Design and Modification of a Clean Diesel Snowmobile

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Abstract

The South Dakota School of Mines and Technology Clean Snowmobile Team has designed, built, and tested a 2018 Polaris Titan with a Kubota D902 diesel engine. This snowmobile has been upgraded and revised in order to not only comply with the rules but also innovate in the field of the competition. Among revisions and upgrades are subsystems such as electronics, clutching, noise reduction, and exhaust. All these systems have been adapted to accommodate the diesel engine and all the differences that come with it when changing from a two-stroke, two-cylinder, gasoline engine. Some of these changes require more adaptation than others, and all have been explained in this document. The data, along with the thought processes behind the changes are also in this paper. Through the combination of theory and real-world examples, the SDSMT Clean Snowmobile Team has put together the best version of its' ideal and practical clean diesel snowmobile.

Innovations

Electronics

The snowmobile's electrical system was updated by using an interactive display from ECU Masters to both control some of the sled's functions and inform the operator of important vehicle information. The system functions via CAN-BUS protocol. ECU Master uses their own protocol, so it was implemented across the whole system. This is a large improvement over the previous year, in which the snowmobile did not have a computer to control some of the electronic functions. On top of that, the display will allow the operator to control the main functions of the snowmobile while integrating crucial information into the display. The display can also be used in a system with other high-powered electronic controllers, this sets the snowmobile up for more advanced systems, such as EGR or active regeneration in the future. These attributes prove that this new system is highly effective and a large improvement over previous years snowmobile.

Clutching

Using the sponsorship gained from TEAM Industries, the snowmobile has improved the top speed and efficiency of the CVT (Continuously Variable Transmission) used in the snowmobile. The new primary clutch features a wider flyweight opening along with a stronger spider, and wider rollers to accommodate the wide flyweights. Also, a heavier spring is employed in the primary clutch to control engagement RPM and shift rate to better match the diesel engine. After testing is completed, a new spring will be selected for the secondary to maximize the engine's potential and the CVT's efficiency.

Oil and Coolant cooling

The previous years' snowmobile employed a degas bottle and radiator, and while this was sufficient, the team decided to update the system with a lighter, sleeker system that includes an oil cooler. This improvement not only makes more room in the engine bay but also reduces cost in both parts and labor required for assembly. The radiator is used to control idle coolant temperatures after hard use and uses an electric fan. The snowmobile also uses the factory style tunnel coolers as the main means of cooling the engine while under operation. The addition of the oil cooler is also an improvement from previous years, as the oil inside the engine tends to heat up under hard engine load. This addition will ensure the longevity of the engine internals as well has reduced under hood heat. Also, to keep up with the rising performance standards, the oil cooler allows the possibility of adding a turbocharger or some other force induction device, in the future.

Noise Reduction

Due to the importance of reducing the sound emissions from the sled a senior design team took on the challenge to make it meet the requirements. The competition requires the snowmobile to meet a sound requirement of 67 dB from 50 ft while moving. An initial test was performed to acquire baseline for the sound levels of the sled, where decibel readings were taken from 50 ft while snowmobile was stationary and moving. Results from this test can be seen in Table 1 and 2.

Table 1. Initial Moving Sound Test Data

Moving			
Plastics Installed (Yes/No)	Side	Decibels (dB)	Speed (MPH)
Yes	LH	72	25
Yes	LH	75	26
Yes	RH	74	22
Yes	RH	73.5	24
No	LH	78	29
No	LH	76	29
No	RH	75.5	26
No	RH	76	27

Table 2. Stationary Moving Sound Test Data

Stationary			
Plastics Installed (Yes/No)	Side	Decibels (dB)	Speed (MPH)
Yes	LH	71	0
Yes	RH	73	0
No	LH	75	0
No	RH	73	0

From here, a goal of 65 dB from 50ft while going 35 MPH was set. To better understand the sources of the sound pollution, the engine was ran outside of the snowmobile, while high-speed cameras measured the vibrations of the exhaust manifold and the engine block. Figure 1 below is a graph of the vibration data.

