Skid-Steer Rock Saw Modification

Kelly Hogue
Kristen Tucker
Matt Gassen
Buck Melton

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Redesign of Skid-Steer Mounted Rock Saw

Kelly Hogue
Kristen Tucker
Matt Gassen
Buck Melton

Biosystems & Agricultural Engineering Department
Oklahoma State University

Submission Date: May 04, 2007

______________________________ ______________

Kelly Hogue Biomechanical Option
Tulsa, Ok December 2007

______________________________ ______________

Kristen Tucker Biomechanical Option
Midwest City, Ok December 2007

______________________________ ______________

Matt Gassen Biomechanical Option
El Reno, Ok December 2007

______________________________ ______________

Buck Melton Biomechanical Option
Lawton, Ok December 2007

______________________________ ______________

Dr. Paul Weckler Senior Design Advisor

______________________________ ______________

Dr. Ronald L. Elliott BAE Department Head

Abstract

A rock saw is a skid-steer attachment used to cut non-reinforced concrete and asphalt as well as other pavement surfaces. One of the many uses for this rock saw is making trenches for laying plumbing or wiring under existing roads and sidewalks. In addition, the rock saw may be used to make a smooth edge along asphalt roadways for the addition of cement curbs. This saw is versatile because it can be powered by a variety of other machines. CONEQTEC Universal produces rock saws capable of various cutting depths. However, their production model is axially driven which limits the depth of cut to less than the blade radius. In order to increase the depth of cut without increasing the blade diameter, the manufacturer designed a prototype in which the blade was rim-driven via a modified ring and pinion gear set. Four senior level students from the Biosystems and Agricultural Engineering Department (BAE) of Oklahoma State University (OSU) have formed a consulting team, Blue Diamond Machinery (BDM), to facilitate the completion of their capstone senior design project under the direction of Dr. Paul Weckler. Blue Diamond Machinery's objective was to modify the CONEQTEC rock saw prototype with the goal of increasing the time between maintenance periods from 50 hours to over 100 hours as well as preventing debris from contacting the motors. To reduce wear, BDM modified the gear set to a circular rack and pinion. Further testing is needed to determine if this gear mesh increased the useful life of the machine. As a result of altering the gear set, the motors were mounted above the blade where they cannot come into contact with debris.

Figure 1: Left to Right - Production Model, CONEQTEC Prototype, BDM Prototype (CONEQTEC 1)

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Laboratory Manager

Bobby Flores, Robert Harrington, and Robert Harshman – Oklahoma State University - Biosystems and Agricultural Engineering Laboratory

Stillwater Steel – Fabrication

Steve Miller – Interstate Tool – Fabrication

Railroad Yard – Fabrication

Jana Moore - Oklahoma State University - Biosystems and Agricultural Engineering

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Problem Statement

CONEQTEC Universal designed a prototype of a skid-steer mounted rock saw. While this prototype functioned, the manufacturer required a gear set with a longer design life for the saw to become a production model. When the saw descended to the maximum cutting depth, the motors were forced to run in debris created by the cut. The manufacturer requested that the rock saw be modified to increase the design life of the gear set as well as to prevent debris from contacting the motors.

Statement of Work

In order to increase design life, BDM changed the ring and pinion gear set to a circular rack and pinion gear set. This altered gear set necessitated the relocation of the motors to above the blade thereby preventing debris from coming into contact with the motors.

Patent Research

The patent search revealed a few designs similar to the prototype. While rock saw devices were found, none were driven from the rim of the cutting blade. All the designs found were driven from the central axis of the blade. Most of these designs were intended for cutting concrete or, in the case of one patent held by Mr. Cochran, for cutting slots in pavement. Though some rim driven blades were found, their intended application was in the logging industry to trim either harvested or fallen trees for transport. The scope of application was found to have a more important role in patent approval than the method in which the machine is operated. US Patent No. 3494389 refers to slashing and loading timber. The machine is designed to lift a load of logs off of a stack and place them on a truck for transport after cutting them to a desired length.

US Patent No. 3915209 refers to the process of harvesting trees and brushwood and an improved saw design for the removal of trees or brushwood. Additionally, Patent No. 3915209 refers to a German and U.S. patent that describes a ring and pinion drive which has a U-shaped frame. However, Patent No. 3915209 states that these patent designs are insufficient due to their limited depth of the cut and the gear configuration is not protected. This design has two plates mounted together to house the ring and pinion drive train and form the saw blade. This assembly results in the gear being easily hindered by wood debris and not easily repairable when damage occurs.

US Patent No. 4738291 describes a tree saw run by a ring and pinion configuration which the saw blade can double as a platform to allow the cut tree to be dumped where the operator chooses instead of allowing the tree to fall where it was cut down. This design appears to have some importance due to the saw blade having intentions to be a load bearing surface as well as having an assembled blade design protected from debris, which could easily be maintained. These patents, while unrelated to our products industry, are still potentially important due to their similarities to our drive train concept. This observation could pose a problem in the new design because of patent infringement. It was deduced from these patents that the driving mechanism is not patentable in and of itself; therefore, the scope of the patent holds higher authority than the drive train design making patent infringement less of an issue.

Patent No. US 7,073,495 B1 describes the method and apparatus for removing concrete debris during operation. The device is powered by a small engine, and the blade is contained in a separate housing. Outside the housing is a set of at least two nozzles that use pressurized gas to produce a stream directed toward the lower support during the use of the saw. This stream is used to help clear debris from the saw decreasing wear on the blade and skids. The streams of gas are directed toward the rear of the housing and toward the front of the blade rather than in the plane of the cutting blade. This configuration should not affect the potential design of a debris removal mechanism for the rock saw because the debris weighs too much to push away with a stream.

Table 1: Patent List

Patent Number	Issued to	Concept	Applicability to project
3494389	Standard Alliance Industries	Slasher Loader	Ring & Pinion Gears
3915209	CEMETSA	Tree Harvester	Saw Blade
4738291	Reggald E. Isley	Power Saw	Gear, Blade
7,073,495 B1	Soff-Cut Int., Inc.	Cutting Concrete	Removal of Debris

Design Specifications: CONEQTEC Universal

CONEQTEC Universal of Wichita, Kansas manufactures attachments for skid-steer loaders to substitute for the standard bucket attachment. One of their attachments is a rock saw which is used to cut non-reinforced concrete and asphalt as well as other pavement surfaces. CONEQTEC's production model of the rock saw is axially driven by a hydraulic motor through a planetary gear set which limits the depth of cut to about 35% of the blade diameter which is slightly less than the radius of the blade.

Figure 2: Production Model Rock Saw (CONEQTEC 1)

In order to increase the depth of cut to greater than the radius of the blade, CONEQTEC developed a prototype in which the blade was driven at the rim of the blade via a modified ring and pinion gear set rather than at the axle. The CONEQTEC prototype achieves a maximum cutting depth of 18 inches with a 32 inch total diameter blade, i.e. the depth of cut is about 55% of the blade diameter. Therefore, if both the CONEQTEC prototype and the production model had the same blade size, the prototype would have a 20% deeper depth of cut.

Figure 3: CONEQTEC Prototype

Ring gear teeth were mounted directly to each face near the perimeter of the wheel. The pinion gear was composed of 5 free-turning cylindrical teeth attached to a disk.

Figure 4: CONEQTEC Prototype – Fully Descended

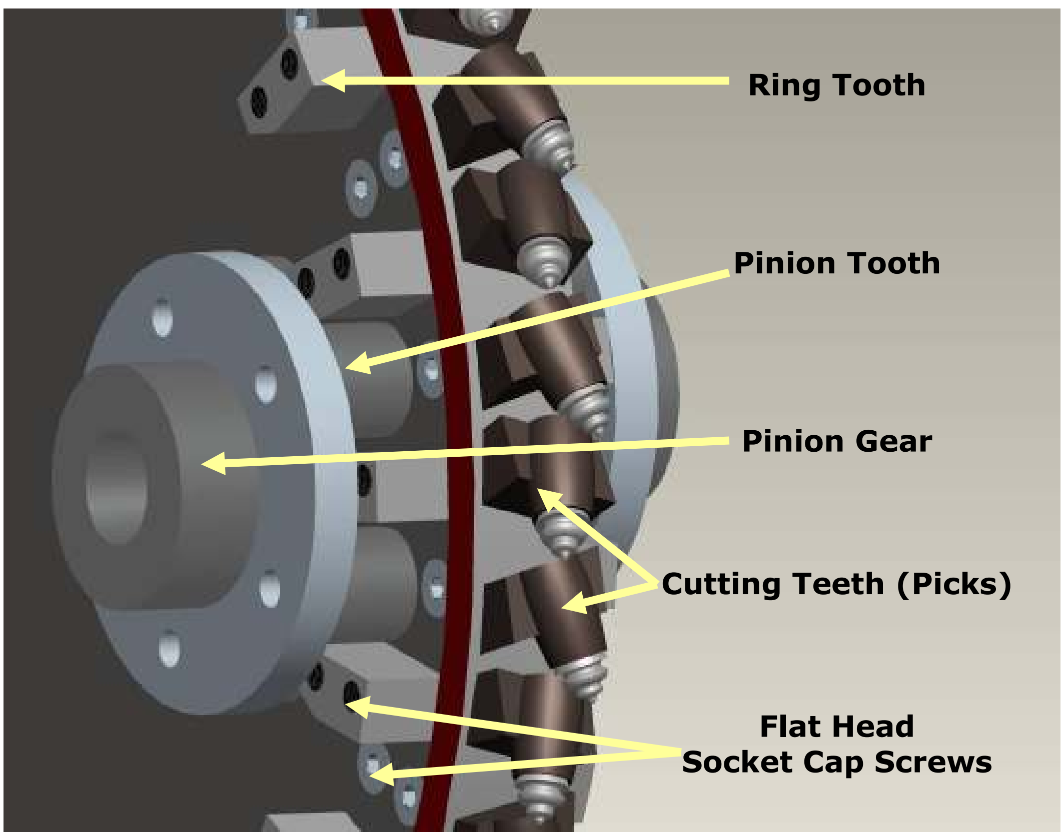

Figure 5: CONEQTEC Prototype Gear Mesh

According to the manufacturer, the major limiting factor was the lower than expected design life of the ring gear teeth. Due to the fact this gear mesh was not sealed, lubrication was not advantageous and was, therefore, neglected. The meshing tolerances were somewhat loose, resulting in some impact/abrasive wear on the contact surfaces of the ring and pinion teeth. However, since the ring gear teeth protruded out to the cutting breadth of the picks, the high rate of wear was caused by abrasion on the outer face of the ring gear teeth as they scraped against the slot being cut by the saw. As shown in Figure 6. The ring gear teeth were attached with flat head socket cap screws (1/2 in – 20, 1.5 in long). Wear was expected on the cutting teeth, or picks. The design life of the cutting teeth was acceptable; therefore, BDM was asked to not focus on improving the cutting teeth.

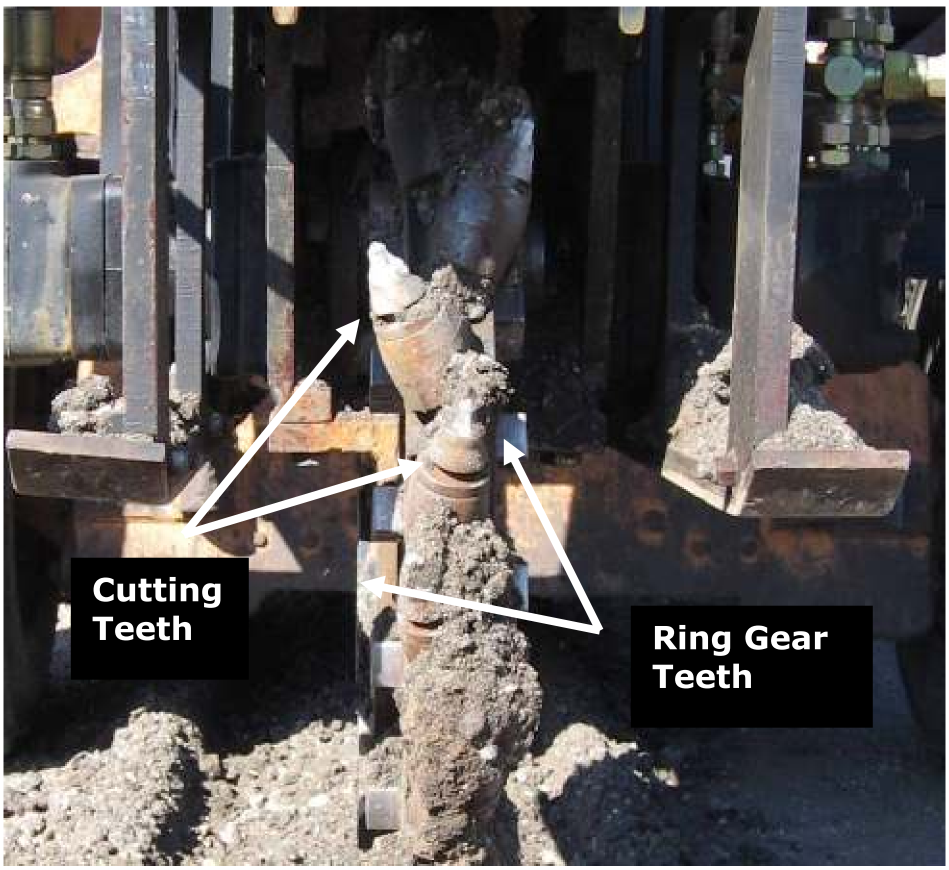

Figure 6: Front View of CONEQTEC Prototype Blade.

A corner from each ring gear tooth was ground down to allow for better clearance when meshing with the pinion gear. On some teeth, the wear was displayed in a very slight arc.

Figure 7: Worn Ring Gear Teeth.

In the production model, one hydraulic motor was mounted directly to the axle of the blade. In the CONEQTEC prototype, they added an additional motor to distribute the rotational force to each side of the blade (See Figure 1). These hydraulic motors were mounted directly to the pinion gears, and a crescent shaped slot was cut into each side plate to allow the motors to descend with the blade. A brace was installed at the top of each slot for reinforcement.

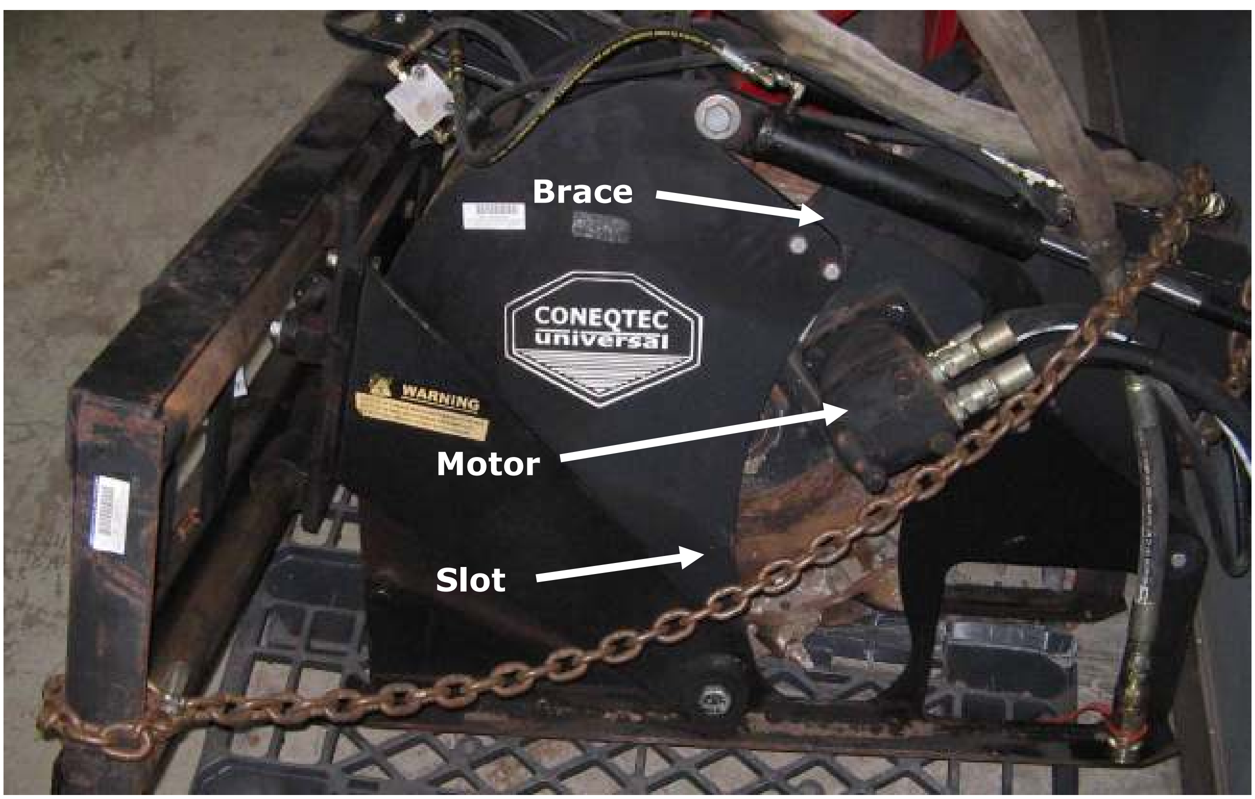

Figure 8: Side View of CONEQTEC Rock Saw Showing Motor Location, Brace, and Shot in Outer Housing.

Special brackets were designed to hold the wheel and the motors in place. The wheel was then able to freely rotate around the axle on two sets of tapered-roller bearings installed in the hub. See the Quantitative Analysis section for motor and hydraulic system details.

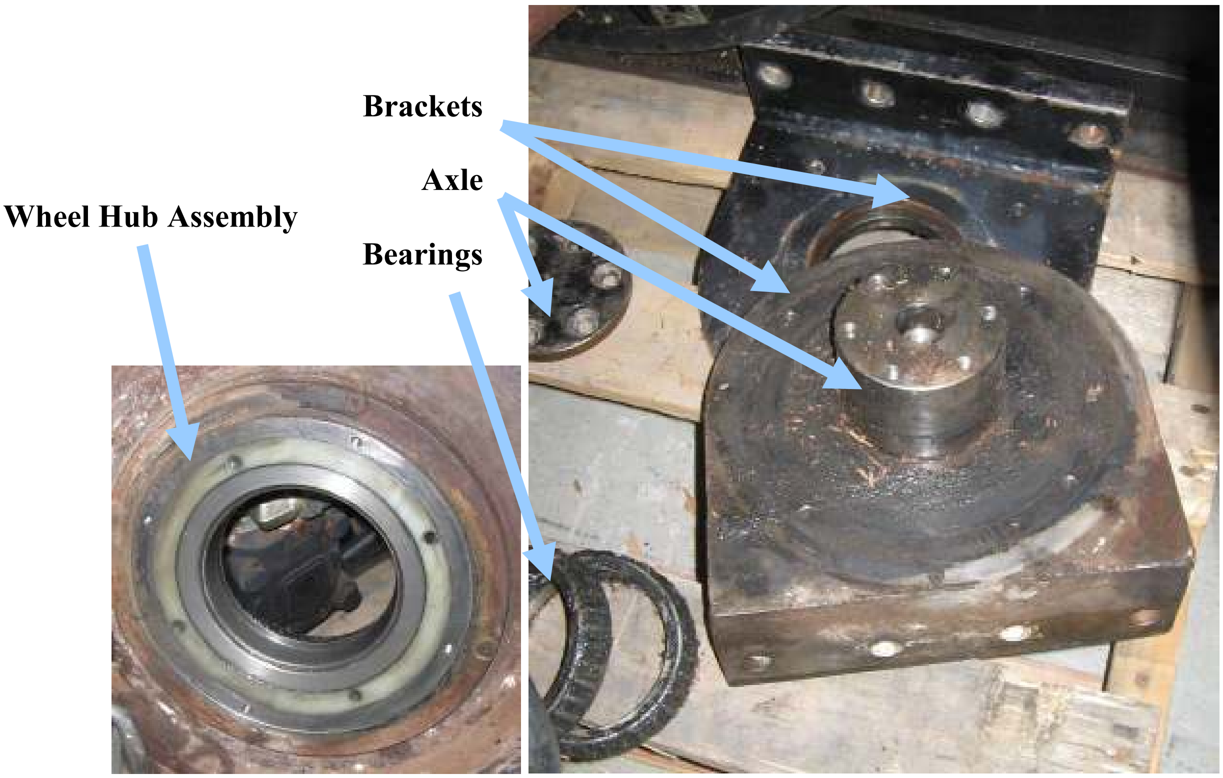

Figure 9: Hub Assembly and Axle of CONEQTEC Rock Saw.

Design Specifications: Blue Diamond Machinery

In order to increase the working life of the saw, BDM altered the gear mesh. The ring gear teeth were replaced with a circular rack composed of gear holes; the pinion gear with cylindrical teeth was replaced with an acme pinion gear. After several iterations in the design process, BDM decided on using three inch tall pieces of ¾ inch diameter round stock and ¼ x ¾ inch bar stock as inserts for each gear hole in the wheel for the pinion gears to press against when driving the blade.

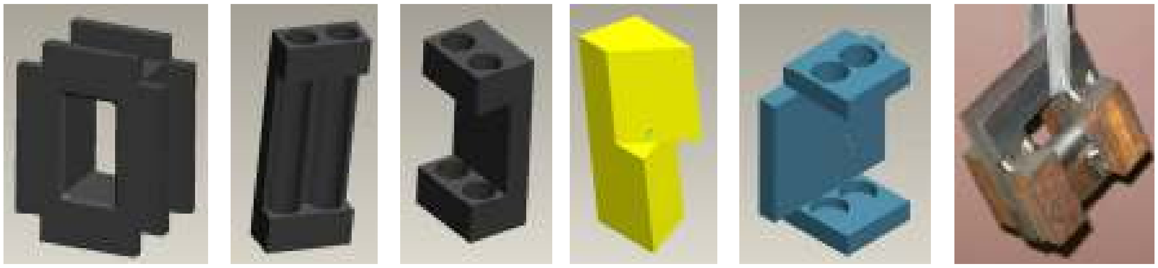

Figure 10: The Progression of BDM Gear Hole Inserts.

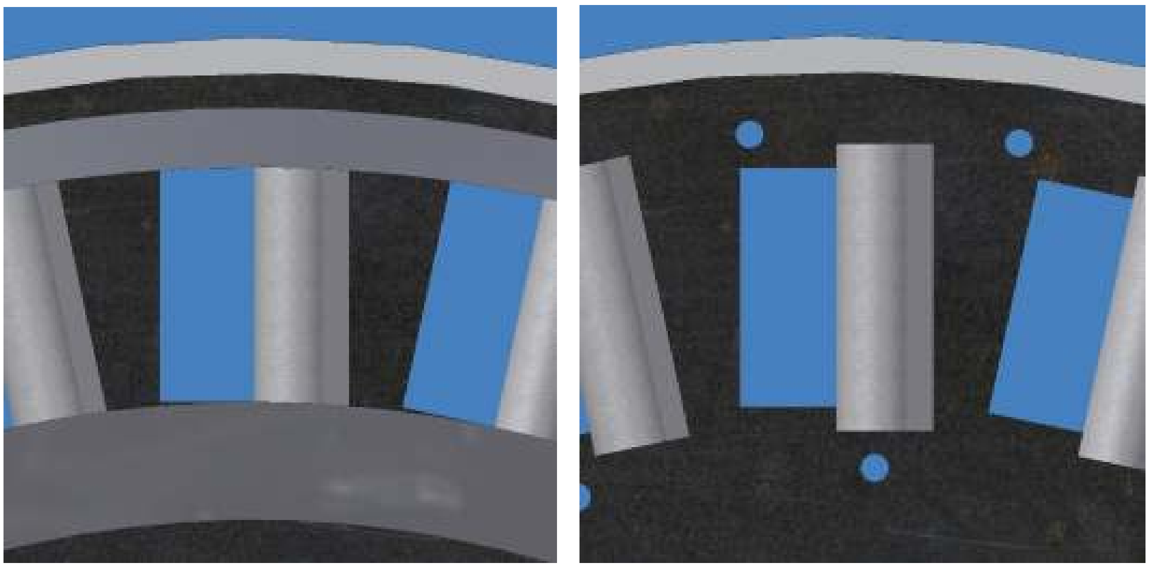

Figure 11: Left - Circular Rack Gear with Retainer Plates
Right - Circular Rack Gear without Retainer Plates

The inserts prevent wear on the wheel itself and are easily replaceable. To improve the ease of maintenance in replacing the round and bar stock, twenty removable retainer plates were bolted to one side of the wheel with 3/4" x 3/8"-16 flat head socket cap screws and twenty were welded to the opposite side. These plates allow the stock inserts to be replaced three sets at a time. The initial wheel and gear hole dimensional calculations did not allow space for the rim-to-wheel weld. Therefore, the outer retainer plates were made shorter in heighth. Later modifications to the Gear Calculator should have fixed this issue.

