D.T.E.

You Dream It. We Build It.

Geothermal Pipe Bending

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2013 Spring Design Report

Prepared for Charles Machine Works, Inc.

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MISSION STATEMENT

D.T.E. is dedicated to coming up with creative and innovative designs with our client's satisfaction as our top priority. We are devoted to designing solutions that are cost efficient, reliable, and exceed all expectations. We promise to put our client's needs first through the entirety of the project. Our innovation can make your engineering dreams come to life.

INTRODUCTION TO PROBLEM

Ditch Witch has always been a leader and innovator of underground construction equipment. In recent years, geothermal heat pump installation has become a large industry and many companies use Ditch Witch trenchless equipment for digging wells. Current methods for geothermal installation involve a large hole and multiple small loops sent down hole. The loops are secured with grout in between the pipe and the ground down hole. One of the biggest problems in the process is adding the grout down hole to secure the pipe. Not only is it costly, but also reduces the efficiency of the geothermal system. Ditch Witch has set out to improve the installation process by reducing the amount of grout needed. To reduce the amount of needed grout, Ditch Witch has requested that D.T.E. design a prototype machine to check the feasibility of reducing the outer diameter of 4.5 inch HDPE pipe temporarily. By doing this, a smaller diameter hole can be dug in the ground. This smaller hole will allow the pipe to create a tight fit once down hole and expanded back to its original shape. This will reduce the amount of grout needed to secure the pipe and also increase heat transfer efficiency.

PROBLEM STATEMENT

Charles Machine Works, Inc. has assigned the task of evaluating the feasibility of bending 4.5 inch outer diameter High Density Polyethylene (HDPE) pipe into a "U" shape cross sectional area. This will reduce the outer diameter to approximately 3.5 inches when folded. In the original requirements, CMW requested we also design a grout line inserter, banding mechanism, and a spooling machine. As the project progressed, those requirements were dropped due to time constraints. CMW did however, ask that we gather some ideas for banding material and test our ideas. If bending the HDPE pipe into the "U" shape is possible using a prototype machine, then CMW will look into designing and building a machine for production purposes.

STATEMENT OF WORK

a. *Scope of Work*

DTE will design and develop a machine to address the problem statement. This machine will crease HDPE pipe into the "U" shaped cross section. The purpose of bending the pipe is to reduce the outer diameter to approximately 3.5 inches. This will allow for a smaller drill hole, tighter fit, and less grout to secure the pipe.

b. *Location of Work*

The work of the project primarily took place in two locations, Charles Machine Works in Perry, Oklahoma and the Bio-systems Lab on Oklahoma State University's campus. CMW took care of all machined parts that could not be made in the BAE Lab. Design, assembly, and testing took place in the BAE Lab.

c. Period of Performance

The projected was assigned to DTE in August 2012. The design process took place from August to December 2012. In January 2013, the design was finalized and sent CMW for fabrication. Assembly began in February 2013 and was completed by the first of April 2013. Testing took place through the month of April and the project was completed by the end of April 2013.

d. Gantt Chart

A Gantt Chart was used to outline what took place during the completion of the project. This chart can be found in Appendix I.

e. Deliverable Requirements

Ditch Witch has requested that DTE design and build a prototype machine to fold HDPE pipe into a "U" shape cross section. The machine was made to handle HDPE SDR 21 pipe with an outer diameter of 4.5 inches. The machine will need to handle 300 feet of pipe at a time. All drive systems need to be powered by hydraulics. Lastly, they requested ideas for banding the pipe along with testing results from those ideas.

f. Work Breakdown Structure

The work breakdown structure is a tabular representation of the tasks necessary to complete the project. The full work breakdown structure is located in Appendix II.

g. Task List

1.0 - Pipe Bending Machine
- 1.1 Dies for bending pipe
- 1.2 Design Frame
- 1.3 Driving mechanism
- 1.4 Bands for holding the pipe in "U" Shape
- 1.5 Banding mechanism

2.0 - Documentation
- 2.1 Solid Works Drawings

2.2 Engineering Calculations
2.3 Gantt charts and MS Project
2.4 Write design report

3.0 - Engineering Review and Approval

3.1 Review and approve engineering
3.2 Review, approve, and finalize Design

4.0 - Fabricate and Procure System Materials

4.1 Order parts and materials
4.2 Procure Materials
4.2 Fabricate and assemble frame
4.3 Fabricate and assemble power systems
4.4 Assemble hydraulic system

5.0 -Testing

5.1 Create test dies to test the pipe in the Instron machine
5.2 Obtain stress, strain, and forces of pipe
5.3 Gather data and analyze to determine whether the design is feasible
5.4 Test the friction between drive rollers and pipe
5.5 Test the amount of force required to move the pipe
5.6 Develop a drive train to apply the required force to the pipe
5.7 Test bands for holding capabilities

6.0 - Integration of system

6.1 Functional checks
6.2 Deliver to Charles Machine Works

COMPETITIVE ANALYSIS

After extensive research it was found that Charles Machine Works does not have any market competition in the development of this machine. This project addressed the research and development of an idea to bend pipe for the use of geothermal wells. As far as the research has shown, this method has not been used before. A prototype was built and from the prototype CMW hopes to learn more about the feasibility of bent pipe and how it can be used in geothermal wells. In conclusion of the project, CMW will decide if they will further research the possibilities of this machine and decide if this method is pursuable. In the event that CMW will further this project into production, decisions will need to be made whether to sell bent pipe or a machine.

Market outcome will vary greatly depending on how this idea is produced. With CMW holding the patent on this idea, they can hold the market for some time. This will allow them to develop the project and assess the best choice between selling pipe or a machine. Selling the pipe itself will have some overhead cost including but not limited to: pipe cost, man hours, and storage. While selling a machine will have overhead also, it could be tied in with their current trenchless machines as a combined unit and help sell units together. Once the design is constituted as feasible, CMW can make further decisions on production.

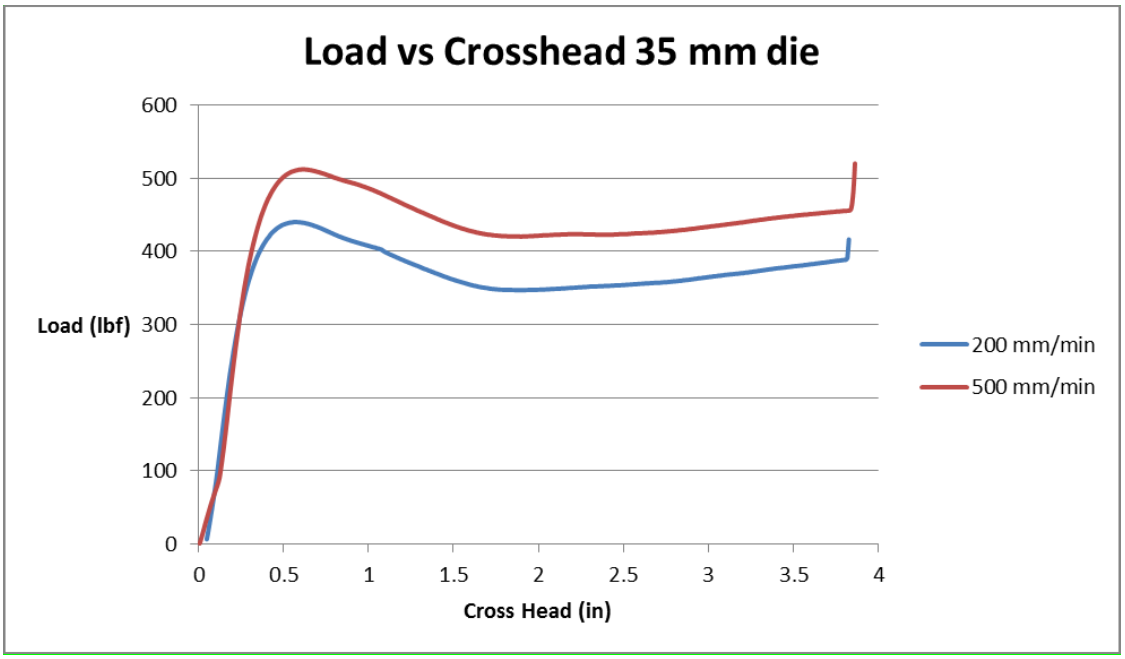
DESIGN ASPECTS

a. *Patent Searches*

The patents that are relevant to the design process were obtained through Google Patent Search. The detailed summary of each of them can be found in Appendix III. Patents 4986951, 4863365, 4998871, 5091137, 5342570, 5861116, and 6119501 contain processes describing how to deform pipe liner. Each process deforms the liner from a circular cross section to a smaller diameter in the shape of a "U" or "W". The processes are similar to the prototype machine in the fact that rollers are used to decrease the outer diameter of pipe. However, these processes differ in the application of heat. Heat will not be applied in the design during the deformation process. These patents also differ in their overall use. These patents discuss using a bent pipe to line another deteriorating pipe.

b. Preliminary Testing and Experiments

The first step in testing was to find the forces it took to crush the pipe. The Instron Machine was used to find the maximum stresses on the pipe when it is crushed and bent. Multiple custom die sets were made to fit the Instron machine (Fig. 1 & 2). Using these die sets the pipe was crushed at different speeds to determine the required forces. The different shapes were used to find the easiest way to manipulate the pipe into the desired shape. The following graph shows the results from the Instron machine at 10 feet per minute and 25 feet per minute with the final die design choice.