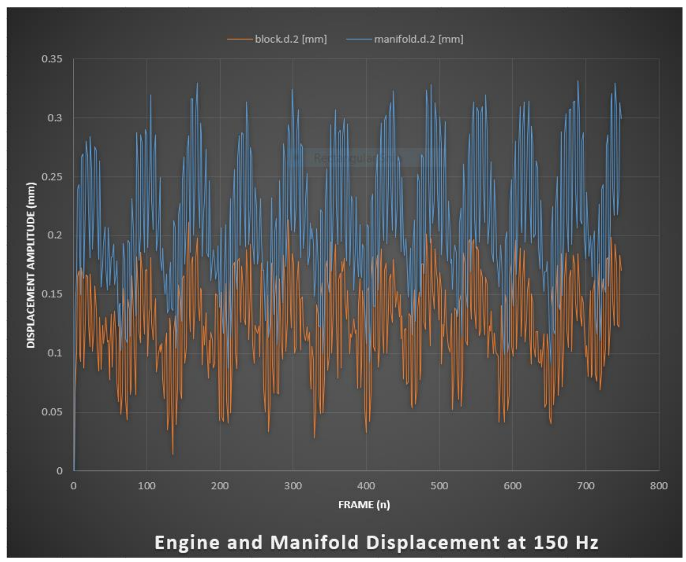

Figure 1. Vibration Data

When looking at this graph, it can be observed that the manifold displacements are larger than the engine displacements. From this, it was determined that any item bolted onto the engine will create larger vibrations and more sound emissions. The team kept this in mind and tried to not bolt anything to the engine that didn’t need to be. So, with the tests completed, the team identified engine knock and rattle, exhaust, and moving drivetrain components contributed the most to high noise levels.

It was noticed from the initial testing that the plastics helped reduce the sound by several decibels, so a trade study was done to find ways to better sound insulate the panels. The best option found was to install Dynamat and Dynaliner on the panels. Dynamat was chosen due to its ability to withstand a wide range of temperatures while still damping sound. So, with the Dynamat installed, the panels will be able to better dampen sound emissions from engine knock and CVT clutch rattle.

Several aspects of the exhaust were also changed to reduce sound emissions. One change was the installation of flex pipe welded in between the engine and DPF, and between the DPF and muffler. This helps isolate engine vibrations from the exhaust lowering the magnitude of exhaust vibration. In line with that, the DPF mounts were changed to bigger and softer mounts compared to the previous year. This assisted in damping and reducing vibration transferred to the frame of the snowmobile. The mounted DPF and flex pipe can be seen in Figure 2.

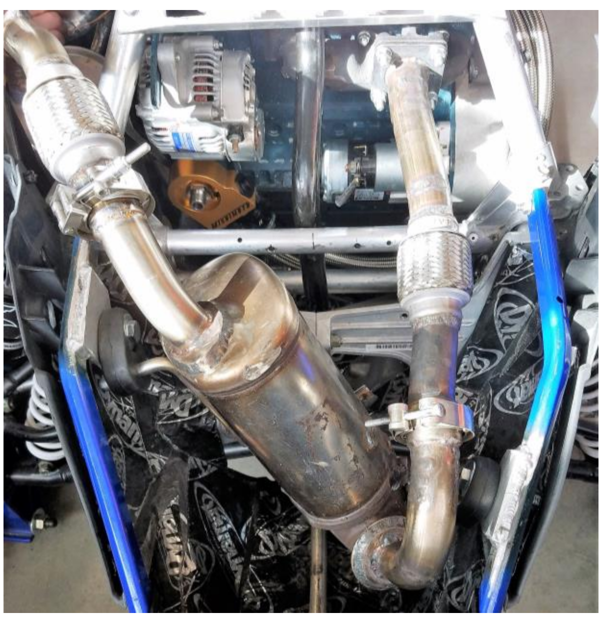

Figure 2. DPF Mounting

Lastly, modifications were made to the track and driver to reduce drivetrain sound pollution. These modifications included taking every other metal slide clip off the track and taking the nubs off the driver. The modifications reduce the mechanical shock introduced when the driver contacts the track during operation.

At the time of completion of this document, the team has not finished the final testing and as result, there is no final data to present.

Motor Mounts

The motor mounts were improved over the previous year's mounts in several ways. First, the motor mounts were thinned down from 0.25 inches thick to 3/16 inches, saving weight. Also, the mounts were designed for adjustment laterally. This gives the engine movement for aligning the clutches with great accuracy, giving superb belt life.

Track

This year a new track was used, it features a lower profile lug at 1.25in, and a more aggressive pitch, at 2.86in. The lugs are also designed for more of a hard pack type of snow. The switch to this style of track was prompted by the type of conditions seen at previous year's competition. The old track was more of a powder/deep snow conditions track, the new Camso Ripsaw Full will better suit conditions for the competition.

Team Organization and Time Management

Team History

The CST formed on campus in 1995 as the Alternative Fuel Vehicle Team starting out as a solar power vehicle team. Then after 11 years in the solar vehicle competition, the organization moved on to the SAE Clean Snowmobile Challenge. The team competed with an electric sled in the Zero Emission class until it was no longer offered in 2017. With a passion for snowmobiles, the team decided to keep competing in the Clean Snowmobile Challenge by switching to the Diesel Utility Class.