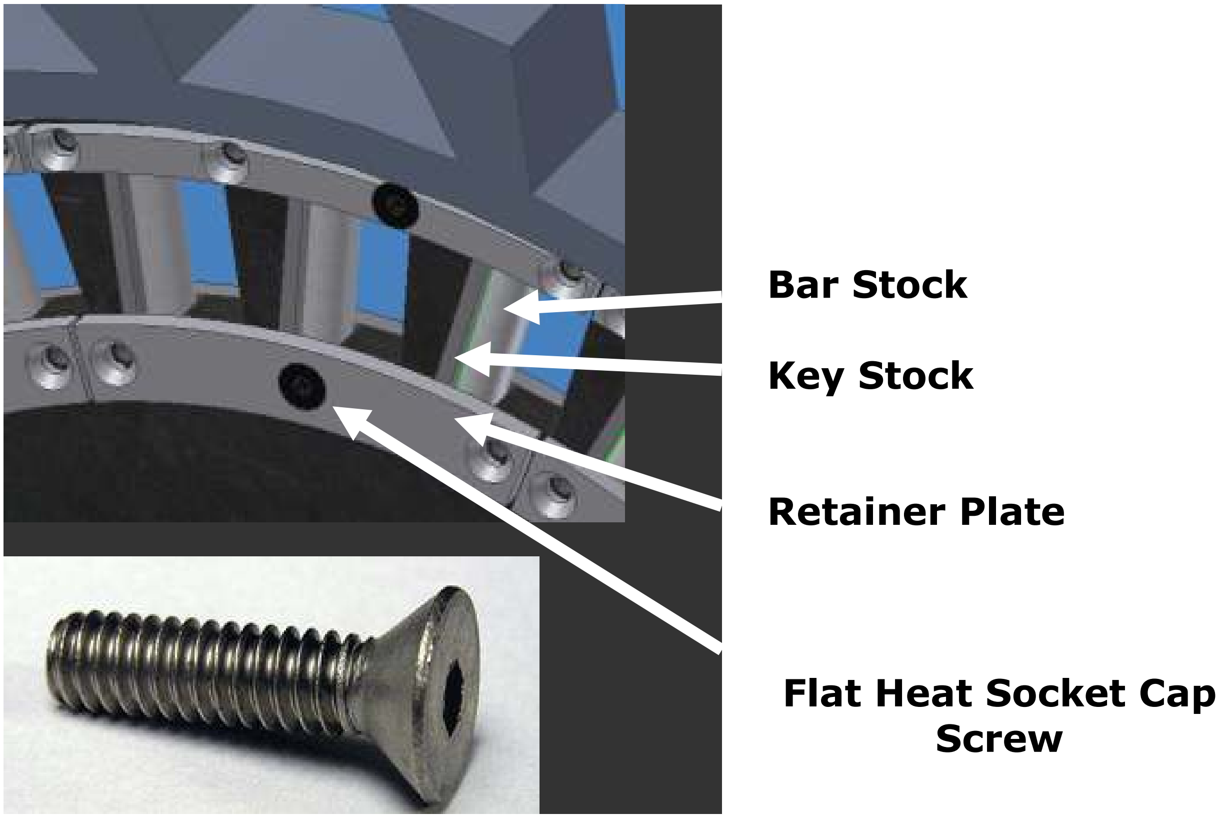

Figure 12: Close Up of Bolt on Retainer Plates and Retaining Bolt.

The recommended material for the round and bar stock is 440C stainless steel. Any strong material will function; a softer, less corrosion resistant material may be less expensive initially, but these inserts will require replacement more often due to the decreased design life. The pinion gears consisted of a set of two acme gears which were designed to mesh into the cutting wheel. These gears were stacked with ¼ of an inch of clearance between the two gears and the wheel to prevent buildup of debris in the gear holes. Due to the curvature of the circular rack, the top pinion gear has a slightly larger diameter than the bottom pinion gear. The stacking was accomplished by making the gear shafts two different lengths.

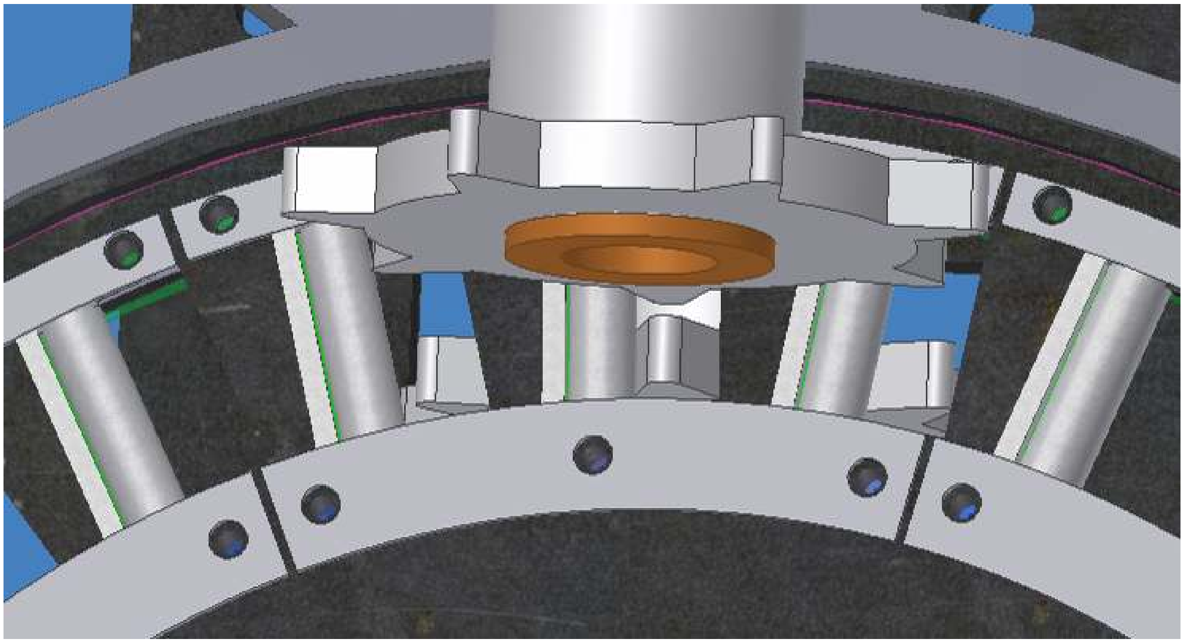

Figure 13: Autodesk Drawing of Gear Configuration on New Wheel Design

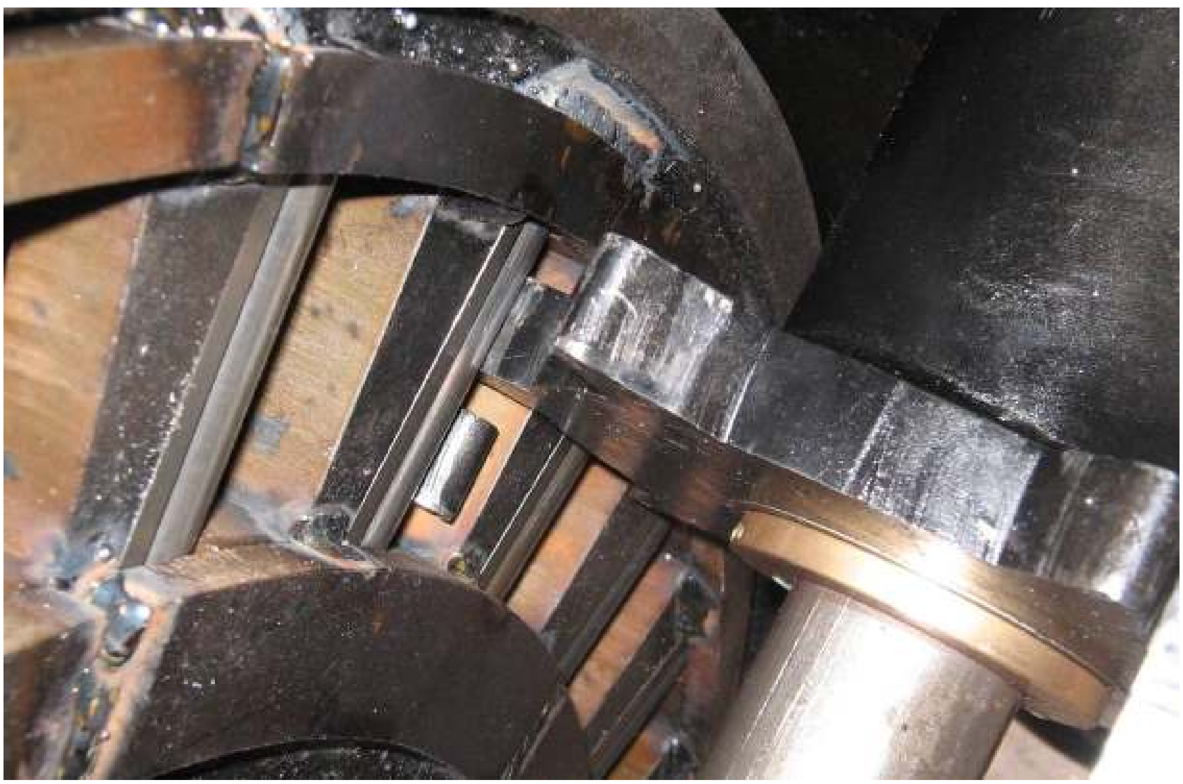

Figure 14: View of BDM's Prototype Gear Mesh

These gears were attached to the hydraulic motors with cylindrical shafts. In order to drive the pinion gears in this configuration, the motors were mounted above the wheel.

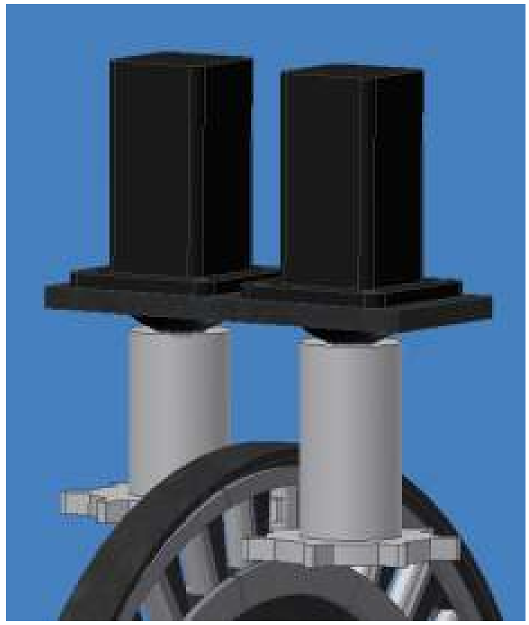

Figure 15: View of Motors and Hydraulic Shafts and Gear Mesh in Relation to Blade.

This modification also eliminated the issue of debris piles adversely affecting the motors. The new prototype's overall blade diameter was increased in size to 32.5 inches, or 38 inches including the rim and cutting teeth. This increase in diameter increased the cutting depth to approximately 23 inches which is about 5% deeper than the CONEQTEC prototype. The outer housing increased in width to 19 inches, in length to 48 inches, and in height to 40 inches in order to accommodate the larger blade. The skid dimensions were increased to fit the new outer housing. In addition, the channel frame assembly was widened to allow room for the gear shafts. The pivot bar was lengthened to accommodate the wider outer housing and channel frame. The hydraulic piston mounting locations and bushing dimensions were modified to accommodate these design changes. No changes were made to the internal workings of the wheel hub and axle.

Quantitative Analysis

The rock saw prototype was designed to function with the most powerful of CONEQTEC Universal's high flow skid steer hydraulic kits. BDM used the same hydraulic system, motors, and pistons as the CONEQTEC prototype. The CONEQTEC Universal super high flow kit allows the skid steer to produce 89 hp, a flow of 34gpm, and a pressure of 4,500 psi. The prototype uses two hydraulic motors to drive the saw. The motors are Sauer Danfoss, 400cc displacement, OMT orbital hydraulic motors. This provides 44.6 hp per motor operating at 160 rpm, producing 1,457 ft/lbs of torque from each motor.

Table 2: Fluids and Strengths Analysis

Hydraulic power kit	**A**	**B**	**C**
Flow (gpm)	34.00	40.00	33.00
Pressure (psi)	4500.00	3200.00	4060.00
Power (hhp)	89.26	74.68	78.17
Hydraulic Motor			
Power (hhp)	44.63	37.34	39.08
Number of Motors	2.00	2.00	2.00
Displacement (cc)	200.00	200.00	200.00
Displacement (gal)	0.05	0.05	0.05
RPM	321.76	378.54	312.30
Torque (ft lbs)	728.52	518.06	657.29
Total Force (lbs)	452.90	322.06	408.62
Cutting wheel			
RPM	75.08	88.33	72.87
Torque (ft lbs)	3122.24	2220.26	2816.96
Diameter (ft)	2.67	2.67	2.67
Force (lbs)	8325.98	5920.69	7511.88
Driving teeth			
Shear Strength (psi)	1006.44	715.69	908.03
Pinion Gear			
Diameter1 (ft)	0.32	0.32	0.32
Diameter2 (ft)	0.30	0.30	0.30
Shear Strength (psi)	301.93	214.71	272.41
Fatigue Load (psi)	**41247**		

This power is transferred from the hydraulic motors with acme gears meshing into the gear holes on the saw blade. The pinion gear teeth apply 450 lbs of force to the replaceable ¾ inch round stock. The gear ratio is 30 driving holes to 7 gear teeth making it 4.3:1. The motors apply approximately 89 hp as well as 2,914 ft-lbs of torque at the picks at 75 rpm. In a wheel made from A36 mild steel with an ultimate strength of 140 ksi, the 1.57 inch minimum spacing between gear holes and 1.0 inch width base of the pinion gear teeth will withstand the maximum possible forces. The shear force experienced between the gear holes is 1000 psi. The shear force experienced at the base of the pinion gear teeth is 300 psi. Both of these values are considerably less than the fatigue load strength of 41,000 psi, therefore, preventing failure.

Figure 16: Pinion Gear Specifications

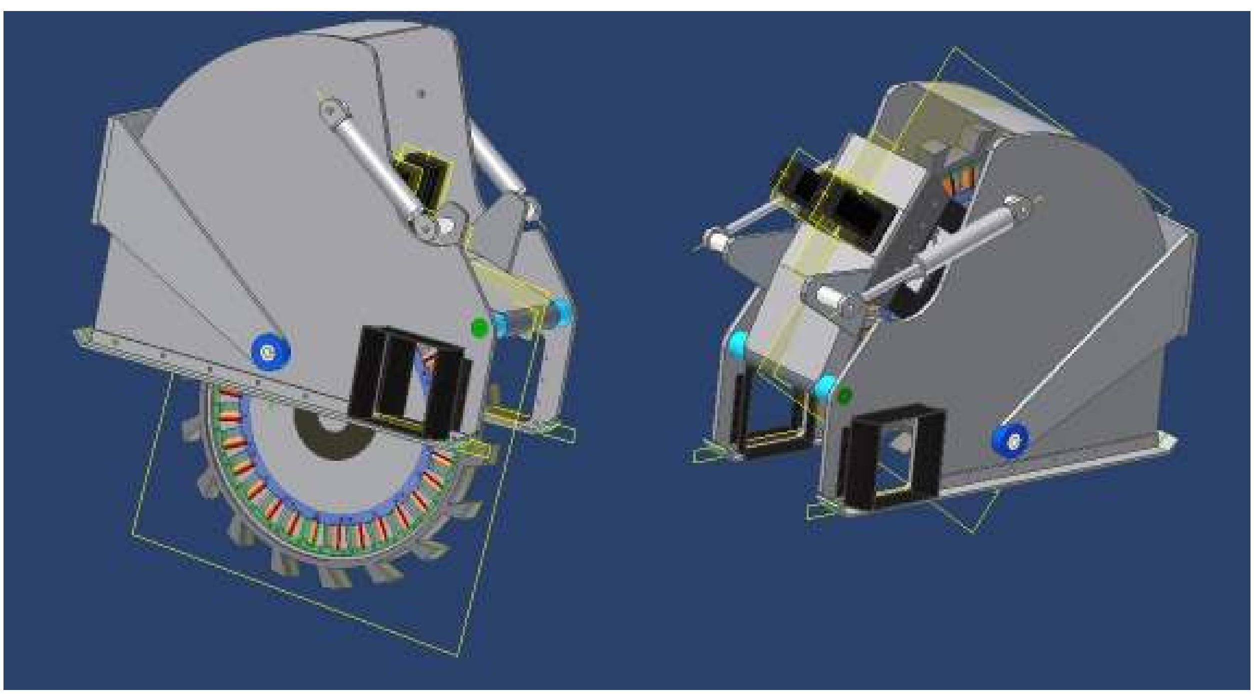

Figure 17: Final BDM Prototype – Full Assembly
Left: Fully Descended. Right: Fully Retracted.

Recommendations

Design and Manufacturing Alternatives

In order to reduce cost, BDM recommends the use of different motors. The current motors can be replaced with motors that have the wheel mount flange housing. The wheel mount flange motors are the same as the current motors with an alternative mounting location.

Figure 18: OMT Wheel Mount Flange Motor (Sauer Danfoss 1)

Instituting this type of motor with make the pinion gears easier to replace and will make the gear retainer parts obsolete. BDM also recommends that an x-y-z adjustable motor mounting system be developed. The combination of using the alternative motors and the adjustable motor mounts may eliminate the costly production of the gear shafts as well as ease the assembly process. BDM would also like to recommend some alternative manufacturing methods. The ear cylinder and plate2 should be one part. The pivot boss inner should be increased to 13 ¼ inches to allow for welding. This part should also have a piece removed from its middle to allow for lubrication.

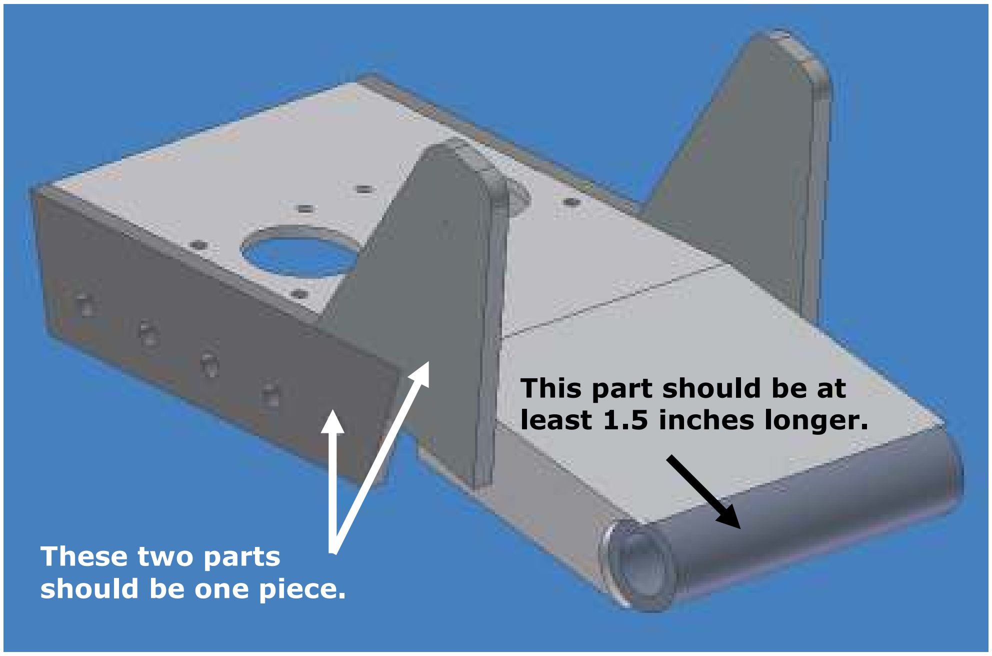

Figure 19: Visual of Recommendations to Make Manufacture Easier on the Channel Frame Assembly.

The next recommendation is to either thread the motor mount instead of plate2, or move the motor mount to the other side of plate2 and then lengthen the mount wheel shaft bracket top, leaving the bolt holes referenced to the inside edge. (Motor mount is a misnomer. It now describes the part the gears protrude through.) If the gear shafts are replaced by conforming to the previous recommendations, the parts in the following picture do not need to be changed. More suitable part names or part numbers should be instituted to avoid confusion during production.

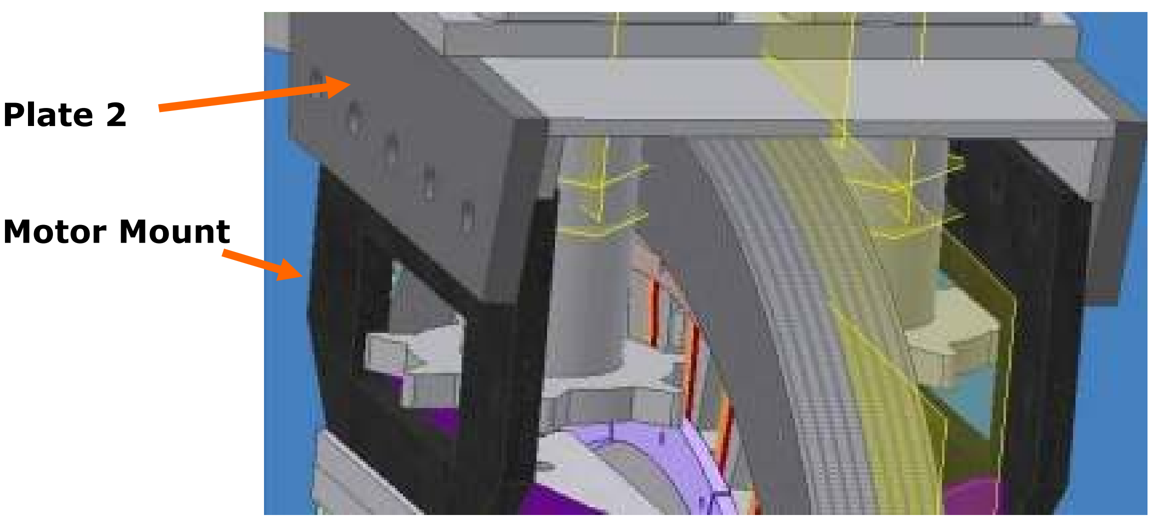

Figure 20: Visual of the Channel Frame Motor Mount Assembly.

Testing

BDM recommends a complete endurance test for the rock saw. This test may include analyzing different materials for the gear hole inserts as well as the pinion gear material. Since the there are 10 retainer plates which retain 3 sets of 2 gear hole inserts, BDM recommends testing up to 10 different materials for a broad wear comparison. The materials BDM recommends for testing range from low carbon steel to highly corrosion and abrasion resistant stainless steels. BDM also recommends testing some exotic materials such as titanium or a Kevlar/ceramic material. These alternatives may be expensive initially; however, a cost benefit analysis may show the exotic inserts to be less expensive if their design life is extended to over a few hundred hours. This test will determine the optimum operational life before replacement of the ring gear teeth. A similar test can be done for the pinion gear. However, a hardened, corrosion resistant stainless steel should be sufficient. The mounting locations of the hydraulic cylinders on the outer housing may need adjustment in order to achieve the maximum depth of cut.

Safety

The last set of recommendations by BDM refers to the addition of safety devices to increase the overall safety of the rock saw. The first would be the addition of a detachable flap to the front opening of the outer housing.

