

Powder Train
University of Idaho
College of Engineering
Moscow, ID 83844

December 13, 2013

NIATT
Attn: University of Idaho CSC Team
115 Engineering Physics Building
Moscow, ID 83844

Attention: Dr. Karen Den Braven Director of NIATT, University of Idaho CSC Team

Subject: Snowmobile Rear Drive System Final Report

It is our pleasure to submit the following final report for the *Snowmobile Rear Drive System* designed for the University of Idaho Clean Snowmobile Competition Team's 2009 Ski-Doo Rev-XP snowmobile.

The attached report contains the final rear drive concept that was designed to improve upon the work done by the previous rear drive team in 2011; specifically in creating a rear drive system that is not only reliable but easy to install and maintain while improving the fuel efficiency and handling of the snowmobile. Enclosed is a review of the processes followed to arrive at the final design along with reference documents and appendices for the maintenance and operation of the rear drive system.

We strongly believe this design will meet the needs of your competition team and continue to help promote NIATT and the University of Idaho CSC Team's portrayal of excellence. We, not only as a team but as individuals, have been greatly appreciative of all advice and support that we have received throughout this project and are extremely thankful for the experience that it has brought to us as we prepare for graduation and seek employment.

If you have any questions, concerns or suggestions please contact us and again thank you for the opportunity to work with you and your team.

Respectfully,

Powder Train
Josh Dalton, Zoltan Kiss, Aaron Patterson

University of Idaho Clean Snowmobile Competition Team Rear Drive System



Josh Dalton

Zoltan Kiss

Aaron Patterson

Faculty Lead: Steve Beyerlein/Dan Cordon

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Graduate Mentor: Chris Ohlinger

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NIATT through the University of Idaho CSC Team



Team Powder Train
University of Idaho
College of Engineering
Moscow, ID 83844

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Executive Summary

The goal of the Powder Train team was to design and manufacture a rear drive system for one of the Ski-Doo Rev XP snowmobiles used by the University of Idaho's Clean Snowmobile Team. Under the direction of the National Institute of Advance Transportation Technology (NIATT), the goal of the rear drive system is to increase the fuel efficiency and handling of the snowmobile without any significant weight gains. The University of Idaho CSC Team will also use this system to demonstrate new technology at the Clean Snowmobile Competition and draw attention to the University of Idaho. Most importantly, the design conforms to the strict rule criteria for the SAE International Clean Snowmobile Challenge.

Incorporating a chain drive system that allows the use of many stock components, and most importantly the stock suspension and braking systems, the design is fully bolt on with no chassis modification or compromises in safety. Retaining a much closer weight to the stock drive system compared to the last iteration of this project the drive is simple to install and use. The design will be tested against the stock drive system on a water jet dynamometer and powered by a controlled electric motor.

The drive is in its final stages of manufacturing and many parts were donated by outside sponsors, thus saving limited team funds but also delaying much of the build. The drive will be ready and tested before the competition in March of 2014.

Background

On a conventional snowmobile drive system the track is driven by a set of driving wheels that are mounted at the front of the track and suspension, directly behind the engine. This setup causes the track to "push" the sled, leaving the tracks slack underneath the rails. This means that there is wasted energy from inefficiencies in the drive train. By moving the driving wheels to the back of the snowmobile we hope to remove this slack and greatly increase the efficiency of the snowmobile. This should also improve handling as the track will be fully contacting the snow and in tension, with no slop.

Background research only turned up one other rear drive system outside the University of Idaho, created by RND Innovators. RND claims that their rear drive system increases efficiency and handling of the snowmobile and have proven with their design that it is possible to create a working rear drive. The RND rear drive does not appear to be commercially available at this time. The University of Idaho rear drive team Rear Motion (2011-2012) also made a working prototype but had difficulties with it and never fully tested the system.