The result showed that force and speed are proportional to each other. Moving the pipe through the system at a faster rate of speed requires a larger force to crush the pipe. Through testing it was also discovered that manipulating the shape of the pipe during crushing resulted in different forces. This led to a redesign of the dies so that the pipe could take the shape more naturally.

Figure 1

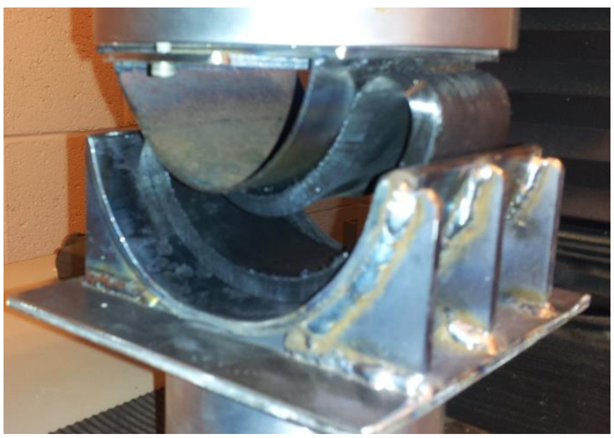


Figure 2

DESIGN CONCEPTS

a. Customer Requirements

Charles Machine Works is requiring DTE to use 4.5 inch outer diameter HDPE pipe. They requested for the pipe to be bent without the use of heat into a “U” shape with an outer diameter to be about 3.5 inches. This HDPE pipe was chosen by CMW for two reasons. The first reason is the size requirement of the pipe needed to properly heat or cool a building. Also, this pipe is the biggest diameter available in a continuous piece.

Most patents DTE found used heat to help shape the pipe. CMW chose not to heat the pipe to ease the process of unfolding it once down hole. Using heat could add an elastic memory to the pipe, causing it to stay bent. To reform the pipe it would need to be pressurized with a heated fluid and that would be difficult to do under the circumstances. Due to the fact that no heat will be used to form the pipe; it will naturally want to unfold on its own. Because of this natural unfolding, CMW requested we also look into some banding choices. The bands will have to maintain the "U" shape while being under high tension. Once down hole the bands will need to be released which rules out any metal bands.

b. *Engineering Specifications*

There were two main objectives to accomplish. The first was to design the machine to bend the pipe. Secondly, DTE tested different banding ideas to find a possible solution.

c. *Concept Development*

i. Design I and Design II

The following two designs were presented fall semester. The final design for the prototype that was built took concepts from both designs. The following explains the two designs and the differences between them. It also follows the evolution of the design and how the final design came to be.

Both previous designs had a set of hydraulic motors at the beginning of the machine to push the pipe through the system. These motors were equipped with rubber disks to create friction on the pipe and propel the pipe through the machine. There was a set of guides before and after the push motors to ensure the pipe stays in line with the dies (See Fig. 3 & 4). The motors could push the pipe at either 10 feet per minute or 25 feet per minute, depending on CMW's preferences.

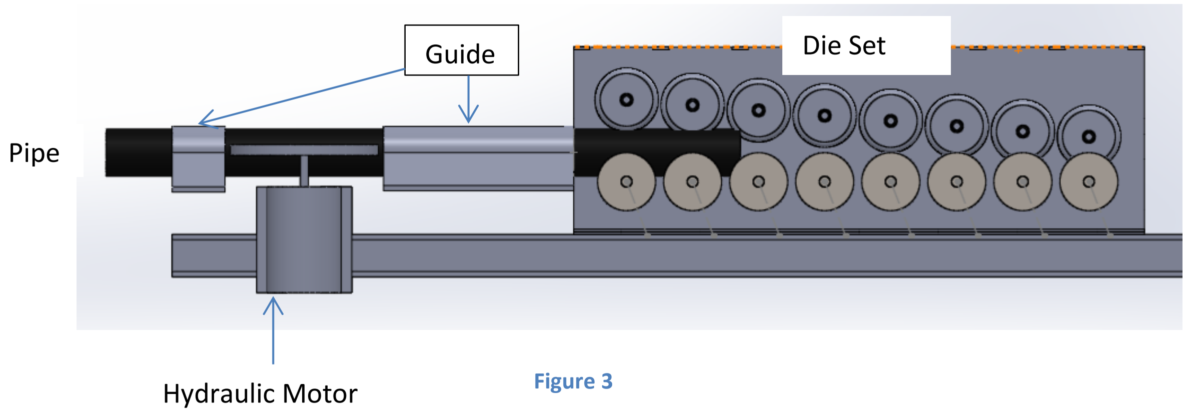


Figure 3

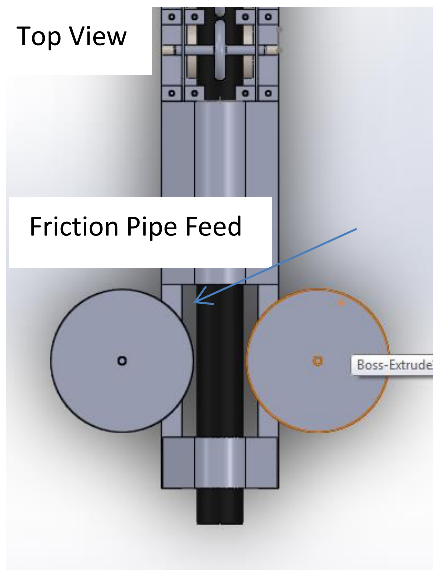


Figure 4

Once the pipe reached the dies, there needed to be a significant amount of linear force on the pipe to feed through the dies. The dies were 1 inch wide and had a diameter of 6 inches with a rounded edge. (See Fig. 5 for die) The dies stepped down in increments of a half inch for every 6.25 inches of linear travel. (See Fig. 6 for die setup). The pipe saw 8 dies that reduced the height of the pipe by 3.75 inches total. The 3.75 inches would bring the top of the pipe in contact with the bottom. Once the pipe had been through all 8 dies the "U" shape would be obtained. (See Fig. 7)