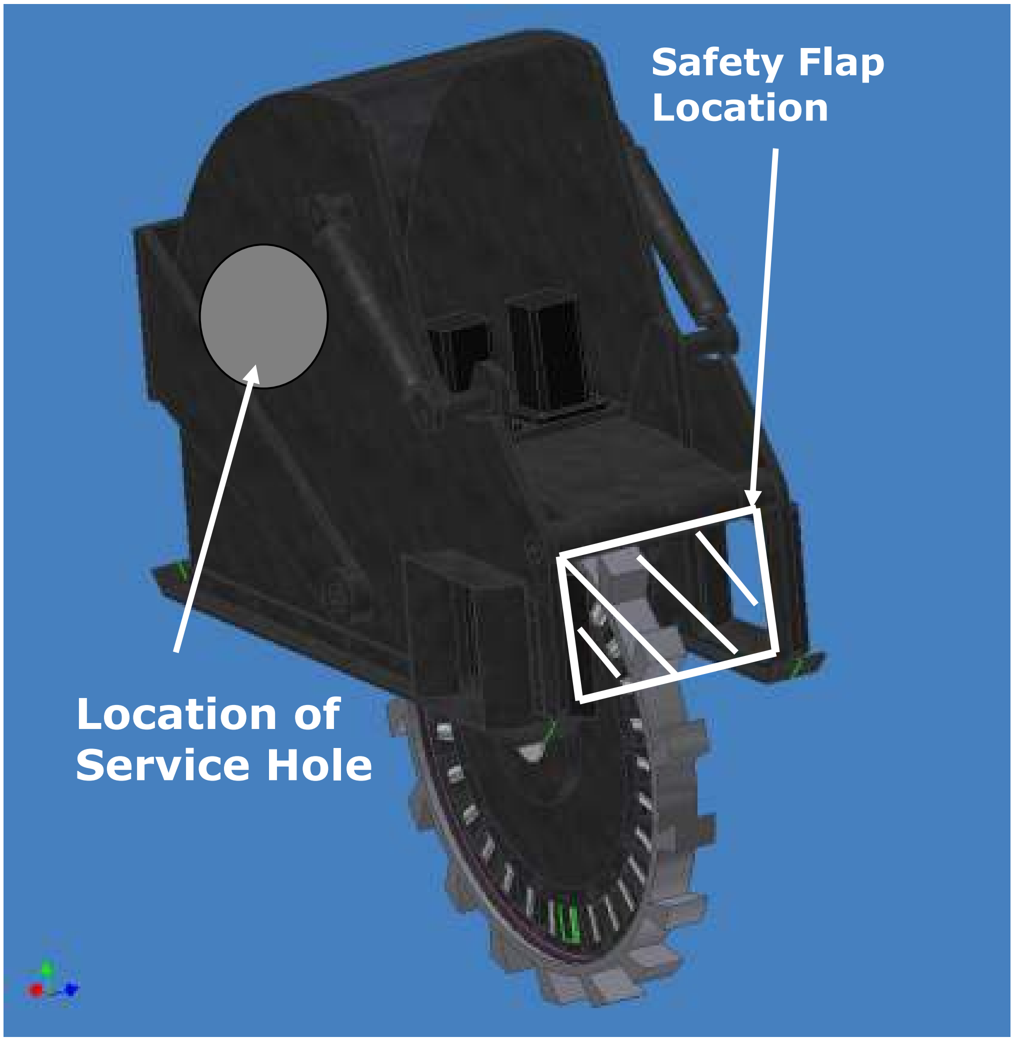

Figure 21: Total BDM Prototype Assembly with Safety Flap Location

This flap may prevent other equipment or appendages from coming into contact with the blade. A hole could but cut in the outer housing to reduce weight and increase serviceability. A hinged or detachable flap could be added in place of the hole to ensure safety.

Budget

Table 3: BDM In-House Budget.

Materials	$1,623.38
Fasteners	$112.27
Tools	$36.40
Total	$1,772.05

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Appendix 1

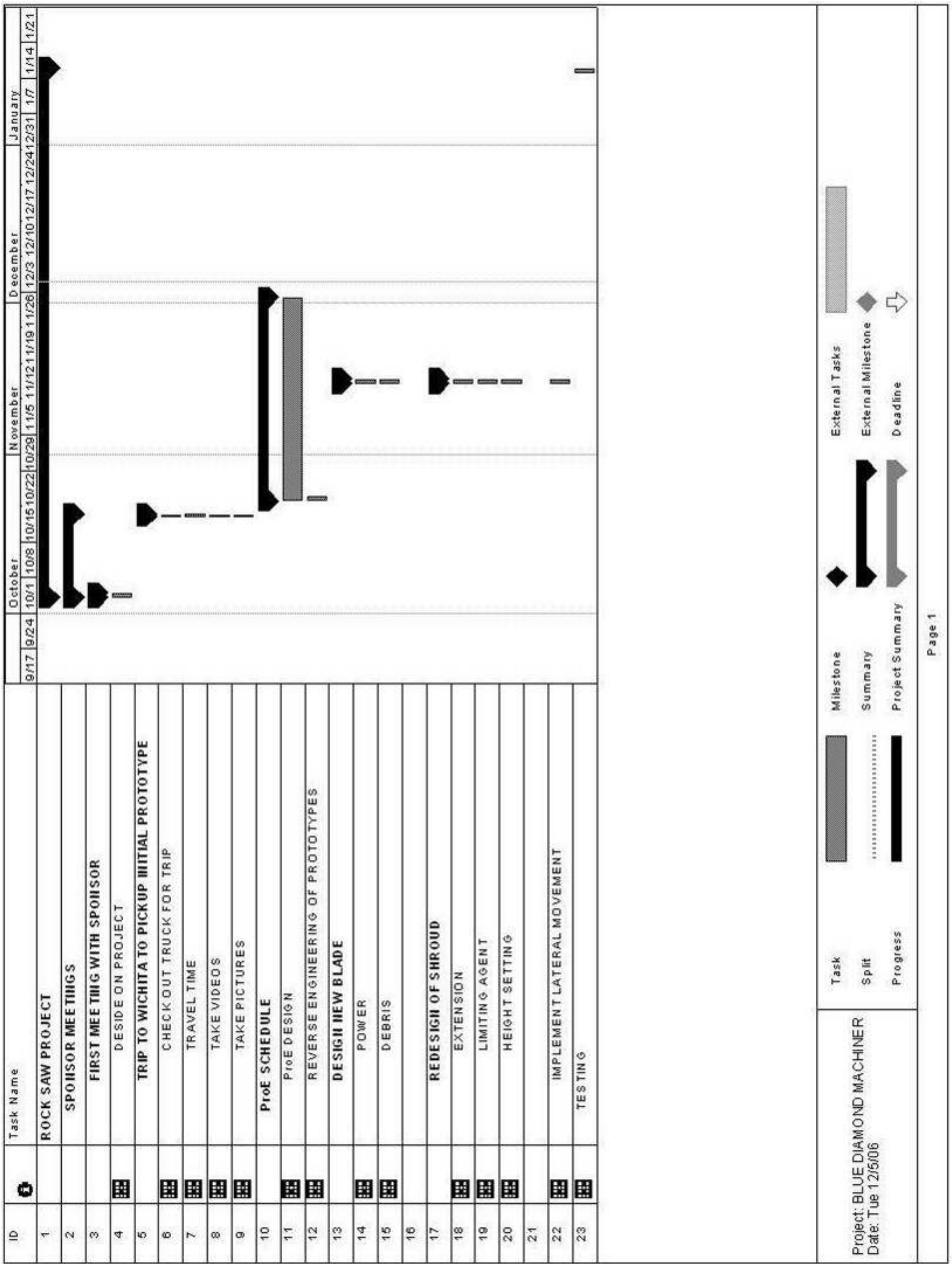
Parts List

Item	Part Number	BOM Structure	Unit QTY	QTY
1	base frame assembly 2	Normal	1	1
1.1	plate back	Normal	1	1
1.2	outer_frame	Normal	1	2
1.3	pivot boss outer frame	Normal	1	2
1.4	pivot pin boss	Normal	1	2
2	pivot boss outer frame cylinder	Normal	1	2
3	motor mount asm to channel asm	Normal	1	1
3.1	channel frame assembly	Normal	1	1
3.1.1	top channel frame	Inseparable	1	1
3.1.1.1	top channel frame top	Normal	1	1
3.1.1.2	top channel frame side	Normal	1	2
3.1.2	front channel frame	Normal	1	1
3.1.3	plate2 new	Normal	1	2
3.1.4	ear_cylinder_right	Normal	1	1
3.1.5	pivot boss inner	Normal	1	1
3.1.6	pivot boss outer frame carriage	Normal	1	2
3.1.7	bolt_bar	Normal	1	2
3.1.8	ear_cylinder_left	Normal	1	1
3.2	wheel_assembly	Normal	1	1
3.2.1	wheel disk	Normal	1	1
3.2.2	wheel_rim	Normal	1	1
3.2.3	.25_in_flatstock	Normal	1	30
3.2.4	.75_in_roundbar	Normal	1	30
3.2.5	inner rim sections 2	Normal	1	10
3.2.6	outter rim sections	Normal	1	10
3.2.7	inner rim sections 2_MIR	Normal	1	10
3.2.8	outter rim sections_MIR	Normal	1	10
3.2.9	ring outer seal	Normal	1	2
3.2.10	ring inner seal	Normal	1	2
3.3	mount wheel shaft assembly	Normal	1	2
3.3.1	mount wheel shaft	Normal	1	1
3.3.2	motor mount	Normal	1	1
3.3.3	mount wheel shaft bracket	Normal	1	1
3.3.4	mount wheel shaft bracket top	Normal	1	1
3.4	motor mount plate	Normal	1	1
3.5	Motor	Normal	1	2
3.6	gear shaft	Normal	1	2
3.7	Top Gear 7 teeth	Normal	1	1
3.8	Bottom Gear 7 teeth	Normal	1	1
3.9	shaft wheel	Normal	1	1
3.10	cap wheel shaft	Normal	1	1
3.11	gear bearing assembly	Normal	1	1
3.11.1	bearing retainer	Normal	1	1
3.11.2	gear bearing	Normal	1	1
3.12	gear bearing assembly wide	Normal	1	1
3.12.1	bearing retainer wide	Normal	1	1
3.12.2	gear bearing	Normal	1	1
4	Cylinder	Normal	1	2
5	piston shaft	Normal	1	2

Appendix 2

Gantt Charts

Fall 2006



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2 SPONSOR MEETINGS
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4 DESIDE ON PROJECT
5 TRIP TO WICHITA TO PICKUP INITIAL PROTOTYPE
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8 TAKE VIDEOS
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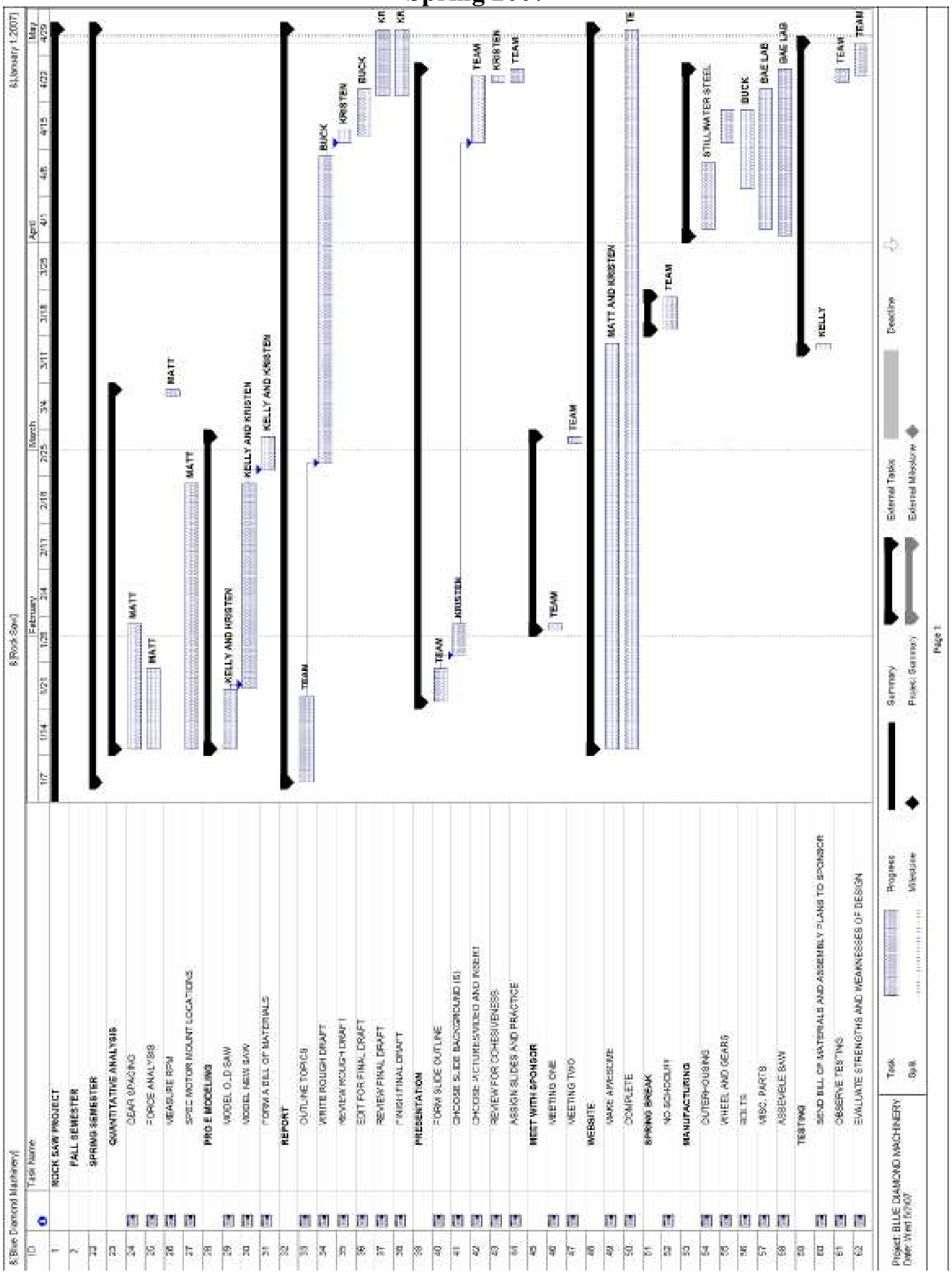
ROCK SAW PROJECT
FALL SEMESTER
SPRING SEMESTER
QUANTITATIVE ANALYSIS
GEAR SPACING
FORCE ANALYSIS
MEASURE RPM
SPEC MOTOR MOUNT LOCATIONS
PRO E MODELING
MODEL OLD SAW
MODEL NEW SAW
FORM A BILL OF MATERIALS
REPORT
OUTLINE TOPICS
WRITE ROUGH DRAFT
REVIEW ROUGH DRAFT
EDIT FOR FINAL DRAFT
REVIEW FINAL DRAFT
FINISH FINAL DRAFT
PRESENTATION
FORM SLIDE OUTLINE
CHOOSE SLIDE BACKGROUND(S)
CHOOSE PICTURES/VIDEO AND INSERT
REVIEW FOR COHESIVENESS
ASSIGN SLIDES AND PRACTICE
MEET WITH SPONSOR
MEETING ONE
MEETING TWO
WEBSITE
MAKE AWESOME
COMPLETE
SPRING BREAK
NO SCHOOL!!!
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OBSERVE TESTING
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Project: BLUE DIAMOND MACHINERY

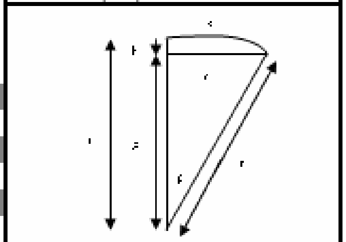
Appendix 3

Gear Calculator

Gear Mesh Calculator			
Wheel Diameter to bottom of hole (D_B)	22.25	in	
Wheel Radius to bottom of hole (r_B)	11.125	in	
Wheel Circumference at bottom of hole (C_B	69.900	in	
Wheel Hole Spacing (d_B)	2.31301756	in	
Angle Between Holes (θ_B)	12.000		0.2094
Arc Length Between Holes (s_B)	2.330	in	
Arc Length Between Gear Teeth (s_G)	2.313	in	
Wheel Disk Radius	16.125	in	
Wheel Disk Diameter	32.25	in	
Wheel Radius With Rim and Picks	18.000	in	
Height of Gear Holes	3.00	in	
Number of Gear Holes (n_B)	30.000	holes	
Wheel Diameter With Rim and Picks	36	in	

Equations

d_B = sin (s_B) * (r_B) = s_G
d=sin(s/r)*r
sin(θ) = d / r
θ=s/r   G=gear
s=r*θ   B=blade or wheel
C=2*π*r
s=arcsin(d/r)*r



THE NUMBER OF HOLES AND THE WHEEL DIAMETER ARE SATISFACTORY.

Note: Feel free to change the orange cells to manipulate the table values.

Gear Ratio	Gear Radius to Base of Teeth (r_G)	Gear Diameter to Base of Teeth (D_G)	Gear Circumference to Base of Teeth (C_G)	Number of Gear Teeth (n_G)	Angle Between Gear Teeth (θ_G)
30	0.368	0.736	2.313	1.000	6.283185307
15	0.736	1.473	4.626	2.000	3.141592654
10	1.104	2.209	6.939	3.000	2.094395102
7.5	1.473	2.945	9.252	4.000	1.570796327
6	1.841	3.681	11.565	5.000	1.256637061
5	2.209	4.418	13.878	6.000	1.047197551
4.285714286	2.577	5.154	16.191	7.000	0.897597901
3.75	2.945	5.890	18.504	8.000	0.785398163
3.333333333	3.313	6.626	20.817	9.000	0.698131701
3	3.681	7.363	23.130	10.000	0.628318531
2.727272727	4.049	8.099	25.443	11.000	0.571198664
2.5	4.418	8.835	27.756	12.000	0.523598776
2.307692308	4.786	9.571	30.069	13.000	0.483321947
2.142857143	5.154	10.308	32.382	14.000	0.448798951
2	5.522	11.044	34.695	15.000	0.41887902
1.875	5.890	11.780	37.008	16.000	0.392699082
1.764705882	6.258	12.516	39.321	17.000	0.369599136
1.666666667	6.626	13.253	41.634	18.000	0.34906585
1.578947368	6.994	13.989	43.947	19.000	0.330693964
1.5	7.363	14.725	46.260	20.000	0.314159265
1.428571429	7.731	15.461	48.573	21.000	0.2991993
1.363636364	8.099	16.198	50.886	22.000	0.285599332
1.304347826	8.467	16.934	53.199	23.000	0.27318197
1.25	8.835	17.670	55.512	24.000	0.261799388
1.2	9.203	18.406	57.825	25.000	0.251327412
1.153846154	9.571	19.143	60.138	26.000	0.241660973
1.111111111	9.939	19.879	62.451	27.000	0.232710567
1.071428571	10.308	20.615	64.764	28.000	0.224399475
1.034482759	10.676	21.351	67.078	29.000	0.216661562
1	11.044	22.088	69.391	30.000	0.20943951
0.967741935	11.412	22.824	71.704	31.000	0.202683397

Appendix 4

Fire Protection Safety Report

System: Blue Diamond Rock Saw Subsystem: Saw Functions			Functional Hazard Analysis				Analyst: Zack Brown & Nick Eschner Date: 4/12/07		
Function	**Hazard No.**	**Hazard**	**Effects**	**Causal Factors**	**IMRI**	**Recommended Action**	**FMRI**	**Comments**	**Status**
Running Saw to Cut Rock	A-1	Exposed Saw Blade Sends Particles Airborn	Bodily Harm in Abrasion, Laceration, Eye Damage, Bruising	Absence of Safety Guards	2A	Install Safety Guards & Require PPE		PPE: Eye, Ear, Body Protection	
	A-2	Exposed Saw Blade Teeth Divide from Blade	Bodily Harm in Abrasion, Laceration	Absence of Safety Guards	2D	Install Safety Guards & Require PPE		PPE: Eye, Ear, Body Protection	
Dry Cutting System	A-3	Airborne Dust and Rock Particles	Respiratory Problems Silicosis	Absence of Respiratory Protection	1A	Equip Employeess with Respiratory Protection		See Appendix A	
Drive System	A-4	System Failure	System Malfunction, Breakdown	Fatigue	2C	Periodic Maintenance			
Saw Blade	A-5	Exposed Saw Blade Teeth (Foreign Object Put Near Running Blade)	Bodily Harm in Abrasion, Amputation, Laceration	Absence of Safety Guards	1C	Keep a Safe Distance from Blade Install Safety Guards			
	A-6	Dull Saw Blade Teeth	Decreased Effectiveness, Productivity	Unmaintained Equipment	3B	Increased Maintenance			
	A-7	Dull Saw Blade Teeth	Increased Friction, Heat	Unmaintained Equipment	3B	Increased Maintenance			
	A-8	Dull Saw Blade Teeth	Increased Noise > 90dBA	Unmaintained Equipment	3B	Hearing Protection			

Cutting Into Ground	A-9	Unexpected Buried Utilities	Break in Gas Line, Electric Line, Sewer Line, Water Line	Unsurveyed Area	2C	Survey Site Prior to Cut		Can Create Explosion And/Or Electricution	
Saw Blade	A-10	Jammed Blade	Damage to Gear Teeth, Hydraulic System, Housing	Forced to Cut Too Much Unexpected Material	2E	Install Proper Guarding		See Appendix D	
	A-11	Jammed Blade	Failure of Blade, System	Material Impeding On Rotary Motion	2E	Install Proper Guarding		See Appendix D	
	A-12	Jammed Blade	System Shutdown	Loss Of Hydraulic Pressure	2E	Install Proper Guarding		See Appendix D	

System: Blue Diamond Rock Saw Subsystem: Hydraulic Functions			Functional Hazard Analysis				Analyst: Zack Brown & Nick Eschner Date: 4/12/07		
Function	**Hazard No.**	**Hazard**	**Effects**	**Causal Factors**	**IMRI**	**Recommended Action**	**FMRI**	**Comments**	**Status**
Control Saw (pitch)	B-1	Broken Hydraulic Line	Inability to control saw pitch	Absence of hydraulic line guards Damage to hydraulic line (puncture, rip, tear, etc.) Poor up keep of hydraulic hose	3D	Pre-operations checks Hydraulic pressure alarms Periodic maintenance		Notified design team	
	B-2	Broken Hydraulic Line	Burn to person	Improper PPE Improper position of operator Poor up keep of hydraulic hose	1D	Labels/Warnings Mandatory training Proper PPE		PPE: Eye, Ear, Body Protection	
	B-3	Broken Hydraulic Line	Injury to eye of person	Improper PPE Improper position of operator Poor up keep of hydraulic hose	2C	Labels/Warnings Mandatory training Proper PPE		PPE: Eye, Ear, Body Protection	
	B-4	Broken Hydraulic Line	Injection of fluid	Improper PPE Improper position of operator Poor up keep of hydraulic hose	2D	Labels/Warnings Mandatory training Proper PPE		See Appendix B PPE: Eye, Ear, Body Protection	
	B-5	Broken Hydraulic Line	Ingestion of fluid	Improper PPE Poor up keep of hydraulic hose	2D	Sanitation stations Proper PPE		PPE: Eye, Ear, Body Protection	

	B-6	Broken Hydraulic Line	Inhalation of fluid fumes	Improper PPE Improper position of operator Poor up keep of hydraulic hose	2C	Proper PPE Ventilated/outdoor work environment		PPE: Eye, Ear, Body Protection	
	B-7	Broken Hydraulic Line	Damage to environment	Poor up keep of hydraulic hose	2C	Periodic maintenance			
	B-8	Broken Hydraulic Line	System shutdown	Absence of hydraulic line guards Damage to hydraulic line (puncture, rip, tear, etc.) Poor up keep of hydraulic hose	3D	Periodic maintenance			
Hydraulic fluid	B-9	Hydraulic Fluid Spill	Damage to environment and wildlife	Improper precautions taken Improper operator training	2D	Add hydraulic fluid in controlled setting to accommodate spill			
		Incorrect Fluid Used	System Failure	Improper training		Warnings/Training			
Hydraulic fluid line	B-10	Loose Line	Burn to person	Improper PPE Improper position of operator Poor up keep of hydraulic hose	1D	Labels/Warnings Mandatory training Proper PPE		PPE: Eye, Ear, Body Protection	
	B-11	Loose Line	Injury to eye of person	Improper PPE Improper position of operator Poor up keep of hydraulic hose		Labels/Warnings Mandatory training Proper PPE		PPE: Eye, Ear, Body Protection	

	B-12	Loose Line	Injection of fluid	Improper PPE Improper position of operator Poor up keep of hydraulic hose	1D	Labels/Warnings Mandatory training Proper PPE		See Appendix B	
	B-13	Loose Line	Ingestion of fluid	Improper PPE Poor up keep of hydraulic hose	1D	Sanitation stations Proper PPE		PPE: Eye, Ear, Body Protection	
	B-14	Loose Line	Inhalation of fluid fumes	Improper PPE Improper position of operator Poor up keep of hydraulic hose	2C	Proper PPE Ventilated/outdoor work environment		PPE: Eye, Ear, Body Protection	
	B-15	Loose Line	Damage to environment	Poor up keep of hydraulic hose	2C	Periodic maintenance			
	B-16	Loose Line	System shutdown	Absence of hydraulic line guards Damage to hydraulic line (puncture, rip, tear, etc.) Poper keep of hydraulic hose	3D	Periodic maintenance			
Pressure	B-17	Low Pressure	System Failure	Poor upkeep	3D	Periodic maintenance			
	B-18	Low Pressure	Damage to System	Poor upkeep		Periodic maintenance			

