REFINING THE UNIVERSITY OF IDAHO CLEAN SNOWMOBILE

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EXECUTIVE SUMMARY

The 2001 SAE Clean Snowmobile Challenge entry for the University of Idaho (UI) provided proof-of-concept for a clean snowmobile using a four-stroke engine, exhaust after treatment, and electronic fuel injection. This combination provided excellent emissions and fuel consumption performance while maintaining acceptable power and nearly acceptable noise production. The 2002 entry built on this design while focusing on improving the overall efficiency of the snowmobile. The BMW engine was tuned for high altitude operation, higher efficiency components reduced chassis losses, and additional sound damping was utilized throughout the chassis.

DESCRIPTION OF PROBLEM

The Clean Snowmobile Challenge (CSC) is a Society of Automotive Engineers (SAE) student design competition, which was first held in March 2000. The competition was designed to give students throughout the US and Canada the opportunity to further snowmobile technology while gaining valuable design experience. Conventional snowmobiles are powered using two-stroke engines. The two-stroke engine is loud, sometimes in excess of 102 dBA at a distance of 15 m (50 ft) [1], and releases substantially more unburned hydrocarbons and other pollutants than would be released by a comparably powered automobile. The goals of the snowmobile competition focus on reducing these undesirable characteristics of snowmobiles.

APPROACH AND METHODOLOGY

DESIGN GOALS

To refine the UI Clean Snowmobile, several design changes were initiated to reduce exhaust gas and sound emissions while increasing fuel economy and maintaining performance. The first goal was to reduce carbon monoxide and unburned hydrocarbon emissions by at least 50 percent when compared to a standard consumer model two-stroke touring snowmobile. Reducing noise from a snowmobile is also a large priority for the competition. The rules required that snowmobiles produced a sound intensity no greater than 74 dB on the A scale when measured on open ground from a distance of 15 m at a wide-open throttle.

The next goal was to improve fuel efficiency beyond that of conventional touring snowmobiles. The target range for the competition snowmobile is 160 km (100 mi). Each snowmobile must complete a 160 km route through Yellowstone National Park while following a park guide pacing them at a moderate speed of 72 kilometers per hour (kph), (45 mph) [2]. This insured that fuel consumption for all snowmobiles was based on the same duty cycle.

To quantify performance and handling characteristics, the student designed snowmobiles also competed in acceleration, hill climb, and handling events. The acceleration event was based on the time taken to travel 152 m (500 ft) starting from a complete stop. To pass this event, the snowmobile must complete this course in less than 10.5 seconds. The hill climb event took place on a set course up the side of Snow King Mountain in Jackson Hole, Wyoming, during the World Hill Climb Championship. Scoring was assessed based on the time taken for the snowmobile to complete the climb. In the event that a snowmobile did not finish the climb, it was scored based on the maximum elevation reached. To assess handling, each of the snow machines was ridden by at least five professional drivers around a closed circuit course and subjectively ranked [2].

Students also submitted a technical design paper describing the approach taken and the challenges met in designing and building their snowmobiles and completed an oral design presentation. These presentations focus on how the teams' snowmobiles accomplished the goals of the competition. The snowmobiles are also subjected to a morning cold start, and must start within 20 seconds without use of starting fluids. All of the student snowmobiles were on display to the public during the course of the World Championship Hill Climb.

SNOWMOBILE CONCEPT

To meet these design challenges, the UI Clean Snowmobile Challenge team took proven technologies from differing areas of transportation and combined them into their competition snowmobile. A four-stroke engine, whose emission and efficiency characteristics already met the competition guidelines, was placed into an aluminum, sport snowmobile chassis. The already attractive qualities of the four-stroke engine were augmented by the addition of a fuel injection system and a single stage exhaust catalyst.

TEAM ORGANIZATION

The 2002 University of Idaho Clean Snowmobile team consisted of nine undergraduate mechanical engineering students, one undergraduate electrical engineering student, one graduate student, and one faculty advisor. The team divided into six sub-groups assigned to work on the different snowmobile systems.

2001 DESIGN SUMMARY

The UI Clean Snowmobile Challenge entry for the 2002 competition is based on the 2001 competition entry. The snowmobile entered in the previous competition performed very well. It proved to be very durable, finishing every competition without any mechanical or electrical failures. It also ranked high in the fuel consumption, handling, and emissions events. The snowmobile had moderate power but missed the qualifying noise measurement by 0.3 dBA. Given the performance and durability of the 2001 entry, it was elected to focus on improving the deficits observed during that competition, while maintaining the same basic design concepts. The following paragraphs summarize these design concepts. For a more complete description, please see the 2001 design paper [3].