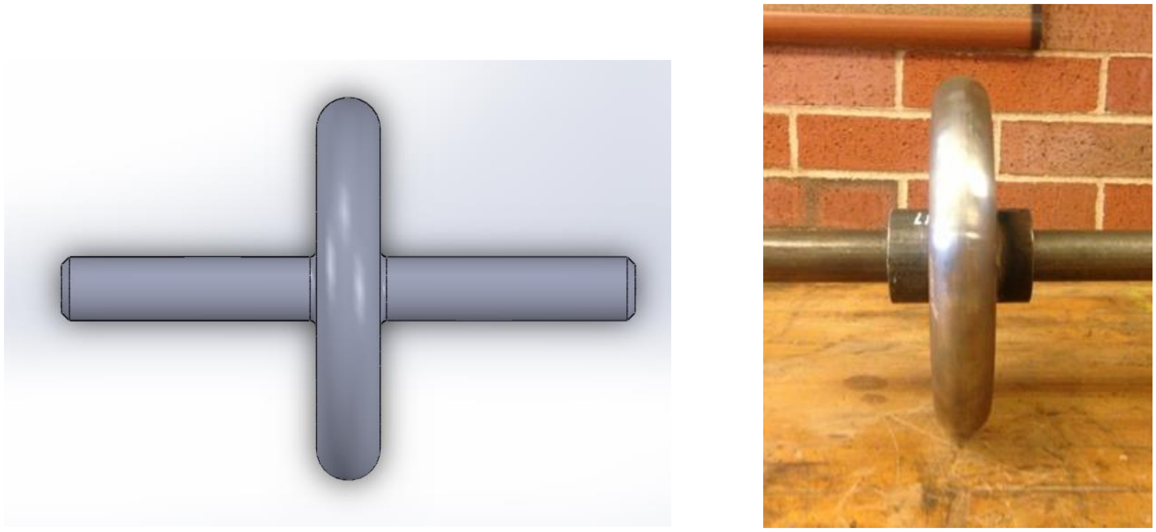


Figure 5 - Upper Die

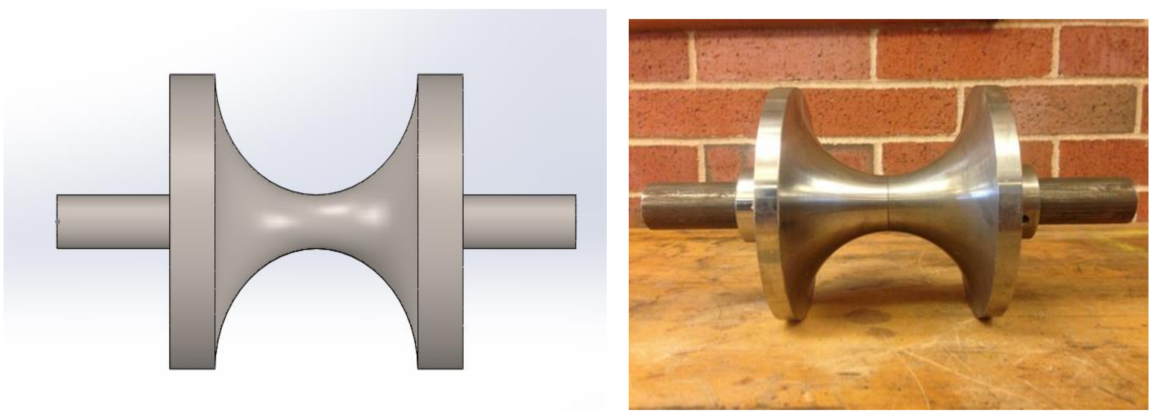


Figure 5 - Saddle

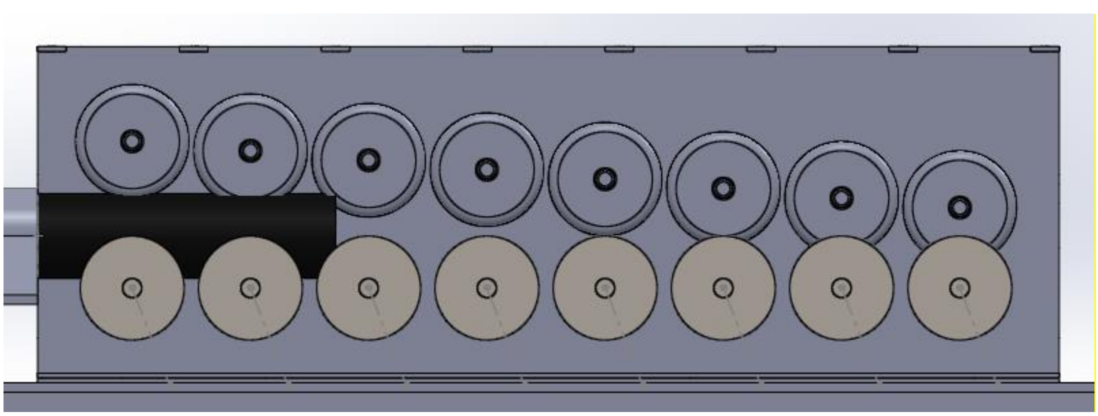


Figure 6

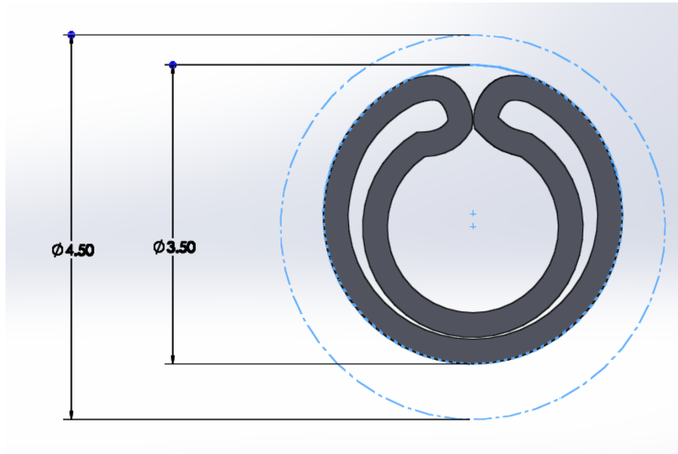
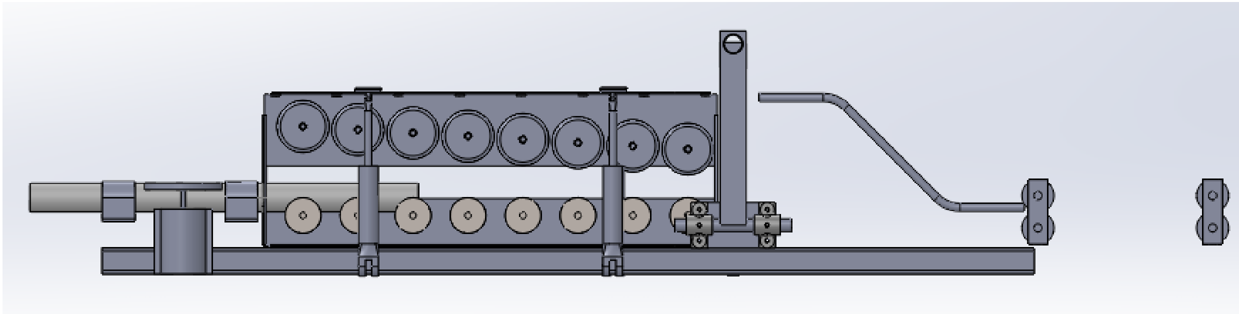


Figure 7

After the die set, the 1 inch grout line would be inserted into the fold of the HDPE pipe. The spool of grout line would be lifted above the machine via hydraulic lift. This would eliminate the need for multiple workers to lift the spool and reduce worker strain and injury. Once the beginning of the pipe had reached the grout line inserter, the machine will need to be stopped so that the operator can line up the grout line with the HDPE pipe. This will ensure the grout line is accessible once the pipe is in the ground. After the dies, the pipe would follow in a track that would ensure it does not unfold before it is banded. Immediately after the insertion of the grout line the pipe would be compressed on the sides in the position it would need to stay in. While under this compression, the bands can be put on the pipe to ensure the pipe stays folded.

Design II is similar to Design I but there would have been vertical separation between the die sets. The following figure illustrates the vertical die separation.



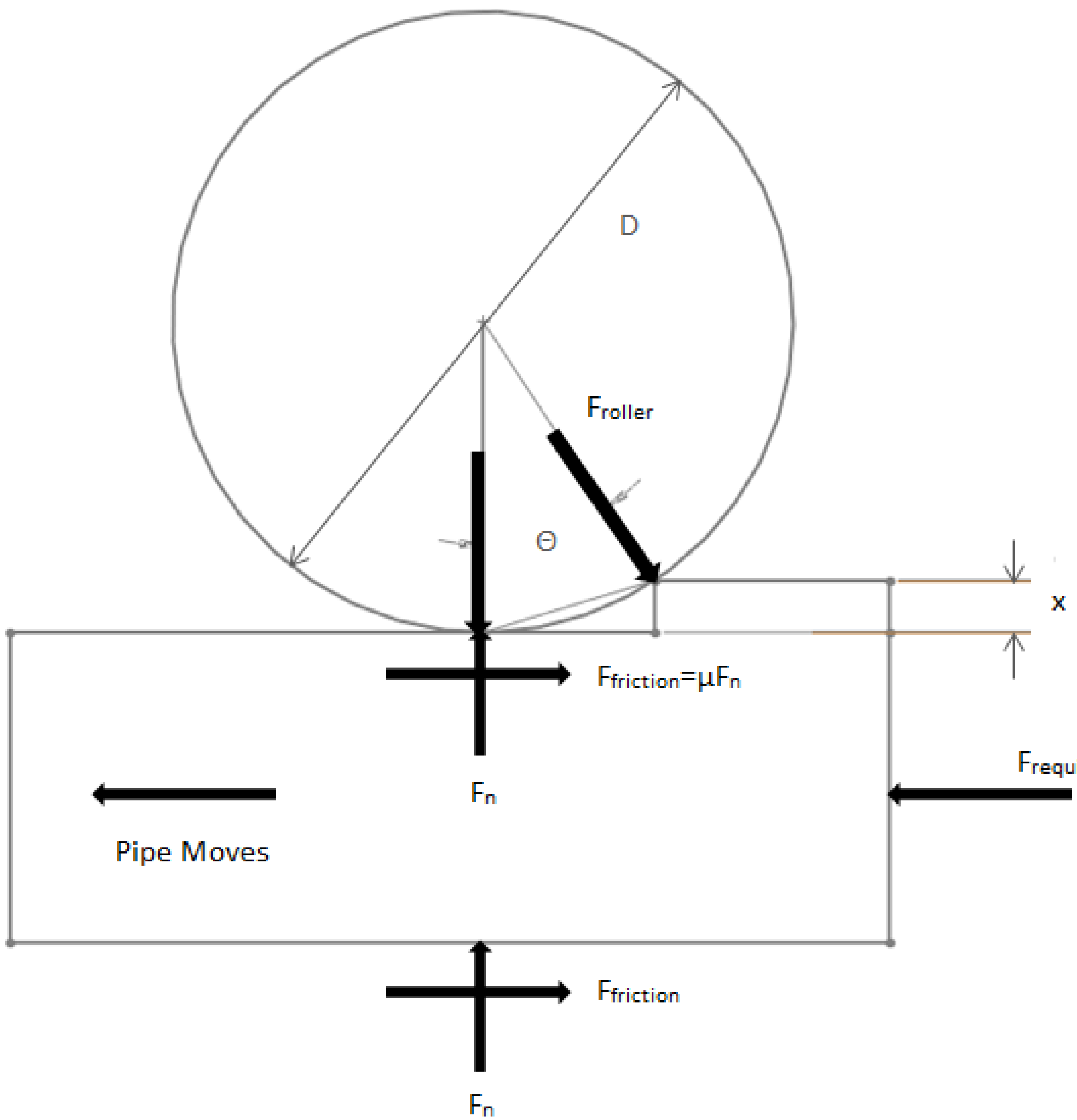
Design II also has the option of moving fast or slow and was equipped at the beginning and end with hydraulic motors to push and pull the pipe. The dies would start in the separated position so the pipe can be inserted into the system. This would leave 6 feet of unbent pipe at the beginning. The dies would then crush the pipe and the pipe would continue through the process described in Design I. This design reduces the initial force it takes to push the pipe through the die set. The design could ultimately use four smaller motors instead of two very large motors to save on cost.