System: Blue Diamond Rock Saw Subsystem: Electrical Functions			Functional Hazard Analysis				Analyst: Zack Brown & Nick Eschner Date: 4/12/07		
Function	**Hazard No.**	**Hazard**	**Effects**	**Causal Factors**	**IMRI**	**Recommended Action**	**FMRI**	**Comments**	**Status**
Electrical System	C-1	Low Power	System Failure	Low Battery Charge	3B	Detach Battery from System Upon Shut-Down, Periodic Maintenance		Periodic Maintance should pick up expired batteries.	
	C-2	No Power	System Will Not Start	No Battery Charge, No Battery	3B	New Battery			
Fuses	C-3	Broken Fuse	System Will Not Work, System Components Will Not Work, System Failure	Overloaded System, Problem In Wiring	3D	Maintanence the System			
	C-4	Broken Fuse	Safety Devices Will Not Engage	Overloaded System, Problem In Wiring	2D	Maintenance the System			

System: Blue Diamond Rock Saw Subsystem: Motor Functions			Functional Hazard Analysis				Analyst: Zack Brown & Nick Eschner Date: 4/12/07		
Function	**Hazard No.**	**Hazard**	**Effects**	**Causal Factors**	**IMRI**	**Recommended Action**	**FMRI**	**Comments**	**Status**
Drive System	D-1	Overheating	Fire	Poor maintenance Mechanical failure	2D	Periodic maintenance Pre-use inspection			
	D-2	Overheating	Release of fumes	Fluid on hot surface Broken hose Boiling liquids	2D	Respirator for protection Be in well ventilated area Allow to cool before work			
	D-3	Overheating	System Break Down	Melting Hose destruction Temperature	2D	Stop work when engine compartment temp. become elevated			
Drive System	D-4	Noise > 90 dBa	Damage to hearing	No hearing protectior Working in confined area To close to work process	3A	Hearing Protection Work in open area			
Drive System	D-5	Hot surface	Burn to skin	Improper PPE Did not allow time to cool Not trained to work on motor Improper Tools	3B	Training Correct tools Gloves and long selves, proper PPE			

System: Blue Diamond Rock Saw Subsystem: Structural Functions			Functional Hazard Analysis				Analyst: Zack Brown & Nick Eschner Date: 4/12/07		
Function	**Hazard No.**	**Hazard**	**Effects**	**Causal Factors**	**IMRI**	**Recommended Action**	**FMRI**	**Comments**	**Status**
Structure (Metal)	E-1	Ungrounded Metal	Electrocution	Lightening; Cut Hot Electrical Line	1D	Survey Site Stop Operations in Presence of a Storm			
Saw Depth Gauge	E-2	Over Exceed Designed Depth	System Failure	Debris Stays in Cut	3D	Periodic Maintenance			
	E-3	Over Exceed Designed Depth	Damage to Depth Gauge, Motor, System	Foreign Objects Depth Gauge, Motor	3D	Periodic Maintenance			
System Controls	E-4	Inability to Leave Vehicle Cab	Users Health At Jeopardy	System Controls Are Stationary	1E	Periodic Maintenance		Design Break-Away System Controls	
System Stability	E-5	System Tipping or Rolling Over	Operator Injury, Death; Property Damage; System Damage	Unlevel Ground; Unlevel System Structure		Survey Site, Periodic Maintenance			
Moving Parts	E-6	Noise > 90dBA	Hearing Damage	Machinery Clanging/ Banging Against Itself	2A	Hearing Protection		Some Noise May Be Mitigated with Maintenance (ie. Oiling).	
Exhaust	E-7	Noise > 90dBA	Hearing Damage	Absence of Muffler	2C	Hearing Protection, Install Muffler			
	E-8	Hot Exhaust Pipe	Skin Damage	Heated Muffler and Exhaust Pipe(s)	2A	Wear Proper PPE, Install Safety Guard Around Piping			

Moving Parts	E-9	Heated Metal Parts By Friction	Skin Damage	Parts Grinding, Rubbing	2A	Wear Proper PPE		PPE can be long sleeves and long pants.	
	E-10	Moving Parts	Bodily Harm By Amputation, Abrasion, Laceration, Pinched Body Part	Parts Crossing Paths	1A	Install Safety Guards		See Appendix C	
Structural Parts	E-11	Spark	Ignite Nearby Fuel	Metal Hitting Metal, Static Electricity	1E	Ground Machinery, Paint Machinery			

System: Blue Diamond Rock Saw Subsystem: User Functions			Functional Hazard Analysis				Analyst: Zack Brown & Nick Eschner Date: 4/12/07		
Function	**Hazard No.**	**Hazard**	**Effects**	**Causal Factors**	**IMRI**	**Recommended Action**	**FMRI**	**Comments**	**Status**
Light	F-1	UV Rays	Damage to Eyes	Sun	3A	Eye protection that is UV rated			
	F-2	UV Rays	Damage to Skin	Sun	3A	Skin protection			
Start Device Keys	F-3	Do have keys	System will not start	Operator error	4C	Find competent operator			
No Fuel (gas)	F-4	Do not have fuel	System will not start	Operator error	4C	Find competent operator			
No Operator	F-5	Do not have operator	System will not work	Operator error	4C	Find competent operator			

APPENDIX A

Silicosis

August 2004

Esta página en Español

NIOSH Publication No. 2004-108:

Silicosis: Learn the Facts!

This document presents information in an easy to read format describing silica exposures, the effects of silicosis, and methods to protect against silicosis.

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Safety Information
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Description of Silicosis
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What Can I Do to Protect Myself and My Family?
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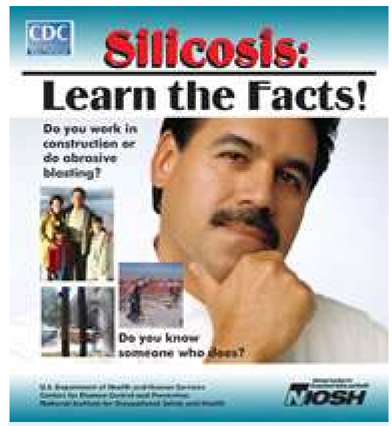

Related Resources/Publications:

NIOSH Safety and Health Topic Page - Silica

This document is also available in PDF format.

The print version contains both the English and Spanish texts.

English Version:
2004-108.pdf
20 pages, 1748kb

Spanish Version:
2004-108sp.pdf
20 pages, 1748kb

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DHHS (NIOSH) Publication No. 2004-108

August 2004

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Safety Information

For more information on silicosis and how it can affect you and your family, visit our Web site at:

http://www.cdc.gov/niosh/topics/silica

For more information or for answers to questions about any safety and health regulatory matters, contact the Occupational Safety and Health Administration (OSHA)

U.S. Department of Labor
Occupational Safety & Health Administration
200 Constitution Avenue
Washington, D.C. 20210

1-800-321-OSHA (6742)
(Spanish speaking staff available)

Silicosis: Learn the Facts!

Do you work in construction or do abrasive blasting?

If so, here are some important facts you need to know:

- Since 1968, more than 14,000 workers in the U.S. have died from a disease called silicosis.
- In the U.S. each year more than 200 workers die with this disease while hundreds more become disabled.

- Many workers with silicosis are only in their thirties; some are as young as 22 years old. Many of them are unable to take care of themselves and their families.

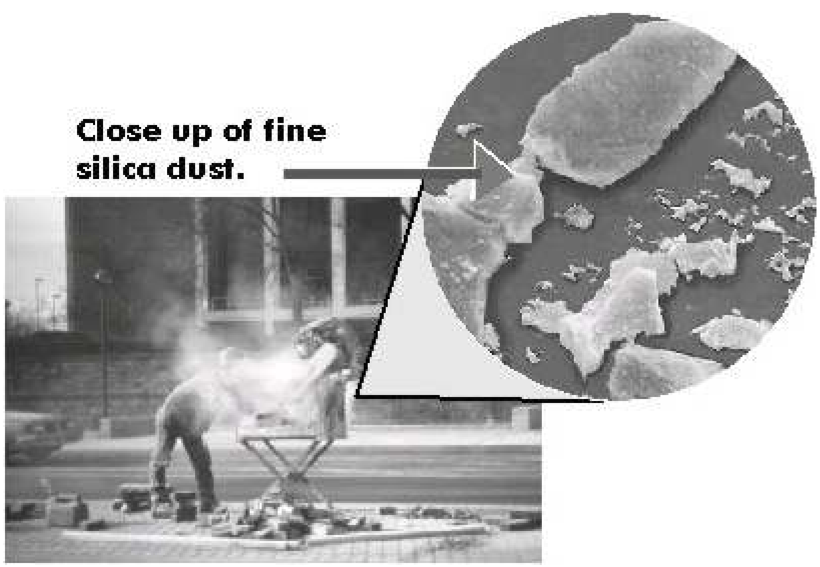
What is silicosis and how can you avoid or prevent it?

This booklet will give you information about silicosis, what causes it, the symptoms, and the ways you can avoid developing the disease.

WARNING!
Silicosis IS NOT CURABLE, but it IS PREVENTABLE. Learn the facts and know how to protect yourself. Silicosis affects both your health AND the welfare of your family.

Description of Silicosis

Silicosis is a disabling and often fatal lung disease caused by breathing dust that has very small pieces of crystalline silica in it. Crystalline silica is found in concrete, masonry, sandstone, rock, paint, and other abrasives. The cutting, breaking, crushing, drilling, grinding, or abrasive blasting of these materials may produce fine silica dust. It can also be in soil, mortar, plaster, and shingles. The very small pieces of silica dust get in the air that you breathe and become trapped in your lungs. Even the very small pieces of dust that you cannot see will harm you. As the dust builds up in your lungs, the lungs are damaged and it becomes harder to breathe.



Are YOU breathing silica dust?

If YOU do one of the following jobs, you ARE at risk for breathing silica dust:

- Removal of paint and rust with powertools;
- Abrasive blasting of bridges, pipes, tanks, and other painted surfaces especially while using silica sand;
- Grinding mortar;
- Abrasive blasting of concrete (many bridges and buildings are made of concrete);

- Crushing, loading, hauling, chipping, hammering, drilling, and dumping of rock or concrete;
- Chipping, hammering, drilling, sawing, and grinding concrete or masonry;
- Demolition of concrete and masonry structures;
- Dry sweeping or pressurized air-blowing of concrete or dust; or
- Jackhammering on various materials.

ATTENTION!
When you wear dusty clothing at home or in your car, you may be carrying silica dust that your family will breathe.

Who is at Risk?

Workers in the following occupations are at risk for developing silicosis:

- Highway and bridge construction and repair
- Building construction, demolition, and repair
- Abrasive blasting
- Masonry work
- Concrete finishing

- Drywall finishing
- Rock drilling
- Mining
- Sand and gravel screening
- Rock crushing (for road base)

ATTENTION!
If you work near dust clouds like the ones in these photos, you might be exposed to silica. You may be exposed even when dust is not visible.

Types of Silicosis

There are three types of silicosis:

1. *Chronic silicosis:* Usually occurs after 10 or more years of exposure to crystalline silica at low levels. This is the most common type of silicosis.

2. *Accelerated silicosis:* Results from exposure to higher levels of crystalline silica and occurs 5 to 10 years after exposure.

3. *Acute silicosis:* Can occur after only weeks or months of exposure to very high levels of crystalline silica. Death occurs within months. The lungs drown in their own fluids.

Healthy Lung

Diseased Lung

Symptoms

Symptoms may not appear in the early stages of chronic silicosis. In fact, chronic silicosis may go undetected for 15 to 20 years after exposure. As silicosis progresses, symptoms may include:

- Shortness of breath
- Severe cough
- Weakness

Because the body's ability to fight infections may be weakened by silica in the lungs, other illnesses (such as tuberculosis) may result and can cause:

- Fever
- Weight loss
- Night sweats
- Chest pains
- Respiratory failure

These symptoms can become worse over time, leading to death.

WARNING!
Victims of silicosis are also at risk for getting lung infections such as tuberculosis (TB). TB is a disease that can be spread by coughing,

sneezing, or talking around your spouse, children, and other loved ones.

Silicosis Has Affected Many Workers and Their Families

The following is based on a true story of a construction worker from Central Texas who died at age 35, leaving behind his wife and four children, ages 10, 14, 16, and 17.

"When I first started working, I was very young and full of energy. I was anxious about starting my first real job in the United States and being able to support my wife and children like I wanted. Sandblasters made quite a bit of money. I noticed that there was a lot of dust, but I never thought that it would hurt me. I wore a bandana everyday to cover my mouth and nose. Everyone said that this was good and that I would be fine. Well, I guess that wasn't so true after all. Now I'm 35 years old, and I have silicosis. No one ever told me about silicosis. My wife noticed that I was doing a lot of coughing and wheezing at night and she was very concerned. Now I get tired very easily, and I have a hard time enjoying the things I used to do like playing games with my children and taking them places. I am often depressed and it bothers me a lot that I'm not able to take care of my family. My doctor said that I have advanced silicosis and probably will die in a few years. Silicosis really changes your life and affects your family. I never pictured myself dying this young and not seeing my children grow up. I wish that I would have known this before it was too late."

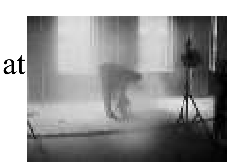
Silicosis cases in Texas

In November 1988, 10 cases of silicosis were reported in west Texas. All of the workers were sandblasters employed at a company that sandblasted oil-well drilling pipes. Each had been exposed to silica dust and had high levels of silica in their lungs. Their job included the use of sandblasting machinery that was in poor condition and leaked silica dust into the air. All of the workers were Hispanic males with an average age of 31 years. One of the workers died from silicosis at the age of 34 [CDC 1990].

Did you know?

- Over 1 million U.S. workers are at risk of developing silicosis.
- Hundreds die of silicosis each year.
- The construction industry has one of the highest numbers of deaths due to silicosis.

Individual cases



A tile-installer was diagnosed with advanced silicosis, emphysema, and asthma at age 49. Although he didn't directly perform risky tasks, he worked near sandblasting and was exposed to silica dust (tile installers can also be directly exposed to silica dust when cutting tile). He did not wear a respirator [NIOSH

1996].

A 39-year-old sandblaster was diagnosed with progressive silicosis and tuberculosis in 1993. He had reported shortness of breath, wheezing, and lack of energy. He had worked for 22 years sandblasting welds during water tank construction. He wore a charcoal filter respirator while sandblasting, but it was the wrong type and did not protect him. Two brothers and three nephews who worked with him all tested positive for tuberculosis as well [NIOSH 1996].

A 36-year-old man in Texas died in 1995 from advanced silicosis after working as a sandblaster for 11 years. He had been exposed to silica dust for only three years while sandblasting oil field pipes and tanks [CDC 1998].

A 30-year-old sandblaster in Texas died 10 years after his first exposure to silica dust. He had been exposed to silica dust for only four years [CDC 1998].

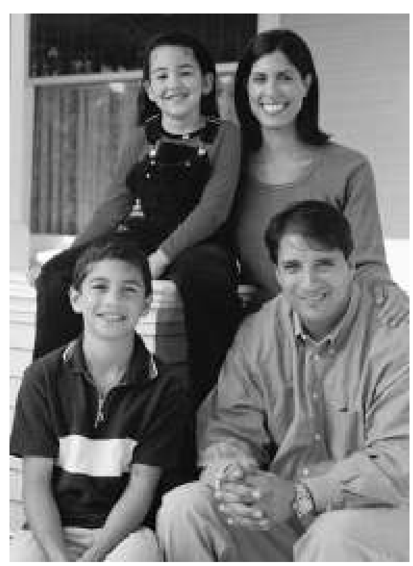
What Can I Do to Protect Myself and My Family?

Silicosis is a disabling and often fatal disease that prevents hundreds of workers from being able to care for their families. It could also prevent you from providing for your family. If your work causes you to breathe silica dust, there are things you can do to prevent silicosis from happening to you.

- Be aware of the health effects of breathing air that has silica dust in it.
- Avoid working in dust whenever possible.
- Know what causes silica dust at your workplace.
- Remember if there is no visible dust, you could be at risk. If there is visible dust, you are almost definitely at risk.
- Reduce the amount of silica dust by doing the following:
    - Use water sprays and ventilation when working in confined structures. For example:
        - Use a water hose to wet dust before it becomes airborne.
        - Use saws that add water to the blade.
        - Use drills that add water through the stem or have dust collection systems.
        - Use blast cleaning machines or cabinets to control dust.

- When water sprays and ventilation alone are not enough to reduce silica dust levels, your employer MUST provide you with a properly fitted and selected respirator (e.g. particulate filter or airline supplied air respirator) designated for protection against crystalline silica.
- Changes should not be made to the respirator.
- Workers who use tight-fitting respirators cannot have beards or mustaches because they do not let the respirator properly seal to the face.
- Take health (or lung screening) programs offered by your employer.
- Sandblasting or abrasive blasting requires the highest level of protection, which is a type CE abrasive blasting respirator (see photo 7).

- Practice good personal hygiene at the workplace:
- Do not eat, drink, or use tobacco products in dusty areas.
    - Wash hands and face before eating, drinking, or smoking outside dusty areas.
    - Park cars where they will not be contaminated with silica.
    - Change into disposable or washable work clothes at the worksite.
    - Shower (if possible) and change into clean clothes before leaving the worksite to prevent contamination of other work areas, cars, and homes.
- It is your employers' legal responsibility to provide a safe workplace. If you think you are not protected call OSHA



at 1-800-321-OSHA (6742) or go to the OSHA Web site: www.osha.gov.

Your employer must make sure that you have the proper protective equipment for reducing silica dust levels; but, it's up to you to use them!

Taking time to protect yourself on the job is worth it.

AFTER ALL, NOTHING IS MORE IMPORTANT THAN YOUR HEALTH AND THE HEALTH OF YOUR FAMILY!

REMEMBER!
If you are a construction worker, you may be exposed to silica dust. To protect you and your family, remember to follow these recommendations each and every time you may be exposed. **Silicosis IS NOT CURABLE, but it IS PREVENTABLE—to live a long and healthy life, learn the facts and know how to protect yourself and your family.**

What Type of Respirator Should I Use?

Choosing the right respirator that fits you snugly is important for protecting your health. Your employer will help you choose the type of respirator you need. ALWAYS USE NIOSH-APPROVED RESPIRATORS. The type of respirator you need depends on:

- The amount of silica dust to which you are exposed, and
- The kind of work you need to do.
- If you must do abrasive blasting, use only a type CE pressure demand abrasive blasting respirator (see photo 7).

Respirators used for protection from crystalline silica should not cause undue discomfort. If you have problems with your respirators, report immediately to your supervisor.

Photo 1

Photo 2

Photo 3

Photo 4

Model Advantage 1000

Covering your face with a cloth such as a bandana or T-shirt WILL NOT protect you.

These are filtering facepiece respirators.

- **Disposable**
- **N-95 Type or higher**
- **Provide minimal protection**

Model Advantage 200
Photo courtesy of MSA.

Half-face mask air-purifying respirator with replaceable N-95 (or higher) filters.

Photo courtesy of MSA.

Full-face mask air-purifying respirator with replaceable N-95 (or higher) filters.

No Protection . . . . Least Protection

Photo 5

Model MM2K
Photo courtesy of MSA.

Photo 6

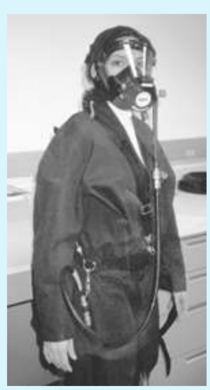


Photo 7

Type CE abrasive-blasting respirator (SAR), operated in a pressure demand or other positive pressure

Powered air purifying respirator (PAPR) equipped with: • **Full facepiece** • **High efficiency particulate filters** **NOTE: Uses battery-powered motor to filter the air.**	**Supplied-air respirator (SAR) equipped with:** • **Full facepiece** • **Pressure-demand or other positive pressure mode.**	**mode.** **NOTE: A tight-fitting mask is worn under the blasting hood.** **This is the only respirator that can be used for abrasive blasting.**
More Protection . . . . Most Protection		

References

The following sources were used in preparing this brochure:

CDC (Centers for Disease Control and Prevention) [1990]. Silicosis: cluster in sandblasters _ Texas, and occupational surveillance for silicosis. MMWR 39(25):433-437. www.cdc.gov/mmwr/preview/mmwrhtml/00001654.htm

CDC (Centers for Disease Control and Prevention) [1998]. Silicosis deaths among young adults _ United States, 1968-1994. MMWR 47(16):331-335. www.cdc.gov/mmwr/preview/mmwrhtml/00052482.htm

Morris J [1992]. "Dusty Trades" victimize Mexican immigrants. Houston Chronicle, Oct (reprint); pull-out sect. 4.

NIOSH [1992 a]. NIOSH Alert: Request for assistance in preventing silicosis and deaths from sandblasting. U.S. Department of Health and Human Services, Public Health Service (PHS), Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS Publication No. 92-102. www.cdc.gov/niosh/92-102.html

NIOSH [1992 b]. NIOSH Alert: Request for assistance in preventing silicosis and deaths in rock drillers. U.S. Department of Health and Human Services, Public Health Service (PHS), Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-107. www.cdc.gov/niosh/92-107.html

NIOSH [1996]. NIOSH Alert: Request for assistance in preventing silicosis and deaths in construction workers. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 96-112. www.cdc.gov/niosh/consilic.html

NIOSH [1999]. Hazard Controls (HC 30): Control of Drywall Sanding Dust Exposures. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 99-113. www.cdc.gov/niosh/hc30.html

NIOSH [2002]. NIOSH Hazard Review: Health Effects of Occupational Exposures to Respirable Crystalling Silica. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2002-129. www.cdc.gov/niosh/02-129A.html

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APPENDIX B

Dangers of Hydraulics

OSHA FATAL FACTS

Hydraulic Pressure

04/05/2005 WMMIC

Fatal Facts - Hydraulic Pressure and the Dangers

- Description of the Accident:
  - A machine operator was fatally injured while he was attempting to bleed trapped air from a hydraulic cylinder located on an automated forming machine. The injuries occurred when he opened a bleed-to-atmosphere type air-bleed valve located on a hydraulic cylinder, causing high pressure hydraulic oil to be injected into his hand.

04/05/2005 WMMIC

The Dangers of Hydraulic Pressure

- Injection Injuries
- Dangerous properties of fluid (toxic)
- Contact with hot fluid
- Other material movement (explosion, whipping hose, etc.)

High Pressure Injection Injuries

What is an High Pressure Injection Injury?

- Fluid at pressure that punctures and penetrates the skin and body tissue.
- injected substance passes rapidly thru the subcutaneous tissue and enters the tendons and deep spaces of hand/body.

High Pressure Injection Injury

- A pinhole leak in a hydraulic hose that's under pressure can release toxic fluid at a speed of 600+ feet per second.
- Close to the muzzle velocity of a gun.
- Sufficient to penetrate protective equipment depending upon velocity.
- Penetration recorded in distances of up to four inches between fluid source and skin.

Where Do You Find?

- Some type of fluid (water, paint, oil-based solvents, etc.) or air
- Measured in force exerted upon a surface per unit area
  - Usually pounds per square inch (PSI)

04/05/2005 WMMIC

Where Do You Find?