ENGINE SELECTION

Candidate engines were ranked based on exhaust gas emissions, noise emissions, fuel economy, weight, cost, and ease of implementation. Four different types of engines were compared. These engines were: conventional two-stroke, four-stroke, fuel-injected two-stroke, and rotary. The engine selected was a 1991 BMW K75RT motorcycle engine. This engine was chosen for several qualities. First, it is a four-stroke engine, which is inherently more fuel efficient, less polluting, quieter, and more tolerant of exhaust after-treatment than its two-stroke counterparts. The engine displacement is 740 cubic centimeters (cc) which is large enough to produce acceptable power, but under the 960cc limit for entry into the competition. Another desirable quality of this engine was that it could be unbolted from the stock motorcycle transmission. This eliminated the need to cut off or use that transmission. The engine was also chosen for its size. Its physical dimensions were such that it could be mounted under the hood of the selected snowmobile chassis. The primary drawback of this engine was its heavier-than-average weight.

Mounting the engine required a few modifications. A baseplate was mounted on the engine in place of the stock oil pan, enabling the engine to be bolted to the chassis frame. The engine output shaft was adapted to the primary clutch using an adapter shaft. A bearing carriage was also designed to support the side loads exerted on the output shaft through the CVT clutches. Figure 1 shows a photograph of the mounting plate, bearing carriage, and support foot as installed on the snowmobile.

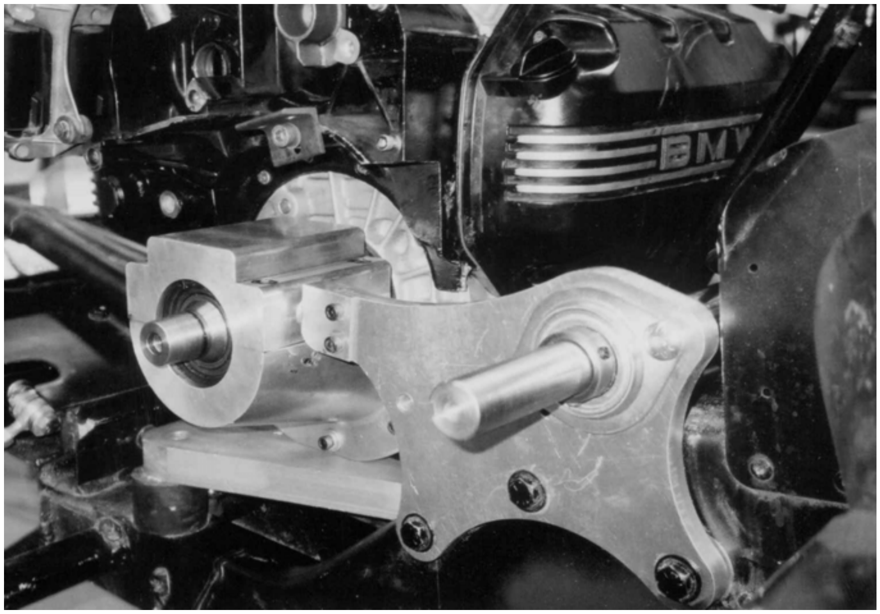

Figure 1 Bearing carriage, motor mounting plate, and support foot.

CHASSIS

The chassis selected for the 2001 competition was a 2001 Arctic Cat SnoPro chassis. It was purchased as a rolling chassis. The lightweight aluminum frame helped to offset the additional weight of the engine. The SnoPro chassis was designed as a racing chassis, and as such has special suspension tuning options not available on a standard chassis. These tuning options were also used to help compensate for the additional weight of the engine. The bearing carriage, which houses the adapted output shaft from the engine, was mounted to the engine using the bolt pattern from the bell housing.

TRANSMISSION

The transmission used for the 2001 competition snowmobile consisted of a standard snowmobile continuously variable transmission (CVT) and chain case. The CVT was tuned for use with the BMW engine. The base primary clutch settings for the competition snowmobile consist of 48.5 gram non-notched cam arms, two 0.152 cm (0.060 in) shims behind the spider, and a red Arctic Cat spring. The primary clutch was connected to a standard Arctic Cat roller secondary clutch, utilizing a 49 degree helix and a blue spring in the fourth hole location. A 0627-004 Arctic Cat belt running on the 27.3 cm (10.75 in) center-to-center distance couples the two clutches.

EXHAUST

The 2001 exhaust system was designed to reduce emissions and engine noise. The exhaust system was routed across the front of the engine compartment, where it could be cooled using incoming air. The naturally lower emissions of the fuel injected four-stroke engine were further reduced by a standard automotive single stage catalytic converter. The final stage in the exhaust system was the stock BMW motorcycle muffler. In places where the exhaust system passed by heat sensitive components an aircraft thermal radiation shielding was used for protection.

