Michigan Technological University's Solutions for a Diesel Utility Snowmobile

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Innovations

For the 2019 competition, the Michigan Tech Clean Snow team is broadening its presence at the SAE Clean Snow Challenge by entering into the Diesel (CI) category. This year's entry is consists of a 2016 Arctic Cat Bearcat 7000XT chassis, powered by a Kohler KDW 993T turbocharged diesel engine.

The modifications made to the engine and chassis were focused on improved engine control and reduced emissions. A servo motor was utilized to control the fuel delivery to the engine. Electronic supplementation was added to the continuously variable transmission (CVT) to improve control of engine operating speeds. These features are controlled by an ECU designed and programmed into an Arduino microcontroller and Raspberry Pi. Emissions reduction was achived by implementing a diesel particular filter (DPF) and diesel oxidation catalyst (DOC).

Team Organization and Time Management

The Michigan Tech Clean Snowmobile Team was formed in 2000 as one of the original seven university teams selected to compete in the inaugural Clean Snowmobile Competition in Jackson Hole, Wyoming. Today, Michigan Tech's Clean Snowmobile Team is a member of the Michigan Tech Advanced Motorsports & Enterprise Program. The Advanced Motorsports Program is comprised of the SAE Student Design Teams at MTU - SAE Clean Snowmobile, Formula SAE, SAE Supermileage, and SAE Baja.

The Michigan Tech Clean Snowmobile Team consists of three primary sub teams - chassis team, SI engine team, and CI engine team. The team is led by an executive board. Josh Carpenter as team president, Alex Spiess as chassis team lead, Logan Eide as SI engine team lead, and Justin Scholl as CI engine team lead. There is a business team for sponsor relations, budget management, and **Manufacturer's** Suggested Retail Price (MSRP) development. Anthony Rettig and Rob Falzon lead the business team.
The entire team organizes its time by setting milestones at the beginning of each season and then organizing them into a team timeline. An example of the timeline is shown in Table 1. Projects are assigned to members each week at the weekly sub-team meetings. These projects work towards achieving the set milestones. Team members are responsible for completing at least five shop hours per week in addition to an hour long weekly general meeting to receive passing course grades. The team developed a computer application this year in which team members sign in and sign out of when working in the shop. This helps the team monitor participation as well as how long certain projects and tasks take to improve future project planning.

The team also uses various tools for communication including Canvas for sending out assignments, Google Hangouts for day-to-day communication, and Google Calendar to reserve time slots for dynamometer operations. This ensures a smooth-running schedule as the two teams share a single dynameter. Google Calendar is also used to schedule and notify members of testing times and dates.

Table 1. Milestone timeline

Project	Due Date
NA Engine - Running at Dyno Cell	11-01-18
Dyno Cell Shakedown / Modifications to Instrumentation	11-15-18
Baseline Emissions Measurement	11-30-18
Baseline Emissions Data Analysis Complete	12-06-18
NA Engine - Mounted In Chassis	12-13-18
Exhaust/Aftertreatment Design Finalized	12-20-18
ECVT Mock-up Completed	12-21-18
ECVT & Design Analysis Proposal	1-1-19
Intake Design Finalized	1-18-19
Intake/Exhaust Assembled	1-25-19
First Engine Startup in Chassis	2-01-19
Turbo Engine Startup in Chassis	2-08-19
Design Paper & MSRP Due	2-18-19
Competition	3-04-19

The Team also participates in the SAE "A World in Motion" program to help develop the next generation of STEM students and give back to the community that has supported Michigan Tech and the Clean Snowmobile Team since its inception. The Team participates in school preview days to encourage prospective students to attend Michigan Tech and current students to join SAE Student Design Teams. The Team raises funds collectively with the other MTU SAE teams and provides tours of team facilities to current and potential team sponsors.

Build Items of the Snowmobile

Chassis Selection

The Team chose the 2016 Arctic Cat Bearcat 7000 XT chassis for entry in the diesel utility class. This chassis was selected because it meets the utility snowmobile chassis requirement and has ample under-hood space for the diesel engine and associated components. The Bearcat 7000 XT is equipped with a 154-inch long, 20-inch-wide track. It was elected to keep the factory track as other track options are not common for this unique size. The factory skis were also used and are 25.4 cm (10”) wide at the tip, and taper to 20.3 cm (8”) wide at the back of the ski. The ski and track combination provide high floatation, a characteristic that desired in utility-oriented snowmobiles.