- hydraulic lines
- airless paint sprayers,
- fluid 100 PSI or above
- high-pressure fuel injection
- high-pressure air lines
- high-pressure grease guns,
- high pressure grease and paint guns most common cause
  - 60% paint
  - 25% grease/oil

04/05/2005 WMMIC

High Pressure

- 100 PSI to puncture skin
- 3000-10000 PSI
  - <2000 PSI - 40% amputation
  - >2000 PSI - 50% amputation
  - <7000 PSI - non prognostic
  - >7000 PSI - 100% amputation
- Amputation rates vary between 16-48%

Severity/Prognostic Factors

- Material injected
  - grease - fibrosis
  - paint - necrosis
  - gangrene
- Paint/paint thinners - pain and swelling in few hours
- greases/oils/hydraulic fluid - pain in a day or two

Toxicology

- Absorption into system
- Organic solvent
- Water based

Injury Info

- Injection typically occurs when operator is trying to wipe clear a blocked nozzle or when operator is attempting to steady the gun with a free hand during the testing or operation of equipment
  - Pad of thumb or index finger (most common)
  - Palm and long finger (second most frequent)
  - non dominant hand
  - Usually pin hole size
  - Men between 21-59


Point of
entry
Incision required to
remove hydraulic oil
04/05/2005
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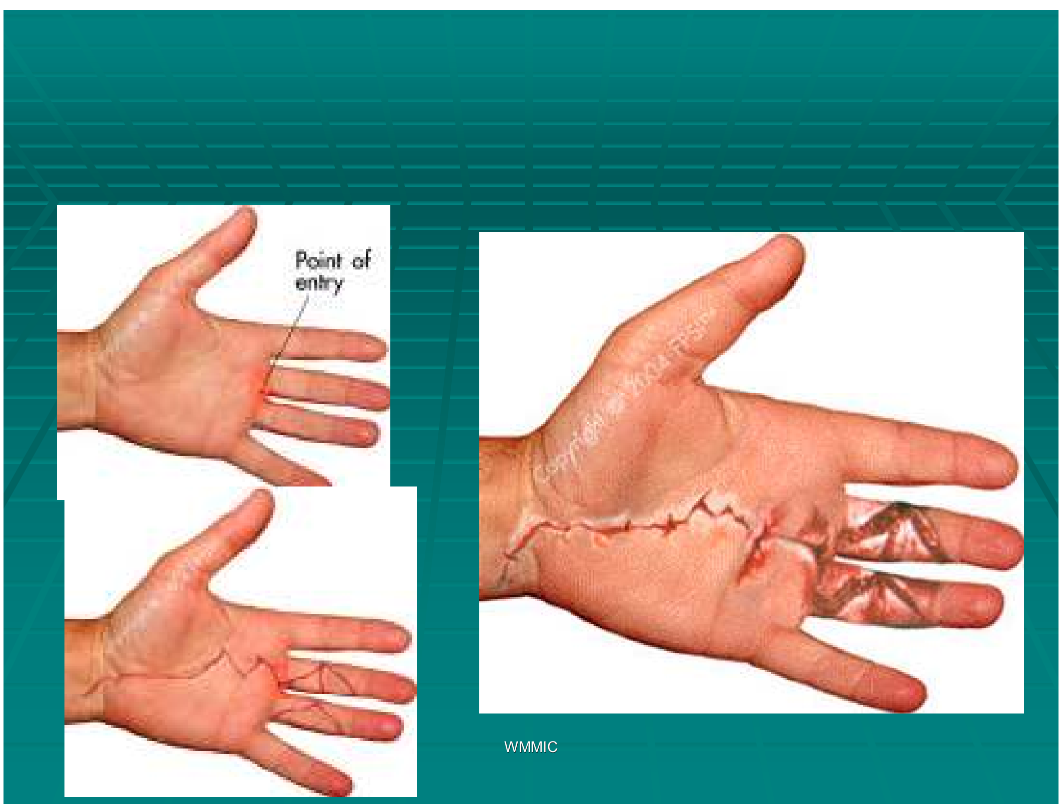
Point of
entry
WMMIC

Burn Injuries

- Complex injuries
- Burns effect kidney, liver and cardiovascular function.

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Degree of Burn

- First Degree
  - Outer layer of skin
- Second Degree
  - First and second layer of skin
- Third Degree
  - All layers of skin
  - Most serious

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Injection Burns

- Hot liquid injected into body
  - Bypassed skin as protective device
  - Debreeing of burn must be surgical
- Toxicity of chemical

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2^{nd} & 3^{rd} Degree Tar Burn

04/

How to Avoid Injection Injuries

- To check a hose for leaks while pressurized, run a piece of cardboard or paper along the hose, wear gloves, long sleeves, and safety glasses
- Don’t “crack” high pressure connectors or lines to “check” for pressure and/or flow

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How to Avoid Injection Injuries

- Shut down all equipment when looking for leaks
- Relieve pressures (Hose, etc.)
- Check to ensure pressure relieved
- Lockout/tagout - deactivation to zero energy

04/05/2005 WMMIC

Courtesty of <www.wmmic.com/Safety%20Shorts/Hydraulic%20Safety.ppt>

APPENDIX C

Death By Moving Machinery Parts

OKFACE Report #03-OK-096-01

SUBJECT: A Concrete Saw Operator was Killed when He was Pinned between the Boom and the rear of a Backhoe

SUMMARY

A 56-year old concrete saw operator died on December 31, 2003, from asphyxiation and compression injuries received when he was pinned between the boom and the rear end of a backhoe. The decedent was working alone at a roadway construction site. He was working in the late evening and early morning hours to finish saw cutting newly poured concrete. The decedent was using a rubber-tired front-end loader and backhoe for lighting and to transport the concrete saws to the maintenance building. The backhoe, which did not have a boom swing lock pin installed, was left running to maintain a charged battery. After completing the work, the victim laid a handheld portable concrete saw on the floor of the backhoe through the opening in the rear. The saw was placed on the right boom swing pedal, causing the boom to swing to the side, pinning the victim between the boom arm and the rear of the backhoe. The decedent was found later that morning by the superintendent and pronounced dead at a local hospital.

Oklahoma Fatality Assessment and Control Evaluation (OKFACE) investigators concluded that to prevent similar occurrences, employers should:

- Ensure that machine guarding is in place, and that any additional safeguards needed to eliminate hazards are utilized prior to equipment operation.
- Ensure that all employees receive documented training on existing and potential hazards on or around mobile and stationary equipment.
- Ensure that special work procedures are in place for all employees working alone, including training on any unique hazards that exist.
- Review modifications or additions to equipment with the manufacturer and obtain authorization from the manufacturer prior to alteration.

INTRODUCTION

A 56-year old concrete saw operator employed by a construction contracting company died on December 31, 2003, from asphyxiation and compression injuries received when he was pinned between the boom arm and the rear end of a backhoe (Figure 1). OKFACE investigators reviewed the death certificate and reports from the Occupational Safety and Health Administration (OSHA), the Medical Examiner, the investigating police officer, and emergency medical services (EMS). An incident site visit and an interview with a company official at the home office were conducted on March 17, 2004.

Figure 1. Backhoe model involved in incident


The contracting company that employed the decedent had been in business for 18 years and, at the time of the incident, employed 65 people. The decedent had worked for the company for five years and had five years of experience as a concrete saw operator. However, he had not been trained on the backhoe's operator's manual or on safe operating procedures, since it was not a part of his normal work duties. When the incident occurred, the victim had worked all day and into the early morning hours in order to complete saw cuts in concrete poured that afternoon.

The company had a management safety and health committee and a written comprehensive safety and health program in place. Also, there were machine-specific safe operating instructions for all equipment used. Training for specific tasks was completed through on-the-job training and equipment manufacturer and company videos. Employees were required to attend weekly safety meetings. Machinery operators were required to be tested for proficiency before they were allowed to operate company equipment.

INVESTIGATION

At the time of the incident, the ground was dry and the temperature was approximately 34 degrees Fahrenheit. The decedent was working into the early morning hours on a level surface of concrete that had been poured the previous afternoon. The decedent was assigned the task of sawing the concrete road surface and was allowed to use a rubber-tired front-end loader and backhoe for lighting and transport of two concrete saws. The backhoe, which was left running to maintain a charged battery, was missing the operator's manual, the boom lock pin, and the swing lock pin. With the engine running, the hydraulic system remained active to the boom and could not be disabled. Installation of the boom swing lock pin and boom lock pin were necessary to prevent movement of the boom. The decedent, who was last seen alive around 2:30 a.m. by a co-worker leaving the site, continued working alone.

Sometime between 2:30 a.m. and 6:30 a.m., the decedent finished sawing the concrete and began to load the backhoe with his tools. From the rear of the backhoe, he proceeded to lay the handheld portable concrete saw on the floor of the cab. The saw was placed on top of the right boom swing foot pedal. With the engine running and the boom swing lock pin not installed, the boom was activated and free to move. The boom swung to the right and crushed the victim between it and the rear of the backhoe. With no witnesses to the incident, the decedent was pinned for an undetermined amount of time. The superintendent, who arrived to work around 6:30 a.m., found the victim.

The decedent was found in a standing position pinned between the boom arm and the back of the vehicle. The superintendent contacted the police, and three officers responded immediately. CPR was initiated and administered until EMS personnel arrived. The victim was transported to a local hospital where he was pronounced dead 35 minutes after being found.

During the investigation, it was determined that the backhoe's factory equipped foot pedal controls had been modified to accommodate an additional set of hand lever controls. When this process was performed, the foot controls were still present and operable; however, the original foot controls became easier to press down than before the installation. With nothing to keep an employee from placing equipment into the operator compartment through the openings on either side of the boom, it remained very easy to actuate the foot pedals with the weight of the equipment or materials.

CAUSE OF DEATH

The Medical Examiner listed the cause of death as asphyxiation due to a compression injury.

RECOMMENDATIONS

Recommendation #1: Employers should ensure that machine guarding is in place, and that any additional safeguards needed to eliminate hazards are utilized prior to equipment operation.

Discussion: The equipment in use at the time of the incident was not equipped with the required lock pins, which would have kept the boom arm from swinging. The model-specific operator's manual specifies to install boom and swing lock pins when use of the backhoe boom is complete. Furthermore, removal, installation, and storage procedures for the pins are outlined in the manual.

Recommendation #2: Employers should ensure that all employees receive documented training on existing and potential hazards on or around mobile and stationary equipment.

Discussion: Utilization of manufacturer's specification manuals and operator's manuals can help to identify hazards that exist around equipment. Also a competent person, defined by OSHA as knowledgeable and experienced in the use of the equipment and the hazards that can be produced, could evaluate the equipment, site, or processes to determine the need for additional hazard controls. Employees should be properly trained on all equipment they operate, and all training should be documented and kept on file with the company.

Recommendation #3: Employers should ensure that special work procedures are in place for all employees working alone, including training on any unique hazards that exist.

Discussion: It is the company's responsibility to provide procedures and training on any specific hazards to which the employee might be exposed. This training might include special procedures for use of equipment when working alone, or when working at a time or place when very few other individuals will be present or in the general vicinity.

Recommendation #4: Employers should review modifications or additions to equipment with the manufacturer and obtain authorization from the manufacturer prior to alteration.

Discussion: It is important to consult with manufacturers prior to making equipment modifications in order to anticipate potential hazards and possible additional safeguards. Some hazards, such as the foot pedals becoming easier to depress with hand lever installation, are known and can be controlled prior to use. All upgrades or alterations should be authorized by the manufacturer and should meet all mandatory safety guidelines established for the upgrading or alteration.

REFERENCES

- 29 CFR 1926.602 Earthmoving Equipment, Occupational Safety and Health Administration
- Association of Equipment Manufacturer's Safety Manual, Backhoe/Loader, 1989.1
- Equipment specific operator's manual
- Operating Techniques for the Tractor, Loader, & Backhoe, Ober Publishing, Northridge, California
- 29 CFR 1910.211-.219 Machine(ry) Guarding, Occupational Safety and Health Administration

The Oklahoma Fatality Assessment and Control Evaluation (OKFACE) is an occupational fatality surveillance project to determine the epidemiology of all fatal work-related injuries and identify and recommend prevention strategies. FACE is a research program of the National Institute for Occupational Safety and Health (NIOSH), Division of Safety Research.

These fatality investigations serve to prevent fatal work-related injuries in the future by studying the work environment, the worker, the task the worker was performing, the tools the worker was using, the energy exchange resulting in injury, and the role of management in controlling how these factors interact.

For more information on fatal work-related injuries, please contact:

Oklahoma State Department of Health
Injury Prevention Service
1000 NE 10th Street
Oklahoma City, OK 73117-1299
nancyk@health.state.ok.us

1-800-522-0204 or 405-271-3430
www.health.state.ok.us/program/injury

Courtesy of <http://www.health.state.ok.us/program/injury/okface/Backhoe.htm>

APPENDIX D

Jammed Saw Blade

Government of South Australia

Hazard Alert

WORKPLACE SERVICES Department for Administrative and Information Services

NO. 30 USE OF CONCRETE CUTTING SAWS June 2001

OBJECTIVE:

The object of this alert is to highlight one of the dangers associated with the use of concrete cutting equipment.

BACKGROUND:

In January 2001 an employee died as a result of injuries he received when the concrete saw he was using became uncontrollable, striking him in the throat area.

This accident follows a similar accident that occurred in Western Australia in September 2000 that also resulted in a fatality.

In both of these accidents the cause was attributed to the jamming of the blade followed by instantaneous reactive forces that caused the saw to become uncontrollable.

The jamming of the blade occurred while cutting of a length of concrete that was only supported at one end. When the beam/pipe was nearly cut through, the downward force distorted the beam pinching the blade.

STATUTORY REQUIREMENTS:

Under section 19 of the Occupational Health, Safety and Welfare Act 1986 an employer is required to provide and maintain a safe working environment and safe systems of work.

Division 1.3 of the Occupational Health, Safety and Welfare Regulations 1995 require employers to take appropriate steps to identify all reasonable foreseeable hazards arising from work which may affect the health or safety of employees or other persons.

PREVENTATIVE MEASURES:

1. Care should be taken when selecting the saw and cutting wheel.
2. Hold the concrete saw firmly in two hands.
3. Maintain good balance and footing at all times. Never cut while standing on a ladder.

4. Do not cut any material with a blade that is not suitable.
5. Do not overreach.
6. Do not cut above shoulder height.
7. Be especially alert for reactive forces exerted by the saw.
8. Be alert to shifting of the work piece or anything that could cause the cut to close and pinch the wheel.
9. Release the pressure on the concrete saw as you reach the end of the cut. Too much pressure may cause the operator to lose control of the saw when the blade completes the cut.
10. Use extreme caution when re-entering a cut and do not turn the wheel at an angle or push the wheel into the cut as this may result in a pinching of the wheel.

FURTHER INFORMATION:
For further information in relation to the contents of this Alert, please contact;
Department for Administrative and Information Services

Workplace Services
GPO Box 465, ADELAIDE SA 5001
Ph: 1300 365 255
Mobile and Interstate callers
Ph: (08) 8303 0400
Website: http://www.eric.sa.gov.au

Courtesy of <http://www.safework.sa.gov.au/uploaded_files/hazaler30i.pdf>

Skid-Steer Rock Saw

Drive Train Modification

by

Blue Diamond Machinery

Team Members

Kelly Hogue
Matthew Gassen
Kristen Tucker
Buck Melton

Prepared for CONEQTEC Universal and Senior Design - BAE 4022

Project Sponsor

- CONEQTEC Universal
- Skid steer attachment manufacturer
- President Gary Cochran

Mission Statement

- Blue Diamond Machinery strives to improve products by implementing high quality designs, increasing efficiency, and surpassing the demands of our clients.

Production Model

- Cutting depth is less than the wheel radius
- To increase depth of cut, the diameter of the blade must increase, therefore, increasing the overall dimensions and weight of the attachment

Provided by CONEQTEC

Patent Search

- Slashing Loader – Ring & Pinion Gears
- Tree Harvester – Saw Blade
- Power Saw – Gears, Blade
- Concrete Saw – Debris Removal

CONEQTEC Rock Saw Prototype

Provided by Coneqtec

Features of CONEQTEC Prototype

- Depth of cut > wheel radius
  - 18 inches deep, 2.5 inches wide
- Powered by hi-flow hydraulic system
  - 89 hhp input to attachment
- Attachment is laterally adjustable

Hydraulic System Specifications

Hydraulic Power Kits	A	B	C
Flow (gpm)	34	40	33
Pressure (psi)	4500	3200	4060
Power (hhp)	89	75	78
Hydraulic Motor			
Displacement (cc)	200	200	200
RPM	320	380	310
Torque (ft lbs)	730	520	660
Total Force (lbs)	450	320	410

Uses

- More versatile than a trencher
- Cut anything other than reinforced concrete
- Install fiber optics, plumbing, etc…. Under existing roadways/sidewalks
- Install cement curbs on asphalt roadways

CONEQTEC Prototype Demonstration

Problem Statement

- Increase cutting depth to greater than blade radius
- Modify CONEQTEC prototype to increase useful life
- Prevent hydraulic motors from running in debris piles

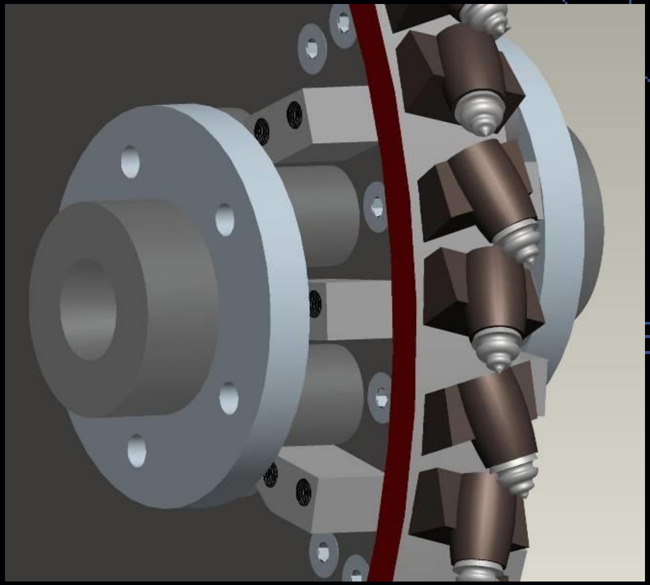
Statement of Work

- Increase useful life of the saw from less than 50 hrs to over 100 hrs.
- Current limiting factor is the high rate of wear on the ring gear teeth.

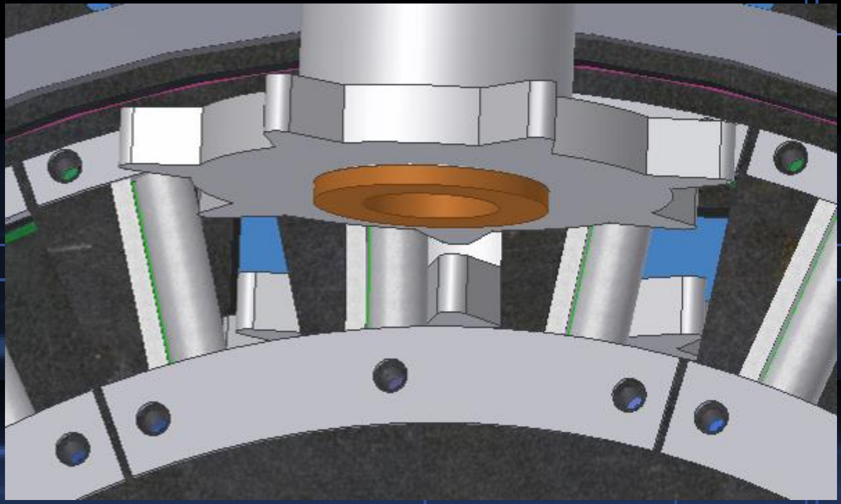
Statement of Work: Gear Mesh

Redesign gear mesh

- Initial design
  - Protruding ring gear teeth mesh with cylindrical pinion gear teeth.



- Alternative design
  - Acme pinion gears mesh into ring gear holes.



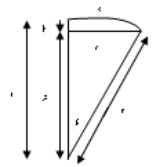
Gear Mesh Calculator

Gear Mesh Calculator

Wheel Diameter to bottom of hole (D_B)	22.25	in
Wheel Radius to bottom of hole (r_B)	11.125	in
Wheel Circumference at bottom of hole (C_B	69.900	in
Wheel Hole Spacing (d_B)	2.31301756	in
Angle Between Holes (θ_B)	12.000	0.2094
Arc Length Between Holes (s_B)	2.330	in
Arc Length Between Gear Teeth (s_G)	2.313	in
Wheel Disk Radius	16.125	in
Wheel Disk Diameter	32.25	in
Wheel Radius With Rim and Picks	18.000	in
Height of Gear Holes	3.00	in
Number of Gear Holes (n_B)	30.000	holes
Wheel Diameter With Rim and Picks	36	in

Equations

d_B = sin (s_B) * (r_B) = s_G
d=sin(s/r)*r
sin(θ) = d / r
θ=s/r   G=gear
s=r*θ   B=blade or wheel
C=2*π*r
s=arcsin(d/r)*r



THE NUMBER OF HOLES AND THE WHEEL DIAMETER ARE SATISFACTORY.

Note: Feel free to change the orange cells to manipulate the table values.

Gear Ratio	Gear Radius to Base of Teeth (r_G)	Gear Diameter to Base of Teeth (D_G)	Gear Circumference to Base of Teeth (C_G)	Number of Gear Teeth (n_G)	Angle Between Gear Teeth (θ_G)
30	0.368	0.736	2.313	1.000	6.283185307
15	0.736	1.473	4.626	2.000	3.141592654
10	1.104	2.209	6.939	3.000	2.094395102
7.5	1.473	2.945	9.252	4.000	1.570796327
6	1.841	3.681	11.565	5.000	1.256637061
5	2.209	4.418	13.878	6.000	1.047197551
4.285714286	2.577	5.154	16.191	7.000	0.897597901
3.75	2.945	5.890	18.504	8.000	0.785398163
3.333333333	3.313	6.626	20.817	9.000	0.698131701
3	3.681	7.363	23.130	10.000	0.628318531
2.727272727	4.049	8.099	25.443	11.000	0.571198664
2.5	4.418	8.835	27.756	12.000	0.523598776
2.307692308	4.786	9.571	30.069	13.000	0.483321947
2.142857143	5.154	10.308	32.382	14.000	0.448798951
2	5.522	11.044	34.695	15.000	0.41887902
1.875	5.890	11.780	37.008	16.000	0.392699082
1.764705882	6.258	12.516	39.321	17.000	0.369599136
1.666666667	6.626	13.253	41.634	18.000	0.34906585
1.578947368	6.994	13.989	43.947	19.000	0.330693964
1.5	7.363	14.725	46.260	20.000	0.314159265
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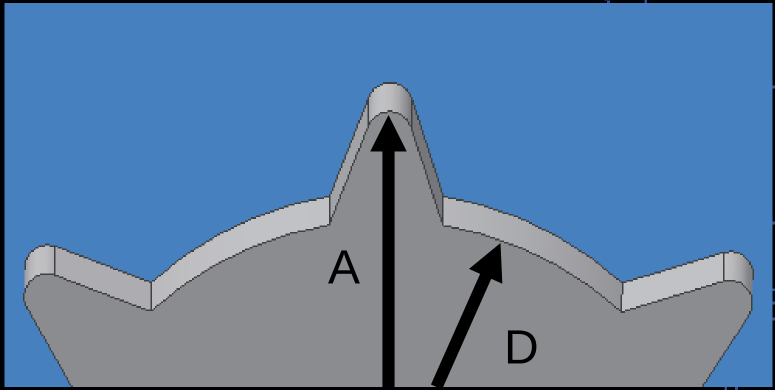
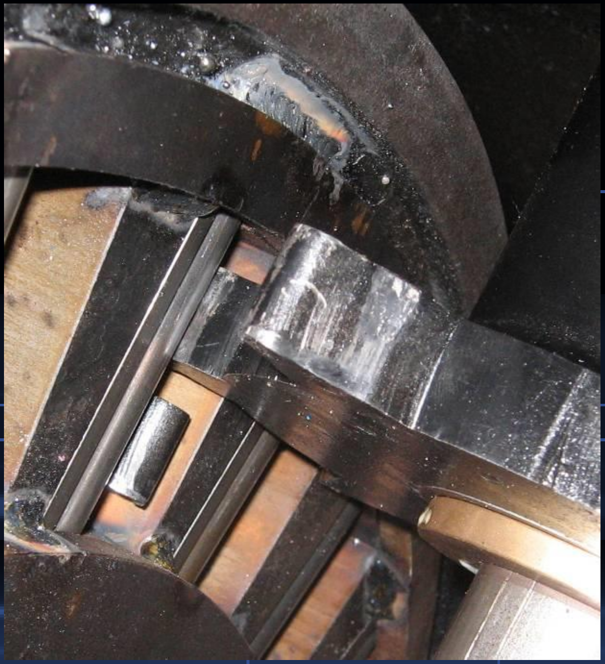
1.363636364	8.099	16.198	50.886	22.000	0.285599332
1.304347826	8.467	16.934	53.199	23.000	0.27318197
1.25	8.835	17.670	55.512	24.000	0.261799388
1.2	9.203	18.406	57.825	25.000	0.251327412
1.153846154	9.571	19.143	60.138	26.000	0.241660973
1.111111111	9.939	19.879	62.451	27.000	0.232710567
1.071428571	10.308	20.615	64.764	28.000	0.224399475
1.034482759	10.676	21.351	67.078	29.000	0.216661562
1	11.044	22.088	69.391	30.000	0.20943951
0.967741935	11.412	22.824	71.704	31.000	0.202683397