ii. Calculations

The forces required to move the pipe through the system in all of the designs were calculated by using the following figure and equations.

$$F_{required} = 2 * F_n * \mu + F_{roller}\sin(\theta)$$

$$F_{total} = \sum F_{required}$$



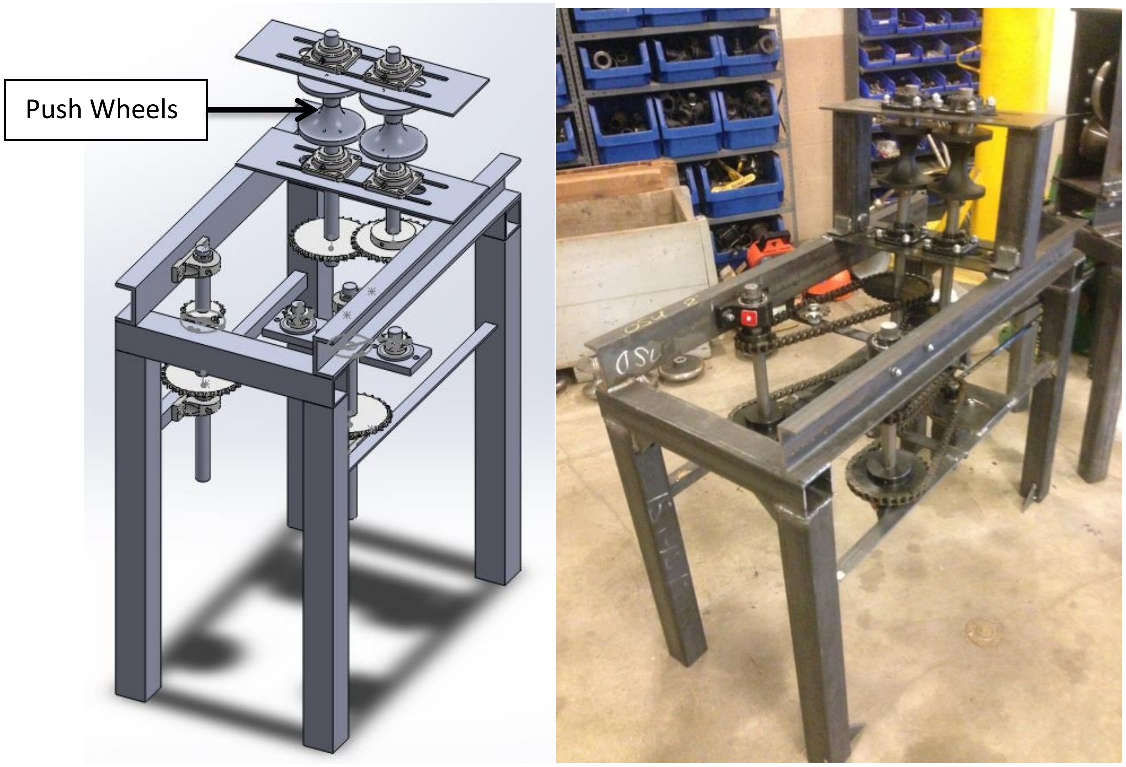
Tables for shaft and bearing analysis and each individual calculation from above can be found in Appendix IV. The following table displays the forces it would take to move the pipe through Design I and Design II and at the different speeds. The final design will require forces similar to Design II, the split design.

Force required to move pipe through system					
Design	**Speed of system**	**Actual Force**		**Force with 1.5 Safety Factor**	
Split Design	Fast (25 fpm)	1691	in*lb_f	**2537**	in*lb_f
	Slow (10 fpm)	1430	in*lb_f	**2145**	in*lb_f
Solid Design	Fast (25 fpm)	1926	in*lb_f	**2889**	in*lb_f
	Slow (10 fpm)	1629	in*lb_f	**2443**	in*lb_f

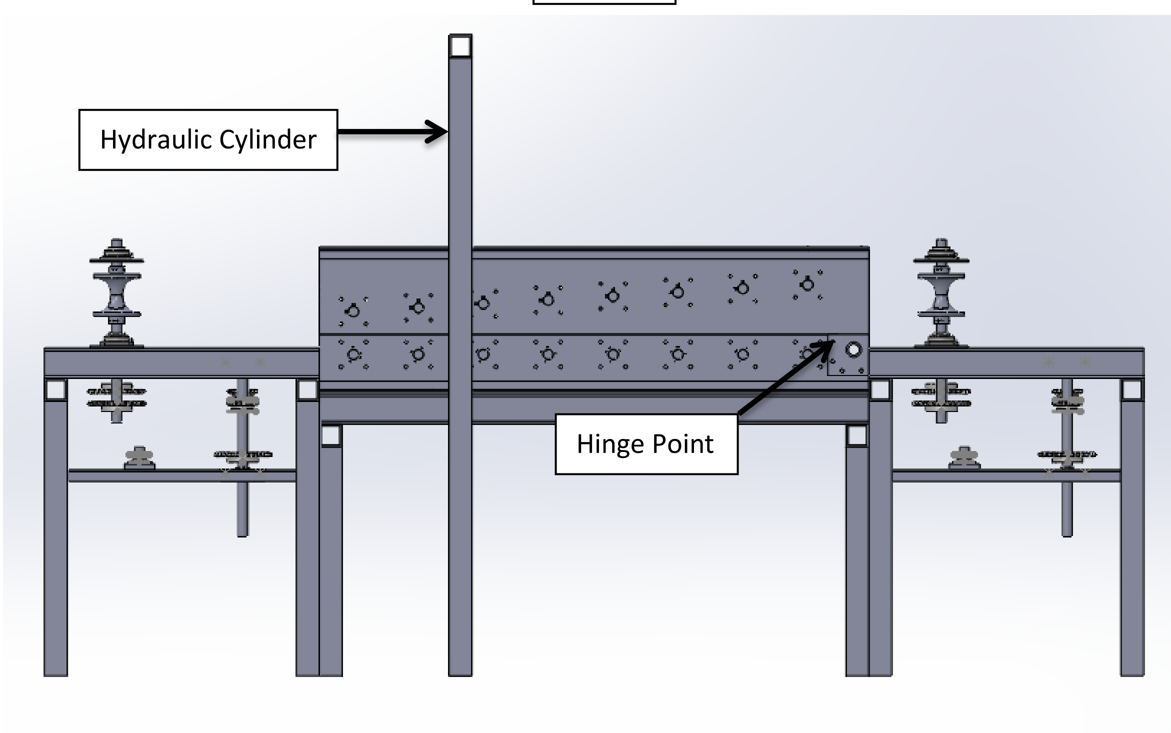
iii. Final Design

The final design that was decided on is a combination of both designs I and II, although it leans more towards the second design. As the figure below illustrates, the prototype has vertical die separation to allow for the reduced force and smaller motors. This is an identical concept to Design II, but instead of four hydraulic cylinders, there is only one and a hinge. The guides were eliminated because the pipe will be secured in the die set once it is in the closed position. The pipe will be pushed through the system via a set of hydraulic motors at the front of the die set (shown below) assisted by another set of hydraulic motors at the end of the die set. The pipe will move through the system as described before in Design Concept I and II.