Instillation of RND's design requires extensive chassis modification and a completely new system with few stock parts. The University of Idaho team's design was proven to be too heavy and unreliable with suspension geometry complications. Through our research and design process we have worked to avoid

these problems and come up with a viable solution that is both reliable and requires little to no chassis modification, with the use of the stock suspension system and OEM parts.

Problem Definition

As a Capstone Design Project, our goal was to provide the University of Idaho Clean Snowmobile Challenge Team a complete and working rear drive system for their 2009 Ski-doo Rev XP snowmobiles. The UIdaho CSC Team specified that they wanted a bolt in replacement drive system that could be swapped easily with the stock system and back again as needed. The design would need to be as no louder than the stock system and quitter if possible, and show proven fuel efficiency gains through testing. Handling will hopefully be improved and weight kept to a minimum; as close to stock as possible. Suspension geometry problems also needed to be solved from the old rear drive system eliminating the damage to the shocks due to impacts with the solid suspension linkages. The design should also be aesthetically pleasing and promote the UIdaho CSC Team and the University of Idaho.

Along with the Snowmobile Team's specifications, the system needed to be in compliance with the Clean Snowmobile Challenge Rules for 2013-2014, providing maximum rider safety and reliability. These rules state that the snowmobile must be powered by the variable ratio belt transmission through the dual clutch system, located between the stock chain case and the engine of the snowmobile, and that all moving parts must be covered by shielding e.g. clutch cover/guard. It also states that all braking modifications done must maintain the original performance of the stock braking system and that if the braking system is moved from its stock location it must be covered by a shield capable of retaining an accidental explosion. A mud flap that is wider than the track and within one inch of contact with the ground when the lightest operator is sitting on the snowmobile is also needed. The last rule that played an role in the design process of the rear drive system is that the suspension has to have a minimum three inches of travel when the heaviest rider is on the snowmobile.



Figure 1. Example of clutch cover and stock brake cover shown from Clean Snowmobile Challenge Competition rules.

An electric motor provided by the University of Idaho FSAE Hybrid Car Competition Team will be used to test the difference in the drive train efficiencies between the new rear drive design and the stock drivetrain. A test stand to fit this motor was designed and built since it needed to be completely mounted to the 2009 Rev XP snowmobile itself with no part reaching the ground. This is due to the way the water jet dynamometer, which will be used to gather all data, works. This mount needed to be completely rigid and built in such a way that the electric motor could be connected to the secondary

clutch jackshaft in its stock location on the snowmobile. The rear drive system and the motor mount needed to be completed and delivered by December 20, 2013 so testing and initial maintenance could be completed before the competition in March of 2014.

Project Plan

Team Powder Train members include Josh Dalton (Quality Control), Zoltan Kiss (Time Management) and Aaron Patterson (Lead Designer). The lead designer will review all engineering designs to determine compliance with team mission statement and team values. The lead designer will also be responsible for file management pertaining to the design of product. Quality control will ensure engineering drawings are uniform, oversees quality in prototyping and finish product, and ensuring the product meets client specifications. Time management will create schedules for design, development and production, will act as liaison between the client and the engineering team. Time management will also work to keep the project on schedule and on budget.

Major tasks included background research on similar projects, development of multiple possible concepts, and the selection of a final concept. Once the final concept was selected it was tested mathematically and proven on paper to work and then presented to the client for approval. After approval was given the design then needed to be manufactured and delivered to the client to be tested by December 20, 2013. Testing would then be completed and needed changes made before competition in March of 2014. Simultaneously, the same process was used to design and manufacture the electric motor mount needed for testing. Figure 2 below shows the project timeline with specific dates and tasks listed.