- Used to calculate gear sizes, gear ratios, and gear hole spacing
- Three independent variables chosen by user
- Warning/Approval messages indicate if gear hole spacing is sufficient

Gear Specifications

- 2 Gears – 7 teeth
- 3/4" thick steel
- 1/4" spacing between gears
- Top Gear
  - Dedendum circle diameter (D): 6.16"
  - Addendum circle diameter (A): 8.08"
- Bottom Gear
  - Dedendum circle diameter (D): 5.76"
  - Addendum circle diameter (A): 7.62"



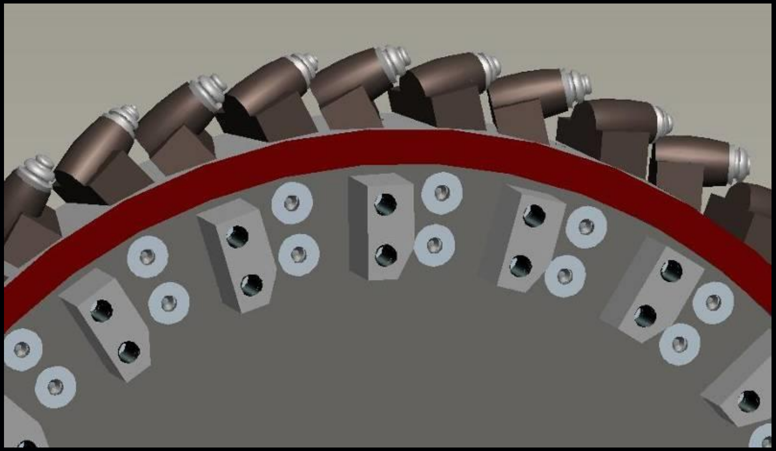


Wheel and Gear Specifications

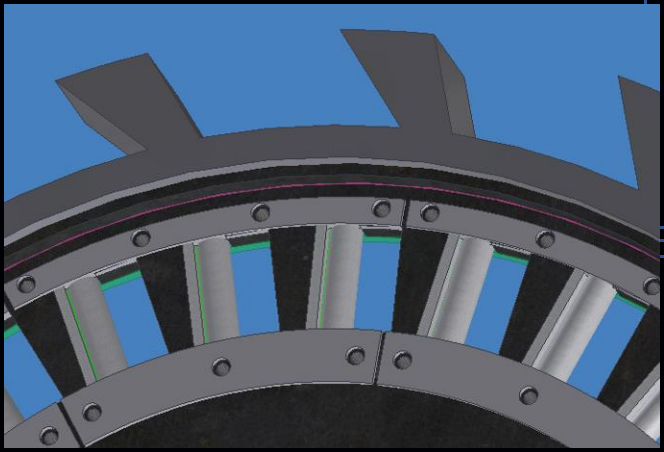
Hydraulic Power Kits	A	B	C
Cutting Wheel			
RPM	75	88	73
Torque (ft lbs)	3100	2200	2800
Force (lbs)	8300	5900	7500
Ring Gear Holes			
Shear Force (psi)	1000	720	910
Pinion Gear			
Shear Force (psi)	300	220	270
Fatigue Load (psi)	41,000		

Ring Gear Evolution

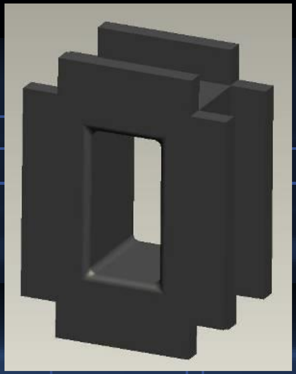
CONEQTEC PROTOTYPE

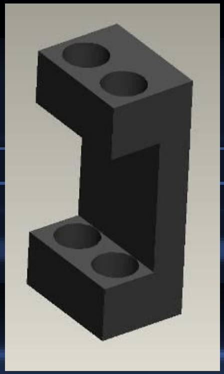
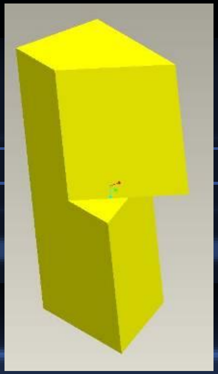
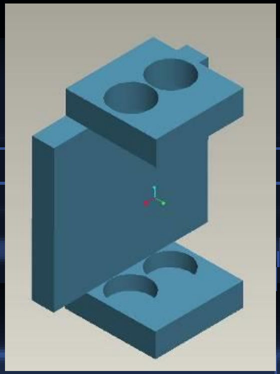
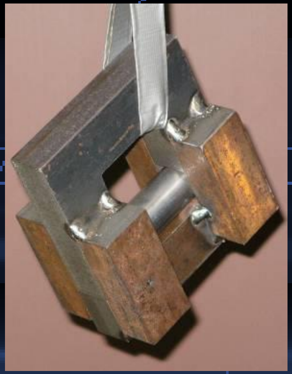


BDM PROTOTYPE

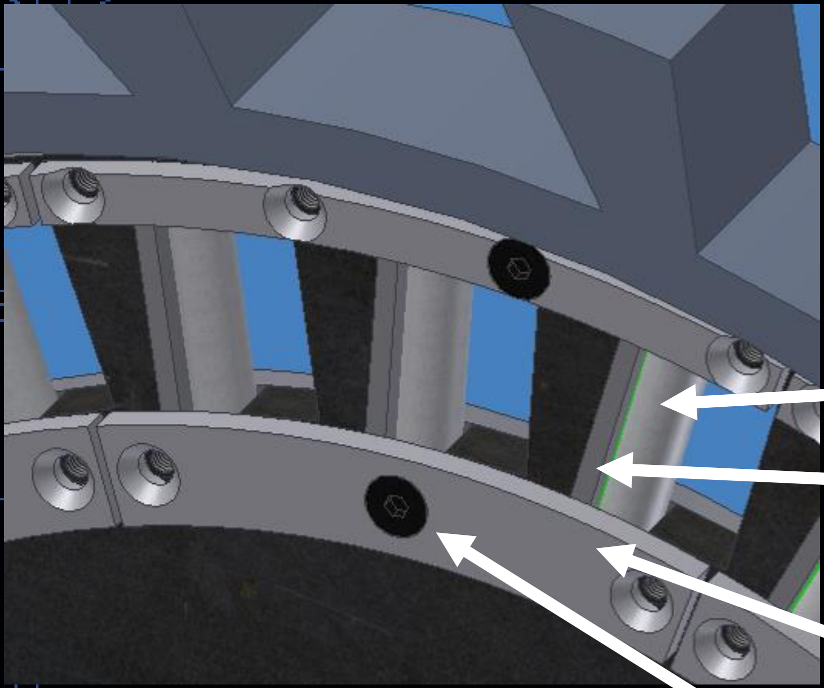


BDM PROTOTYPE INSERT PROGRESSION



Final Ring Gear Design



- Gear holes cut into the wheel
- Inserts used to prevent wear on gear holes
  - Bar Stock: 3/4” x 3”
  - Key Stock: 1/4” x 3/4” x 3”
  - Retainer plates – 3/8” thick
  - Bolted on one side
  - Welded on opposite side
  - Flat head socket cap screws 3/8” x 3/4”

BDM Gear Mesh Demonstration

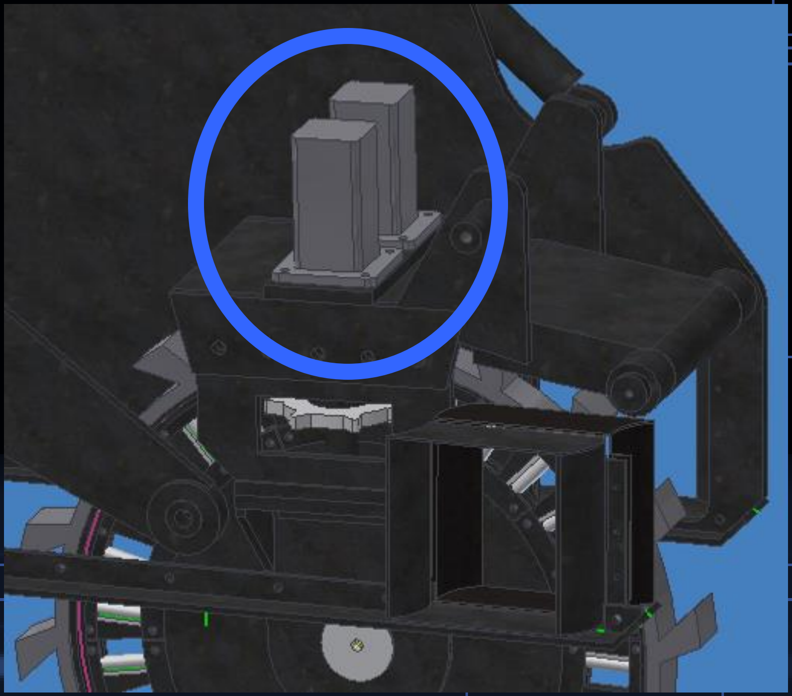
Statement of Work: Motors

- Prevent hydraulic motors from running in debris

Motor Repositioning

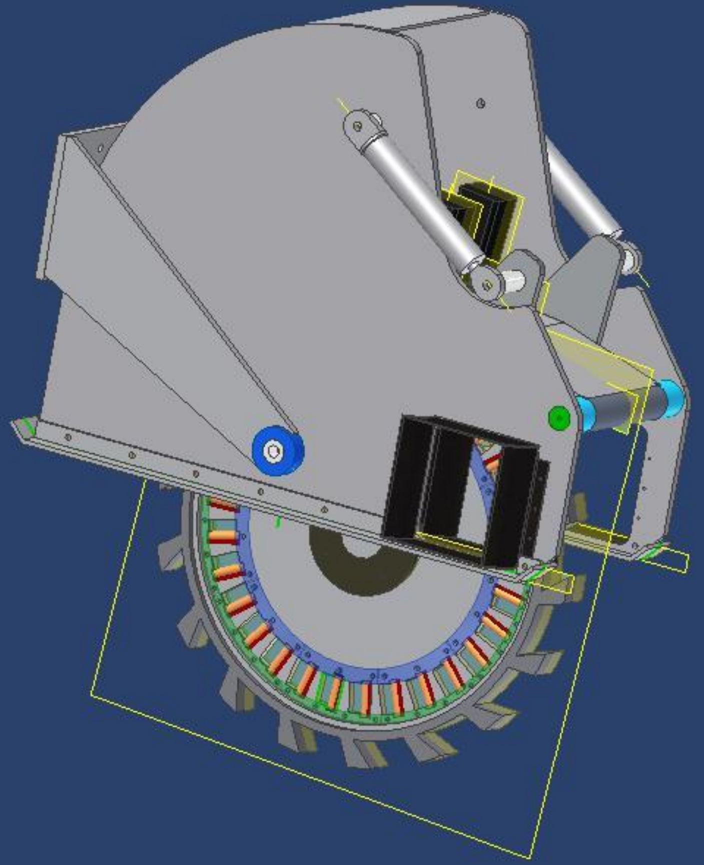
Rotate motors into a vertical position by mounting above the wheel.

CONEQTEC Prototype

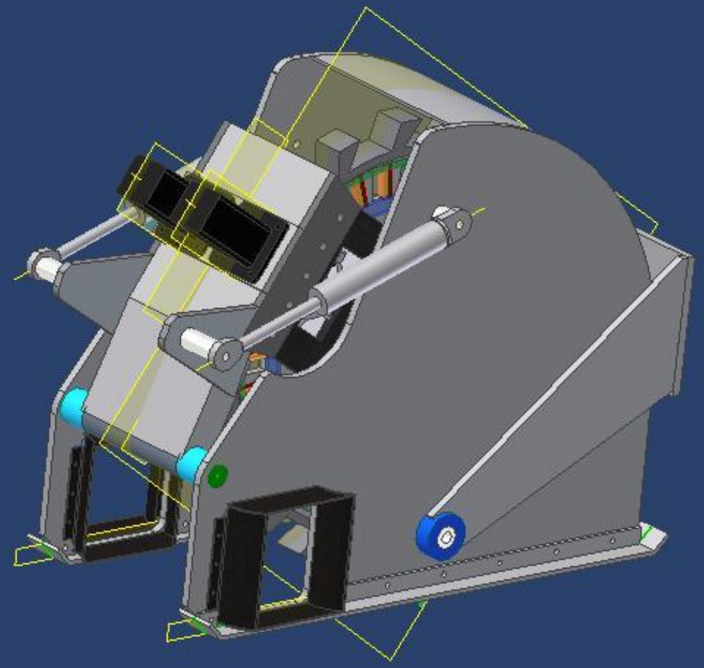


BDM Prototype

BDM Rock Saw Prototype



Fully Descended



Fully Recessed

Budget

Materials	$1,623
Fasteners	$112
Tools	$36
Total	$1,772

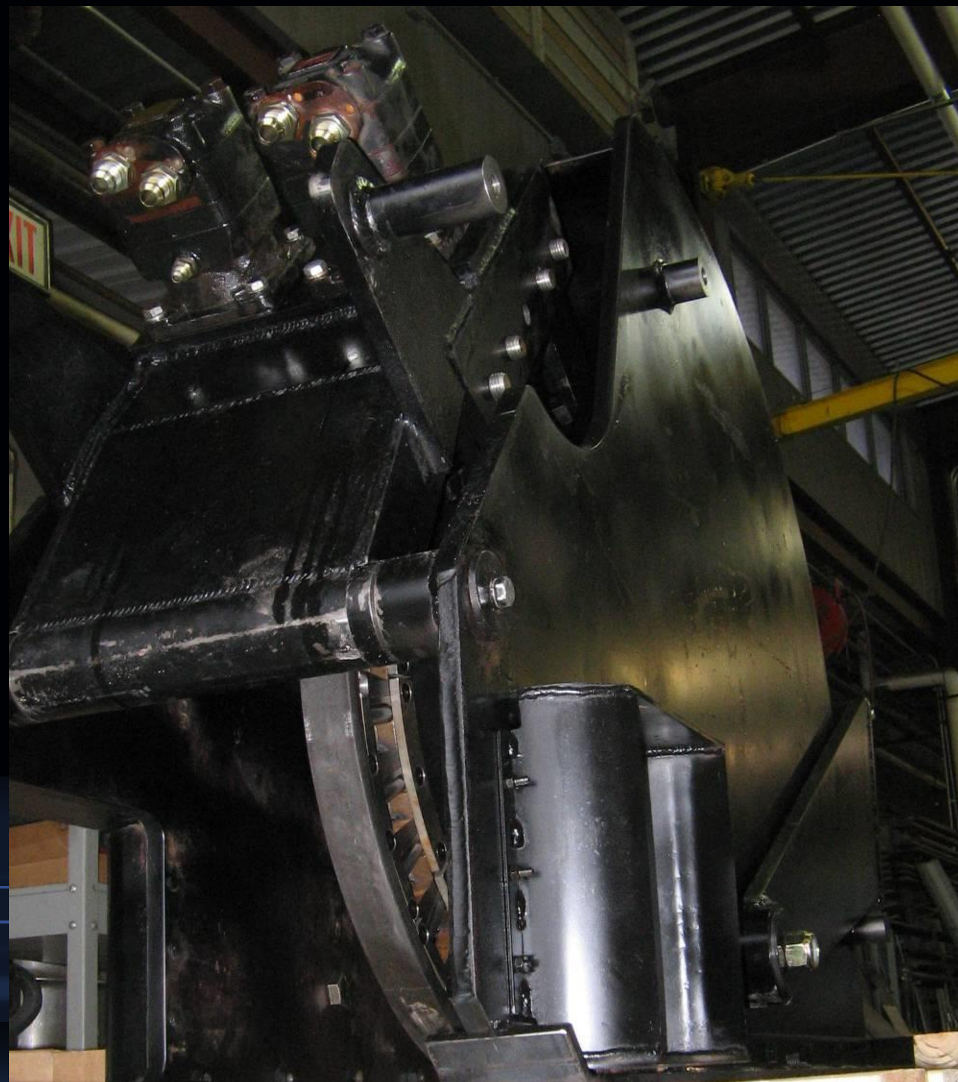
Recommendations

- Replace gear shafts by using hydraulic motors with wheel mount flange
- Make motors vertically and laterally adjustable to allow for gear adjustability
- Attach a front debris flap for added safety
- Holes could be added to outer frame to reduce weight and increase ease of maintenance

Recognitions

- Gary Cochran – CONEQTEC Universal
- Dennis Skraba – CONEQTEC Universal
- Dr. Paul Weckler – OSU BAE Senior Design Professor and Advisor
- Wayne Kiner – OSU BAE Laboratory Manager
- Bobby Flores, Robert Harrington,
  and Robert Harshman – OSU BAE Laboratory
- Stillwater Steel – Fabrication
- Steve Miller – Interstate Tool – Fabrication
- Railroad Yard – Fabrication

Questions?



Blue Diamond Machinery

Blue Diamond Machinery

BAE 4012

12/5/06

Design Team:

Kelly Hogue
Kristen Tucker
Matt Gassen
Buck Melton

Mission Statement

Blue Diamond Machinery strives to improve products by implementing high quality designs, increasing efficiency, and surpassing the demands of our clients.

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Problem Introduction

Implementation of the skid steer loader has greatly advanced the capability and efficiency of the construction industry. Many attachments are now available to enable a single skid steer to perform different tasks. Four senior level students from the Biosystems and Agricultural Engineering department (BAE) of Oklahoma State University (OSU) have formed a consulting team, Blue Diamond Machinery (BDM), to facilitate the completion of their capstone senior design project under the direction of Dr. Paul Weckler. BDM has chosen to redesign a skid steer mounted rock saw driven by a high flow hydraulic system in order to increase the saw's useful life to longer than its predecessor designed by CONEQTEC Universal.

Statement of Work

CONEQTEC Universal, of Wichita, Kansas, manufactures attachments for skid-steer loaders to substitute for the standard bucket attachment. CONEQTEC Universal has recently redesigned their existing rock saw to achieve a deeper cut via a ring and pinion drive mechanism powered by a hydraulic motor in order to reduce the size of the cutting blade. This project was suspended when CONEQTEC Universal observed that the new design does not have the same useful life as the original, larger diameter design driven by a center mounted hydraulic motor.

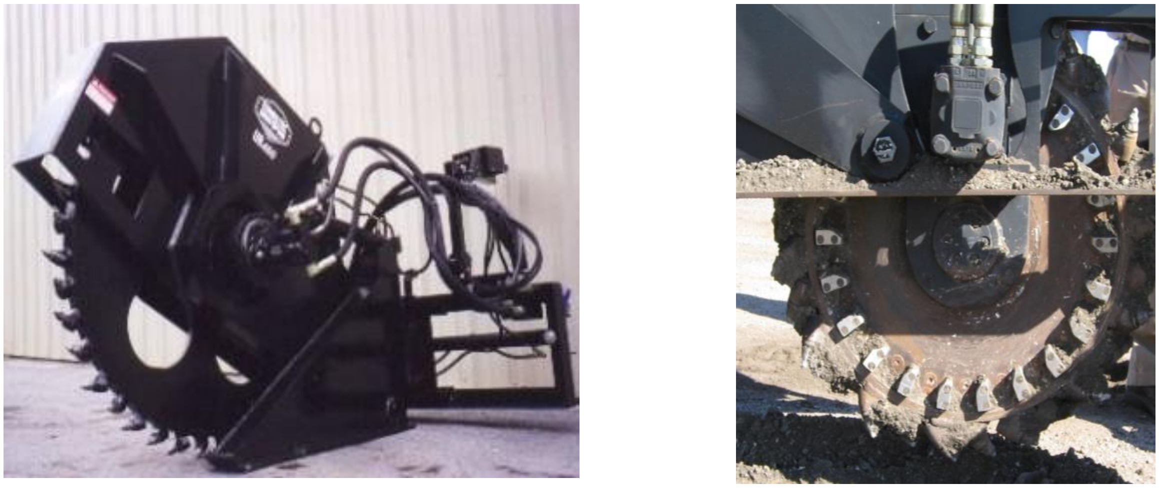


Figure 1: Left- The production rock saw. Right- the prototype rock saw.

After BDM met with CONEQTEC Universal, to observe the working prototype, potential issues with their design were observed. One problem CONEQTEC Universal would like to resolve is the high rate of wear on the ring gear teeth produced during standard operation. The other problem is to prevent the hydraulic motors used to drive the blade from descending into and being operated in the debris piles created during operation.

Several possible solutions have been devised to reduce the wear on the teeth:

- The first solution is to increase the tolerances of the gear mesh between the pinion gear attached to the hydraulic motor and the ring gear teeth attached to the saw blade.
- The second solution is to perform a surface treatment and/or add a surface coating to the gear teeth in order to increase their resistance to wear.
- The third solution is to manufacture the teeth out of a tougher more resilient material.

- The fourth solution is to eliminate the ring gear teeth by designing a new gear configuration which meshes directly into strengthened rectangular holes cut into the blade.
- The fifth solution is to institute a combination of two or more of the preceding solutions.

Two methods to prevent the hydraulic motors from descending into the debris piles during operation include the following:

- Install a guard on each hydraulic motor to force the debris away from the motors.
- Reduce the range of motion of the motors by changing the depth gage on the side of the rock saw. This solution, however, will require a larger blade size to obtain the same depth of cut that is currently reached by the prototype and by the current production design.

Patent Research

The patent search revealed some designs similar to the prototype. While rock saw devices were found, none were rim driven. All the designs found were driven from the center of the blade. Most of these designs were intended for cutting concrete or, in the case of one patent held by Mr. Cochran, for cutting slots in pavement. Though some rim driven blades were found, their intended application was in the logging industry to trim either harvested or fallen trees for transport. The scope of application was found to have a more important role in patent approval than the method in which the machine is operated.

During a portion of the patent search, several patents were found with designs which drive the saw blade in a similar manner as instituted in the rock saw prototype design. These patents, however, are intended for use in the logging industry for either cutting down trees or sizing logs for a transport crane. All of the designs have a ring and pinion configuration for the driving mechanism; however, the intended use is different. US Patent No. 3494389 refers to the slashing and loading of timber. The machine is designed to lift a load of logs off of a stack and place them on a truck for transport after it cuts them to a desired length. US Patent No. 3915209 refers to the process of harvesting trees and brushwood as well as an improved saw design for the removal of trees or brushwood. Patent 3915209 also refers to older patents that utilize different sawing methods. Patent No. 3915209 also refers to another US patent that uses a similar method of harvesting trees Patent No. 3915209 also refers to a German and US patent that describes a ring and pinion drive which has a U-shaped frame. Patent No. 3915209 states that these patent designs are insufficient due to their limited depth of the cut and the ring and pinion gear configuration is not protected. In this design, there are two plates mounted together to house the ring and pinion drive train and form the saw blade. This results in the gear assembly being easily hindered by wood debris and not easily repairable when damage occurs.

US Patent No. 4738291 describes a tree saw run by a ring and pinion configuration. However, this patent differs from the previous patent in that it has a full disk blade. Also, the saw blade can double as a platform to allow the tree to be dumped where the operator chooses instead of allowing the tree to fall where it was cut down. This design appears to be more appropriate than the previous two patents because the saw blade is intended to be a load bearing surface as well as being an assembled blade design protected from debris, which could easily be maintained. These patents, while unrelated in scope, are still potentially important due to their similarities to our drive train concept. This observation could pose a problem in the new design because of patent infringement. From these patents, however, it was deduced that the driving mechanism is not patentable in and of itself; therefore, the scope of the patent holds higher authority than the drive train design making patent infringement less of an issue.

Patent No. US 6,203,112 B1 describes a road cutting apparatus that can be installed to the front end of a self-propelled machine. The design uses an engine that includes a power take-off (PTO) mounted on the apparatus. The PTO is connected to a belt drive connected to a driving pulley. This pulley turns the circular cutting blade. The road cutting apparatus has a blade diameter of 36". The engine used is powered by gas, diesel, or electricity. To help clean and cool the blade, a spray nozzle is mounted at the inner surface of the blade housing. As an extra feature, there is a laser alignment device to ensure cutting accuracy. This apparatus differs from the rock saw prototype by using a belt driven system. No hydraulic motors are used for power, and the driving shaft to the circular cutting blade is located at the center of the blade. Our main constraint from this patent is the laser alignment device for accuracy, if we would like to have a guided system.

Patent No. US 7,073,495 B1 describes the method and apparatus for removing concrete debris during operation. The device is powered by a small engine, and the blade is contained in a separate housing. Outside the housing is a set of at least two nozzles that use pressurized gas to produce a stream directed toward the lower support during the use of the saw. This stream is used to help clear the debris from the saw to decrease wear on the blade and the skids. The streams of gas are directed toward the rear of the housing and toward the front of the blade rather than in the plane of the cutting blade. This configuration should not affect the potential design of a debris removal mechanism for the rock saw due to the weight of the materials that will be cut with the prototype.