1st & 3rd section



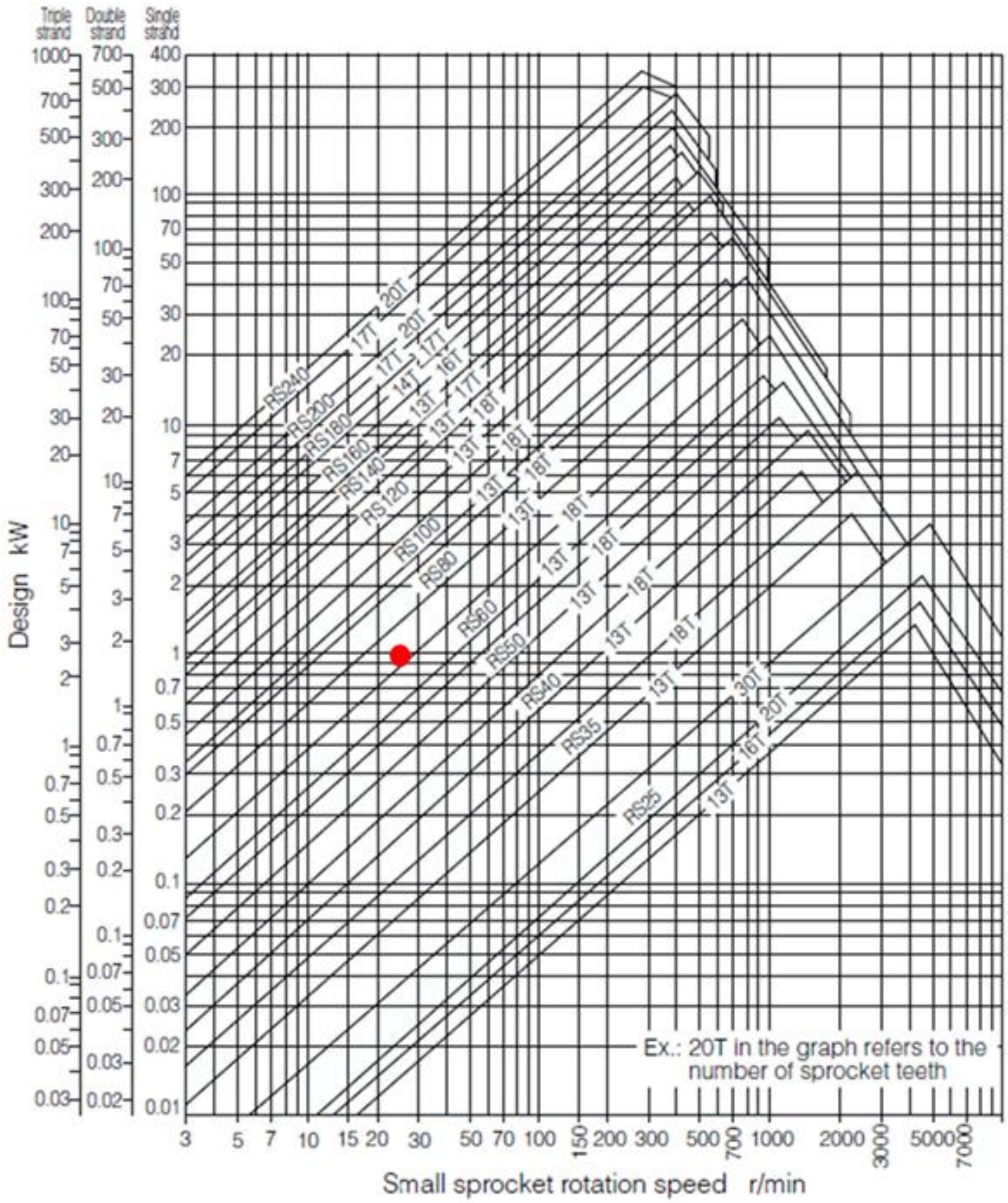
Die Set



iv. *Feasibility Evaluation*

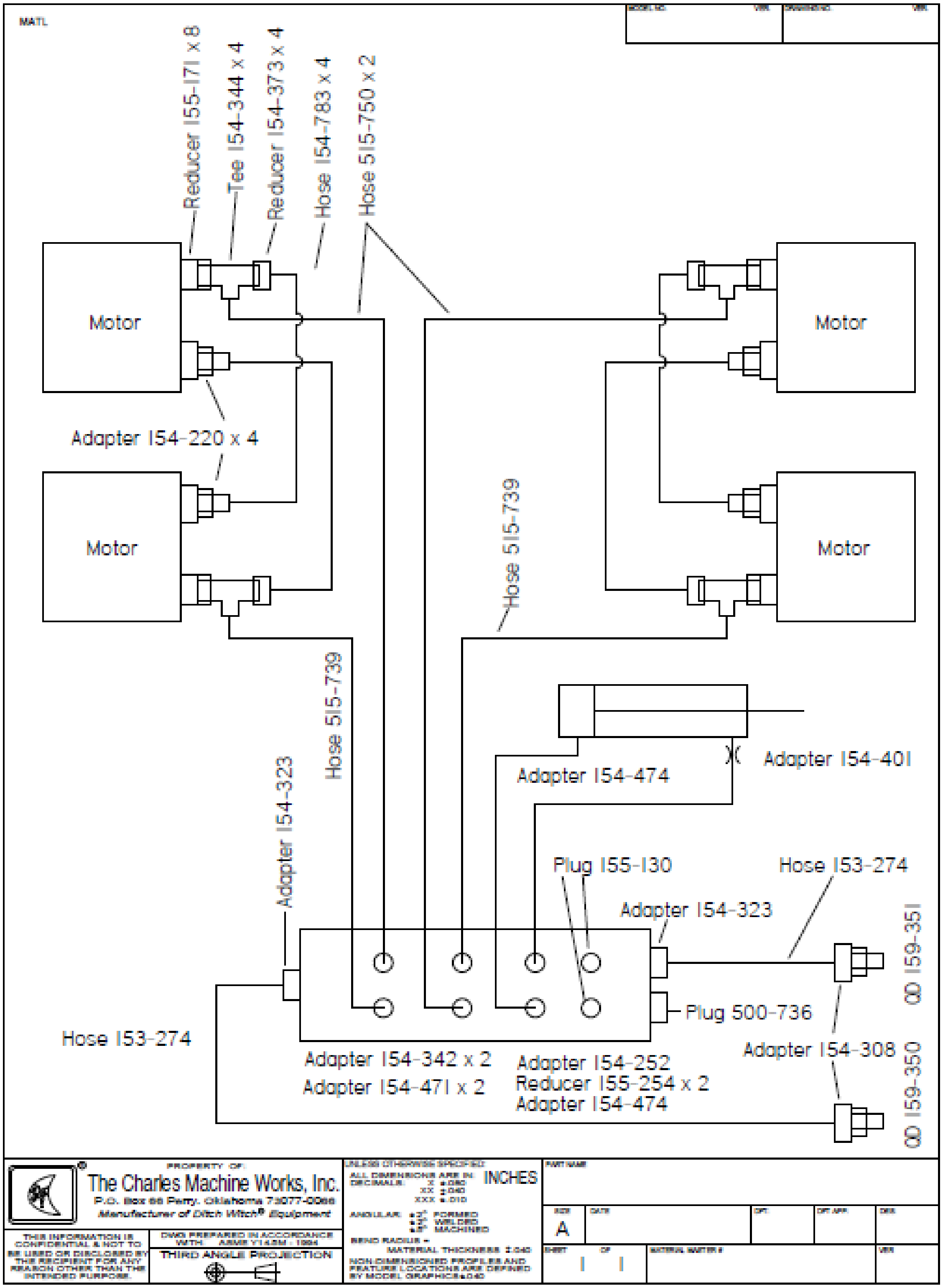
The final design helped to reduce the force needed by a single motor to feed the pipe through the system due to the die sets being split. Without the split the push motors would have to apply all the force to get the pipe through the system. Once the pipe reaches the last set of hydraulic motors, it will be easier to move the pipe through the system. This reduces the power requirements by half for each push motor at the front. Each hydraulic motor will get two gallons per minute at 2000 psi for a speed of 26 rpm and a torque of 2800 inch pounds. The motors will have a 1:6 gear ratio to obtain the needed speed and torque required. Overall, each push roller will spin at 4 rpm (10 feet per minute to the pipe) and apply 17,000 inch pounds of torque. In order to get the speed down to 4 rpm we consequently acquired more torque than actually needed. The chain size was determined using a roller chain selection table as seen below. The push rollers will be lined with a rubber adhesive to help with traction between the roller and the pipe. During testing we will be able to find a coefficient of friction for the pipe and make suggestion on the best friction material.

3. Roller Chain Provisional Selection Tables



The final design was split at the dies so that the push motors are always assisted by the second set of hydraulic motors. This allows the push motors to have a smaller torque and that reduces the cost. However, the final design will have an added cost from the hydraulic cylinder needed to split the housing. This design is feasible and backed up by engineering. Therefore, the final design was chosen because of the reduced force and power requirements.

The entire machine will be powered by hydraulics. CMW suggested hydraulics because most all their machines in the manufacturing plant are ran off hydraulics. The hydraulics also allows us to incorporate all moving parts into the same power system. This will eliminate cluster and reduce the complexity of the machine as a whole. The hydraulic schematic can be seen below.


MATL
Reducer 155-171 x 8
Tee 154-344 x 4
Reducer 154-373 x 4
Hose 154-783 x 4
Hose 515-750 x 2
Motor
Motor
Motor
Motor
Adapter 154-220 x 4
Hose 515-739
Hose 515-739
Adapter 154-323
Adapter 154-474
Adapter 154-401
Plug 155-130
Hose 153-274
Adapter 154-323
Plug 500-736
Adapter 154-308
OD 159-351
OD 159-350
Hose 153-274
Adapter 154-342 x 2
Adapter 154-471 x 2
Adapter 154-252
Reducer 155-254 x 2
Adapter 154-474
PROPERTY OF:
The Charles Machine Works, Inc.
Manufacturer of Ditch Witch® Equipment
THIRD ANGLE PROJECTION
INCHES
A

d. Prototype Testing

The prototype was built to help DTE and CMW learn more about the feasibility of bent pipe and how it can be used in geothermal wells. The more data that DTE could collect through testing would ultimately help CMW design a final product. Testing started with the Instron machine to get an initial idea of the required forces. Testing on the Instron helped reveal the material properties and behavior which ultimately lead to the design. In between the initial testing and construction, different banding techniques were tested. After that, the machine had completed construction so the testing of the machine's functionality began. First, the push rollers were tested to see if they would be able to move the pipe through the system as intended. The initial testing of the completed prototype failed so various tests on the rollers, dies, and pipe took place to gather data to improve the design. All testing is discussed below in its designated section.

i. Instron testing

Instron testing was necessary to get initial force requirements for design. This was a great starting point to determine if it was possible to bend the pipe. As discussed above in preliminary testing, the forces peaked around 500 pounds. This was a rough number due to the fact that the tested pieces were only 3 inch long pieces of pipe. A longer piece of pipe will try to resist bending even more. Therefore, higher numbers are estimated to determine the required linear force to move the pipe.

ii. Banding

Banding techniques were a side note to the overall project. Due to the fact that the bands needed to break down hole, it was decided metal bands would not work.

Three different ideas were tested. These ideas were large zip ties, baling twine, and duct tape.