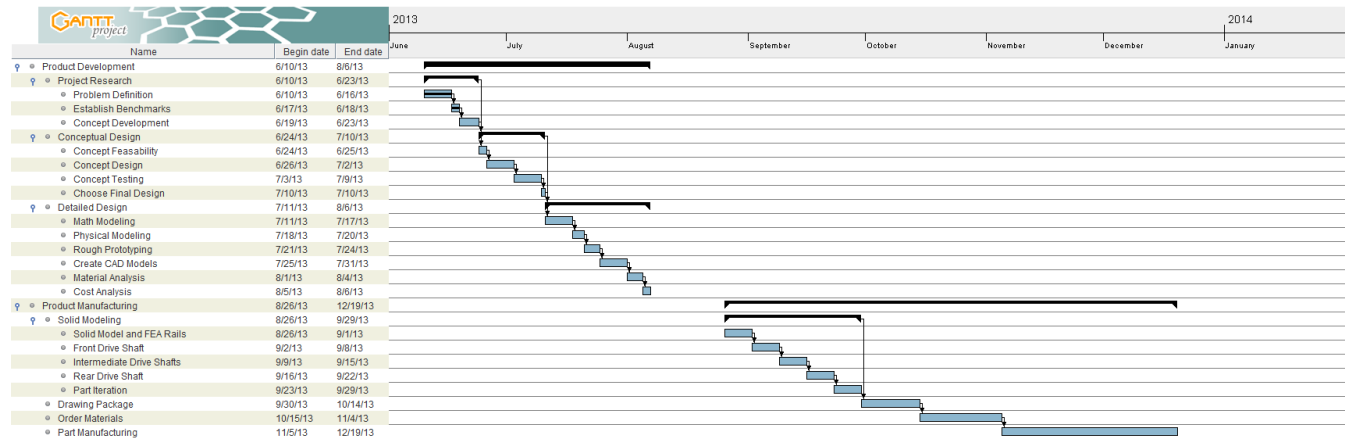


Figure 2. Gantt chart showing specific project processes and deadlines.

Concepts Considered

Existing Products

Before we started our own design we initially investigated ideas that had already been built and were on the market. The only design that was found outside the University of Idaho was a rear axle and chain drive system created by *RND Innovators* out of Ontario, Canada. This system is a complete rework of the snowmobile's rear suspension and rails that requires extensive modification to the tunnel and chassis of the snowmobile. According to RND, the design greatly increases the fuel efficiency, improves the handling characteristics and provides much better braking (much shorter stopping distance) to the snowmobile. Although this design does not meet our specific goals due to its complexity and use of almost no OEM parts, it had an important influence on the design process by proving a lot of the characteristics that the team was hoping to achieve through a rear drive system



Figure 3. RND Innovators rear drive

The only other rear drive system come across in research was the system designed and built by the University of Idaho's *Rear Motion* capstone design team in the 2011-2012 school year. A completely chain driven design, it was created as a proof of concept for the UIdaho CSC Team to see if they would pursue a similar design in the future and possibly use for the Clean Snowmobile Challenge competition. The design worked but was susceptible to chain breakage and suspension geometry problems (which resulted in the destruction of multiple shocks/dampeners) along with being extremely overweight. The design provided a chain drive model to start working off of and supplied additional information about the brake location and weight savings options.



Figure 4. Team *Rear Motions* chain driven rear drive design

Hydrostatic Drive Concept

A more radical approach to solving the rear drive problem that was first discussed was a hydrostatic drive option. Hydrostatic drives are used almost exclusively by the farming and construction industries with a small part of that going to home lawn care etc. Positive aspects to these drive systems include a constant maximum torque available at all times and no limit to possible gear ratios. The design also allows for the use of the stock suspension and provides a very unique and new characteristic for the snowmobile competition. This system would require little modification to the snowmobile and would be made up of a small number of components with fewer moving parts when compared to other options. Drawbacks to the design include the very high weight of the equipment and the high cost of components.

