DESIGN OF THE UNIVERSITY OF IDAHO CLEAN SNOWMOBILE

FINAL REPORT
SEPTEMBER 2001

Report Budget Number KLK303
NIATT Report #N01-16

Prepared for

OFFICE OF UNIVERSITY RESEARCH AND EDUCATION
U.S. DEPARTMENT OF TRANSPORTATION

Prepared by

NIATT

NATIONAL INSTITUTE FOR ADVANCED TRANSPORTATION TECHNOLOGY
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EXECUTIVE SUMMARY

The Clean Snowmobile Challenge is a Society of Automotive Engineers (SAE) student design competition that was first held in March 2000. The competition is 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 a two-stroke engine. 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 primary goals of the snowmobile design focus on removing these undesirable characteristics from snowmobiles.

The goals of the 2001 University of Idaho (UI) Clean Snowmobile Team were to reduce snowmobile exhaust and sound emissions while maximizing fuel efficiency and performance. The competition snowmobile consisted of a four-stroke BMW K75RT motorcycle engine mounted into a 2001 model Arctic Cat SnoPro chassis. A special motor mount was designed to attach the engine to the chassis, and special carriage developed to match the primary clutch to the engine. A custom exhaust system consisting of a single stage catalyst and muffler was designed to control hydrocarbon and noise production. Modified electrical and fuel pumping systems were implemented to maintain the stock fuel injection system.

The UI Clean Snowmobile for 2001 finished fifth in its first year of competition. It exceeded the emissions reduction requirements. The competition snowmobile achieved a 59 percent reduction in carbon monoxide, an 84.1 percent reduction in unburned hydrocarbons, and a 39.7 percent reduction in nitrogen oxides. The reduction in the combined unburned hydrocarbons and nitrogen oxides was 83.5 percent. The competition requirements were a 25 percent reduction in carbon monoxide and a 50 percent reduction in the combined unburned hydrocarbons and nitrogen oxides. The results from the fuel economy test showed that the competition snowmobile completed the 162 km (100 mi) course while consuming 19.08

liters (5.04 gallons) of gas, resulting in a fuel economy of 8.43 km/l (19.8 mpg), second best in the competition. The fastest acceleration run for the Idaho competition snowmobile was 8.28 seconds, while the loud side of the snowmobile produced sound emissions of 74.7 dBA at 50 feet. Thus, unfortunately the sound emissions for that side were slightly above the 74.4 dBA requirement. During the cold start test, the competition snowmobile started up within two revolutions of the engine, fastest in the competition. The UI snowmobile placed second in the handling event. The snowmobile also possessed sufficient power to make it to the top of the hill climb. During the competition, the snowmobile had no problems and required no maintenance or repairs.

The UI Clean Snowmobile showed reduced emissions well below the competition's requirements. Fuel economy was doubled, and sound emissions were reduced to a level 0.3 dBA above competition requirements. All of this was done without significantly affecting the snowmobile's performance or durability. The cost involved in producing this snowmobile is $950 above the cost of the chassis. The UI Clean Snowmobile provides an excellent balance between cost, environmental soundness, and consumer acceptability.

DESCRIPTION OF PROBLEM

The two-stroke cycle engine is currently used in a myriad of applications requiring a lightweight construction and a comparatively high power output. These applications range from a weed- eater motor to an alternative power unit for hybrid electric vehicles. Perhaps key among these applications are recreational vehicles such as motorcycles, personal watercraft and snowmobiles. The trouble with the power plants that drive these applications is that they are noisy and have poor emissions quality. Both of these characteristics are unacceptable in today's world where clean air and quiet countrysides are valued more highly than ever before.

Currently there are a number of approaches that people have taken to try and correct these problems. Research institutions like the Queen's University of Belfast are trying to find ways to improve the polluting nature of two-stroke engines. Some recreational vehicle manufacturers like Redline Snowmobiles are working with lightweight four-stroke engines.

