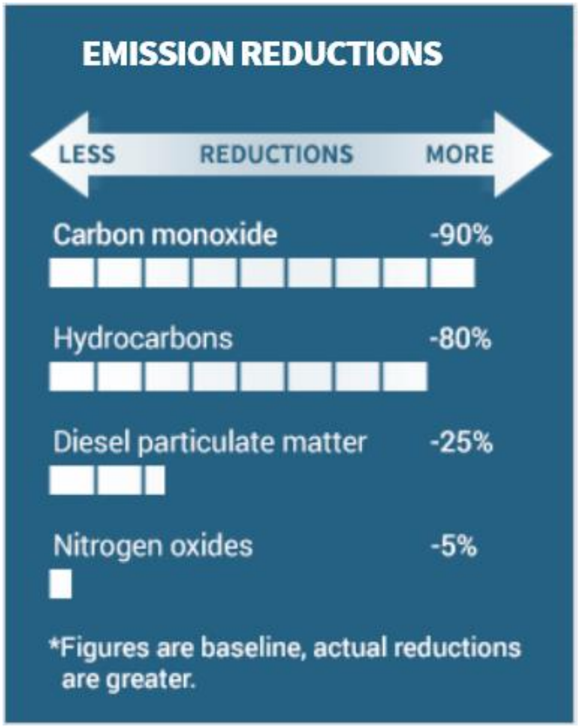

Figure 2, Emission Reductions

monolith substrate made of a wash coated stainless steel foil to maximize the catalytically working surface available to react with exhaust gases. The metallic catalyst was chosen over ceramic for its ability to withstand higher exhaust temperatures anticipated with the high revving snowmobile application of the Kubota D902. The header pipe and catalyst are wrapped in heat tape to help maintain a constant operating temperature above 300°C (570°F). This will ensure maximum catalytic efficiency, as shown in Figure 3.

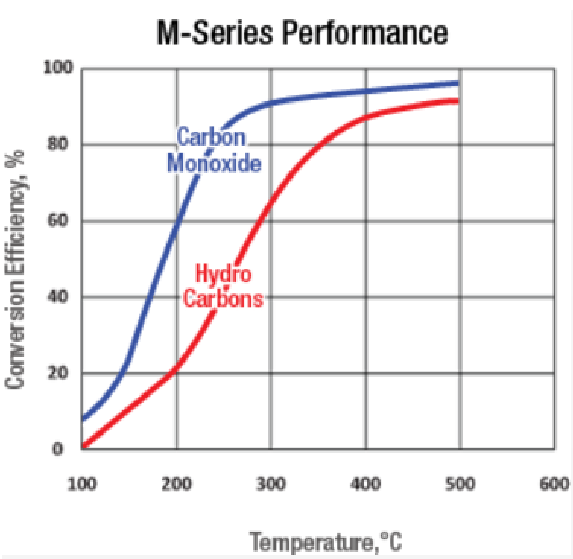

Figure 3, Exhaust Temps related to catalytic efficiency

Modifications

Steering

The steering system was modified to accommodate the diesel engine through the addition of universal joints and supporting brackets as shown in Figure 4.

Figure 4, Steering shaft

The supporting brackets were designed to keep the steering shaft from moving laterally and vertically. To accommodate for the diesels engine placement, the steering needed modifications to have normal functionality. The Bearcat's stock steering design was a straight shaft that was positioned under the front chassis brace.

Cooling System

The stock cooling components were implemented with the Kubota diesel engine through minor piping and hose changes. The stock component mounting locations where also able to be maintained by rerouting the hoses around the engine wherever there where conflicts. This system was deemed acceptable for handling the cooling needs of this snowmobile. A test was performed in 40 degree Fahrenheit conditions, where the snowmobile was run for one hour without issue. This confirm that there were no overheating concerns.

Battery and Battery Box

With a higher compression engine, a larger battery, having more cold cranking amps and absorbed glass mat technology was selected. We secured the battery box to the tunnel utilizing sound dampening materials to aid in reducing tunnel resonance. We also secured the battery directly to the tunnel for safety purposes.