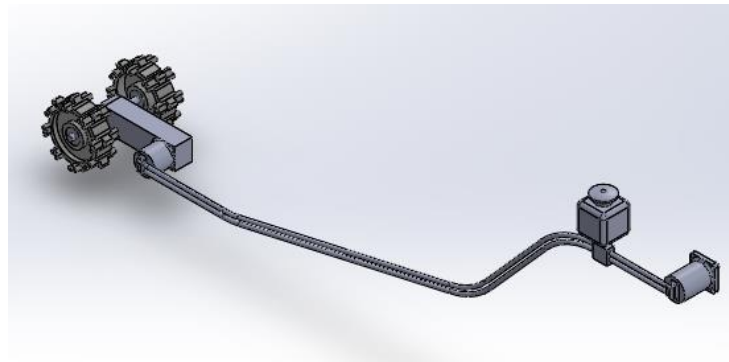


Figure 5. Hydrostatic drive concept

The design would have a pump driven by the front driveshaft that pressurizes the system to drive the hydraulic fluid down the lines. This fluid would then drive a hydraulic motor attached rear driver wheels, which would then turn the track. The system would also have to include a return line, cooling tank, and fluid reservoir.

Drive Shaft Concept

Drive shafts are very common in almost all motorized vehicle applications and seemed like a viable option for this project. A shaft design would be very strong and easily bolted into place while also allowing for installation in the center of the snowmobile (optimizing the center of mass for ideal handling characteristics). Manufacture of this type of design would be fairly simple with a manageable amount of total parts. U-joint angle problems and the lack of off-the-shelf parts would be downsides to a driveshaft system as well as being much heavier than the stock drivetrain. Undesirable suspension modification would be necessary to fit the shafts and the supporting structure would also be an issue.

This system would likely have to use some type of bevel gear system to transmit power from the stock driveshaft behind the engine to an intermediary shaft that travels down to the rails and suspension assembly. A universal joint would then connect this shaft to a main driveline that is supported between

the two rails and travel to the rear driving wheels. A second set of bevel gears would connect the main driveline to the driving wheels which would then power the track.

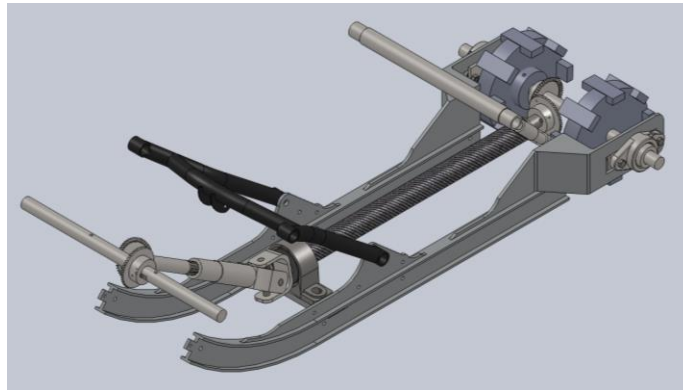


Figure 6. Drive shaft concept.

Chain Drive Concept

Team *Rear Motion* and *RND Innovators* have both proven that a chain drive system is a viable option that can work well. It allows for the use of the stock suspension and many off-the-shelf parts, reducing the overall cost and limiting weight gains. Manufacturing of custom parts would be possible along with multiple options for routing the chain to a set of rear drive wheels. Along with the added benefit of being able to choose the gear ratios, the design would also be able to keep the same overall geometry of the stock system and maintain a low center of gravity (improving handling).

This system uses a front driveshaft located behind the engine to drive a tensioned chain that travels to the front of the track suspension via another driveshaft. A system of drive shafts and sprockets would continue to power the chain to the rear drivers, which in turn would then power the track.