FUEL SYSTEM

The fuel system used on the 2001 competition snowmobile was based on the stock BMW multi-port Bosch fuel injection system. The only major modification to the system was the selection of an external fuel pump instead of the stock in-tank pump. The fuel lines were modified using ball valves and T-fittings to accommodate an external fuel tank for use in dynamometer testing.

ELECTRICAL

The finished electrical system on the 2001 snowmobile was composed of both the snowmobile chassis electrical system and the BMW motorcycle electrical system. The chassis electrical system was made up primarily of wires routed to the lights, shutoff switches, and hand warmers. The engine electrical system was made up of the engine management and fuel injection systems. The chassis and engine systems were then adapted together. This required the removal of all the non-essential systems from the motorcycle electrical system and the addition of a special circuit to adapt the chassis engine shutoff system to the motorcycle engine shutoff system.

SNOWMOBILE LAYOUT

To mount the four-stroke engine in the chassis, available space under the hood had to be allocated very carefully. The BMW motor was designed to fit into a street motorcycle chassis. Thus, the engine management components are designed to fit lengthwise along the span of a motorcycle frame. However, a snowmobile chassis only allows for engine component placement centrally under the hood and around the motor. Therefore, the electrical and cooling systems had to be tightly woven within the confines of the bulkhead to integrate the motor into the chassis. In the end, the majority of available room under the hood and beneath the seat was occupied.

The cooling system was rerouted to the right side of the engine. Electrical components were distributed between the area around steering post and fuel tank, and under the seat. The fuel pump was mounted tightly between the tunnel floor and the snowmobile firewall, with the remaining components of the fuel system in their original motorcycle configuration on the top of the engine. Looking at the snowmobile engine compartment from the seat, the exhaust system was routed outward towards the front left side of the engine compartment, bending to the right across the front of the nose cone and exiting longitudinally along the right side of the belly pan. The CVT is housed on the left side of the motor, and the belt drive system is opposite the secondary clutch on the right side of the engine.

2002 SNOWMOBILE DESIGN

ENGINE MODIFICATIONS

The primary focus was to improve the performance of the 1991 BMW K75RT motorcycle engine already incorporated into the design. The engine has a 740 cubic centimeter displacement composed of three multi-port fuel injected cylinders. Several performance enhancement options were evaluated, including turbocharging, aftermarket electronic fuel injection kits, new ignition systems, and cylinder boring and or stroking to produce a larger displacement. It was decided that no major modifications to the engine would be conducive to the goals of the competition if reliability, cost, emissions, noise, and fuel economy were considered. Because the engine was not properly tuned directly before the 2001 competition it was concluded that gains could be made in performance and economy by tuning the engine. Due to the high mileage on the engine, compression tests were conducted to ensure proper engine operation and all seals and gaskets were replaced. In addition to this, a tune-up was performed. This included changing the spark plugs, synchronizing the throttling valves, and changing the oil and filters. To enhance the performance of the engine, a high-flow air filter was installed, and a medium weight 5W-30 oil was added for lubrication.

CHASSIS MODIFICATIONS

The 2002 chassis used was the same Arctic Cat SnoPro used in the 2001 competition. However, several modifications were made to improve its efficiency. A high performance suspension was added to help offset the additional weight resulting from the engine. To achieve the proper suspension response, the valves throughout both the front and rear suspensions were adjusted. The suspension was also resealed to prevent the entry of water into the oil systems.

One source of inefficiency in a snowmobile chassis is the interface between the track and the rails which guide and suspend it. A significant portion of the snowmobile's weight is supported at this location. The motion of the track across this support causes friction, which reduces the power that could otherwise be used for propulsion. To reduce this friction, the stock chassis was equipped with a plastic hyfax. This provided a relatively slick bearing surface at this key interface. To further reduce the frictional losses at this location this hyfax was replaced with a hyperfax system. This replaced the plastic on the stock chassis with a mixture of high-density plastic and Teflon. The addition of this system was expected to reduce frictional power loss and increase the durability of the surface.

Another source of losses in a snowmobile chassis is the path followed by the track as it travels around the suspension underneath the tunnel. This path is composed of some tight turns as the track goes around the drivers and again as it goes around the rear roller wheels. These tight turns make the track more difficult to rotate. To alleviate some of these losses, 20.3 cm (8 in) diameter rear roller wheels were installed in place of the existing 15.2 cm (6 in) wheels. The stock chassis also incorporated four wheels at this location. To reduce weight and increase vehicle turning performance, the two outermost wheels were removed.