Engine Selection

For the diesel engine selection, the Team decided to use a four stroke, liquid cooled, 993 cc, 3-cylinder turbocharged diesel engine from Kohler Company. The engine is part of the Kohler KDW engine family and is identical in dimensions with the KDW1003 engine that is found in the powersports industry in utility terrain vehicles (UTV). The addition of a turbocharger from the factory on the KDW993T engine added the potential of more power and lower emissions due to leaner engine operation. Specifications of the Kohler 993 engine are below in Table 2.

Table 2:Engine specifications

Parameters	**Description**
Engine	Kohler KDW 993T
Engine Type	Four-stroke
Cooling	Liquid
Cylinders	3
Displacement	993cc
Power	72.4 hp
Bore	75 mm
Stroke	77.6 mm
Ignition	Compression
Compression Ratio	22.8:1

Aftertreatment/Muffler Selection

The target for the aftertreatment was to reduce the hydrocarbons (HC), carbon monoxide (CO), and particular matter being produced by the engine. In order to reduce these emissions, the Team implemented a diesel oxidation catalyst (DOC) and a diesel particulate filter (DPF).

An additional focus of the exhaust system was to address the sound frequencies being produced by the engine. The approach taken was to use the turbocharger along with a muffler to reduce the sound characteristic of the snowmobile.

Design Content of Snowmobile

Chassis

Chassis Modifications

To install the Kohler engine into the Bearcat snowmobile chassis, the existing chassis engine mounts and supporting structures required modification. The original chassis tubes that supported the stock engine needed to be removed. These tubes connected two crossbars on the front subframe, and formed a loop reaching rearward to where the stock engine was mounted. As these tubes were solely used for mounting the engine they were not replaced. A finite element analysis (FEA) was conducted on the entirety of the front chassis to confirm it maintained structural integrity with the tubes removed. Figure 1 shows the model used for the FEA of the chassis. The modified front frame, with the new engine mount plates and original engine mount tubes removed increased the rigidity of the chassis; the maximum deflection under an identical load case decreased by 10%. Tabs located on the front bulkhead used to mount the stock engine were also removed. No other modifications to the chassis were needed, as the original over structure had enough clearance for the diesel engine.

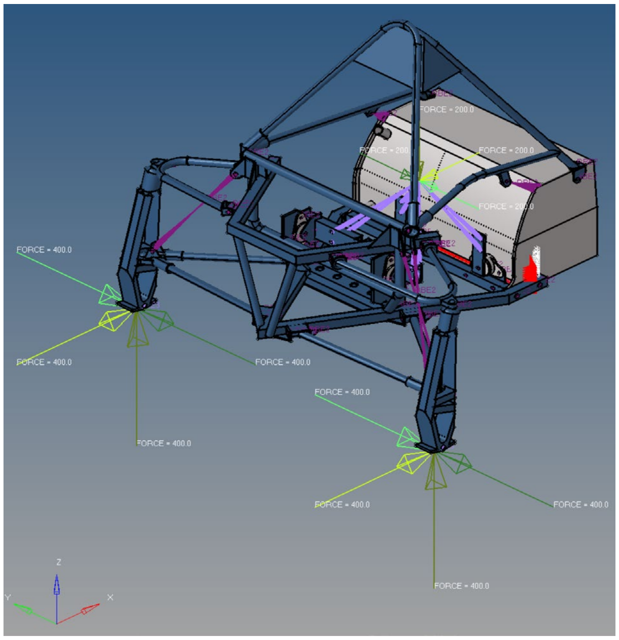


Figure 1: Finite element model of the front chassis as modified

Engine Mount Design

The engine mount design consisted of two steel plates and one supporting bar. The steel plates were welded to the front of the Bearcat subframe with isolation mounts within them. The parts were trimmed for close fitment with the tubing of the chassis and welded where the chassis subframe encountered the plates. The two supporting arms span the front of the engine block to accept the isolation mounts lateral mounting holes. A small section was cut out for clearance of the oil drain piping for the turbocharger. Holes were drilled through the supports to fasten the engine block to the supports, the clutch side holes were reinforced with collars due to close proximity to the tubing’s edge. To secure the bar to the isolation mounts installed in the chassis, 3.2mm plate was cut, fitted and welded to the bar. A 1" square steel bar was integrated into the chassis at the back of the bulkhead to provide a mounting place for the rear engine mounts. The ends of the bar were threaded so as to replace nuts such that the bar would use existing bolts that secured the front frame section to the bulkhead. The mounting plates were bolted to the steel bar, and two 6.4mm steel plates were fabricated to attach the engine to the rear isolation mounts. A36 steel was used as the material for the entirety of this project. All fabricated mounts can be seen in Figure 2, and their CAD models are shown in Figure 3.