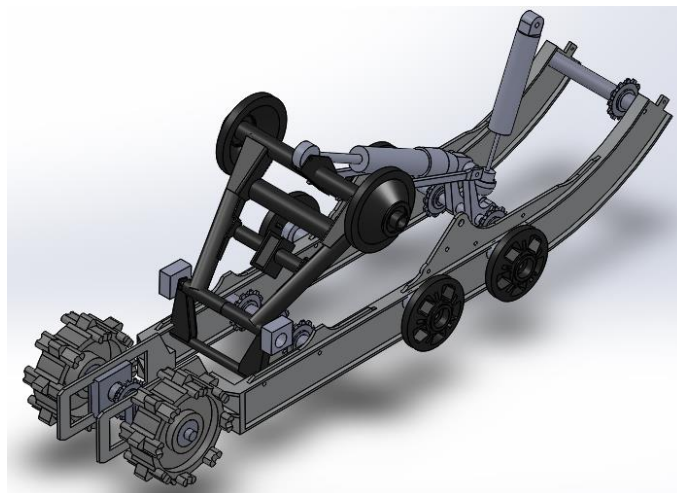


Figure 7. Chain drive concept

Concept Selection

Determining the final design was heavily deliberated and scrutinized with constant discussion with the UIdaho CSC Team and the Powder Train team’s advisors and mentors. A finalized list of the most important criteria was developed, focusing on the use of the stock suspension system, low weight, snow pack, overall efficiency, simplicity, and total cost. These criteria were then placed in a matrix and a scoring system that represents the performance and importance of each. This decision matrix is shown below in Figure 7.

Decision Matrix

	Weight						
	3	3	5	3	2	3	
	Use Stock Suspension	Weight	Snow Pack	Drive Efficiency	Simplicity	Cost	Total
Hydro-Static Drive	2	1	2	1	1	1	27
Drive Line	0	1	1	1	0	0	11
Belt	1	2	0	1	2	1	19
Chain	2	2	1	1	2	2	30

Note: Feasibility Chart used to determine final design decisions. Design headings were determined using the design requirements outlined in the problem statement.

College of Engineering University of Idaho

Figure 8. Decision Matrix

Although this matrix was used to aid in the decision process, a significant amount of time was spent discussing other possible solutions and the effects each would have. The validity of each concept was then discussed again with the University of Idaho CSC Team and with the Team’s advisors. Each design was revisited and evaluated several times to form a complete consensus as to the correct direction to take. Other important factors that tailored into the final decision included the availability of parts and the ability to make or outsource components that couldn’t be purchased. The Team’s budget and available time were also driving factors in the decision process, as was the availability of experienced machinists to help in the production of parts that could not be purchased.

Once a final decision was made a formal design review was held where team Powder Train presented the finalized concept and manufacturing plan to receive further correction by the CSC Team, their advisor, and the Powder Train team advisors. Once this review was completed and signed off on by the clients the manufacture stage could begin. Any needed changes that arose after that would still go through the decision process and be signed off on by the client before proceeding. After all was said and done we were pleased to have chosen the chain drive concept as our final design to move forward with.

System Architecture

The design of the chain drive is fairly simple but each component is quite unique in its structure and purpose. The overall system is made up of a front drive axle that receives a power input from the engine via the chain case and then transmits this power itself by chain to the first intermediate axle mounted on the rail/suspension assembly. This assembly consists of the stock suspension system bolted to the snowmobile itself and a set of custom rails that guide the track and are used to mount the intermediate drive shafts and the rear drive axle. The three intermediate drive shafts start at the front of the rails and guide the chain through the suspension system via sprockets to the rear drive axle in the back of the rail/suspension assembly. This rear drive axle is what meshes with the lugs on the track to turn it, resulting in the motion of the snowmobile. A more complete breakdown of the main components of the rear drive design is outlined below.



Figure 9. Chain drive conceptual design

Front Axle

The front axle is a very unique part of the rear drive design and serves a dual purpose as it not only transmits power from the engine to the main body of the rear drive but also is used in the braking of the snowmobile. This is done by a shaft-in-shaft design that consists of the main axle that receives and transmits the power from the engine (inner shaft) which is then mounted inside a modified version of the stock front axle (outer shaft) via bearings and spacers. This outer axle holds the front drive wheels that would normally power the track in a conventional snowmobile and is connected to the stock brake rotor, in its stock location. This setup allows the outer axle to spin freely as the track is driven by the drive system and only come in contact with the track lugs, allowing the snowmobile to be stopped by the stock brake system without interference between the brake and the drive system. This design not only saves space and weight but also provides a uniqueness factor for the University of Idaho CSC Team to use at competition. Figure 10 outlines the front axle assembly and figure 11 is a dissected view.