Multiple sizes of zip ties were ordered ranging from a tensile strength of 50 pounds all the way up to 250 pounds. To test this idea, a 3 inch piece of pipe was bent into the U shape using a vice. Once the desired shape was reached, a 50 pound zip tie was placed around it and the pipe was released. The 50 pound zip tie broke instantly so we tried the 75 pound zip tie and got the same results. Next we tried the 125 pound zip tie. It held together briefly before breaking. It was decided to use a larger piece of pipe to get a more accurate situation, so a 3 foot piece of pipe was bent with a press brake. Next, the largest zip tie (250 pounds) was placed 12 inches apart and it instantly failed. After multiple tests, it was found that 3 inch spacing, as shown below, was the greatest spacing allowed for the zip ties to hold. Due to spacing requirements, this idea was not feasible for production.

Next, baling twine that has a tensile strength of 100 pounds was tested. It was decided it would be difficult to tie individual bands with the twine so it was wrapped around the pipe instead. A continuous, tight wrap was tested to begin with (figure 8). It did not fail, so spacing was increased to test the maximum spacing allowed. This is shown in the figure 9. The testing showed that failure would occur around 2 inches of space between wraps. The twine and wrap were very successful and would be DTE's top recommendation. The down fall would be designing a machine that could wrap the pipe as it came out of the system.

Figure 8

Figure 9

The third banding method that was tested was duct tape. The duct tape did not break through testing, but did stretch out within a few hours allowing for the pipe to unfold. Duct tape was a complete failure.

iii. **Friction**

The initial design of the push rollers on the pipe called for custom made rollers. These push rollers would be injection molded with a polyurethane material that would get a minimal coefficient of friction of 0.8 . This would guarantee that the linear force required to push the pipe through the system could be overcome. Unfortunately, the cost turned out to be too much for the custom push rollers so the design had to be rethought. Two types of materials were used to gain friction for the push rollers. In the first attempt, rubber strips were wrapped around the roller. These did not have near enough friction to move the pipe. Next, a rubber adhesive paint was used. Testing was done to determine what kind of linear force was acquired for each of these.

iv. **Linear force**

We set up winch system to test the actual force needed to move the pipe through the system. Using this we also tested the functionality of the dies and the force the push rollers could apply to the pipe. Using a winch, hydraulic cylinder, and a pressure gauge, we acquired data for each roller as the pipe moved through the system (see fig. 10 & 11 below). From this we could calculate the force being applied to the pipe. While pulling the pipe through the die system we found that each die added around 215 pounds of linear force to the pipe. Overall, it took 1500 pounds to pull the pipe through the system. Knowing this CMW can go back and redesign the drive system to work more efficiently.

We also tested the force the drive rollers could apply with the rubber paint on them. One drive system is capable of applying 1,000 pound of force to the pipe.

Theoretically, with 2 drive systems we should be able to move the pipe through the dies. However, we encountered a problem with the rubber paint wearing off quickly. We would suggest finding a more permanent solution than the paint, like a rubber coating or wheel.

The last thing we tested was the functionality of the dies to achieve the "U" shape that we desired. Once the pipe was pulled through the dies we could see that we had achieved the "U" shape as seen in figure 12.

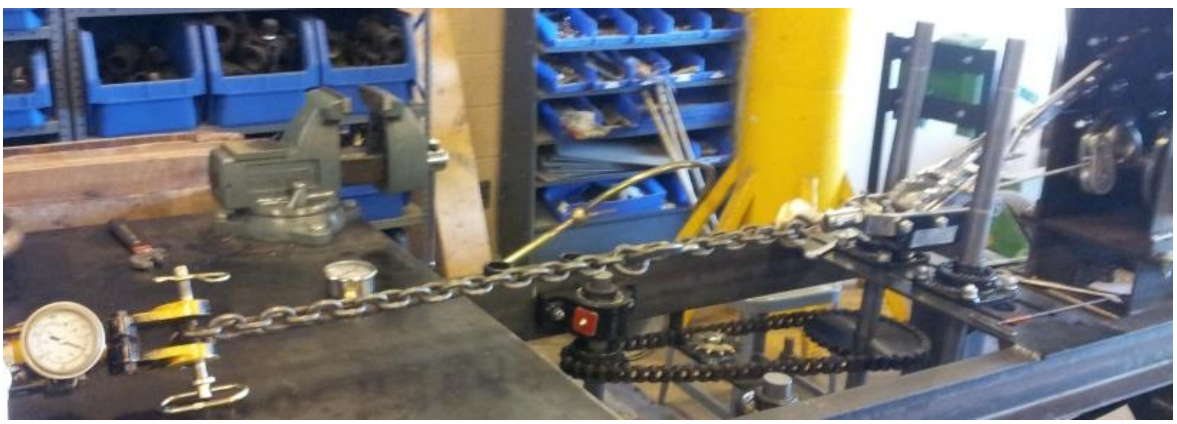


Figure 10

Figure 11

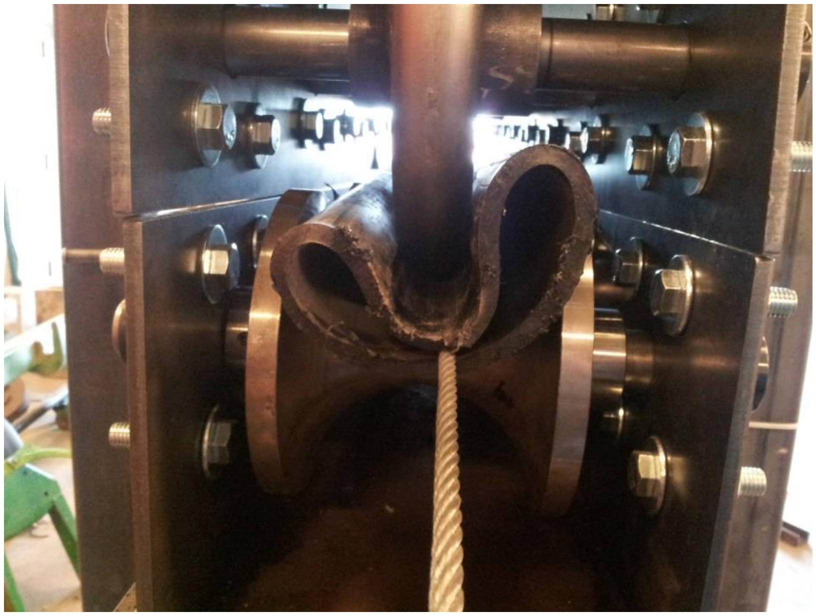


Figure 12

e. Recommendations

DTE's recommendation for this project would be a reevaluation of the methods for moving the pipe through the system. We suggest looking into other methods for moving the pipe while keeping the die set design as is. A major design change we would recommend is powering the dies so that they will help grab and move the pipe along. We would also recommend using the twine wrap for an adequate method of banding the pipe.

ENVIRONMENTAL, SOCIETAL, AND GLOBAL IMPACTS

The environmental, societal, and global impacts at this point are hard to foresee. It could be expected that this project could have a positive effect on the environment and society because of its tie to the geothermal industry. Geothermal has a positive effect because it uses a renewable resource to heat and cool houses. The theory behind this idea would be to reduce grout and the number of wells needed per house. Ultimately the less grout and wells needed reduces the environmental impact. This design should also reduce the cost of geothermal installation so there would be a positive effect on society. Cheaper prices could mean more people will step away from conventional HVAC systems to the more environmentally friendly geothermal.

ACTUAL VS. PROPOSED BUDGET

Since the project at hand is a prototype that will be a continuation of a research and development project at CMW, there was no set budget. The main purpose of the project is to check the feasibility. If reducing the diameter of the pipe can result in a tighter fit down hole then less grout needs to be used. Less grout will allow this method to be superior to other designs and bring CMW into the geothermal market. However, a proposed budget was formed.

A table with a breakdown of the proposed cost for each part can be found in Appendix V. For the overall proposed cost, the following table shows the budget that was set forth for each individual option. The costs vary depending on the different designs and the different speeds that the machine could be ran at. Also, proposed in the budget for the faster speed was an automated bander that will not be used. This added about $5,000 to the cost to the faster speed.

Drive System	Design	Speed of System	Total Cost
Direct Drive	Split	Fast (25 fpm)	$20,707.79
		Slow (10 fpm)	$15,807.79
	Solid	Fast (25 fpm)	$20,557.79
		Slow (10 fpm)	$15,557.79
Gear Drive or Chain Driven	Split	Fast (25 fpm)	$20,937.79
		Slow (10 fpm)	$15,037.79
	Solid	Fast (25 fpm)	$18,887.79
		Slow (10 fpm)	$14,187.79

The budget actually came up less than what was proposed. A breakdown of the cost of each part can be found in the appendix, but the following table shows what was actually spent.