Figure 2: Assembled engine mount components in the snowmobile.

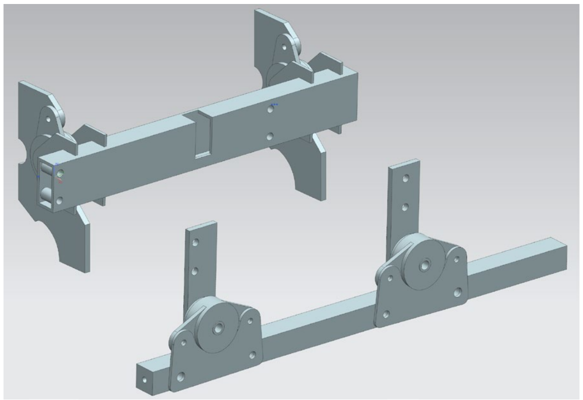


Figure 3: CAD model of the engine mount assembly.

Engine Mount Design Analysis

To determine the performance of the engine mounts under load, a FEA was prepared. Load cases corresponding to an impact of 5g, which simulates a deceleration from 10 mph in less than 0.1 seconds, was used. An additional load case was used for engine operation, with an estimated engine torque of 136 N-m (100 ft-lbs). The loads were applied at the centroid of the engine and distributed to the engine mounts as installed in the chassis. The requirement for the 10 mph impact load cases was that the engine mounts did not experience a stress above the minimum strength of A36 steel, which was 400MPa (58,000 psi). The requirement for the maximum operational torque load case was that the engine mounts would not experience a stress level above the yield strength of A36 steel, which was 248MPa (36,000 psi), with a safety factor of at least 2. Table 3 shows the results of the FEA for each load case.

Table 3: FEA results for engine mounts for each load case, and the factor of safety

Load Case	Maximum Stress	Factor of Safety
Impact Z-	36,000 psi	1.61
Impact Z+	36,000 psi	1.61
Impact Y-	30,000 psi	1.93
Impact Y+	30,000 psi	1.93
Impact X-	56,000 psi	1.03
Impact X+	56,000 psi	1.03
Maximum Torque	15,000 psi	2.4

Exhaust and Aftertreatment

The Team worked with automotive catalyst manufacture to select a DOC and DPF according to the sizing parameters of the engine and chassis. The specifications are shown in Table 4. Using the sizing specifications provided from the manufacture, a prototype system was created using PVC piping. This provided an affordable prototype that would ensure that all the components would fit within the provided packaging space. A picture of the prototype system shown in Figure 4 below.

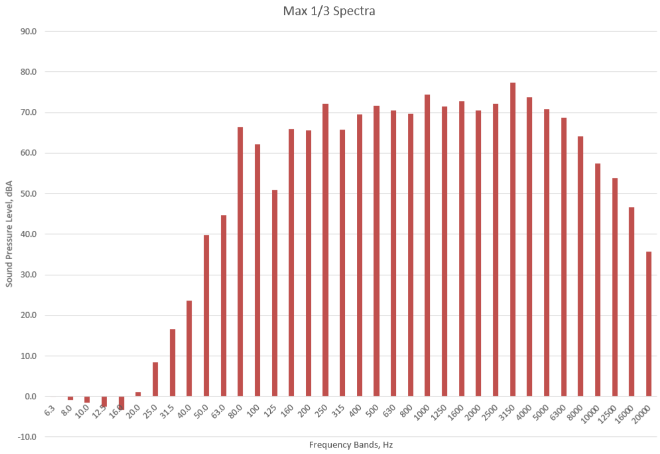
Table4: DOC and DPF sizing specifications

Component	**Dimensions**
DOC	6'' L x 4'' Dia.
DPF	5'' L x 6'' Dia

Figure 4: Prototype mock-up of aftertreatment system

Initial sound testing was carried out on the naturally-aspirated engine by routing the exhaust from the manifold outlet to the original exhaust port found on the Bearcat chassis using a section of flex pipe. The open exhaust test allowed the team to characterize the exhaust noise frequency contributions. A J1162 sound test was conducted and it was found that with an open exhaust, the primary noise contribution was in the 3150Hz band and was contributing 77.3 dBA, while the first harmonic of the engine firing frequency, 80Hz, was measured to be 66.5dBa. this observation directed the muffler design to target higher frequency noise rather than low frequency noise. Figure 5 below shows the sound data plotted over all frequency ranges.