Patent Number	Issued to	Concept	Applicability to project
3494389	Standard Alliance Industries	Slasher Loader	Ring & Pinion Gears
3915209	CEMETSA	Tree Harvester	Saw Blade
4738291	Reggald E. Isley	Power Saw	Gear, Blade
6,203,112 B1	Amer. Standards Const. Co.	Road Cutting Apparatus	Gear System
7,073,495 B1	Soff-Cut Int., Inc.	Cutting Concrete	Removal of Debris

Table 1: Patent List

Definition of Customer Requirements

CONEQTEC's major objective is to increase the useful life of the gear teeth on the saw. The current high rate of wear on the gear teeth could be caused by the accumulation of debris on the teeth of the ring and pinion gear configuration. When this debris enters the gear mesh, it abrasively wears the teeth. In addition to increasing the useful life of the teeth, CONEQTEC would like to prevent the motor from descending into the debris when cutting at the maximum depth.

Design Concepts

The alternative design concept is to remove the current ring system and replace it with sleeves that insert into rectangular holes in the blade. These holes allow the pinion to mesh directly into the blade, thus, forcing the blade to rotate. This alternative design replaces the ring teeth attached to the blade used to drive the gear with the gear guard sleeves. These sleeves should be easier to replace when worn out and should not wear in the same manner or at the same high rate as the current teeth setup. This gear configuration consists of a miter gear set with connects the hydraulic motor to the pinion gear. In the following figure, the alternative drive train is illustrated.

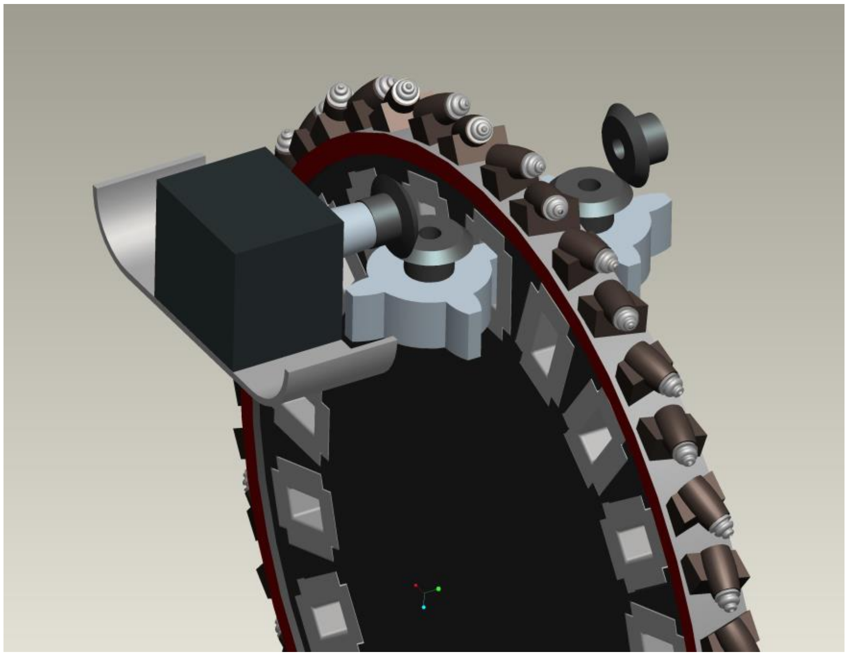


Figure 2: The alternative design for the new gear mesh. Use of miter gears to drive the new pinion gears in the new design of the ring gear.

Mechanical Engineering Design has aided in the redesign of the gear configuration [1]. The alternative design will retain the same ratings as the current prototype while increasing the useful life of the gear assembly. One of the problems evident in the current gear configuration is the clanking of the gears during normal operation which indicates a need for an increase in the tolerances to remove the unnecessary shear and impact stress as well as amplify abrasiveness. In the pinion and ring gears, bending, wear, ultimate strength, hardness, and factor of safety will be accounted for in the selection of the gear material.

CONEQTEC Universal would like to increase the useful life of the rock saw prototype from approximately 50 hours to over 100 hours. The current prototype uses a 40 horsepower supply from the skid steer via a high flow hydraulic system. One of the major issues BDM must address is the durability of the current gear teeth. Mr. Cochran, President of CONEQTEC Universal, informed the team that the gear teeth were wearing out at a fast enough rate to prevent the product from being marketable. The rock saw currently has a ring and pinion gear configuration. The pinion consists of round roller teeth which mesh with teeth attached near the outer perimeter of the saw.

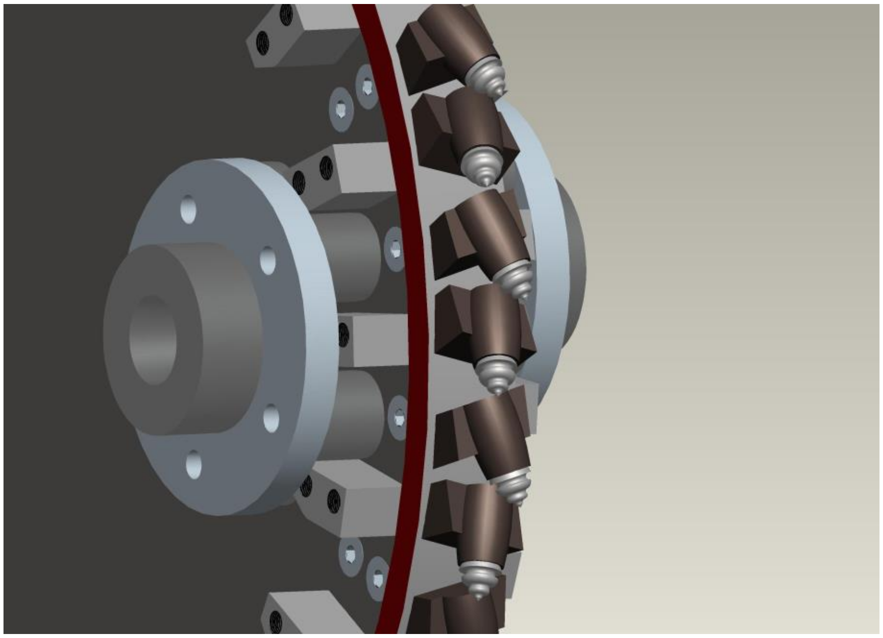
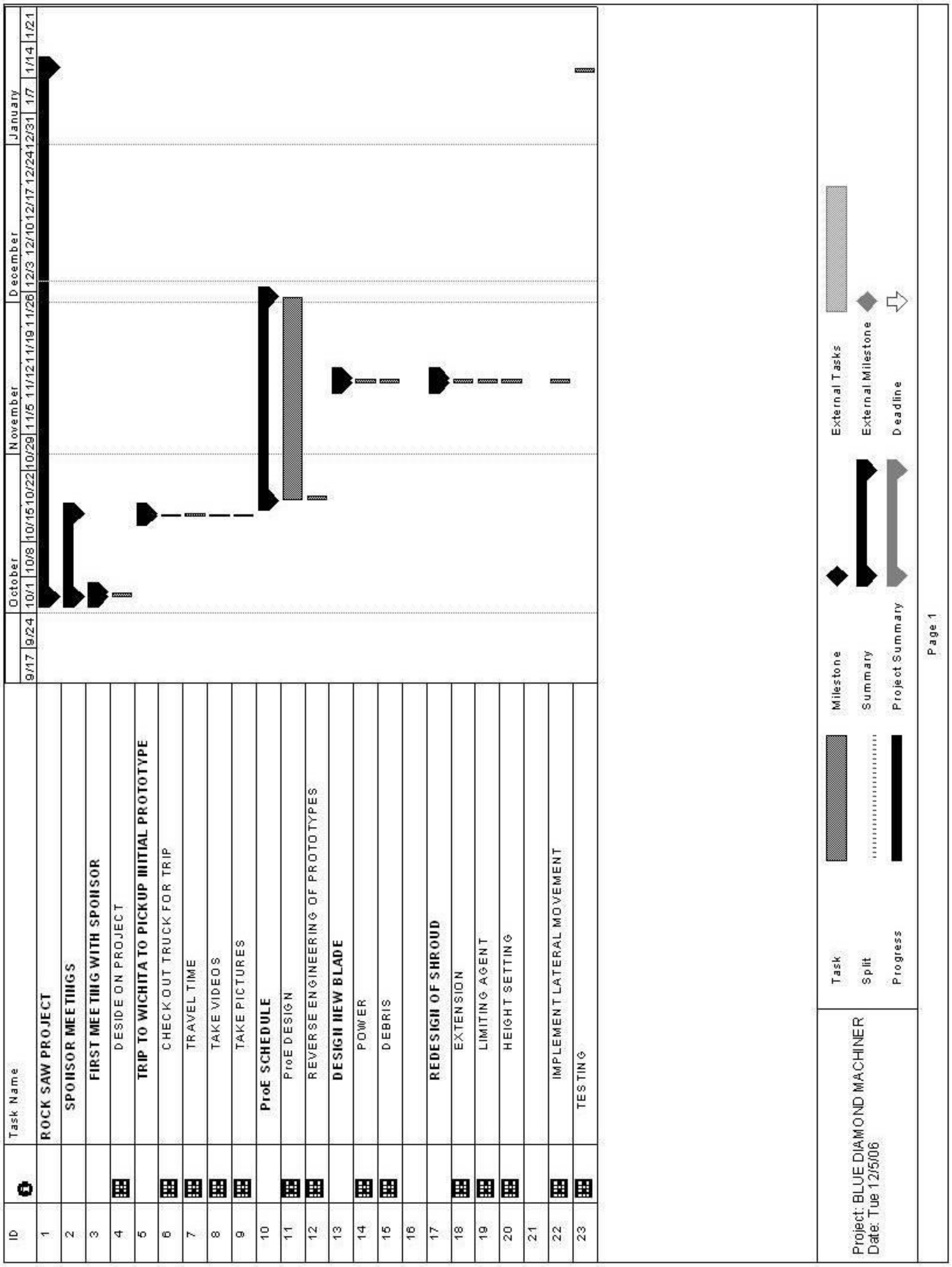


Figure 3: Prototype Gear Mesh.

The gear material needs to withstand the high levels of wear due to contact with abrasive debris while in use [1]. The most common solution to gear wear is lubrication. However, in this case, the gear teeth are subjected to debris and earthen material. This factor eliminates the possibility of using liquid lubricants due to the lubricant's tendency to absorb contaminants. If abrasive material adheres to the gear teeth, this will only exacerbate the problem of gear wear. The possibility of using a solid lubricant may be a better idea than using a liquid lubricant, but it still presents some issues regarding longevity. Since the gear teeth are in a harsh environment, constantly being worn by abrasive material, the solid lubricant would be removed too quickly to make this possibility feasible. Therefore, the only other alternative found was to perform a surface treatment and/or apply a surface coating to the gear teeth. While researching this new prospect, several possibilities for surface treatments were found. The following is a list of some of the possible surface treatments and coatings researched: shot, water-jet, and laser peening as well as roller burnishing, explosive hardening, cladding, mechanical plating, case hardening, hard facing, thermal spraying, surface texturing, ceramic coating, *Speedliner* coating, vapor deposition, diffusion coating, electroplating, electroless plating, electroforming, anodizing, conversion coating, coloring, hot dipping, porcelain enameling, organic coating, ceramic coatings, painting, ion implantation, diamond coating, and diamond-like carbon. Since there are many options for surface coatings, more research needs to be completed before the proper treatment and/or coating can be decided upon [3]. Instituting one of these treatments and or coatings should greatly decrease the wear on the gear teeth, therefore, extending the useful life of the gear.

Some factors must be taken into consideration when analyzing additional treatments, coatings, or change of materials including the following: mechanical properties, physical properties, protective properties, bond strength between coating and base metal, wear resistance, fatigue failure, breaking strength, and stresses [2]. In the few months, testing and evaluation of the surface treatment and the surface coating can be done by attaching the teeth to a mock blade and running them through a box containing several different types of rock and sand determine if durability increased after the treatments or coatings are applied. The alternative design concept can be run through a modeling program or by building and running a prototype which will be tested in a similar manor to the testing of the treated teeth.

Appendix A-Gantt Chart



Appendix B-Three Dimensional Modeling Pictures

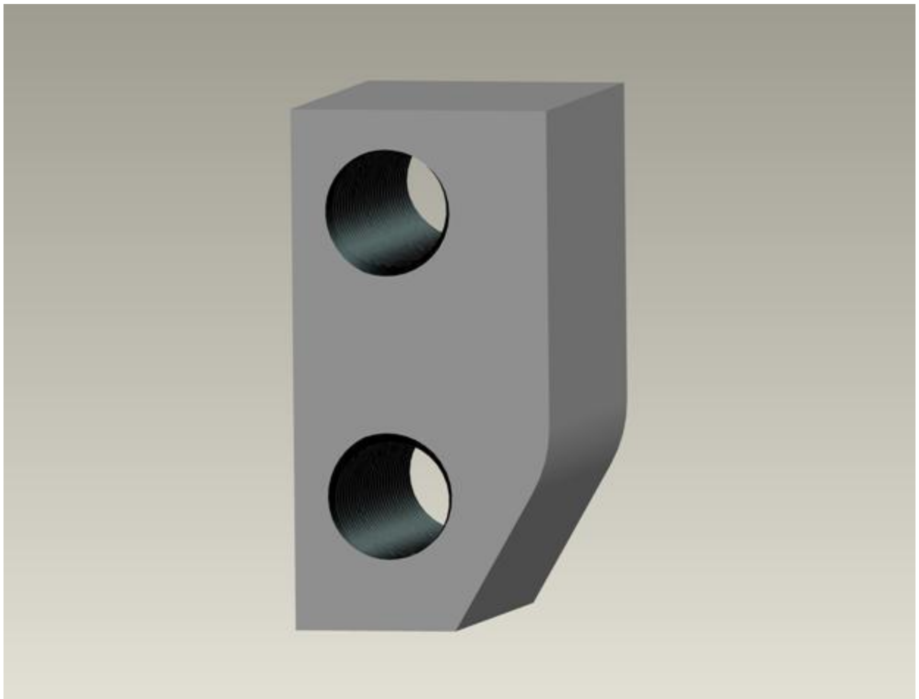


Figure B1: Current design of saw teeth (ring gear).

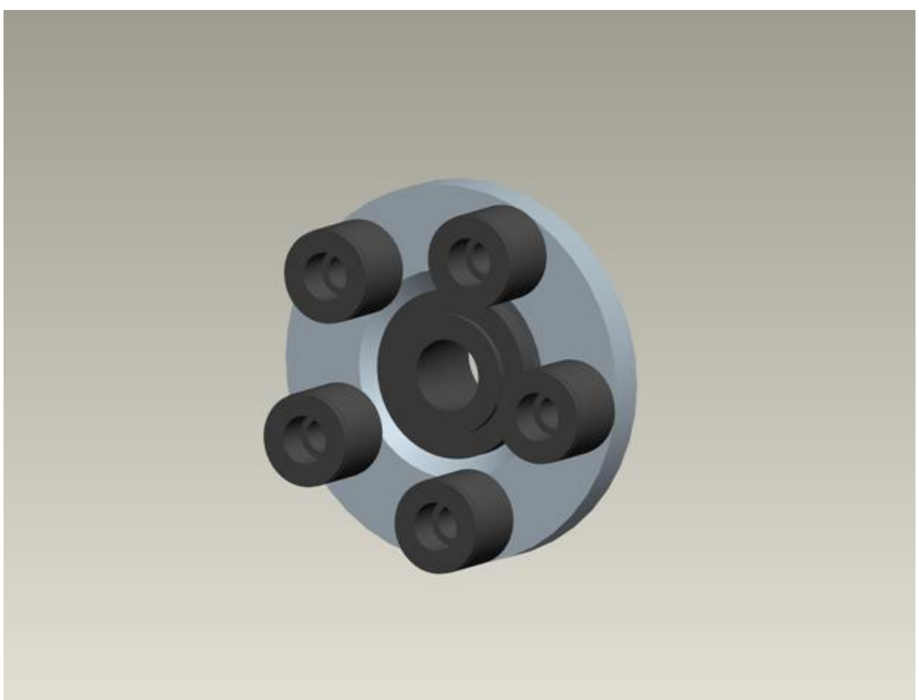


Figure B2: Hydraulic driving gear (pinion gear).

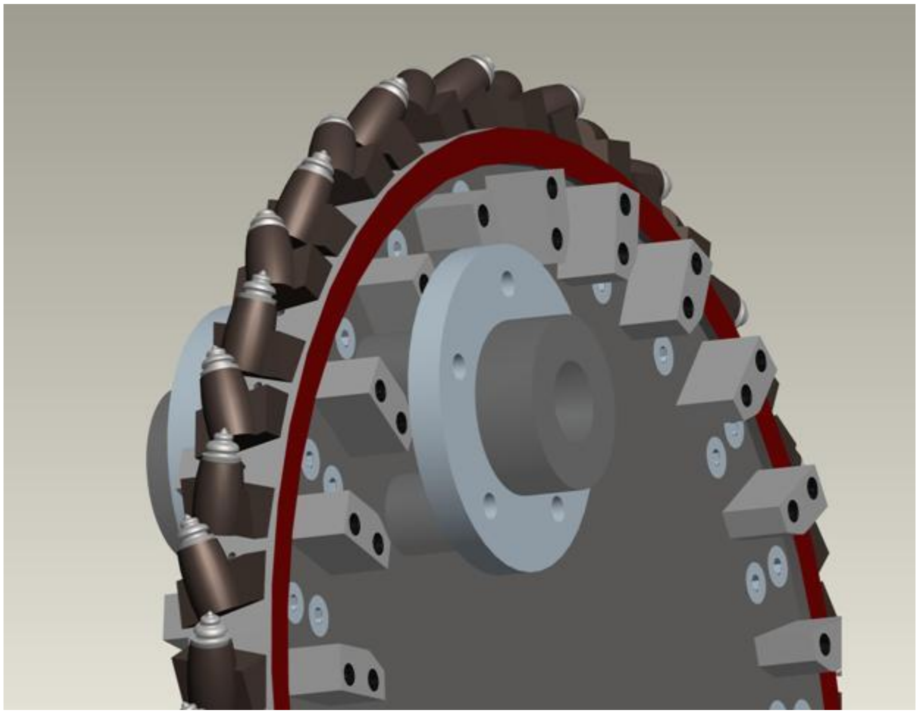


Figure B3: Current gear mesh.

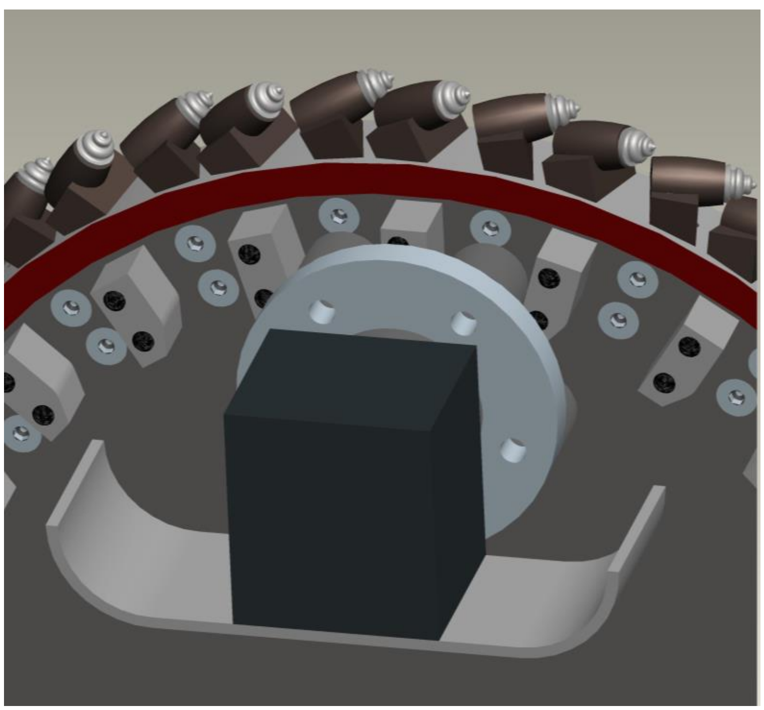


Figure B4: Skid plate (ski) mounted on a mock hydraulic motor.

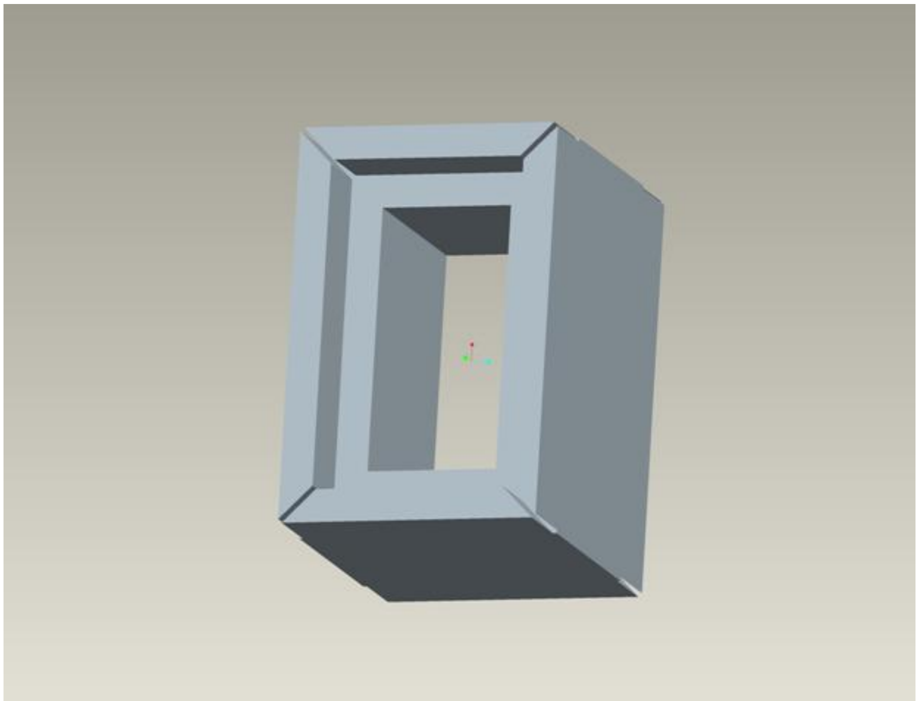


Figure B5: Gear guard in inserting position.

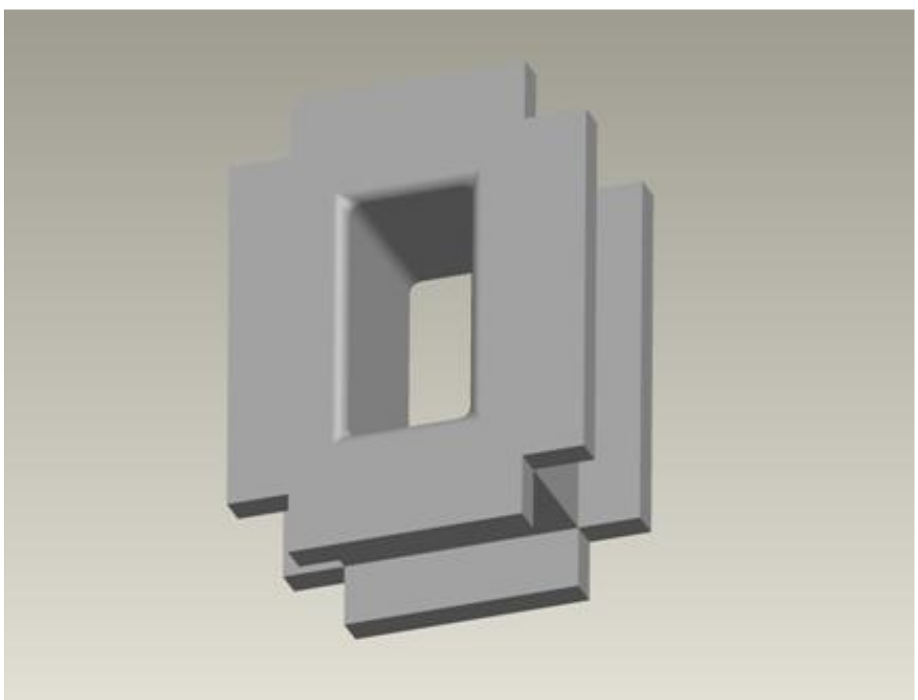


Figure B6: Gear guard in expanded position.