Further modification was made to the stock chassis with the addition of a belt drive system. This system is described in the transmission section of this paper, but its implementation required some chassis alterations. This system couples the jackshaft to the shaft that drives the track. This system required that the track's drive shaft be relocated slightly below and slightly behind the stock location. This helped to reduce the severity of the angle made by the track and the drive cogs, and as a result helped make the track easier to turn. However, this reduced the length between the drive cogs and the rear roller wheels, and as a result would require a shorter track. To maintain the same track length, a custom extension was added to the back of the rails. This extension enabled the rear roller wheels to be mounted behind and above their stock positions. This extension also allowed for the increased diameter of the rear wheels.

TRANSMISSION IMPROVEMENTS

The transmission system on a snowmobile is composed primarily of a continuously variable transmission, and a chain case containing a chain and sprocket system to further reduce the velocity and increase the torque output to the drive shaft, and ultimately the track. The CVT couples the engine power output to the jackshaft. It is made up of two clutches, the primary clutch attached to the engine output, and a secondary clutch attached to the input of the jackshaft. The primary clutch senses engine speed and increases the pulley diameter as engine speed increases and inversely, reduces the pulley diameter when the engine speed decreases. The secondary clutch senses the torque output at the interface between the track and snow. As the track torque increases, the pulley diameter on the secondary clutch is reduced. In addition, as the torque diminishes, the pulley diameter is increased. The purpose of this type of transmission is to maintain the engine operation within the range of peak power. As track torque increases the effective gear ratio of the CVT is modified so the engine operating point remains the same. The drawback to this system is that if the CVT is not set up properly, a great deal of power is lost through the clutches. To properly set up the CVT, engine dynamometer tests were performed to determine the engine speed at which peak engine power occurs. Then a series of field tests were run with different components to determine clutching.

First, we incorporated a lightweight clutch. The second part of the transmission is the chain case. This is composed of two sprockets and a chain used to reduce the speed and increase the torque transferred to the track. This gear reduction system is encased in a metal housing and bathed in oil. Instead of this chain case system, the 2002 University of Idaho clean snowmobile utilized a belt drive system. This system is composed of two cogged drums each about 5 cm (2 in) deep, and a matching cog style belt. This system was chosen to reduce the vehicle weight and reduce the amount of rotating mass. A gear reduction of 2.1:1 was chosen as a moderate balance between speed and torque transferred to the track. The drum diameters are substantially larger than the diameters of the sprockets in the chain case and as such transfer power more efficiently. Figure 2 shows a picture of the belt drive installed on the 2002 snowmobile.

Figure 2 The belt drive system.

EXHAUST SYSTEM

The goal of the exhaust and emissions team was two-fold. The first effort was to design an exhaust system that satisfied the space constraints of the snowmobile chassis while including both a silencer and some form of exhaust emissions aftertreatment. The second was to reduce the harmful exhaust emissions, specifically unburned hydrocarbons, oxides of nitrogen, and carbon monoxide. The layout of the 2002 snowmobile made the design of the exhaust system more challenging. The 2002 vehicle contained a belt drive system instead of the standard chain case. This system is much more sensitive to heat than a typical chain case, thus it is more important to keep heat sources farther away from that system. This effectively decreases the volume available for the exhaust system. The exhaust system for the 2002 snowmobile contains a small two-stage catalytic converter and muffler. The role of the catalytic converter was to oxidize unburned hydrocarbons and carbon monoxide while reducing oxides of nitrogen. The muffler then dissipated sound energy to reduce noise emissions.

FUEL SYSTEM

The fuel system used on this year’s competition snowmobile is the same Bosch Jetronic LE that was used in the competition for the previous year. This is the stock fuel injection for the BMW engine. The presence of fuel injection helps the engine burn more cleanly and efficiently. Fuel injection allows fuel consumption to be precisely metered and controlled. The injectors are connected to a control box, which is in turn connected to a number of sensors which sense throttle position, engine temperature, engine speed, and the amount of air being drawn into the engine [4]. Based on these variables, the fuel injection control computer determines the amount of fuel required for optimal performance. Therefore, fuel is used more efficiently than it would be in a naturally aspirated engine.

The BMW's electronic fuel injection does not automatically adjust the fuel/air mixture for changes in altitude. Therefore, during high altitude operation the fuel flow must be reduced to maintain stoichiometric operation. The engine management system used by this engine was not conducive to the addition of an aftermarket fuel injection system. However, there was a way to tune the mixture through the mass airflow sensor on the engine intake.

The airflow sensor on the engine was tuned using a tuning screw. Adjusting this screw alters the flow of air into the engine. Using this method to tune the engine over several adjustments points at idle, a calibration table was developed. This table relates air to fuel ratio to adjustment position. The use of this table helped the team tune the snowmobile at the competition elevation. BMW also produces a high altitude plug, which is essentially a shunt that closes a circuit within the engine control system. The BMW engine repair manual specifies the use of the tuning screw to set the carbon monoxide production of the engine to be about two percent [5]. This was accomplished using a five-gas analyzer with a probe placed in the exhaust before the catalyst.