Organization and Management

The SDSMT clean snowmobile team has seven officers to organize and manage the project. The following is a list of the officers and their duties.

1. President: Organize meetings, events, set schedules
2. Vice President: Assists the President
3. Design/Manufacturing Lead 1: Ensure team meets the deadlines for the build; Assist with the design and manufacturing for all sub-systems
4. Design/Manufacturing Lead 2: Same as design and manufacturing lead 1
5. Electrical Lead: Oversees the design and manufacturing of the electrical sub-system
6. Safety Officer: Ensures the team follows safety protocols when working in the shop; Manages the team's chemical supply
7. Treasurer: Manages the team's finances

From there, team members pick sub-systems to work on, based on their individual interests. To get freshman involved right away, the design/ manufacturing leads assign each freshman a simple project to get started on, for example, a freshman was given the project of designing and building a new fuel filter bracket. This allows the younger team members to get involved with the design and building right away, making them more comfortable working with the team along with voicing their ideas on different design problems.

Outreach and Funding

Center of Excellence for Advanced Manufacturing and Production, also called CAMP, is a program that unites SDSMT's collegiate design teams under one organization. The CST helps CAMP participate in multiple events that outreach to college students and the local communities, such as the Wharton 5K/10K Run, exhibition fairs, and Rapid City's Pumpkin Festival, Pumpkin Chuckin.

Another outreach activity done by this team is called STEM Night. STEM Night is an event that promotes SDSMT and the STEM field to Rapid City's local high schools. The team presents the sled and talks to the high school students about the snowmobile along with the CSC competition it is used for.

The team also helps with Nostalgia Nights, which is a fundraiser for the library of SDSMT, at a local movie theater. Team members volunteered to hand out door prizes to the audience before a classic movie is played. The team is showcased before the event to the audience.

Funding for the Clean Snowmobile Team come from several places. One big source of funding comes from sponsors. To keep sponsors up to date, a seasonal newsletter is sent to them giving sponsors progress reports on the sled and thanking them for their support. Another method the team uses to maintain a good relationship with sponsors is through updates on the team's social media page. Social media is a great way for the team to give shout outs to the sponsors with a picture of their product on display to the team's followers.

Another source of income is the crowdfunding fundraiser. With college financial budgets becoming tighter, the team is searching for other possible ways to fund the snowmobile project. Setting up a crowdfunding fundraiser helps promote the team as a professional group of student engineers, helps promote the SAE competitions, and aids the team finance to build the diesel snowmobile.

Build Items

Chassis

The SDSMT clean snowmobile team utilizes a 2018 Titan Polaris XC chassis. The Polaris sponsorship helped the decision to use this chassis, but overall the Titan chassis fits very well with what the diesel utility class is asking for. It features ample amounts of floatation, while still maintaining an average snowmobile overall size. The floatation helps in off-trail maneuvers, such as deep snow turning or pulling. The on-trail performance is handled by a fully articulating rear skid, and Fox QS3 clicker shocks on all corners. It also comes with a large cargo area over the tunnel on the rear of the snowmobile adding to the chassis' utility capabilities. This area also offers hold downs for Polaris bags, racks, and even two-up seat options. This cargo area was designated to remain clear when designing the sled for this competition, as to retain this feature. The engine bay was also considered in this decision, and the Titan chassis can fit our engine, transmission, and emission control devices without compromising the factory over or understructure. The factory motor mount positions were used in the mounting of the diesel engine.

Engine

After utilizing a decision matrix, the team selected a Kubota D902 engine. This engine is a 4 stroke, compression ignited, diesel engine. The specifications given by Kubota for the engine can be seen in Table 3.

Table 3. Kubota D902 Specifications

Displacement	0.898 L (54.8 cubic inches)
Cylinders	3
Stroke	2.9 in
Bore	2.83 in
Compression Ratio	24:1
Valves per Cylinder	2
Aspiration	Naturally Aspirated
Emissions	Tier 4 California Compliant
Power	24.8 HP @ 3600 RPM
Torque	41.4 lb-ft @ 2600 RPM
Firing Order	1-2-3
Dimensions (L * W * H)	17.1 x 15.8 x 21.4 (in)
Dry Weight	159 lb

The power and torque output of the engine were measured during the 2018 competition and can be seen in Table 4. The measurements were obtained using a dyno and the testing was done while the engine was installed in the snowmobile along with a full exhaust (muffler and emission control devices) installed.