In response to ever more stringent regulations on exhaust pollutants and noise imposed by the National Park Service and other government agencies, the Society of Automotive Engineers (SAE) instituted a student competition. The goal of the SAE Clean Snowmobile Challenge is for student organizations to produce a snowmobile that will conform to the national parks regulations and still perform well enough to obtain public approval. The UI Clean Snowmobile Team competed in this event for the first time in 2001 with a snowmobile powered by a four-stroke motorcycle engine.

APPROACH AND METHODOLOGY

The main design goals focus on reducing exhaust gas and sound emissions while increasing fuel economy. The first goal was to reduce carbon monoxide emissions by at least 25 percent and a combination of unburned hydrocarbon and nitrogen oxide emissions by at least 50 percent when compared to a standard consumer model two-stroke touring snowmobile. Reducing noise from a snowmobile was also a large priority for the competition. The SAE rules require that snowmobiles produce a sound intensity no greater than 74 dB on the A scale when measured on open ground from a distance of fifty feet 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 100 miles. Each snowmobile must complete a 160 km (100 mi) route through Yellowstone National Park while following a park guide pacing them at a moderate speed [5]. This insures that fuel consumption for all snowmobiles is based on the same power cycle.

In order to quantify performance and handling characteristics, the student-designed snowmobiles also compete in acceleration, hill climb, and handling events. The acceleration event is based on the time taken to travel 152 m (500 ft) starting from a complete stop. In order to pass this event, the snowmobile must be able to complete this course in less than twelve seconds. The hill climb event takes place on a set course up the side of Snow King Mountain in Jackson Hole, Wyoming. Scoring is assessed based on the time it takes the snowmobile to complete the climb, or the maximum height reached if it does not reach the top. To assess handling, each of the snow machines is ridden by eleven professional drivers around a closed circuit course and subjectively ranked [5].

In addition, students must submit a technical design paper describing the approach taken and the challenges met in designing and building their snowmobiles. Each team also provided an oral design presentation. This presentation must focus on how the individual snowmobiles accomplished the goals of the competition. During the course of the World Championship Hill Climb, all snowmobiles were on display to the public. The sled was also subjected to a morning cold start, and was required to start within one minute without the use of starting fluids.

The team's goal was to not only produce a snowmobile that met or exceeded all of the other design goals, but to produce it while maintaining a price tag comparable to a current market model. In order 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 motorcycle 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.

Engine

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. To rank these engines, each of the selection criteria was weighted by its importance to the competition. This importance was determined by the percentage of the overall competition score allocated for each of the criteria. The criteria whose scores most influenced the overall score were weighted higher. As such, exhaust and sound emissions were weighted most, while weight and consequently handling were weighted lightly.

The four-stroke engine led in the categories of emissions, fuel economy, and noise output while maintaining a relatively high ease of implementation. This method of reasoning illustrated the most feasible solution given the design parameters. Furthermore, in the last decade there have been significant advances made in four-stroke technology that improve the power to weight ratio. Four-stroke engines naturally burn cleaner and are more fuel-efficient than two-stroke engines. Four-stroke engines burn a significantly higher percentage of the fresh fuel charge per power stroke because the engine goes through a discrete power stroke where none of the products of combustion are lost. The engine then goes through a discrete exhaust stroke where all of the combustion products are forced out of the engine. In two-stroke engines, there is a period of time when both the intake and exhaust ports are open at the same time. As a result, some of the fresh charge is swept out the exhaust port without going through combustion process. This process is wasteful and usually results in high levels of unburned hydrocarbon emissions.

The next phase of engine selection was to specify a particular four-stroke engine. Again, several criteria were outlined to compare the engines that were encountered. These criteria concerned the design constraints imposed by the Clean Snowmobile Competition and the various mechanics of snowmobiles. Competition guidelines impose a displacement limit of 960 cubic centimeters on four-stroke engines [5]. The engine should provide a balance between power and weight that is conducive to snowmobiling. The engine should physically fit under the hood of a commercially available snowmobile chassis. It should be easily adaptable to a standard snowmobile continuously variable transmission (CVT). The engine should be fuel injected. It should possess power and torque curves similar to a stock snowmobile engine, in order to insure the availability of clutch parts.