Figure 5: Straight Piped Sound Data



In an attempt to reduce these frequencies a muffler was added after DPF. The selection of the muffler was based on size and exhaust routing constraints. A finished depiction of the exhaust and aftertreatment system shown in Figure 6.

Figure 6: Final exhaust and aftertreatment mock-up

A turbocharger was implemented in order to increase engine power output, help reduce emissions, and assist in reducing the sound characteristic of the engine. Due to space restrictions and vibration of the diesel engine, the addition of the turbocharger required the construction of a fixed mounting bracket on the chassis of the snowmobile. The engine side of the turbocharger exhaust piping contained a flexible pipe to reduce vibrations transferred between the engine and the chassis. The components on the exhaust side of the turbocharger were mounted using a combination of 5 cm diamete stainless steel piping and 5cm diameter flex piping. The flex piping was implemented to aid with the packaging of exhaust as well as to reduce the vibration of components along the system. All components were connected with V band clamps and flanges.

Intake

Because of the physical characteristics of the turbocharger compressor wheel, the noise at the inlet to the turbocharger is much different from the noise at the compressed air outlet.

In the post-turbo air intake, the team is utilized an intercooler to remove the compression heat. By cooling compression intake air, the density increased and provided a higher volumetric efficiency. This process both decreases emissions by allowing more complete combustion of hydrocarbons and carbon monoxide, as well as allowing more fuel to be injected and providing a higher overall power output from the engine. Increasing power output of the engine important to provide an improved rider experience from a small displacement engine. From the outlet of the intercooler, a combination of thin wall stainless steel tube and silicone charge air tubing routes the cooled compressed air into the engine intake.

The pre-turbo air intake design features a custom expansion chamber to utilize the limited space inside the front end of the sled, as well as it's noise reducing capabilities. The expansion chamber measures at 23cm by 15cm in diameter, and 2.3mm thick/ The air intake features a foam air filter to help damp high frequency air intake noise

Fuel System

The engine must be supplied fuel at 0.7 bar (10psi) and a maximum flow rate of 3.8L/min (GPM) at wide open throttle The Team tested the Arctic Cat Bearcat pump with manufacturability in mind. To ensure that the factory fuel pump would provide adequate performance, the pump was tested for both pressure and flow characteristics with diesel fuel. The stock fuel pump was tested to provide fuel at over 1 gallon/minute at 6 volts with the required fuel rail supply pressure of 0.7 bar, far exceeding the necessary flow rate for the engine. Figure 7 shows the results of testing where the fuel pump supply voltage was varied, and the resulting deadhead pressure was measured.

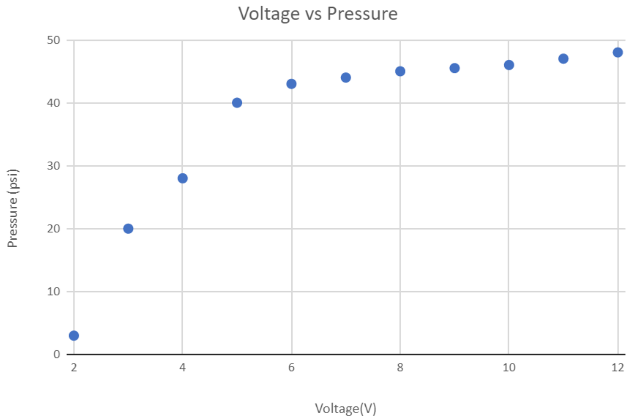


Figure 7: Deadhead fuel pressure vs supply voltage

The stock fuel pump was sized to supply fuel at much higher pressure and flow rates than required by the diesel engine. It was desired to reduce the voltage applied to the pump. This reduced both the power consumption of the fuel pump, and reduced the fuel flow rate, increasing the consistency of fuel pressures throughout the fuel system. The Team used a DC buck converter to drop the voltage supplied to the fuel pump in order to achieve a lower volume fuel supply at the required pressure, reducing the risk of overpowering the fuel pressure regulators, and ensuring steady performance throughout all engine load cases.

A main concern involving the use of the stock fuel pump was its performance with diesel fuel in colder temperatures. Given the tendency for diesel fuel to thicken in colder temperatures and the pump being designed for gasoline, the fuel system was tested to ensure that pressure and volume of fuel supplied by the pump were not diminished by cold weather. The snowmobile was cold soaked overnight with temperatures as low as -24° C (12 F). Testing verified that the filter socks on the pump were starving the pump of fuel during the cold temperature conditions. The fuel socks were replaced with a more suitable filter and the pump was verified to flow an adequate amount of fuel during subsequent testing.