Actual Budget						
Part	Description	Quantity	Type	Size	Cost	Total
Motors	Drive System	4	Hydraulic	11.9 in^3 2000 series	160.79	$643.16
Cylinders	Moves Die Set	1	Tie Rod Ends	2"x1" 2000 psi	$93.36	$93.36
Bearings	Die Set	40	4 bolt flange	1"	$24.23	$969.20
	Drive	8	Pillow Block	1.25"	$26.15	$209.20
Fasteners	Nuts/Bolts	1200	Grade 2	3/8", 1/2"	$94.05	$94.05
Control Valve	Hydraulic Control Valve	1	Hydraulic	4 valve	$431.32	$431.32
Clevis Pin	1.25"	1	Standard Steel	4"	$15.33	$15.33
	1.5"	1	Standard Steel	6"	$25.70	$25.70
Sprockets	10 tooth	4	Keyed	#60	$6.40	$25.60
	15 tooth	4	Keyed	#60	$9.10	$36.40
	30 tooth	8	Keyed	#60	$25.95	$207.60
	Idler	8	Keyed	#60	$7.49	$59.92
Chain	Roller Chain	4	Standard Chain	65 Pitch	$14.08	$56.32
	Roller Chain	4	Standard Chain	70 Pitch	$14.05	$56.20
	Connector Link	8	Standard Chain	#60	$0.95	$7.60
Machined Parts	Dies, Saddles, Die Box	See Machined Parts Table For Breakdown				$2,612.00
Steel	C-channel, Tubing, Angle	See Metals Table For Breakdown				$586.84
Hydraulics	Hose and Fittings	See Hydraulics Table For Breakdown				$288.02
					Total	$6,417.82

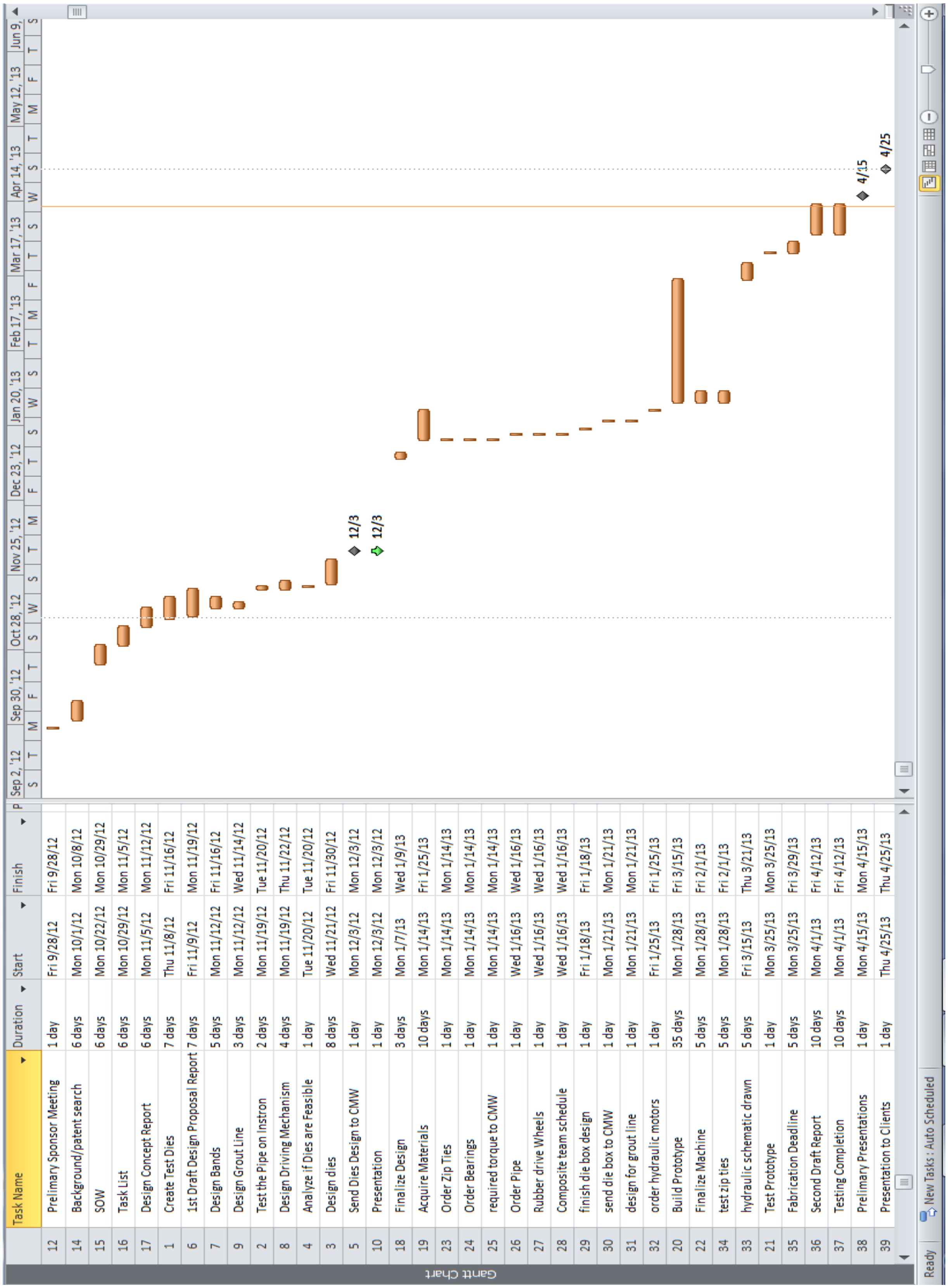
This is significantly less than what was proposed. The table below shows some of the costs that were not used and some part costs were severely over estimated. This accounts for the difference between the actual and proposed budgets.

Comparison of Budgets			
Part	**Proposed**	**Actual**	**Difference**
Motors	2600	643.16	-$1,956.84
Cylinders	550	93.36	-$456.64
Bearings	2116	1178.4	-$937.60
Fasteners	500	94.05	-$405.95
Control Valve	750	431.32	-$318.68
Sprockets	90	329.52	$239.52
Chain	40	120.12	$80.12
Materials	2592	3198.84	$607.05
Hydraulics	1500	288.02	-$1,211.98
Other	4300	41.03	-$4,258.97
Total	**15037.79**	**6417.82**	**-$8,619.97**

APPENDIX

I. Gantt Chart
II. Work Breakdown Structure
III. Patents
IV. Calculations
V. Proposed Budget
VI. Actual Budget

APPENDIX I-Gantt Chart



	Task Name	Duration	Start	Finish
12	Prelimary Sponsor Meeting	1 day	Fri 9/28/12	Fri 9/28/12
14	Background/patent search	6 days	Mon 10/1/12	Mon 10/8/12
15	SOW	6 days	Mon 10/22/12	Mon 10/29/12
16	Task List	6 days	Mon 10/29/12	Mon 11/5/12
17	Design Concept Report	6 days	Mon 11/5/12	Mon 11/12/12
1	Create Test Dies	7 days	Thu 11/8/12	Fri 11/16/12
6	1st Draft Design Proposal Report	7 days	Fri 11/9/12	Mon 11/19/12
7	Design Bands	5 days	Mon 11/12/12	Fri 11/16/12
9	Design Grout Line	3 days	Mon 11/12/12	Wed 11/14/12
2	Test the Pipe on Instron	2 days	Mon 11/19/12	Tue 11/20/12
8	Design Driving Mechanism	4 days	Mon 11/19/12	Thu 11/22/12
4	Analyze if Dies are Feasible	1 day	Tue 11/20/12	Tue 11/20/12
3	Design dies	8 days	Wed 11/21/12	Fri 11/30/12
5	Send Dies Design to CMW	1 day	Mon 12/3/12	Mon 12/3/12
10	Presentation	1 day	Mon 12/3/12	Mon 12/3/12
18	Finalize Design	3 days	Mon 1/7/13	Wed 1/9/13
19	Acquire Materials	10 days	Mon 1/14/13	Fri 1/25/13
23	Order Zip Ties	1 day	Mon 1/14/13	Mon 1/14/13
24	Order Bearings	1 day	Mon 1/14/13	Mon 1/14/13
25	required torque to CMW	1 day	Mon 1/14/13	Mon 1/14/13
26	Order Pipe	1 day	Wed 1/16/13	Wed 1/16/13
27	Rubber drive Wheels	1 day	Wed 1/16/13	Wed 1/16/13
28	Composite team schedule	1 day	Wed 1/16/13	Wed 1/16/13
29	finish die box design	1 day	Fri 1/18/13	Fri 1/18/13
30	send die box to CMW	1 day	Mon 1/21/13	Mon 1/21/13
31	design for grout line	1 day	Mon 1/21/13	Mon 1/21/13
32	order hydraulic motors	1 day	Fri 1/25/13	Fri 1/25/13
20	Build Prototype	35 days	Mon 1/28/13	Fri 3/15/13
22	Finalize Machine	5 days	Mon 1/28/13	Fri 2/1/13
34	test zip ties	5 days	Mon 1/28/13	Fri 2/1/13
33	hydraulic schematic drawn	5 days	Fri 3/15/13	Thu 3/21/13
21	Test Prototype	1 day	Mon 3/25/13	Mon 3/25/13
35	Fabrication Deadline	5 days	Mon 3/25/13	Fri 3/29/13
36	Second Draft Report	10 days	Mon 4/1/13	Fri 4/12/13
37	Testing Completion	10 days	Mon 4/1/13	Fri 4/12/13
38	Prelimary Presentations	1 day	Mon 4/15/13	Mon 4/15/13
39	Presentation to Clients	1 day	Thu 4/25/13	Thu 4/25/13