After comparing various different engines, a 1991 BMW K75RT motorcycle was selected. This is a motorcycle engine, so it was not too large for the competition, but still produces enough power to run a snowmobile. It is fuel injected. It fit nicely under a snowmobile chassis hood with little modification to the hood. It fell within the displacement criteria at 740 cubic centimeters. It produces peak power at 8500 rpm [3], which is similar to a stock snowmobile engine. This engine also allowed for ease of adaptability to a CVT. Unlike most motorcycle engines in which the engine and transmission are cased together, the BMW engine can be unbolted from the transmission leaving a short splined shaft power takeoff. All of these characteristics made this engine an excellent choice for the competition snowmobile.

Chassis

Competition guidelines state that the chassis must be commercially available [5]. The only other criteria used were that the chassis needed an engine compartment large enough to accommodate the BMW engine and had to be as light as possible to offset some of the additional weight introduced by the engine selection.

A 2001 Arctic Cat Limited Edition “SnoPro” chassis was chosen. This chassis was best suited for our application for three main reasons. First, the SnoPro edition chassis could be purchased brand new from the factory in a “rolling” chassis form. Rolling chassis come delivered ready for full operation but without the engine and engine management systems. The scope of this competition is not to build a chassis, so purchasing a rolling chassis was the best solution. Second, this SnoPro chassis is designed with extra detail paid to the suspension tuneability and overall chassis durability, enabling it to withstand the rigors of closed circuit racing. The added suspension control is required to handle the increased front-end weight due to the four-stroke engine. Finally, the chassis was selected because it is thirty pounds lighter than a consumer Arctic Cat chassis. This reduction in weight helps offset the heavier engine.

Very little chassis modification was required. The chassis was delivered with everything that was necessary to run the snowmobile, including chassis electrical wiring for lights and instrumentation, except the engine. The chain case gear ratio was changed to enable the snowmobile to better meet the goals of the competition by decreasing the upper drive sprocket to 18 teeth, resulting in a final chain case speed reduction of 18:40 with a 70 pitch 15 link chain.

Engine to Chassis Adaptation

The BMW engine was designed to mount in a hanging configuration in the motorcycle frame. As a result, the structural engine mount locations are on the upper half of the engine. The chassis, however, is designed to accept an engine with mounts on the bottom. Located on the bottom of the motor is a fourteen-bolt pattern to which the engine oil pan is mounted. This bolt pattern lies in a flat plane at the base of the motor. The presence and orientation of this bolt pattern facilitated the fabrication of a combination oil pan and motor mount plate. This part matches up with the engine mount points on the chassis bulkhead, and also substitutes for the original oil pan. This was accomplished by using two templates and a placement jig. First a chassis template was mounted to the bulkhead rails and the oil pan template was mounted to the base of the motor. In order to correctly position the engine on the chassis, consideration was given to the alignment of the existing secondary clutch on the chassis with the primary clutch on the engine. If the two clutches are not aligned properly the heat developed from belt friction could destroy the belt. This alignment is a function of two things: the offset distance of the primary clutch from the motor, governed by the length of the shaft connecting the motor to the clutch, and the length of the belt coupling the two clutches. The adapter shaft for the primary clutch is discussed in the transmission section of this paper (p.9).