ELECTRICAL SYSTEM

The electrical system is essentially the same as that used on the 2001 snowmobile. This year the electrical system has been spread out so that each component is easily accessible. Many of the relays and fuses along with the engine control unit were placed in a box located under the seat. Additional fuses were installed to protect the electrical system from short-circuiting. The same safety features are in place on the electrical system as were there on the 2001 snowmobile [3]. The tether switch and engine shutoff switch are connected in series to a relay that cuts power to all the essential systems in the engine. In this configuration, the engine cannot run without both the engine shutoff and tether switches in place. Figure 3 shows a picture of the electrical system layout underneath the seat.

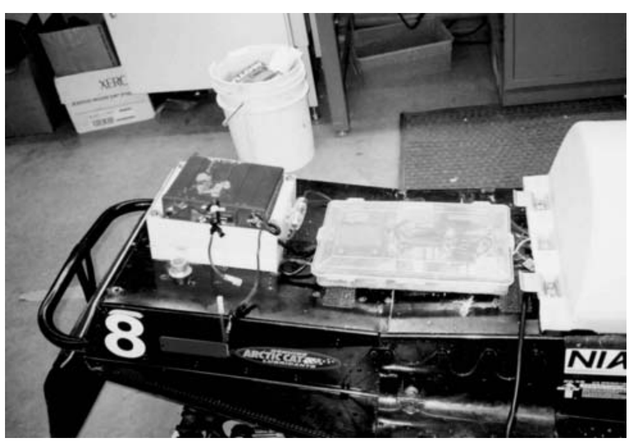

Figure 3 Electrical box and battery under the seat.

SOUND

During the 2001 Clean Snowmobile Challenge, the University of Idaho team barely missed an acceptable sound level measurement. This failure cost at least 100 points, and as a result, several places in the final standings. To avoid similar problems this year additional measures were taken to reduce sound production and sound transmission. To reduce sound production in the snowmobile a larger muffler was installed in place of the stock motorcycle muffler used on last year's snowmobile. This increased the diffusing volume through which the sound must travel, and as a result, energy is dissipated within that volume. Key areas of interest for sound damping are around the clutches, around the belt drive, under the tunnel, and around the engine. To dampen sound resonance under the tunnel, three layers of a sound absorbing surface spray were applied to the underside of the tunnel. Sound damping around the clutches and belt drive system was accomplished using egg crate foam on the outsides of the covers for each of these systems. Engine sound damping was accomplished by lining the entire underside of the hood with foam. Careful consideration was given to the cooling and/or heat insulating of all of the foam lined systems.

SAFETY

The competition snowmobile has several safety features. The first safety feature is the tether switch. This tether attaches to the rider. If the rider is separated from the machine, it stops electricity from reaching any of the electrical systems. The tether circuit is in series with two other switches, the kill switch and the ignition key. If any of these are disconnected, then all engine electrical power is disconnected, including the ignition circuits, fuel pump, and the chassis electrical system.

The electrical system on the competition snowmobile is powered by a twelve-volt battery. The battery is well isolated inside a plastic battery box. The battery used contains dry cells and as such cannot spill. A clutch guard is in place over both the primary and secondary clutches. The guard is made of 0.3175 cm (0.125 in) thick plate aluminum and extends down to the centerline of the clutches. This feature will protect the rider and observers from parts that may break during snowmobile use. An aluminum guard is also in place over the belt drive connection between the jackshaft and the drive shaft.

DURABILITY

As with all consumer products, it is important that the competition snowmobile stand up to the rigors of everyday use. Both the engine and the chassis were purchased, and both are independently rugged, since each was designed by their respective companies to withstand moderate to aggressive use. This is the case with most of the purchased components, and since the competition snowmobile is made up primarily of purchased components, this snowmobile in is expected to be very durable.

In addition, all fabricated parts are overbuilt. The adapter shaft is designed to have near infinite life. The engine mount is made of 3.8 cm (1.5 in) thick aluminum, and the bearing carriage is basically a solid piece of aluminum. With these considerations, the durability of the competition snowmobile is exceptionally high.

COST ANALYSIS

To compare manufacturers' production costs of each of the different teams' design strategies a standardized system was developed and utilized by the SAE CSC organizers that would score each of the snowmobiles based on the components used in them. Various components were then weighted based on how much they would cost a manufacturer implementing a particular design strategy. The fuel system on the competition snowmobile consisted of fuel injectors, a fuel pump, and throttle bodies. The power plant is a 740 cubic centimeter displacement four-stroke engine. Exhaust after treatment consists of a muffler, two-stage catalytic converter, and heat insulation. The only electronics involved in the competition snowmobile are an engine management system and a battery. Noise insulation was employed to dampen sound emissions from the engine compartment. The driveline included an aftermarket belt drive system. After processing the scores based on these components, the final estimated cost to a manufacturer would be $904 for implementing the University of Idaho Team strategy.