Drive line and suspension modifications

Graphite infused hyfax were chosen over the standard polymer hyfax due to their lower coefficient of friction, lower operating temperatures, and increased durability. This increases fuel economy and driveline efficiency. The graphite composition in the slides withstands higher temperatures, which decreases the tendency for the slides to melt to the track clips.

Belt Drive

A C3 Powersports Syncro Drive system was implemented in the chassis due to the diesel engines maximum engine speed of 3600 RPM. To reach the minimum speed of 35 MPH on the endurance run, the gear ratio had to be raised. This system increased efficiency, alleviated friction, and reduced mass. In fact, the belt drive reduces rotating mass by 8 pounds with an overall weight savings of 11 pounds [5]. The belt drive has no need for oil, therefore, it is more environmentally friendly and requires less maintenance. One of the largest benefits to the belt drive is a reduction in noise compared to the traditional chain drive resulting from the materials used.

Anti-Stab Kit

An anti-stab kit is mounted to the front of the skid and acts as another row of small bogie wheels that eliminates rail tip failure. This helps eliminate vibration caused by the rail tips clicking on track clips as the track rides onto the slide rails. One goal agreed upon by the driveline team was to reduce contact with the hyfax and the clips. To do so, bogie wheels were added 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 hyfax temperature.

Big wheel kit

The implantation of larger diameter rear idler wheels reduces the torque required by minimizing the angular acceleration of the track. By following the enlarged radius, the amount of track deflection is mitigated, minimizing the energy wasted from bending the track. A big wheel kit was added to the sled to reduce the losses associated with bending the track over a tight radius. Additionally, the big wheel kit adds aesthetic appeal through incorporating our school into the design as shown in Figure 5.

Figure 5, Larger rear idler wheels

Hayes Brakes

Hayes Trail Trac ABS system was added to improve stopping distance in all situations, specifically icy conditions where the track may lock up. Inexperienced and seasoned riders alike can also see value in the ABS system through better control. This is vital in emergency situations where an inexperienced rider may panic and apply the brakes too firmly, which can cause unexpected movement. This system can also benefit bystanders and wildlife through decreased stopping distance.

This year the design of our ABS system changed to provide better reliability and consistent track speed readings. This was done by making a more rigid mount for the hall effect sensor and by having the sensor read radially around the tone wheel as opposed to axially. The benefit to reading radially is that the reading is not subject to shaft floating and therefore is less likely to misread. Another great aspect to Hayes Trail Trac system is the ability to disable the system.

Sound

The track that we are utilizing has Arctic Cat's quiet track technology. According to Jason Davis at Camso, "This track has additional geometry on the inside of the track that look like small ramps in order to have the idler wheels span the fiberglass rods in the track and lower the dB of the track." [6] as shown in Figure 6.

On the slide rails, idler wheels were positioned in order to cancel out the sine wave that occurs while the track is in motion to demote track noise. A staggered pattern was followed so that the wheels are not running in line with each other. This reduces the compression of the track as a wheel passes over, effectively resulting in less rubber compression for the next bogie wheel, therefore less noise

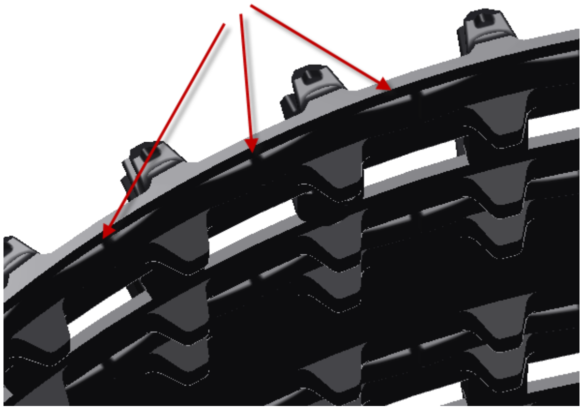

Figure 6, Quiet ramp technology

is produced. Phasing the wheels correctly is important so that no two wheels are hitting the track at the same time. To reduce vibration noise, more wheels were added to the system.

To reduce tunnel resonation, the chassis was coated with automotive undercoating. This reduces sound levels by adding mass to the system. The additional mass mitigates the amplitude of vibration, which directly correlates to sound level. Similarly, a multilayer foam was strategically utilized to deaden noise.