The length of the adapter shaft governs the lateral, side-to-side, placement of the engine in the chassis. The belt length then governs the front-to-back position of the engine. Selecting a drive belt center-to-center distance of 27.3 cm (10.75 in) allowed for the construction of a placement jig that could place the engine at the correct fore and aft position in the chassis and

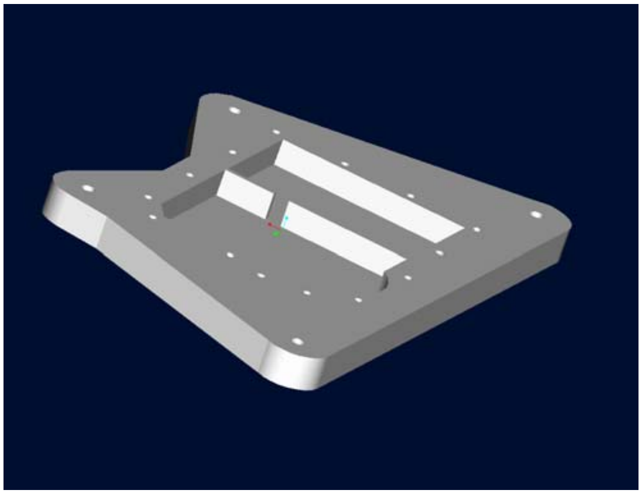

Figure 1. Motor Mounting Plate

locate the two templates relative to each other. This illustrated the relationship between the bolt pattern for the chassis mounts and the bolt pattern for the oil pan. Given the individual bolt patterns and their relation to each other, a mounting plate that doubled as an oil pan was constructed mounting the engine to the chassis through the bolts in the oil pan. Figure 1 shows the motor mounting plate/oil pan.

Drivetrain

The design goal for the power train of the competition snowmobile was to accelerate the sled safely and reliably while delivering the maximum power to the track and thereby the snow. The drivetrain consists of everything from the stub shaft protruding from the engine to the snowmobile track. These components are an adapter shaft, a standard ninepin primary clutch, a secondary clutch (coupled to the primary clutch via a belt), and an 18:40 gear reduction between the secondary clutch and the snowmobile track.

Transmission

In order to transfer power from the engine through the chassis drive train, a standard Arctic Cat nine post primary clutch was used. 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 is connected to a standard Arctic Cat roller secondary clutch, utilizing a 49-degree torque bracket 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.

Transmission-Engine Adaptation

One of the great benefits of the BMW engine is that the transmission could simply be unbolted from the engine. Once the transmission was removed, the engine output was exposed as a splined stub shaft. However, the primary clutch required a shaft with a taper.

To couple the primary clutch to the engine output shaft, an adapter shaft had to be designed and fabricated. One end of this shaft matched the engine output shaft; the other end was tapered to accept the primary clutch. This adapter shaft is a billet component cut out of 4140 high strength low alloy steel. The diameter of the shaft was fixed by the diameter of the taper in the clutch and the matching diameter on the engine output. This material was selected in order to withstand the torque and moment applied as a result of the CVT. Figure 2 shows the adapter shaft.

The bearings supporting the BMW motor output shaft were not designed to handle the side load generated by the CVT belt tension. In order to isolate the internal motor bearings from the side loads, an additional set of bearings had to be introduced. These bearings fit around the adapter shaft and were supported by a bearing carriage. The bearing carriage mounted to the engine through the boltholes, which originally mounted the transmission bell housing. Figure 3 shows a solid model of the bearing carriage. The next issue to arise was that the bell housing material was not intended to withstand the loads that were applied on it through the

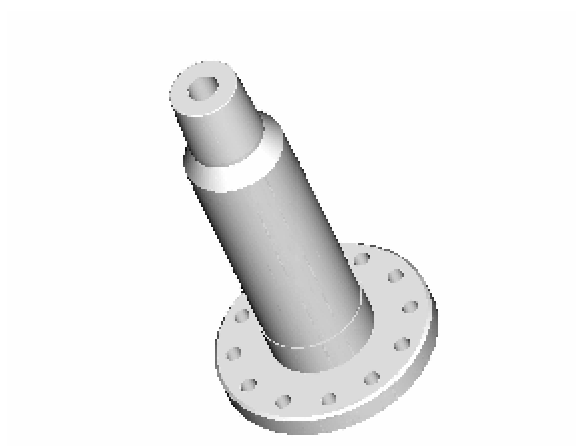

Figure 2. Engine Adapter Shaft

bolts in the bearing carriage. Without added support the CVT belt tension would pull the bolts out of the engine block. This problem was solved by using an aluminum foot mounted to the chassis against the bearing carriage, relieving some of the load from the bolts attaching the carriage to the engine. Figure 4 shows an exploded view of the bearing carriage, bearings, adapter shaft and support foot.