TESTING AND RESULTS

To quantify these improvements and better predict competition performance a series of tests were performed on both the engine and chassis. These tests included engine and chassis dynamometer testing done before and after modification, as well as sound, emissions, and fuel consumption tests.

INSTRUMENTATION

Seven primary instruments were used in conducting these tests. Engine tests were performed using an engine dynamometer. The dynamometer is a 22.9 cm (9 in) water brake that bolts on the output shaft of the engine. The dynamometer head is mounted on the engine in place of the primary clutch. The chassis dynamometer tests were performed using a snowmobile chassis dynamometer. This device provided a testing stand for the snowmobile chassis. It coupled to the snowmobile track through a complementary track mounted on the stand. This dynamometer track was then connected to the same nine-inch water brake dynamometer head used during engine testing. Figure 4 shows a picture of the 9 inch dynamometer head attached to the engine output as the snowmobile was sitting on the chassis dynamometer. The sound measurements were done using a sound meter accurate to within 1.5 decibels. Emissions testing was performed at each of the four modes outlined in the 2001 SAE Clean Snowmobile Challenge rules [6]. Emissions measurements were taken using a garage-style five-gas analyzer. This device used both infrared and electro-chemical methods to measure the gas composition by volume. The five-gas analyzer measures unburned hydrocarbons (UHC) as hexane in parts per million (ppm), oxides of nitrogen (NOx) in ppm, as well as carbon monoxide (CO), oxygen gas (O2), and carbon dioxide (CO2) in percent by volume. These volumetric measurements were then converted to mass measurements using an exhaust temperature sensor and exhaust mass flow meter. Fuel consumption was also measured at each of the five modes specified in the 2001 SAE CSC rules. (See Table 1.)

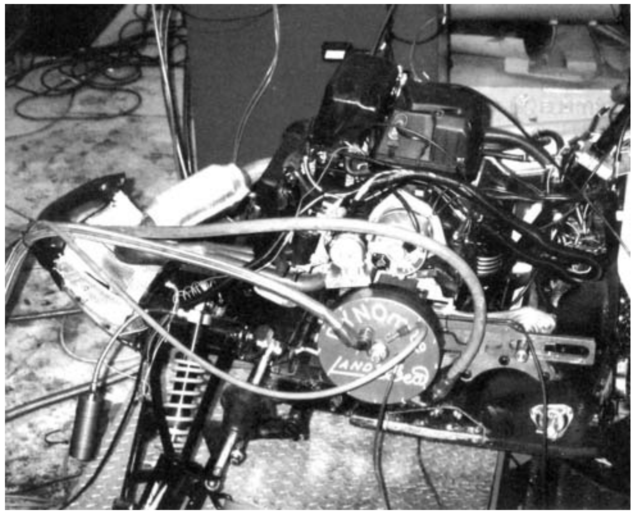

Figure 4 Dynamometer mounted to engine

EMISSIONS AND FUEL CONSUMPTION

Emissions and fuel consumption were measured at four specific operating points prior to any modifications to the 2001 design. The operating points take the form of a percent of the maximum vehicle or engine speed and a percent of the maximum vehicle or engine torque. The 2001 SAE CSC scoring was based on measurements at these points. When measuring engine-based parameters the torque used is the torque at the engine output and the speed is the engine speed in RPM. When measuring chassis-based parameters the torque is the torque produced at the track, and the speed is the track speed in miles per hour. The formulation of each of these specific points is covered in detail in a paper by the Southwest Research Institute [7]. This paper references five specific modes. However, during the 2001 competition measurements at mode 4 were not taken. Since our intention was to compare our data to those taken at the 2001 CSC competition, mode 4 data were not taken in the following tests. Table 1 shows the percentage of maximum engine torque and speed that corresponds to each operating mode. Included in the table are the specific speed and torque values used while testing the University of Idaho snowmobile.