During cold start testing it was also determined that the OEM battery with 17.2Ah and 230 cold cranking amps (CCA) would not be sufficient. The Team chose to relocate a larger battery behind the seat providing 37Ah and 640 CCA. The battery was secured to the sled by strapping it to a steal cradle that was then riveted to the tunnel and encased in the factory rear storage cover. This provided a factory appearance and was a modification that could be easily implemented in a production version of this snowmobile.

ECVT Design

The team decided to implement an electronic CVT assist due to increased control of engine speed and load conditions during snowmobile operation. The application of the ECVT allows the team to optimize the engine operating point for fuel economy and emissions at cruising speeds and allows for better throttle response and reduced turbo lag by allowing the engine to rev to peak RPM before placing high torque demand on the engine. In addition, the ECVT is instrumental in supplying adequate belt clamping force with the lower engine operating speeds of the diesel engine. During testing of the conventional CVT, the primary clutch could not supply enough belt clamping force to prevent belt slip at full shift, even with the heaviest commercially available clutch weights. The performance advantages of controlling belt clamping force independent of engine RPM drove the development of the electronically assisted CVT.

The physical design of the electronic continuous variable transmission (ECVT) consist of both machined parts as commercially-available off the shelf parts. The ECVT uses a stepper motor to electronically apply force to the primary clutch. The stepper motor assists the clutch through the use of a ball screw and slide rails. The carriage of the ball screw is fastened to the slide rail where an arm is attached which protrudes down to the clutch face. Attached to the end of the arm is an automotive throwout bearing. To save the clutch from wear, a bushing is placed in between the throwout bearing and the outer face of the clutch. Mechanical force is transferred from the stepper motor to the ball screw through a circular motion which moves the carriage on the ball screw in turn moving the attached arm. The physical implementation and how the assembly is attached to the engine is shown in Figure 8. Caution was taken to secure the assembly and clutch cover in a way that would not interfere with the stock side panels.Because the clutch assembly will be operating at speeds up to and exceeding 3600RPM, the clutch and electrical assist components will be encased in a metal shield to protect the rider in the case of a mechanical failure. The shield was constructed in accordance with SAE Clean Snowmobile Challenge rule 8.4.7 Figure 9 shows an alternate view emphasizing the ball screw and slide rail components.

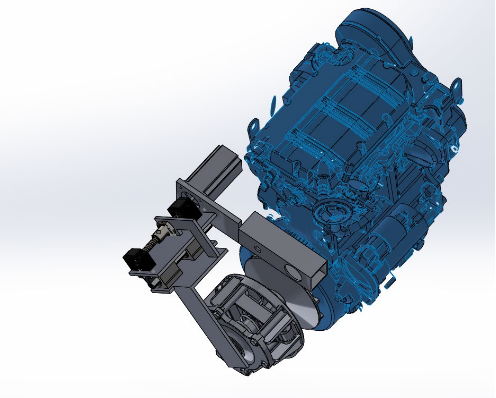


Figure 8: ECVT CAD model stepper motor.

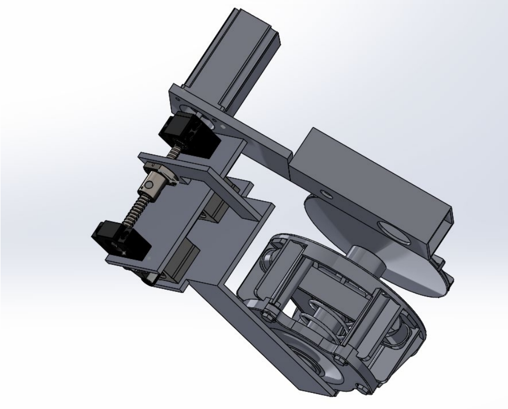


Figure 9: ECVT CAD component view

A feasibility engineering study was conducted by calculating the desired force supplementation and sizing the stepper motor and components to adequately meet the supplementation requirements.

The target peak supplementing force was determined to be 200 lbs force on the moving sheave of the primary clutch. The 200lbs force requirement was generated from approximating typical belt clamping force from a standard snowmobile clutch. The factory Arctic Cat Bearcat engine redlines at 8000 RPM with 54g clutch weights. At peak engine operation the belt clamping generated by the flyweights was calculated to be approximately 980lbs. The team determined that a good starting point would be to target a plus/minus 10% supplementation in clamping force. The theory behind the operation of the ECVT was to under-weight the clutch by 10% and supplement the clutch with a 0-20% addition in clamping force. using the 20% target in increased belt pressure, and the calculated 980lbf requirement for the factory clutch system, a 200 lbf minimum supplementation force was targeted.