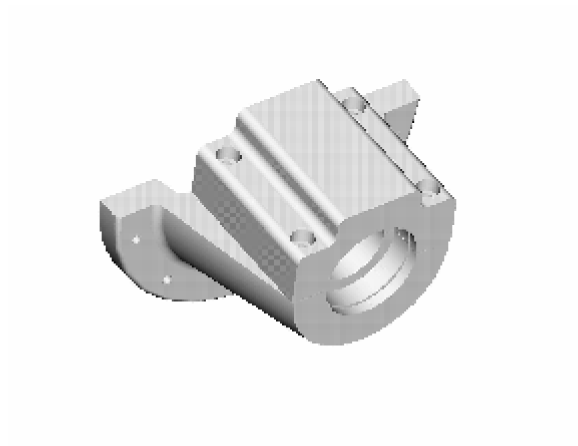

Figure 3. Adapter Shaft Bearing Carriage

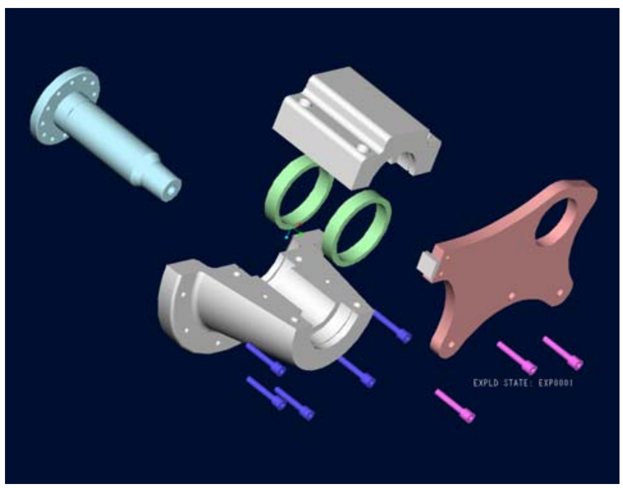

Figure 4. Assembly of Fabricated Parts

Exhaust System

Unlike two-stroke engines, a four-stroke engine is rather forgiving of exhaust treatment. This feature allows the exhaust to be cleaned and silenced beyond the limits of most two-stroke engines. The exhaust design for the competition snowmobile targets carbon monoxide and unburned hydrocarbons in three ways. A four-stroke engine, which burns fuel more efficiently, was selected. Second, an electronic fuel injection system regulates the delivery of fuel more effectively than a carburetor. The fuel injection system is discussed in greater detail in the fuel system section (p. 13). Finally, a standard automotive single stage catalytic converter was added to the exhaust system. This component uses a catalyst to burn off the majority of the unburned hydrocarbons in the exhaust stream before they can escape into the environment.

The exhaust system was routed to fit within the confines of the engine compartment. The head tubes were built to channel the exhaust towards the front center of the engine compartment where the catalytic converter was placed. Heat that is produced by the catalytic converter was dissipated by placing the converter in the front of the nose cone where it could be force induction cooled by the air passing through the front of the snowmobile. The exhaust was then channeled around to the right of the engine where the stock muffler would have been located. This was a convenient location since this is where the exhaust silencer would have been on a two-cycle snowmobile. To provide a radiant heat barrier between the plastic belly pan and the exhaust system, critical surfaces were covered with aircraft heat shielding.

Figure 5. Catalytic Converter and Heat Shielding

To achieve the goal of an operating sound pressure level of below 74 dBA, the stock BMW motorcycle muffler was maintained, along with the added catalytic converter. The BMW K75 is a very quiet motorcycle and the original muffler remains intact, so the snowmobile should also be quiet. This muffler is located along the right side of the engine where it would have been for a two-stroke engine and is surrounded by heat shielding. Figure 5 shows the placement of the catalytic converter and the heat shielding along the body panels.