Table 1. Mode Points in Percentage, Engine Modes, and Chassis Modes

	Speed	Torque	Engine Speed	Engine Torque	Track Speed	Track Torque
	% Max	% Max	RPM	ft - lbs	MPH	ft - lbs
Mode 1	100	100	7000	100	51	33
Mode 2	85	51	5950	51	43.35	16.83
Mode 3	75	33	5250	33	38.25	10.89
Mode 4	65	19	4550	19	33.15	6.27
Mode 5	Idle	0	Idle	0	0	0

Brake specific emissions and fuel consumption measurements were taken using the engine dynamometer operating at each of the four CSC modes. Emissions measurements were taken both before and after the catalytic converter to characterize its performance. Table 2

Table 2 Emissions and Fuel Consumption Measurements Taken Before and After the Catalyst

Pre-Cat	**Brake spc**				**BSFC**
	CO	**CO2**	**HC**	**NO**	**BS fuel**
	g / kWh	**g / kWh**	**g / kWh**	**g / kWh**	**g / kWh**
Mode1	193.3	1113.5	3.51	17.3	464.3
Mode2	99.1	1828.4	6.56	17.78	702.9
Mode3	107.1	3225.7	7.62	24.67	1001.3
Mode5*	134.8	8928.1	106.6	15.2	851.6
Post-Cat	**Brake spc**				**BSFC**
	CO	**CO2**	**HC**	**NO**	**BS fuel**
	g / kWh	**g / kWh**	**g / kWh**	**g / kWh**	**g / kWh**
Mode1	216.6	1121.2	1.25	2.44	464.3
Mode2	72.8	1919.4	0.79	0	699.4
Mode3	1.61	3790.6	1.19	10.94	1002.3
Mode5*	4.17	9026.3	2.95	13.64	851.6

* Mode 5 Data are in units of grams per hour (g/hr)

summarizes the brake specific fuel consumption, UHC, NOx, and CO emissions before and after the catalyst for each of the four modes. The table is divided into two parts. The top half of the table contains data taken before the catalytic converter, and the bottom half contains data taken after the catalytic converter. Since the data are presented in a mass per kilowatt-hour, or brake specific form, the fifth mode data are instead presented in units of grams per hour because there is little or no power being produced (although there are certainly emissions produced at idle).

ENGINE AND CHASSIS

Preliminary engine, chassis, and sound tests were performed on the snowmobile prior to any modifications. This provided a baseline to which the results of tests performed after all the modifications could be compared. The baseline engine dynamometer test was performed to develop lugging curves for engine torque and power. This was done by setting the engine speed to values ranging from 7500 to 2000 RPM. At each engine speed, a load was applied to the engine by the water brake. The magnitude of the load was just below the load required to stall the engine at each RPM point. The torque at each point was then measured and plotted on a graph with torque on the ordinate and engine RPM on the abscissa. This torque curve illustrated the maximum torque produce by the engine and at which engine speed this torque was produced.

The baseline chassis dynamometer testing was performed similarly, except that the snowmobile track speed was varied between 96 and 32 kph (60 and 20 mph). The track torque and power were then plotted on the ordinate with track speed along the abscissa to form chassis torque and power curves. This provided a characterization of the track speed at which the snowmobile produced the most torque and power.

These engine and chassis tests were taken again after most of the modifications were in place. Figure 5 compares the engine torque and power curves for before and after modifications. The torque curves are in units of foot-pounds and the power curves are in units of horsepower. This figure shows that the modifications made to the engine did not significantly change its performance. The maximum torque before modification was about 70.05 N-m (51.70 ft-lbs) produced at 6500 rpm and after modification that figure was reduced to 68.56 N-m (50.6 ft-lbs) produced at 6000 rpm. This represents a reduction of about two percent. Based on the estimated error during testing, the change measured was not significant.

Figure 5 Engine torque and power Curves, before and after modification.

On the other hand, the drivetrain modifications did make for some significant improvements in power delivered to the track. Figure 6 shows a comparison of the track dynamometer power measurements taken both before and after chassis modifications were made. This chart represents data taken at the output of the chassis dynamometer, and as a result does not factor in the power lost within the dynamometer apparatus. Because of this the figure does not represent power produced by the snowmobile at the track, however for comparative purposes the power at the dynamometer output is sufficient to characterize the gains made with the modifications in place. Before the chassis modifications, the maximum dynamometer power was 28.3 kW (38 hp) at 80.5 kph (50 mph), and after the modifications that number was increase to 35.8 kW (48 hp) at 80 kph (50 mph). This reflects a 26 percent increase in power at the track compared to the power before modifications. This shows that the modifications made to the chassis were valuable. The primary modifications were the addition of the belt drive system and the increased diameter of the rear roller wheels. These changes reduced rotating mass, and improved the efficiency of the powertrain.

Figure 6 Track dynamometer power before and after modification.