To meet the actuator force requirement of 200lbf, the motor and ball screw were sized to provide adequate belt clamping force across all engine speed ranges. The stepper motor chosen for the design is capable of producing 290 in-oz peak torque and 40 rev/s peak speed. The torque/speed characteristic of the selected motor are shown below in Figure 10.

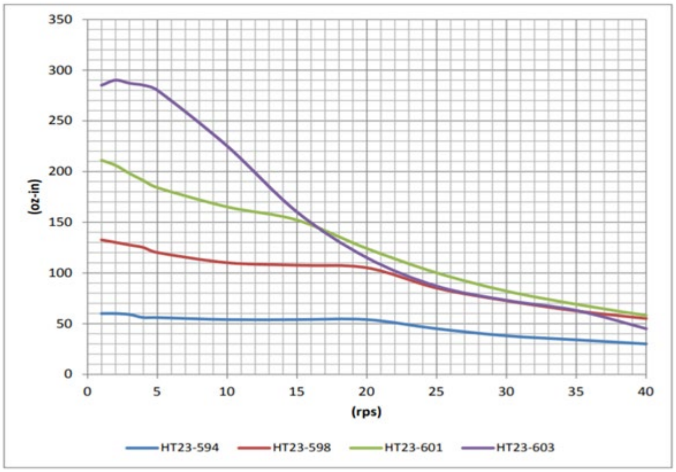


Figure 10: Stepper motor torque/speed characteristic

The torque of the stepper motor transmitted through a 10mm diameter ball screw with a pitch of 6.35mm/rev gives a linear force. The linear force provided by this component arrangement is calculated in Equation 1 where P is the ball screw pitch in mm, Fa is the linear force, and Td is the motor torque.

$$T_d = \frac{F_a \cdot P}{2000 \cdot \pi \cdot \eta} \quad (1)$$

The maximum linear force provided by the stepper motor and ball screw was calculated to be 44 lbf. The linear force of the stepper motor at peak speed was also calculated to be 102 lbf at a linear speed of 10 in/s, and 18 lbf at a linear speed of 5 in/s.

Engine and Vehicle Control

In order to improve performance and control of the KDW993T, the Team made advancements to the snowmobile engine control and CVT.

The ability to control the engine was increased by replacing the standard cable/governor fuel rail actuator linkages with an electronically controlled fuel rail system. This allowed for more precise control of the amount of fuel sent to the engine and allowed the team to compensate fueling for increased manifold pressure due to the turbocharger application.

The vehicle control was improved by supplementing the conventional CVT with and electronic stepper motor. The goal of the electronic CVT assist was to supplement the CVT clamping pressure for increased power due to turbocharging. The ECVT system allowed for more precise control of engine operating speed for given vehicle speeds and user throttle input

The control of both the engine fuel rail and ECVT was implemented using an Arduino microcontroller and Raspberry Pi. Both systems were needed to take advantage of the computation speed capabilities of the microcontroller for engine control, and allowing the raspberry pi to control higher level, less time sensitive tasks including vehicle control and display systems. A block diagram of the control system is shown in Figure 11.