Fuel System

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 that sense throttle position, engine temperature, engine speed and the amount of air being drawn into the engine [6]. 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 fuel injection system employed by the competition snowmobile does not employ a lambda loop system. This means that the fuel injection controller does not vary the fuel supplied to the engine based on the unburned hydrocarbons measured after the catalytic converter. Figure 6 shows a diagram of the fuel supply system. The path of the fuel goes from the tank to a fuel pump then to a fuel filter and onto the fuel rail. From there, the fuel goes either to the injectors and into the engine, or it is bypassed through a fuel pressure regulator and returned to the tank. Fuel injection systems are high-pressure systems, often in excess of 200 kPa (30 psi). This pressure helps to atomize the fuel as it enters the combustion chamber, where it can more completely mix with the incoming oxygen and thus combust more efficiently.

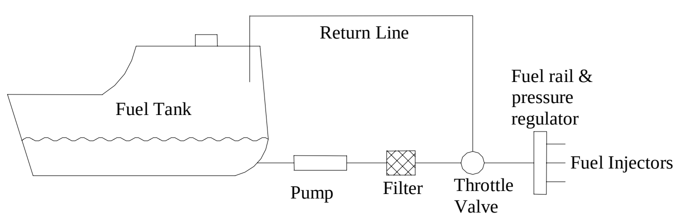

Figure 6. Fuel Delivery System Diagram

The high-pressure nature of this system is at the root of one of the challenges that were faced in adapting this system to the snowmobile. On the motorcycle the fuel pump was located in the fuel tank where it could be cooled by the fuel reservoir. The BMW system was designed to deliver fuel at 250 kPa (36 psi) at a rate of 0.78 l/min (12 gallons per hour-gph). This target pressure and flow rate were particularly hard to match because the required flow rate for the fuel is so low. Automotive fuel pumps have rated fuel flow rates of much higher than twelve gallons per hour. Another difficulty was finding an external fuel pump that would handle the required pressure. An external fuel pump was chosen for ease of adaptation to the snowmobile. No adaptations were made to the air and fuel sensors, fuel rail, electric control system, or throttling valve. Replacements in the fuel system included the fuel tank, electric fuel pump and connecting lines. The in-tank fuel pump that was standard on the BMW was replaced with an external pump that delivered the necessary pressure, but at a flow rate of 2.6 l/min (40 gph). This pump was an aftermarket fuel pump for a motorcycle with a higher displacement than the BMW. Since the BMW only requires a fuel flow rate of 0.78 l/min, the rest of the fuel returns to the tank through the fuel pressure regulator.

Electrical System

The electrical system consists of two major components, the engine electrical system and the chassis electrical system. These two systems were already in place when the engine and chassis were obtained. The chassis electrical system was designed for use with a two-stroke engine with a pull-cord start [2]. The BMW engine did not require some of the components on the chassis and required some elements that were not on the chassis. Both electrical systems required modification.

The Arctic Cat SnoPro chassis already had the necessary wiring in place to control the lights and hand warmers. It also came with a tether and kill switch for stopping the engine and turning off all electrical systems in the case of an emergency. The kill circuit built into the chassis electrical system was designed for use with a two-stroke engine. With this configuration, the kill switch grounds a wire coming from the ignition circuits [2]. This would stop the engine, and therefore turn off all electrical systems. In order to use the existing circuit, a relay was adapted so that when one of the switches was flipped, the circuit that originally grounded the ignition circuits would energize the relay. The relay was wired in such a way that if it were not energized, power would flow through it to the rest of the electrical systems. But if the relay were energized, it would switch and disconnect the power supply from the electrical systems. Pulling the tether or flipping the kill switch will activate the relay actuator and cut electrical power to the engine and chassis.