SOUND

A sound test was performed under similar conditions as the CSC acceleration and noise event before any modifications were made. The snowmobile was transported to a site near Elk River, Idaho. At this site is a flat, snow-covered airstrip where the snowmobile could be run at wide-open throttle with minimal sound reflection from the environment. The snowmobile was run three times in each direction at wide-open throttle. The sound meter was placed 15.24 meters (50 ft) away from the center point in the run as specified in the 2001 SAE CSC rules. These results closely matched those from the 2001 Clean Snowmobile Challenge. One suspected cause of the excessive noise measured at the 2001 competition was a hole cut into left side body panel to help cool the clutches. It was hypothesized that the presence of this hole allowed clutch noise to escape. During the testing done at Elk River, measurements were taken before any modifications with the cooling hole first open, and then covered. Figure 7 compares the average of sound levels taken on the right hand side and the left hand side, both with the cooling hole covered and uncovered. The sound pressure level measured with the hole opened is about 75.05 dBA on the left side, where the clutches are located, and 72.81 dBA on the right side. These results match closely to those obtained from the 2001 competition. With the cooling hole covered, the left side sound level was measured as 73.68 dBA and the right side was 72.25 dBA. With the cooling hole covered, the snowmobile would have met the required 74 dBA criterion for both sides of the snowmobile. Considering the application of additional sound damping mechanisms such as egg crate foam and surface sprays the 2002 competition snowmobile was expected to, and did, perform better in the sound event.

Figure 7 Noise emissions from both left and right sides, with and without the hole covered.

After the modifications were made, sound measurements were made at Togwotee Pass near the competition site at an altitude of over 9000 feet. These measurements showed sound levels at 69-70 dBA at that altitude.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

Competition Results and Conclusions

Based on our results during the competition, it is evident that the modifications made to the snowmobile were well worthwhile. The modifications made to the engine did not directly improve the snowmobile performance, but most certainly extended the life of the engine and the results of the engine tests showed that the engine was operating properly during the 2001 competition. The tests also revealed that without extensive alteration the performance of the BMW K75RT engine cannot easily be improved. The results of the chassis tests showed that significantly increasing chassis efficiency is possible with only a small amount of work. The power at the track was increased by 26 percent with no change in engine power. Since engine performance was unaltered, it was expected that the emissions and fuel consumption of the snowmobile would be maintained at an acceptable level. The 2001 snowmobile achieved a 59 percent reduction in CO, an 84.1 percent reduction in UHC, and a 39.7 percent reduction in NOx. The reduction in the combined UHC and NOx was 83.5 percent. Figure 8 shows the results for the University of Idaho Snowmobile in the 2002 competition. The 2002 UI snowmobile achieved an 82 percent reduction in CO and over a 99.5 percent reduction in UHC when compared to the control snowmobile, second best in the competition, and one of only six snowmobiles to meet the emissions requirements.

Figure 8 Emissions results in the 2002 CSC competition

The sound emissions were reduced by the addition of a larger muffler and better hood sealing. These were sufficient to reduce the sound levels below the 74 dBA at required by the competition. The University of Idaho was one of only three schools whose snowmobiles met this stringent requirement. In comparison, the standard stock snowmobile used as a control was measured at 80 dBA. Figure 9 shows the sound emissions results for the University of Idaho in both 2001 and 2002.

Figure 9 Sound results in the 2001 and 2002 CSC competitions

The University of Idaho 2002 CSC competition snowmobile was one of only four snowmobiles to complete the 100 mile endurance run. It did so with a fuel economy of over 18 miles per gallon, best in the competition, and an improvement of 56 percent over the control snowmobile.

The University of Idaho 2002 snowmobile also won the World Championship Hill Climb in Jackson Hole, and was named "King of the Hill" for the SAE CSC Division for 2002 (taking home both the belt buckle and bragging rights). In combination with the performance in the events of handling and acceleration, the Hill Climb victory also assured the University of Idaho the Award for Best Performance.

The University of Idaho also scored third in the Design Paper, second in the Static Display, and fifth in the Oral Presentation, and was awarded the "Best Design" trophy.
Overall, the Idaho team was awarded First Place in the 2002 CSC competition, with a total of 1171 points. We achieved the Best Fuel Economy, Best Design, Best Performance, and King of the Hill awards. The modifications made to the 2001 competition snowmobile certainly were worthwhile.
post-competition emissions testing

Based on performance during the competition, the top five finishers in the emissions portion of the competition were invited to bring their snowmobiles to the Southwest Research Institute (SwRI) for more detailed emissions testing. The University of Idaho was one of two student teams who attended. Detailed emissions testing of the type done at the 2001 CSC [7] were performed on the student-built sleds, and also on two commercially available four-stroke snowmobiles. The University of Idaho 2002 competition snowmobile was the cleanest one tested. Figures 10 and 11 show the results of the testing for carbon monoxide (CO) and unburned hydrocarbons (UHC). The emissions results are also shown for a typical two-stroke touring snowmobile.

Details of the testing methods and results are given in reference [8].

Figure 10 Emissions results for carbon monoxide at SwRI

Figure 11 Emissions results for unburned hydrocarbons at SwRI

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