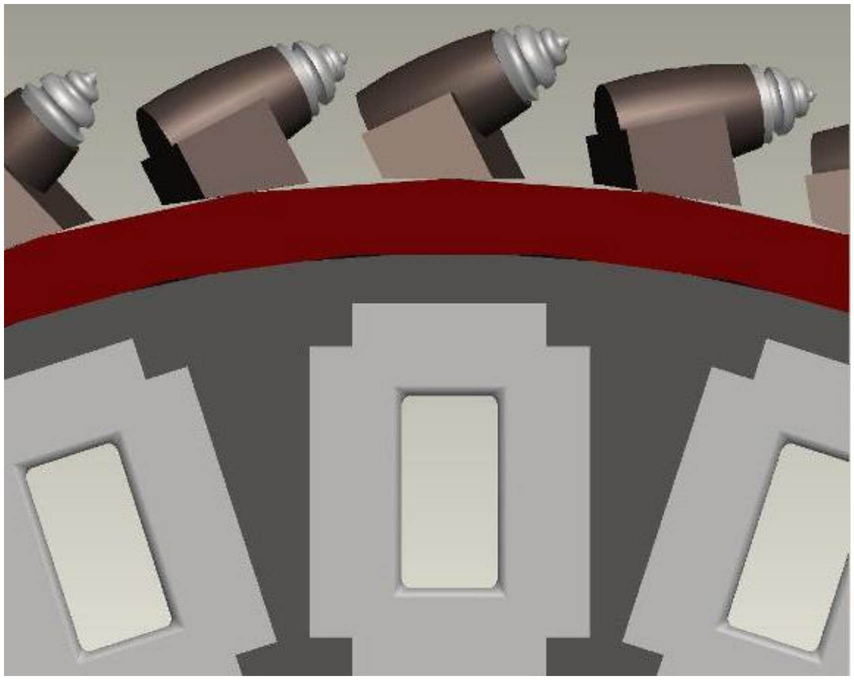


Figure B7: Implementation of alternate design of the gear guard.

Appendix C-Budget

Materials	
gear guards	$ 100.00
driving gears	$ 214.00
miter gears	$ 156.00
Treatments	
Speedliner coating	$60.00
surface treatments	TBD
Testing	
motor	$ 200.00
testing debris	$ 20.00
testing container	$ 15.00
testing plate	$ 70.00
Total Cost (approximately)	$ 835.00

References

[1] Shigley, Joseph E., and Mischke, Charles R., and Budynas, Richard G. 2004. *Mechanical Engineering Design*. 7th ed. New York, NY. McGraw-Hill Companies, Inc.

[2] Tushinksy, Leonid., and Kovensky, Illiya., and Polkhov, Alexandr., and Sindeyev, Victor., and Reshedko. 2002. *Coated Metal: Structure and Properties of Metal-Coating Compositions*. Germany. Springer-Verlag Berlin Heidelberg.

[3] Kalpakjian, Serope, and Schmid, Stephen R. 2003. *Manufacturing Processes for Engineering Materials*. 4th ed. Upper Saddle River, NJ. Pearson Education, Inc

Patents

Markley, Charles E. 2006. Method and Apparatus for Cleaning Concrete During Cutting. US Patent No. 7073497 B1

Cook, Eugene. 2001. Attachable Road Cutting Apparatus. US Patent No. 6203112 B1

Thibodeau, John L. 1970. Slasher-Loader. US Patent No. 3494389

Denis, Bernard. 1975. Machine for Harvesting Trees and Brushwood. US Patent No. 3915209

Isley, Reggald E. 1988. Power Saw Including Removable Circular Cutting Element and Holder. US Patent No. 4738291

Redesign of Driving Teeth to Improve Performance

by

Blue Diamond Machinery

Team Members:
Kelly Hogue
Kristen Tucker
Matthew Gassen
Buck Melton

Prepared for CONEQTEC Universal and BAE 4012

Mission statement

- Blue Diamond Machinery strives to improve products by implementing high quality designs, increasing efficiency, and surpassing the demands of our clients.

Project sponsor

- CONEQTEC Universal
- Manufacturer of skid steer attachments
- President Gary Cochran

Production Model

- Minimal cutting depth
- To increase depth of cut, the diameter of the blade must increase, therefore, increasing the weight of the attachment.

Provided by CONEQTEC

Problem Statement

- Increase cutting depth to greater than blade radius
- Improve prototype to increase useful life
- Prohibit hydraulic motor from descending into debris piles

Features of prototype

- Depth of cut is close to blade diameter
  - 18 inches deep. 2.5 inches wide
- Powered by hi-flow hydraulic system
  - 40 hp input to hydraulic motors
- Laterally adjustable
- CONEQTEC patented design

Rock Saw Prototype

Provided by Coneqtec

Statement of Work

- Increase useful life of gear teeth from less than 50 hrs to over 100 hrs.

Statement of Work (cont'd)

- Prevent hydraulic motors from descending into debris

Statement of Work (cont'd)

The longevity problem of the rock saw is due to wear on the gear teeth attached to the saw blade.

Options:

- Redesign gear mesh
- Increase wearability of gear teeth

Statement of Work (cont’d)

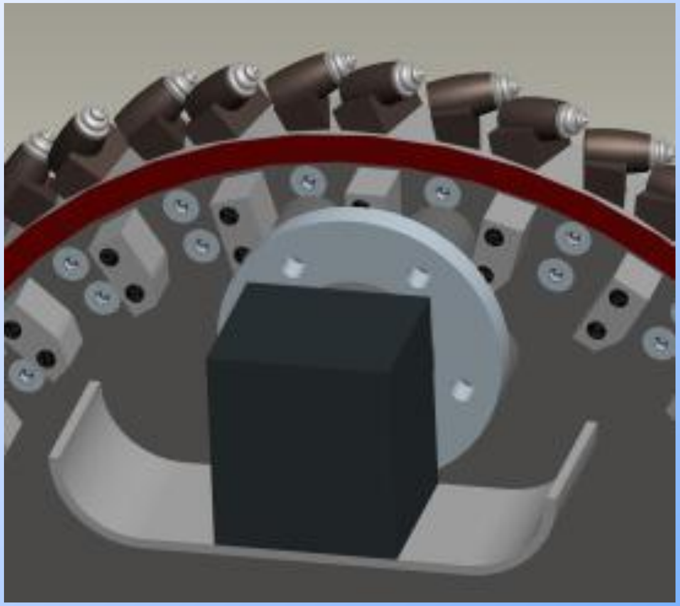
Test for increase in wearability of gear teeth after instituting the following:

- Surface treatments
- Surface coatings
- Harder material

Statement of work (cont'd)

Prevent hydraulic motors from descending into debris

- Install a ski guard on motors



- Install a stop on depth control

Research

- Patents
  - Rim driven
  - Cutting (Concrete)
- Literature
  - Track Trenchers
  - Rock Saws
  - Surface Treatments
  - Surface Coatings
  - Gear configurations

Research (cont'd)

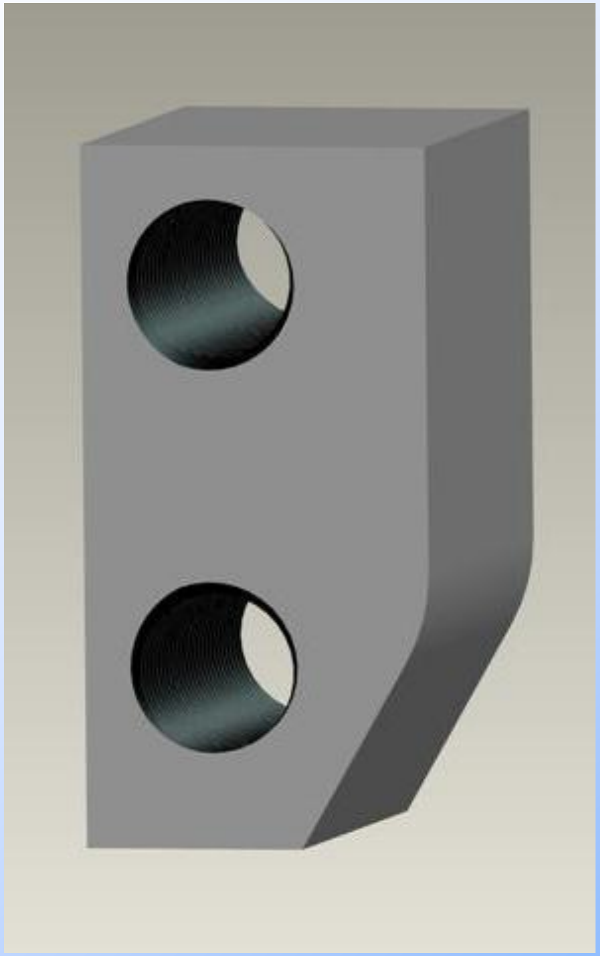
- CONEQTEC Patents
  - Slot cutter depth control
  - Auxiliary implements attachments

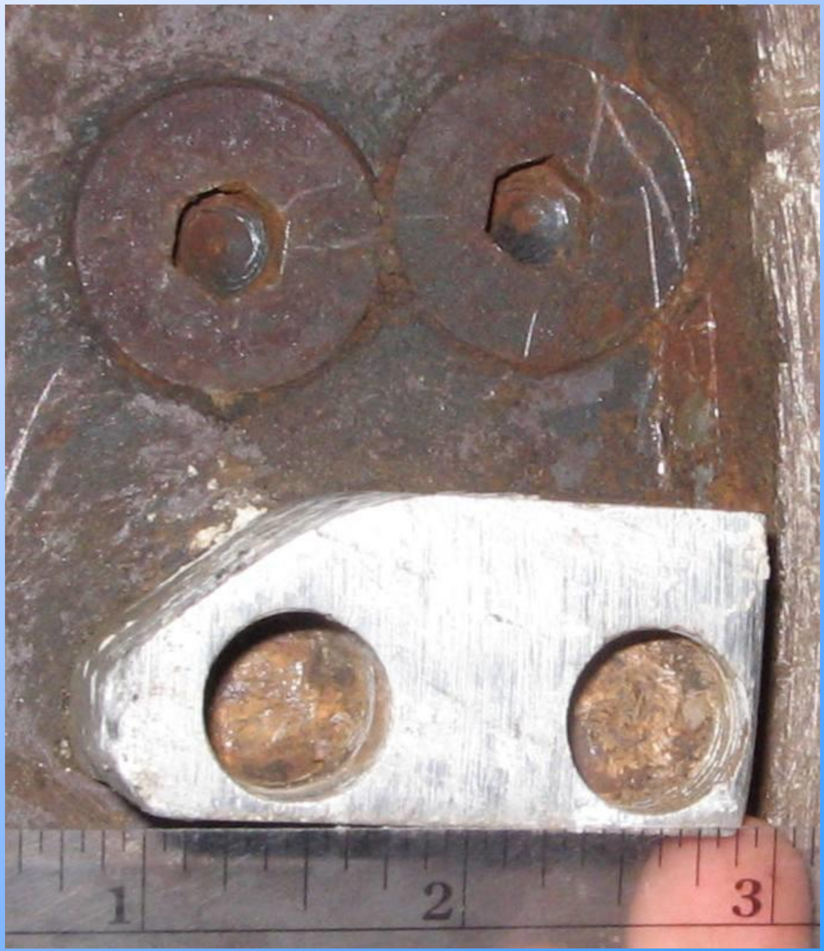
Possible Solutions

Increase useful life of gear teeth

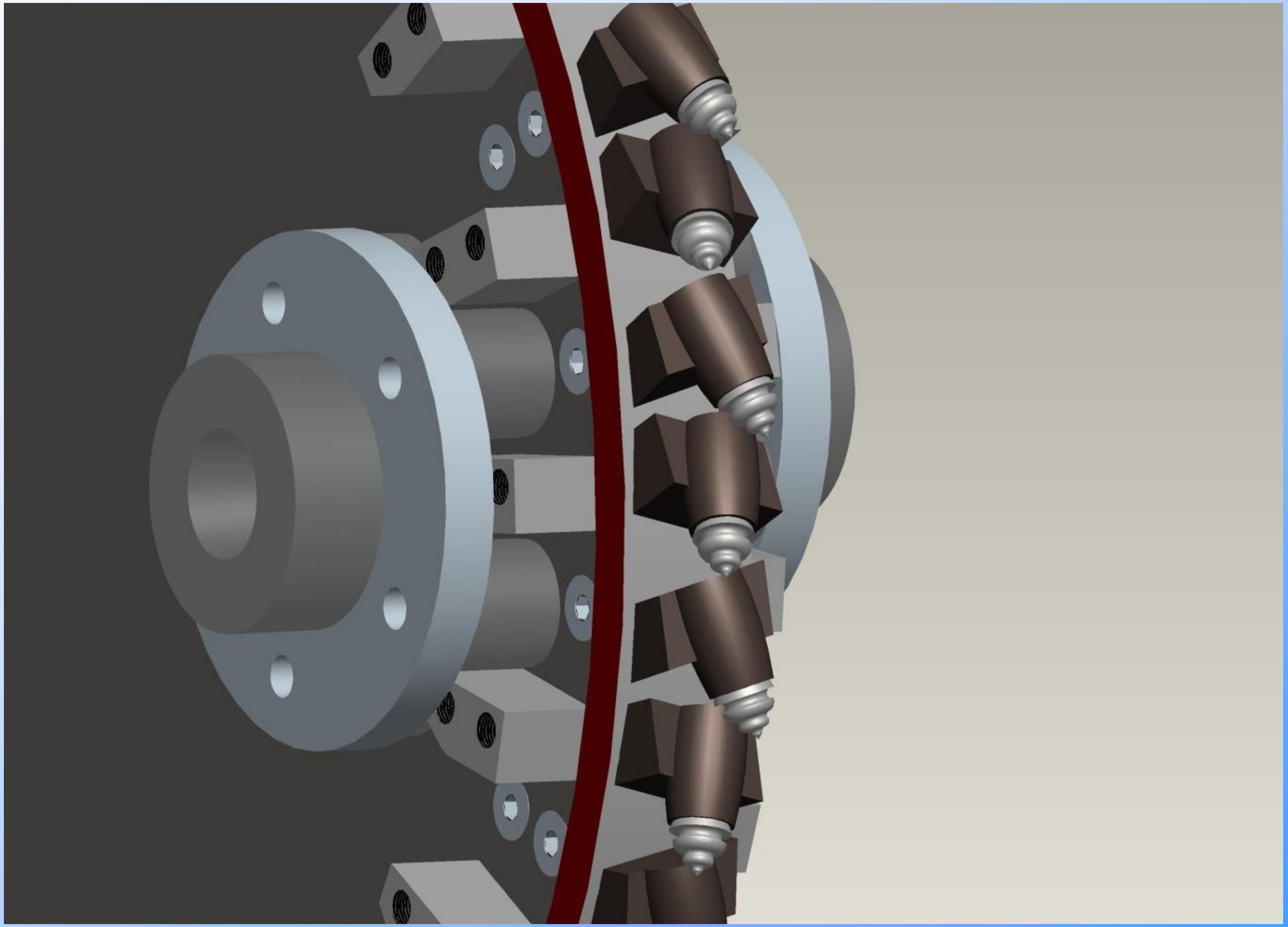
- Change gear tooth material
- Increase tolerance of gear mesh
- Surface treatments
- Surface coatings

Prototype Ring Gear Teeth





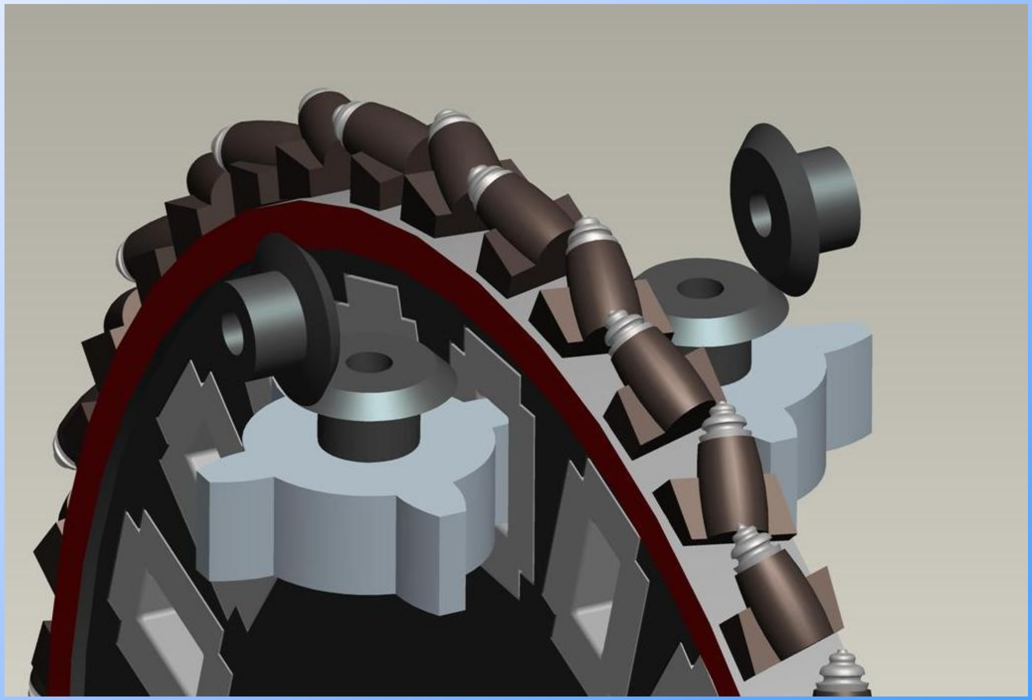
Prototype Gear Mesh



Possible Solutions (cont'd)

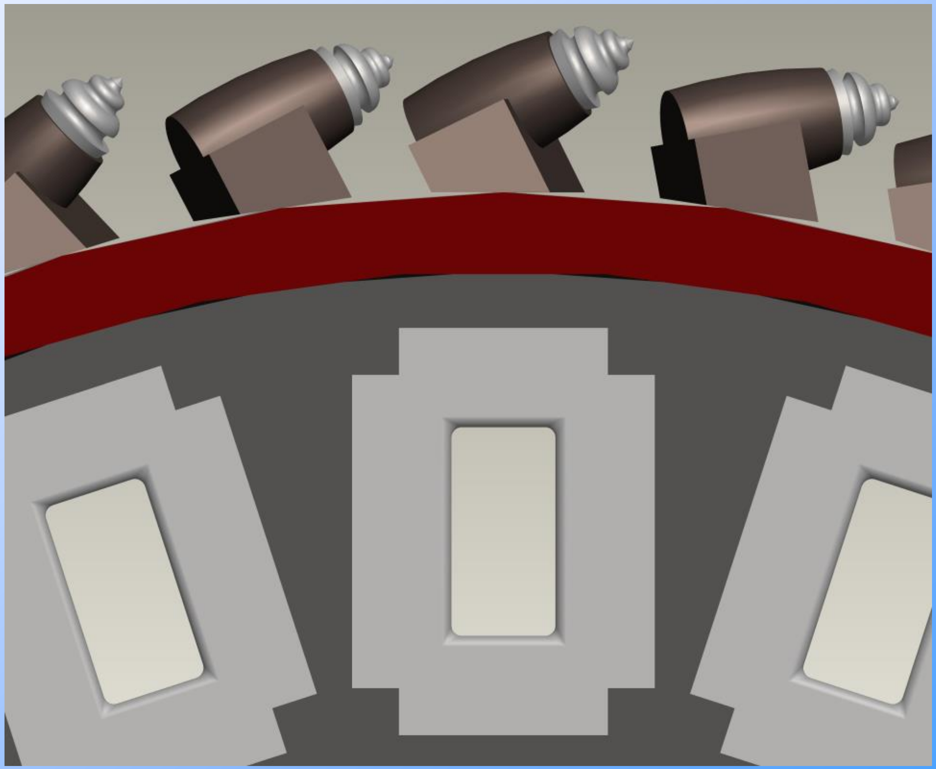
Institute Alternative Design

- New gears mesh into blade eliminating current ring teeth wear

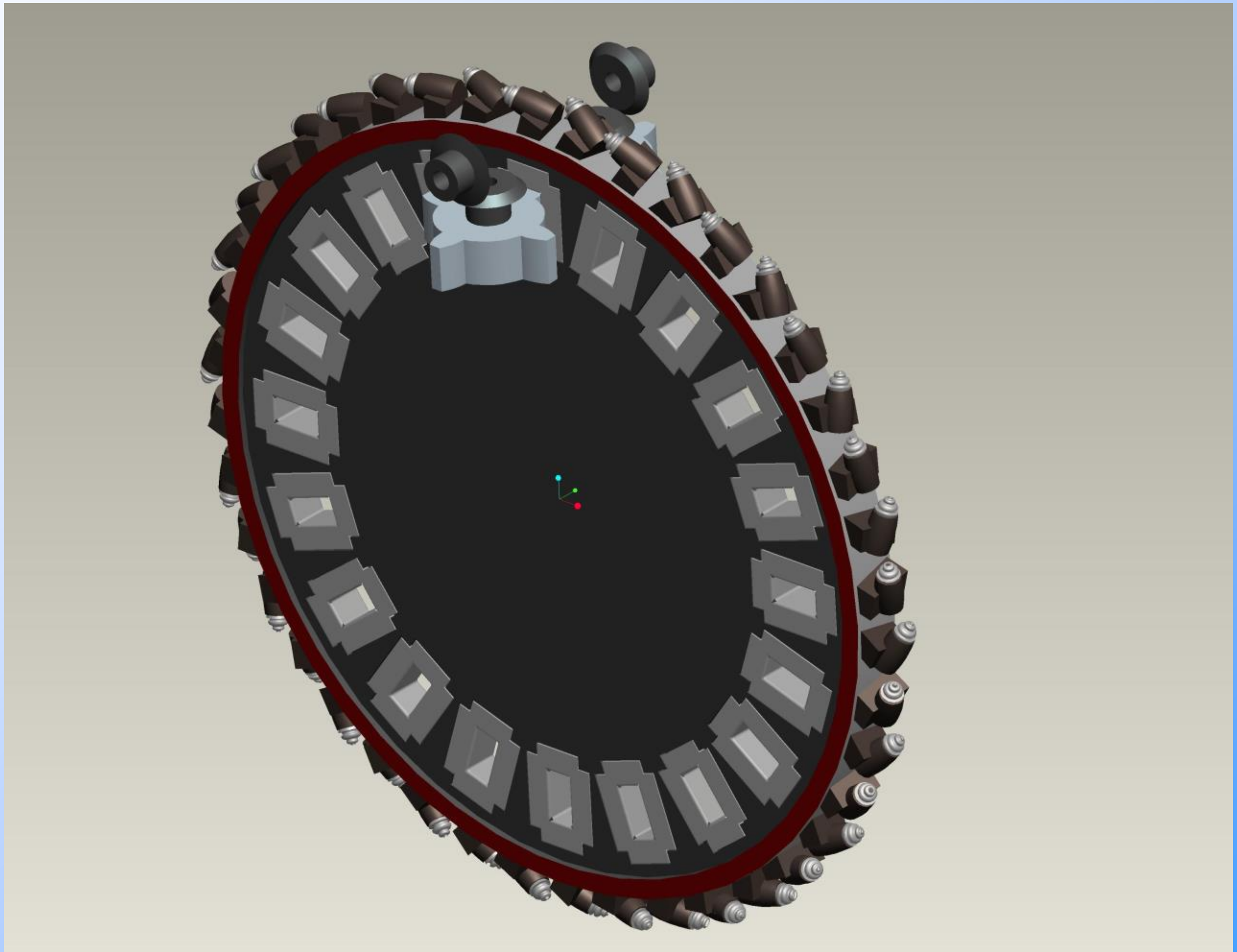


Alternative Design Cont.

- Gear guards are installed on blade to protect blade from gear mesh wear



Alternative Gear Mesh Design



Proposed Budget

Materials	
gear guards	$ 100.00
driving gears	$ 214.00
miter gears	$ 156.00
Treatments	
speedliner coating	$60.00
surface treatments	TBD
Testing	
motor	$ 200.00
testing debris	$ 20.00
testing container	$ 15.00
testing plate	$ 70.00
Total Cost (approximately)	**$ 835.00**

Project Schedule

- Fall Semester
  - Patent Search
  - Design Concepts
- Spring Semester
  - Fabrication
  - Testing
  - Final Design

Thank You

- Gary Cochran and CONEQTEC
- Dr. Paul Weckler
- Jana Moore
- BAE Lab

At this time

we would like

to open the floor to

any

QUESTIONS?