Use of the BMW K75RT engine required modification of the motorcycle wiring in order to eliminate all unnecessary components. These components included all dashboard readouts, optional equipment, headlights and turn signals. The manufacturer's wiring diagram was used to determine which of these components could be removed without impeding engine operation [4]. Eliminating unnecessary equipment from the engine wiring allowed ease of troubleshooting problems in the engine and chassis electrical systems by separating them from each other. One of the primary reasons for choosing the BMW K75RT engine was that it is fuel injected. This feature augmented the four-stroke engine's natural ability to burn more cleanly and use fuel efficiently. This feature also required a great deal of peripheral electronics that had to be adapted to the snowmobile chassis. These electronics primarily took the form of two boxes housing the control for the fuel injection system, and the electronic ignition system. Along with these boxes there were several fuses and relays. These fuses and relays were gathered and placed into another box where they could be easily accessed. All three boxes were then mounted to an aluminum plate and placed in the engine compartment directly behind the wall separating the engine compartment from the instrument console.

Safety

Safety is always of the utmost importance when snowmobiling. As such, the UI competition snowmobile hadseveral safety features built into it. The first safety feature was 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 three switches, the tether, 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. Also, if the airflow sensor senses that no air is flowing into the engine then it turns off the fuel pump [6]. Therefore, if the engine dies, the fuel pump will stop pumping.

The electrical system on the UI competition snowmobile is powered by a twelve-volt battery. The battery is well isolated inside a plastic battery box. The battery is made of a gel cell and as such cannot spill. A clutch guard is in place over both the primary and secondary clutches. The guard is made of one-eighth inch thick plate aluminum and extends down below the centerline of the clutches. This feature will protect the rider or observers from parts that may break during snowmobile use.

Snowmobile Layout

In order 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

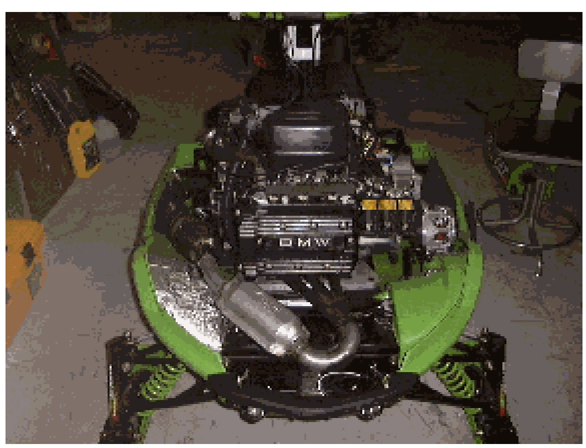

Figure 7. Front View of Snowmobile and Components

component placement located centrally under the hood 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 our chassis. In the end, the majority of available room under the hood and behind the seat was occupied. Figure 7 shows the layout of the components in the engine compartment.

The cooling system was rerouted to the right side of the engine. All electrical components are placed between the steering post and the fuel tank on an electrical panel. The fuel pump is mounted tightly between the tunnel floor and the electrical panel, 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 is routed directly outward from the front of the engine, bending to the right and exiting longitudinally along the belly pan. The CVT is housed on the left side of the motor and couples with the stock drive train. Figure 8 shows the placement of the battery in the rear compartment of the seat.

Durability

As with all consumer products, it is important that the competition snowmobile be able to stand up to the rigors of everyday use. The strategy used to insure that the snowmobile remained durable under normal operating conditions had two parts. The first part of the strategy revolved around the nature of the components used. Both the engine and the chassis

Figure 8. Battery Box Location

were purchased and both are independently rugged, since each was designed by its respective company 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 is expected to be very durable.