Figure 10. Front axle assembly

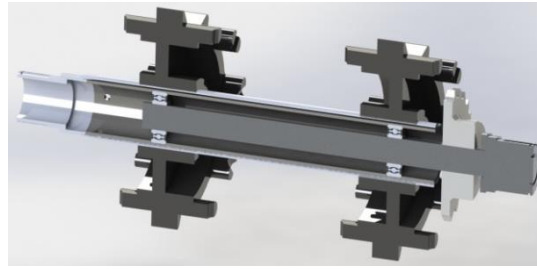


Figure 11. Section view of front axle assembly.

Rails Sub-Assembly

Using the stock suspension system was a very high priority for team Powder Train and the rails sub-assembly uses multiple unique components to accomplish this goal. One of the toughest challenges the team faced was finding a way to transmit power through the narrow and collapsing design of the SC-5 suspension unit that comes standard on the 2009 Rev XP snowmobile. This task was accomplished through the design of a new taller set of rails that allow the chain to travel over and then back under the suspension linkages via three intermediate drive shafts. These drive shafts were designed to be mounted directly before the two main suspension linkage mounts and the farthest forward location on the rails, allowing the chain to travel through the suspension without coming in contact with it during normal operation. The aluminum shaft material and hex shape and size were chosen based off of torque maps completed to model the actual power output of the engine so fatigue and wear can be avoided. The sprockets and chain were also chosen off of these torque maps and a final gearing ratio of 1 to 1 was achieved, to match the ratio that the stock drive system would be providing.

The rails were designed to allow the suspension system to be mounted exactly how it would be on a stock set of rails, simplifying the assembly of the system and allowing for OEM replacement parts as needed. It also provides a narrow profile for the mounting of the rear driving unit and available space for the bearing housings that support the intermediate drive shafts. FEA analysis was done through Solidworks to select a material and verify the strength and life expectancy of the rails. Being one of the more challenging parts to build due to the material and limited manufacturing capabilities, the team was greatly appreciative of the manufacture and donation of the custom rails by *Ice Age Performance*.



Figure 12. Custom Rail Design

The rear driving unit is the final component of the rear drive system and consists of a set of drive wheels mounted to a hex aluminum shaft that serves as the rear axle. This shaft is mounted to the rails via two bearing housings that serve as the connection points for the track tensioners which allow the track to fit correctly on the system. The drive is powered via the chain from the intermediate shafts by a final sprocket mounted on the rear axle. The rear drive wheels were constructed and donated by *Avid Products*, greatly simplifying the construction of this unit. All FEA analysis and math/torque models used in the selection of materials, sizing, and components can be found in Appendix (.....).

Future Work

As of the writing of this report, the prototype rear drive system remains incomplete, largely due to delays from parts and material suppliers. There is a lot of work that would have to be done to prepare a working prototype. The drawings for all the parts that have been manufactured and need to be manufactured can be found in the appendices.

The front axle, assembly 01, was completely finished but unfortunately there is a wobble as the inner shaft (part 01-03/01-07) turns that may require the inner shaft to be re-manufactured. This is believed to have occurred because during manufacture the hex part of the shaft (part 01-07) was clamped in the lathe to turn down the outer diameter of the splined end (part 01-03) and the hex surface was not uniform. Whatever the cause, there was not time to order new materials and re-make the inner shaft. The inner shaft was also made from an aluminum that is not as strong as the alloy the design originally called for, and there is the possibility that it could fail under max torque. The material that was used for the inner shaft was chosen because it can be welded. The original material considered for the inner shaft was to be 7075-T6 aluminum alloy. In order to avoid welding, the splined end cap could be broached using the hexagonal profile chosen for the shaft. A hole for a pin could then be drilled through the shaft and splined end together to retain the spline end cap.