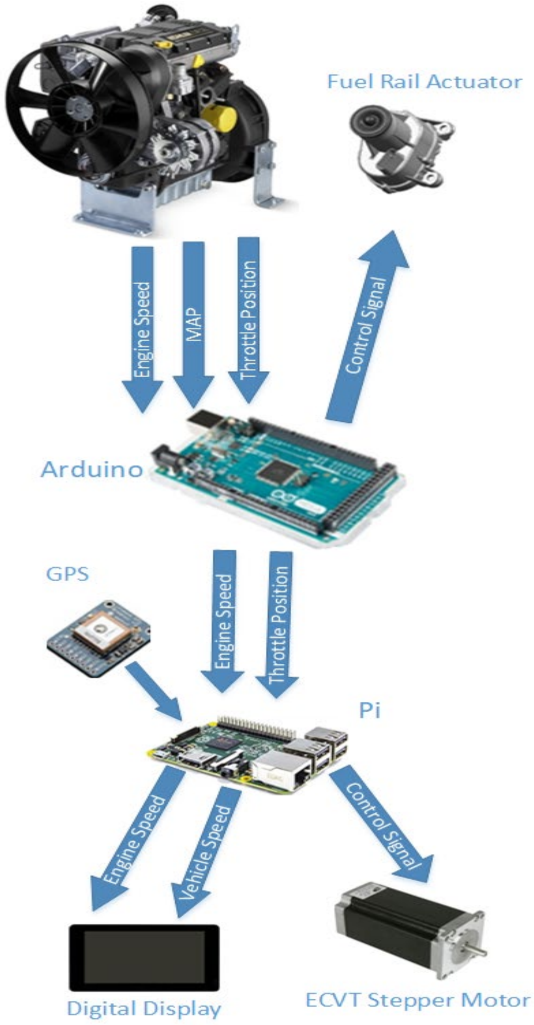


Figure 11: Engine control layout

Using the Arduino as a microcontroller, the Team implemented an embedded control system architecture responsible for receiving engine state inputs from the engine to generate stable fuel rail controls. The Arduino also sent critical engine operating parameters to the Raspberry Pi, which controlled the ECVT stepper motor, vehicle speed, and user display functions.

Data Acquisition

To acquire data from the engine, the Team implemented a crankshaft position sensor, throttle position sensor, fuel servo position, and MAP sensor. These sensor signals were read and monitored at set sampling intervals using C code on the Arduino. In the early stages of development all initial testing and validation was conducted out on the dynamometer, with the inclusion of an emergency intake air valve to prevent engine runaway for the safety of operators and equipment.

To determine the engine speed the team used a magnetic hall-effect sensor and a 35-tooth alternator pulley spaced 10 degrees apart, with one tooth missing. The hall effect sensor was connected to the Arduino via a digital input pin and calculated engine speed based on elapsed time between the rising edge of each tooth pulse. The engine speed calculated was averaged and validated using absorber RPM of an attached water brake dynamometer.

Throttle position and the development of a drive-by-wire system were accomplished by creating a link between the throttle control on the handlebars and a Mikuni throttle position sensor. The position sensor output was read through the Arduino's 8-bit ADC, reporting an integer value from 0 to 1024, which was scaled to 0%-100%. The position of the fuel rail servo motor and MAP sensor value were measured using the same technique.

Control Strategy

FUEL RAIL ACTUATOR strategy

The fuel rail was controlled using the Arduino and a Bosch GPA-S general purpose actuator. The actuator features a DC motor and a hall-effect position sensor, allowing it to be operated as a servo motor. The actuator's internal DC motor is controlled by a PWM signal from the Arduino. The Arduino has two PID controllers that manage the control of fuel for to engine.

The first PID controller generates a target fuel rail position based off of engine speed, Throttle Position, and MAP sensor reading. This PID controller is programmed for low overshoot and high disturbance rejection. The 2nd PID controller drives the actual stepper motor position to the generated target position. The compartmentalization of the two controllers allows for optimization of the fuel rail position tracking, while maintaining stability of the relatively slow response and long sampling delays of the engine control parameters.

Speed and throttle position is fed into a PID controller to generate a correction factor which is then converted into a PWM signal. The PWM signal is then fed into a L293D IC motor driver which steps up the current as the Arduino is not capable of outputting a large enough current to drive the actuator. In order to ensure safe operation and to prevent a possible runaway situation, the code within the Arduino incorporates the following function safety checks seen in Table 5.

Table 5: Fuel rail actuator faults and conditions

Condition/ Fault	**Action**
Loss of communication	Command fuel rail closed
Loss of power	Fuel Rail sent to closed position
Fuel Rail Position reading >95% (short circuit protection)	Command fuel rail closed
Fuel Rail Position reading <5% (open circuit protection)	Command fuel rail closed
Throttle position reading >95% (short circuit protection)	Command fuel rail closed
Throttle position reading <5% (open circuit protection)	Command fuel rail closed
IF (Engine speed > 4,300RPM) (engine runaway protection)	Command fuel rail closed

ECVT Actuator strategy

A 2D lookup table holds a map of ideal target engine speeds based off the vehicle speed and user throttle command. The Raspberry Pi then continuously pulls engine speed, vehicle speed, and throttle position to produce a target engine speed from this table. The target engine speed and actual engine speed are then inputted into a PID controller which calculates an error factor. Based off the error a PWM signal is used to move the stepper motor clockwise or counter-clockwise opening or closing the sheave. Figure 12 below shows a model of the control strategy.