Neoprene material was applied to the clutch cover due to its characteristics of never rotting or mildew. The material remains flexible and durable to follow the contours of the drive cutch cover. This was applied to the exterior of the guard to decrease sound emitted by the clutches. This material is made from rubber that is then coated in nylon which makes it extremely strong but still remains lightweight. To further control sound, an acoustical barrier with absorber was added to the body panels to help with heat reduction and sound attenuation. The material consists of a sound absorbent foam that is then layered with a vinyl barrier and a foam decoupler.

The stock clutching set up presented a challenge to utilizing the diesel's low rpm and high torque characteristics to efficiently propel the snowmobile. The clutch engagement had to be lowered to accommodate the rpm constraints set forth by this engine. The OEM Bearcat had significantly wider engine operating speed than the Kubota. The engagement rpms were lowered using a combination of lighter springs, heavier weights, and helixes allowing the sled to utilize the torque curve of the Kubota D902.

Cost Analysis

As a part of the CSC we are subjected to a cost analysis for our sleds. Our team's focus this year for MSRP, was to reduce the use of purchased aftermarket parts. For instance, our previous year's rear idler wheels were from Tricked Out Toys. This year our wheels were designed and machined by the team. Producing the wheels in house leads to a lower overall MSRP cost. To display our manufacturing skills, the UW-Platteville's logo pickaxes were incorporated into the wheels. Another aspect to our sled's overall cost is the simplicity of engine management. The Kubota D902 meters fuel with a mechanical, high pressure pump. This simple design is cost effective because it does not require additional electronic systems to control. The overall calculated cost for UW-Platteville's utility class diesel snowmobile is $12,094.13 This is an additional cost $1,995.13 over the stock Bearcat.

Conclusion

The UW-Platteville CSC Team has successfully designed a quiet, efficient, and environmentally friendly snowmobile. The team believes that this could be a marketable snowmobile because of the technology that the diesel engine presents and the vast opportunities for advancements, but its integration into the snowmobile industry is likely to be a gradual transition.

This competition has played a large role in the improvement of snowmobile design. The implementation of a diesel engine is continuing the tradition of engineering excellence in environmental and societal responsibilities. It is important to remember that in most cases snowmobiling is a privilege and not a right, the industry and its connoisseurs must continue to fulfill their duties to the.

Through extensive research and development, the UW-Platteville CSC Team has produced a snowmobile that is performance oriented and environmentally conscious. The aforementioned modifications have created a snowmobile that meets and exceeds the required competition standards. The team was able to deliver a snowmobile consisting of ample power, excellent handling, and improved fuel economy. Furthermore, this snowmobile not only meets the EPA's emissions standards set in 2012, but surpasses them. The team was able to make these improvements with only an estimated added cost of $1,995.13 over the stock snowmobile MSRP for a total of $12,094.13

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Acknowledgements

The University of Wisconsin - Platteville CSC Team would like to thank our sponsors: Arctic Cat, Kubota, Ford, Motec, HB Performance Systems, Camso, Mercury Marine, Larson Davis, Nitro Lubricants, Denso, Gates, Waupaca Foundry, Monroe Trucking, Bikeman Performance, Badger State Ethanol, Garage-Toys, FXR, HMK, Midwest Prototyping, Wells by Welch, Pioneer Ford, Byron Snow Bears, Kettle Moraine Riders, Isaar Trailriders, Oneida Swamp Stompers, Midwest Motor Sports, Division Sixx, Throttle Threads, and many others who made this project possible.

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Abbreviations

Clean Snowmobile Challenge (CSC)
Society of Automotive Engineers (SAE)
Environmental Protection Agency (EPA)
National Parks Service (NPS)
University of Wisconsin (UW)
Diesel Oxidization Catalyst (DOC)
E-TVCS (Three Combustion System)
spherical-combustion chamber (Swirl Chamber)
rotations per minute (RPM)

Appendix

Table A1

RATED POWER CLASS	EMISSION STANDARD CATEGORY		EXHAUST (g/kw-hr)					OPACITY (%)		
			NMHC	NOx	NMHC+NOx	CO	PM	ACCEL	LUG	PEAK
kW < 19	Tier 4 Final	STD	N/A	N/A	7.5	6.6	0.40	20	15	50
		CERT	--	--	5.6	2.0	0.31	8	6	13