The custom rails, assembly 02, needed for the design came in from the manufacturer after long delays and too late to be of much use in designing parts. The parts that attach directly to the rails had to be re-designed to mate up once the rails were actually in hand. As a consequence, all of the parts that were designed to attach directly to the rails have not even begun manufacturing except the supports for the rear axle (parts 02-02 and 02-03), which are not finished. The rear axle supports are about 40% complete and need quite a few hours of attention before they're completely machined. Even then, there are concerns that the designed parts may not survive serious testing because they too were designed at the last minute after the rails became available.

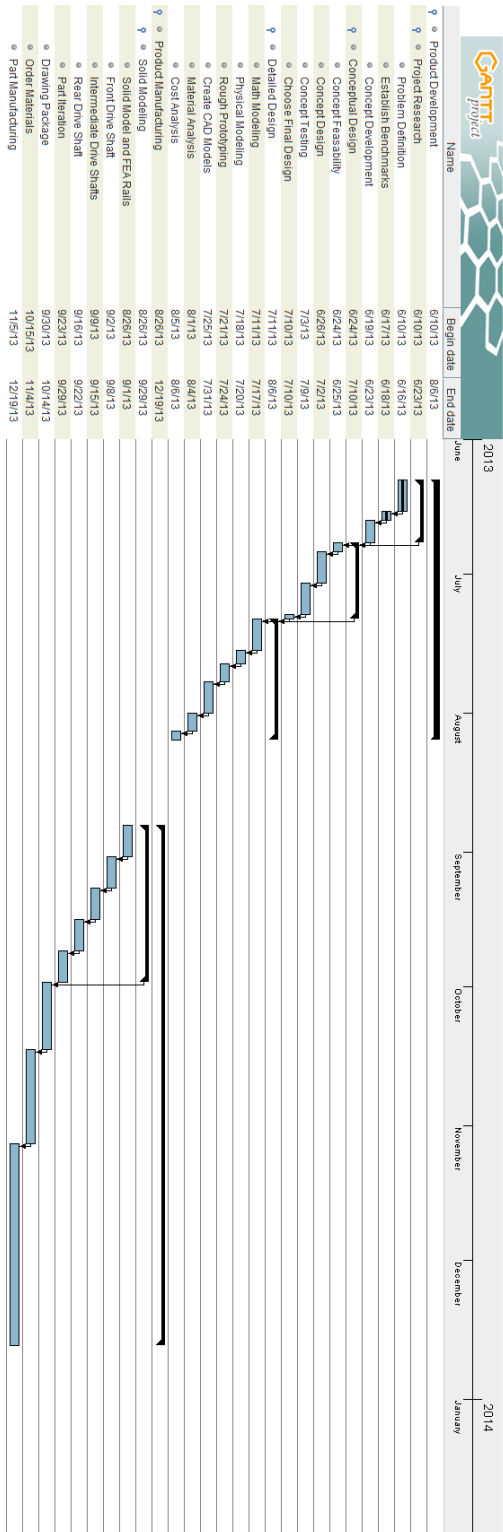
The other parts that haven't been started consist of the all of the bearing housings for the intermediate axles (assemblies 04, 05 and 06). The axle for the first intermediate shaft, part 04-01, has not been manufactured but the material is available. The axle for the second intermediate shaft, part 05-01, has been made but is the wrong size so it needs to be modified. The axle shaft for the third intermediate axle, assembly 06, is finished. The bearing for the first intermediate axle's right-side bearing housing, which is a different size than all the other intermediate axle bearings, is on order. The material chosen for the intermediate axle shafts is also not the original alloy wanted. 6061-T6 aluminum was used because it could be ordered and received quickly. Given ample time and resources, a 7075-T6 alloy would be preferred because of its significantly higher yield strength.

The bearing housing assemblies and the axle shaft for the rear axle assembly, assembly 03, are unfinished and the bearings are still on order. All the other bearings needed for the design are on hand.

The supplier for the sprockets sent an incomplete order, so the sprocket for the rear axle and two of the sprockets for the intermediate axles are on order, but the rest of the sprockets are available.