The second part of the strategy has to do with the fabricated parts. 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.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

Testing

After the snowmobile was running properly, tests were run to determine if the machine would meet the design goals. The snowmobile was tested for emissions, fuel economy, acceleration, noise emissions, and ability to start cold. The emissions test was performed on a snowmobile chassis dynamometer. The test procedure consisted of four modes, each run for different periods of time [7]. The times are designed to reflect the percentage of time at certain operating points in real applied situations. Table 1 illustrates the modes, operating points, and weight values for the actual emissions test procedure. This test cycle is based on normalized speed and torque, where 1.0 represents 100 percent of the maximum value. As the snowmobile was evaluated through the test cycle, emissions information was obtained at each operating point. Measurements were made of unburned hydrocarbons, carbon monoxide, and nitrogen oxides. While the test cycle used was adapted from that recommended by Wright and White [7], it should be noted that Mode 4 was not tested in this particular sequence, and the weights of the other modes were adjusted to what is shown in the table.

Table 1 Snowmobile Engine Test Cycle

Mode	1	2	3	4	5
Nspeed	1.0	0.85	0.75	0.65	Idle
Ntorque	1.0	0.51	0.33	0.19	0
Weight, percentage	18	39	36	0	7

This table was adapted from “Development and Validation of a Snowmobile Engine Emission Test Procedure” [7].

Fuel economy was tested by first filling the gas tank to a known level. Then the snowmobile was taken on the 100-mile endurance course in Yellowstone National Park. When the snowmobile returned, the amount of fuel required to fill the tank to the previous known level was recorded. This value divided by the distance was the fuel economy.

Acceleration was tested by driving the snowmobile along a 152 m (500 ft) course while recording the time taken to traverse the course. Noise levels were taken simultaneously. Midway through the course, at a point 15 m (50 ft) away from the track, a sound measuring device was set up. Sound data were taken on each side of the snowmobile three times. The three data points were averaged for each side. The side with the loudest average was recorded. Cold startability was tested by keeping the snowmobile in a cold environment overnight and starting it the next morning.

Results

The UI Clean Snowmobile for 2001 finished fifth in the competition. It exceeded the emissions reduction requirements. The competition snowmobile achieved a 59 percent reduction in carbon monoxide, an 84.1 percent reduction in unburned hydrocarbons, and a 39.7 percent reduction in nitrogen oxides. The reduction in the combined unburned hydrocarbons and nitrogen oxides was 83.5 percent. The competition goals were a 25 percent reduction in carbon monoxide and a 50 percent reduction in the combined unburned hydrocarbons and nitrogen oxides. The results from the fuel economy test showed that the competition snowmobile completed the 162 km (100 mi) course while consuming 19.08 l (5.04 gallons) of gas, resulting in a fuel economy of 8.43 km/l (19.8 mpg), second best in the competition. The fastest acceleration run for the Idaho competition snowmobile was 8.28 seconds, while the loud side of the snowmobile produced sound emissions of 74.7 dBA at 50 feet. Thus, unfortunately the sound emissions for that side were slightly above the 74-dBA requirement. During the cold start test, the competition snowmobile started up within two revolutions of the engine, fastest in the competition. The UI snowmobile placed second in the handling event. The snowmobile also possessed sufficient power to make it to the top of the hill climb. During the competition, the snowmobile had no problems and required no maintenance or repairs.

The UI Clean Snowmobile showed reduced emissions well below the competition’s requirements. Fuel economy was doubled and sound emissions were reduced to a level

0.3 dBA above competition requirements. All of this was done without significantly affecting the snowmobile’s performance or durability. The cost involved in producing this snowmobile was $950 above the cost of the chassis. The UI Clean Snowmobile provides an excellent balance between cost, environmental soundness, and consumer acceptability.

Recommendations for Future Projects

The project snowmobile functioned very well within the limits of the competition, but there is room for improvement. The BMW engine that was used was ten years old and had over 30,000 miles on it. The fuel injection system should be calibrated for the specific altitude of the competition. Improvements could be made to the drive train in order to reduce losses. Such improvements include increasing the diameter of the rear bogie wheel and replacing the chain gear reducer with a belt-driven one. A custom exhaust system specific to the BMW motor could be implemented. More soundproofing should also be added, especially around the clutches.

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