Table 4. Measured Kubota D902 Specifications

Peak Torque	40.6 lb-ft (55 N-m)
Peak Power	25.3 HP (18.87 kW)

In Figure 3 below, the torque (N-m) and power (kW) can be seen plotted against the engine RPM.

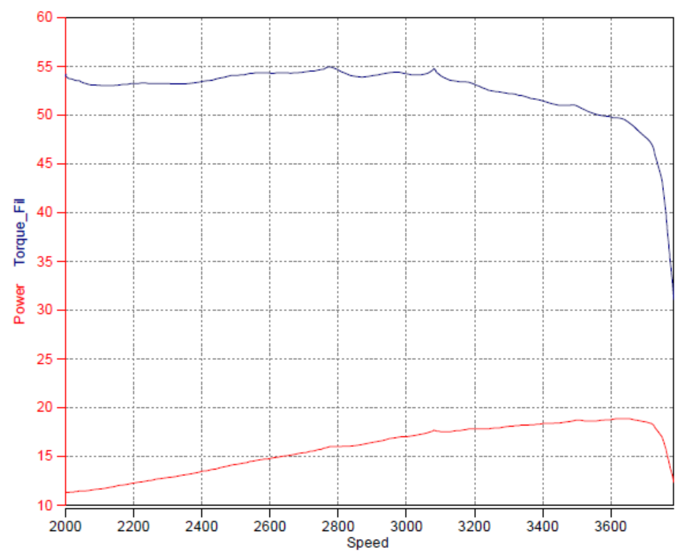

Figure 3. Torque and Power vs RPM

Track and Studs

The track used is built by Camso, and it is called the Ripsaw Full. The length and width are 155 by 20 in, and the lug depth and pitch are 1.25in and 2.86in. The total weight of the track before modification is 65lbs. The studs used this year are from Woody's and are the 1450 Grand Master Carbide Studs with Round Grand Digger Support Plates.

Muffler

The exhaust will be using two mufflers in series to reduce noise pollution from the engine exhaust. The mufflers are from Walker, and part of the Quiet-Flow line of mufflers.

Emission Control Devices

To meet and exceed the emission requirements of the competition several emission control devices were used. As a team, a goal was set to pass the soot requirements of 50 mg/KW-hr along with achieving an e-score of 200 or higher calculated from Equation 1 below.

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

E = E-Score (theoretical maximum value is 210)
HC, NOx, and CO is the calculated brake specific emissions in g/Kw-hr

(1)

In selecting the Kubota D902, the team took the first step to achieving this goal. Due to the impressive work of the Kubota engineering team, the design of the cylinder head and the piston of this engine acts as an emission control device. The E-TVCS IDI allows the engine to meet Tier 4 California Compliant emission standards without any exhaust treatment. The untreated or raw emissions can be seen in Table 5 provided by Kubota. Abbreviations in this table as follows:

1. STD = Certification Standards
2. CERT= Certification Levels
3. NMHC = Non-methane Hydrocarbon
4. NOx= Nitrogen Oxides
5. CO= Carbon Monoxide
6. PM= Particulate Matter

Table 5. Kubota D902 Raw Emissions

	EXHAUST (g/kW-hr)				
	NMHC	NOx	NMHC+NOx	CO	PM
OPTIONAL STD	N/A	N/A	7.5	6.6	0.40
CERT	--	--	5.6	2.0	0.31

The E-TVCS IDI accomplishes Tier 4 through matching the injection nozzle with the injection pump along with matching the injection nozzle throat with the piston head. A picture diagram created by Kubota, of the E-TVCS IDI, can be seen in Figure 4.

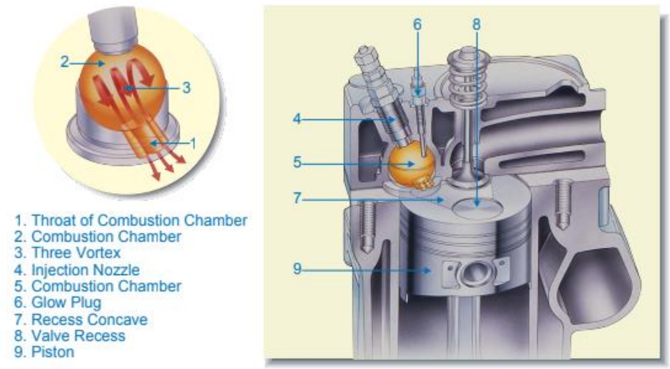

Figure 4. E-TVCS IDI

These raw emissions give the snowmobile an E-score of 205 achieving the goal of a scoring 200 or higher.