No chains have been ordered since the complete assembly would be needed for measurements. The tensioner that would be needed to keep the chain running from the front axle to the first intermediate axle tight has not even been designed because the assembly is incomplete so none of the space restrictions are known.

Appendices



2013 CSC Rear Drive Budget					
Item	Piece	Cost	Total	D	Supplier
ANSI #50 Chain sprocket, 14 tooth	5 ea	\$ 6.90	\$ 34.50		Triple R Inc., (712) 957-1405
ANSI #50 Chain sprocket, 30 tooth	2 ea	\$ 18.11	\$ 36.22		Triple R Inc., (712) 957-1405
7075-T7351 Aluminum Hex Bar, 1 in OD	7 ft	\$ 7.23	\$ 50.61		Online Metals.com, (800) 704-2157
7075-T651 2 1/4" Aluminum bar	1 ft		\$ 50.46		Online Metals.com, (800) 704-2157
1020 Structural Steel Tube, 2 .25" OD, 2" ID	2 ft	\$ 17.50	\$ 35.00		MetalsDepot.com, (859) 745-2650
Drivers	2 ea	\$ 124.95	\$ 249.90	Y	Avid Products, (866) 666-2843
Slide Rails, Custom Build	2 ea		\$ -	Y	Iceage Performance, (877) 542-3243
Suspension System, used	1 ea	\$ 500.00	\$ 500.00		Unknown
Bearings - Unknown Specifications	10 ea	\$ 25.00	\$ 250.00		VXB Ball Bearings, (800) 928-4430
ANSI 50 StainlessSteel Roller Chain	10 ft	\$ 10.00	\$ 100.00		Roller Chain 4 Less, (800) 356-2336
Chain Tensioner	1 ea	\$ 100.00	\$ 100.00		
Lovejoy Coupler	1 ea	\$ 60.00	\$ 60.00		Applied Industrial Tech., (208) 746-2386
		Total	\$ 1,216.79		

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EXPO 2013



CSC Rear Drive

Team Powder Train

Sponsored by the University of Idaho Clean Snowmobile Team through NIATT




Problem Statement

When a conventional front drive snowmobile moves forward the track is pulled into tension on the top so that the slack is between the rails and the ground. This is hypothesized to decrease handling and cause inefficiencies in the track that lead to higher fuel consumption.

Client Requirements

Roll in design with no chassis modification
Minimum possible weight
No increase in track noise, decrease noise if possible
Decrease fuel consumption by increasing efficiency in the track
Improve handling

Design

The design centers around a chain drive system. The stock front axle was modified to be a two part axle that transfers power from the chain case on the right side of the snowmobile to a drive chain. The two independently rotating parts of the front axle are designed to allow the snowmobile to drive in both forward and reverse without the transfer of power interfering with the brake, which is on the left end of the front axle. The drive chain on the front axle transfers power through a series of intermediate axles to the rear axle. The rear axle has drive wheels mounted on it that drive the track. The bearings for the rear axle are in sliding housings which allows the track tension to be adjusted.

Suspension and Rail assembly



The design integrates the stock suspension system.

The rear axle is integrated into the rails. The rails sweep to the inside to keep the assembly narrower than the drive wheels and reduce the stress on the rear axle.

Sliding bearing housings allow track tension to be adjusted.

The brake attaches to the left end of the front axle.

The chain case, which transfers power from the engine, connects to the right end of the front axle.

The wheels on the front axle, which drive the snowmobile in the stock configuration, spin freely unless the brake is applied.

Front axle



Intermediate axles transfer power from the front axle to the rear axle via drive chains.

The outer part of the front axle holds the brake to the front wheels and allows braking even if a drive chain snaps.

Slotted ball bearings separate the inner and outer axles.

The inner part of the front axle transfers power from the engine to the chain-drive system.

The two part front axle allows each end to rotate independently preventing interference between the brake and the chain-drive system.

Team Powder Train



Aaron Patterson



Josh Dalton



Zoltan Kiss