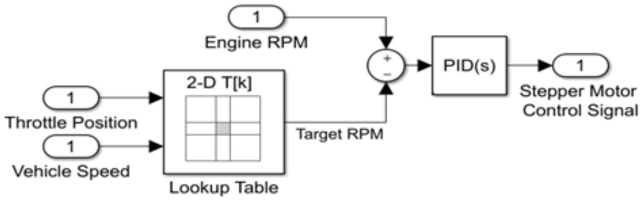


Figure 12: ECVT control strategy

During all operating situations the Raspberry Pi is responsible for monitoring and flagging all faults detailed in Table 6. This ensures proper and safe operation and control. All faults seen below require a key cycle to clear. If the ECVT causes the engine to shut down, the ECVT will be deactivated until it is reset by clearing the fault on the Raspberry Pi. During startup, the Raspberry Pi will wait to allow engine cranking until the ECVT return switch has been made and glow plugs have turned off, this will prevent accidental snowmobile movement in the case of the ECVT remaining engaged. In the event that the ECVT is to remain fully engaged, when the throttle is released the snowmobile brakes will prevent the snowmobile from moving.

Table 6: ECVT Fault Conditions

Condition	**Command**	**Error Threshold**	**Shutdown Threshold**
Key On & Engine Speed =0	Return Electric Assist	Switch not made >2s	Switch not made >2s

Track Speed=0 & Throttle Command=0	Return Electric Assist	Switch not made >1.5s	N/A
Brake Lever Pulled	Return Electric Assist	Switch not made >1.5s	Switch not made >3s
Electronic Assist Active	Actuate Electric Assist	Switch made >5s	N/A

Digital Display

A fully programmable 7in display was integrated using the Raspberry Pi. The Pi allowed access to various engine parameters calculated with the Arduino. The display enhances the usability and functionality of the snowmobile by allowing the rider to monitor key parameters such as engine speed, GPS-based vehicle speed, and other features such as, time of day, elevation, and a wait to start indicator for glow plugs. The fully programmable display also aided in the calibration efforts as key parameters were visible during testing.

Cost/MSRP

To keep manufacturing costs as low as possible, every component added to this year's CI entry was carefully analyzed. After implementation of new components, the final MSRP value of the 2019 MTU CI entry was calculated to be $13,822.00. Since the entry includes advancements in noise reduction, emission reduction, and rider comfort, the MTU CSC Team is confident that the extra $4,473.00 will provide increased value to the customer.

Summary/Conclusions

Michigan Technological University's snowmobile for the 2019 Clean Snowmobile Challenge is a carefully tested and modified iteration of the 2016 Arctic Cat Bearcat. All modifications were completed with manufacturability in mind to ensure future implementation would be feasible. Particular attention was paid during the engine mounting and exhaust fabrication processes to ensure that minimal modifications were made to the chassis, and the snowmobile maintained a clean factory outward appearance. The engine control unit was custom built specific to the engine and fuel rail control characteristics to provide flexible and accurate engine performance. The factory CVT transmission was also modified to optimize engine operating point for different snowmobile speeds and throttle inputs. A turbocharger was added to improve the overall power characteristic of the small displacement diesel engine and improve the emissions output by providing a leaner burn at all engine operating points. The modifications made to the Clean Snowmobile challenge snowmobile were carefully tested and validated to prove their reliability and overall benefit to the performance of the snowmobile, while improving the noise and exhaust emissions characteristic of the snowmobile.

References

Contact Information

Dr. Jason R. Blough is an Associate Professor in the department of Mechanical Engineering at Michigan Technological University and the faculty advisor for both the MTU Clean Snowmobile Team and the SAE Student Chapter at Michigan Tech.

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Acknowledgement

The Michigan Technological University Clean Snowmobile Team sincerely thanks our 2019 sponsors for their contributions and assistance in helping our team engineer a sustainable future for the snowmobile industry:

Arctic Cat Inc
Braap Wraps
Denso Corporation
Fiat Chrysler Automobiles
Ford Motor Company
General Motors
HMK
Deere & Company
Kohler Company
Magna International Inc.
Meritor Inc.
Milwaukee Tool
Nexteer Automotive
Polaris Industries, Inc
Saudi Aramco
V-Converter

Definitions/Abbreviations

CAD	Computer Aided Design
CI	Compression Ignition
CO	Carbon Monoxide
CSC	Clean Snowmobile Challenge
DC	Direct Current
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
ECVT	Electronic continuously variable transmission

HC	Hydrocarbons
MAP	Manifold Absolute Pressure
MTU	Michigan Technological University
MSRP	Manufacturer's Suggested Retail Price
NA	Naturally Aspirated
PID	Proportional-Integral-Derivative
PWM	Pulse-width Modulation
SAE	Society of Automotive Engineers
UTV	Utility Terrain Vehicle