The particulate matter still needed to be reduced to desired levels, so the team decided to go with a two-part, exhaust filter, where the first part of this filter is a DOC (diesel oxidation catalyst) and the second part is a DPF (diesel particulate filter). This filter can be found in production Turbocharged Direct Injection Volkswagen automobiles. Buying this filter used, allowed the team to acquire a DPF to reduce the particulate matter emissions in a very affordable way compared to buying a newly manufactured small DPF. With this filter installed, the engine was run through the Ramped Modal Cycle underload from a dyno and had the exhaust emissions tested. These emissions can be seen in Table 6.

Table 6. Emissions with Exhaust Treatment

Pollutant	Amount	Units
CO	0	g/kW-hr
HC+NOx	5.77	g/kW-hr
Soot	1.03	mg/kW-hr

As seen in the table, the DOC part of the filter effectively eliminated carbon monoxide emissions, increasing the E-score to 206 while the DPF reduced particulate matter (soot) by 99.97% thus achieving the team's emission goals.

Skies

The team selected 8” wide Powder Hounds Manufactured by Slydog ski to be used on the sled. These skis are wider than many snowmobile skis, thus helping to distribute weight and improve the overall handling of the sled with the increased amount of weight in the front end.

Electronics

The electrical system this year includes a digital dash from ECU Masters. This display will control most of the primary functions of the snowmobile, including start/stop of the engine, fuel pump operation, engine cooling fan, neutral safety switch, and the glow plugs. The ADU will also display all the essential vehicle information, including:

- GPS vehicle speed
- Engine RPM
- Coolant temperature
- Oil temperature
- Oil pressure
- Exhaust Gas Temperature (EGT)
- Selected gear

The data needs to be collected in real time for the display to be useful and relevant, so careful thought went into each displayed value. The GPS speed data is collected through ECU Master’s GPS speed kit, this makes it an accurate and compatible tool. The engine RPM was more challenging, as it required a high sampling rate for adequate accuracy. The snowmobile incorporates a tail-shaft speed sensor and a tone ring from an Eaton semi-truck transmission. These two parts combined use metal teeth and a magnetic pickup to determine the rotational speed of a shaft. The tone ring is mounted to the front pulley of the crankshaft, which gives the most accurate engine RPM. As for coolant and oil temperature, AEM electronics offer sensor kits with the data sheets included. The sensor kits come with the sensor, a bung for installation, and the necessary wiring connectors to incorporate into the existing harness. The oil pressure and EGT sensors were from AEM as well and came with everything necessary, as the same case with the temperature sensors. The selected gear (High-Low-Neutral-Reverse) shown on the display uses the factory potentiometer, which is located on the transmission.

The lights and heated grips are controlled through switches on the handlebars and relays, this keeps the wiring harness and junction box as simple as possible.

Oil Cooler

The oil cooler used is a universal kit from our sponsor Mishimoto. It features a 10-row stacked core and a sandwich plate that is placed in between the filter and filter housing. The cooler lines are braided stainless high-pressure hoses with -10 AN fittings.

CVT

The snowmobile has a sponsored Team Industries primary clutch driving the stock Team Industries secondary clutch. Equation 2 shows how to calculate the shift ratio if all other variables are known.

$$Shift\ Ratio = \frac{Engine\ RPM \cdot (Track\ Driver\ Diameter + Track\ Thickness)}{MPH \cdot Final\ Drive\ ratio \cdot 336} \quad (2)$$

The shift ratio is defined as the ratio of the primary to the secondary clutch. A shift ratio of less than 1 means that the primary is overdriving the secondary. The engine RPM was measured at full throttle, 3600 RPM. The driver diameter was measured to be 6.25 inches and the track thickness was measured to be 0.5 inches, this added together is 6.75 inches. The top speed on pavement measured using GPS was 42mph. The final drive ratio, which is considered “High” in the transmission, is 2:1. 336 is the unit conversion between all the standard units used in this equation. The final answer calculated is a shift ratio of 0.86 and proves the proper shifting characteristics of the primary clutch. More testing will be done before the competition to determine the proper spring rate to be used in the secondary. The proper backshift will be determined by the total weight of the finished snowmobile, and the atmosphere in which testing will occur. The atmosphere plays a role in the engine output, and since Rapid City is at approximately 3200 ft, and our test site is 4000+ ft, the final adjustments will be made at the competition, in which the elevation is only 650 ft.

References

1. "Emissions." *Kubota - For Earth, For Life*, www.kubotaengine.com/emission-2.

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