APPENDIX II-Work Breakdown Structure

WBS	Task	Element	Definition
1	**0**	**Geothermal Pipe Bender**	**All work to develop a machine that will bend Geothermal pipe into a U-shaped cross section**
2	**0**	**Initiation**	**Work that starts the project**
	1	Sponsor Assignments	Instructor assigns the project and sponsors
	2	Team Name and Logo development	Team members are to develop the team name and logo for their group and deliver to instructor
	3	Preliminary meeting with Sponsor	Team meets with a representative of Charles Machine Works, Inc. to understand the problem and requirements for the final product
3	**0**	**Planning**	**Work that plans the process of design**
	1	Team statement development	The development of the problem statement for the problem set forth by Ditch Witch
	2	Gather Background	Team gathers background on the problem and conducts research on potential solutions. This also includes patent searches.
	3	Statement of Work	The development of the a narrow definition of the problem and a definition of what the final machine will consist of
	4	Task list	Development of a list of deliverables
	5	Business Plan	Agriculture Economic Team develops a financial analysis and business plan for the project
	6	Project Website	Develop a website that displays the project in its entirety
	7	Design Concept Report	Development of preliminary design concepts for the machine
	8	Testing	Test the HDPE pipe to make sure that the preliminary design concept if feasible and adjust design if needed
	9	Design Proposal Report	Deliver a compiled analysis that includes SOW, Task List, Business Plan, and Design Concepts that will be presented to the sponsor
	10	Design Proposal Oral	Team will present an oral presentation

		Presentation	to sponsor, instructors, and department head that will show the proposal of the project
4	**0**	**Execution**	**The actual execution of the project**
	1	Finalization of design proposal	Team works with sponsor to make final adjustments to proposed machine so assembly can begin
	2	Acquire Materials	Gather all materials to build machine. This includes hardware and facility. Ditch Witch has offered to help in the building of things such as the dies that would be difficult to do in the BAE lab
	3	Development of Prototype	Involves the actual development of the geothermal pipe bender
	4	Testing	Evaluate the prototype and test for defects
	5	Final Prototype Development	Finalization of prototype so it can be delivered to client
	6	Final Report	Deliver final report that includes revised design proposal report and final design of machine
	7	Demonstration	Final prototype is demonstrated and presented to sponsor, instructors, peers, and department head

APPENDIX III-Patents

BEFORE 1992: These patents are out of date but are relevant to our project and a good source of ideas.

The following patents are either in relation or a continuation of each other. They describe a method for bending circular shaped cross-sectional thermoplastic pipe liner into U-shaped cross-sectional liner temporarily, to then be placed into the pipe and reformed into its original circular cross-sectional shape. The pipe liner is deformed through a process involving rollers and heat. After the liner is placed inside the desired pipe it goes through a pressure and heating process. The following figures illustrate the process for the patents below.

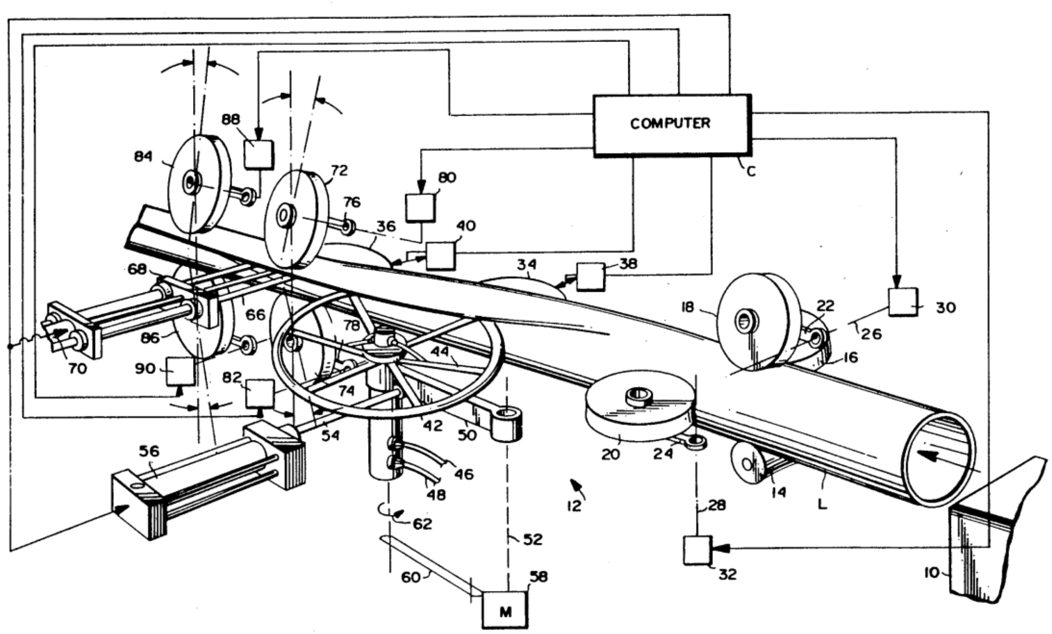


FIG. 1

Patent number: 4986951 (Pipe Liner Process)

Filing date: Apr 29, 1988

Issue date: Jan 22, 1991

Patent number: 4863365 (Method and apparatus for deforming reformable tubular pipe liners)

Filing date: Jul 27, 1987

Issue date: Sep 5, 1989

Patent number: 4998871 (Apparatus for deforming plastic tubing for lining pipe)

Filing date: Jan 19, 1989

Issue date: Mar 12, 1991

Patent number: 5091137 (Pipe lining process)

Filing date: Nov 21, 1990

Issue date: Feb 25, 1992

AFTER 1992: These patents are still to date and need to be taken into account when designing.

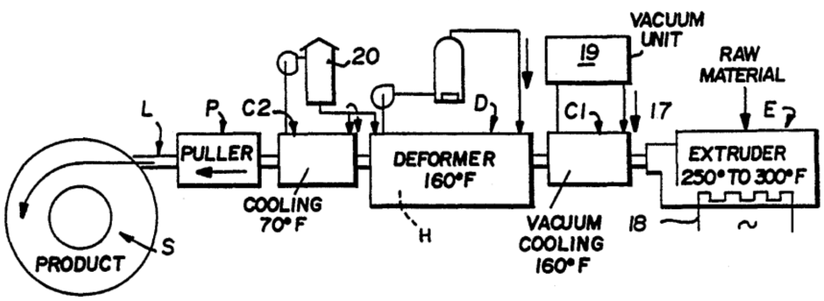
Patent number: 5342570 (Method and apparatus for deforming reformable tubular pipe liners)

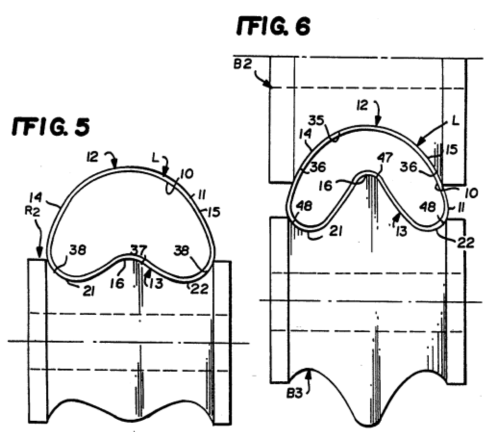
Filing date: Aug 9, 1990

Issue date: Aug 30, 1994

This patent is for a process to deform pipe liners to line new and old pipe into a U-shape to be placed and then unfolded within the pipe that is needed to be lined, so the fit is tight.

Our project shares similar ideas with the use of rollers, although the main difference with this patent and our project is the use of heat and the use of unusually shaped rollers. The pipe is continuously extruded and heated then cooled during the process of deformation using rollers and guidance rollers. The following figures show the overall process and the guidance rollers.



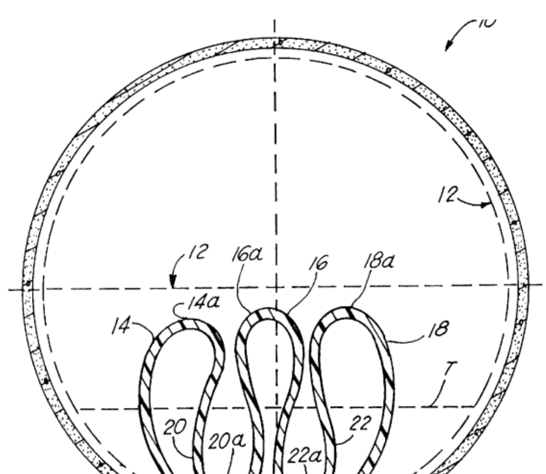


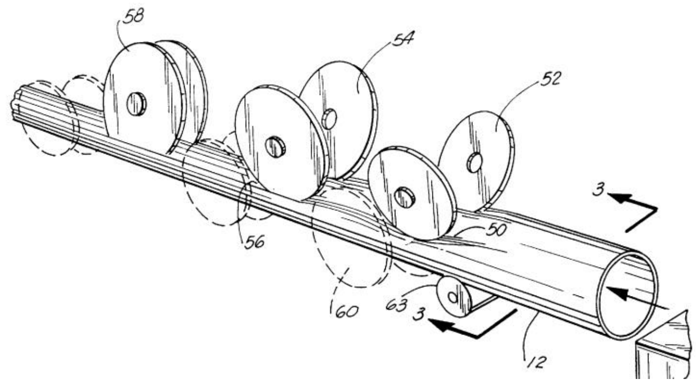
Patent number: 5861116 (Process for installing a pipe liner)

Filing date: Sep 17, 1996

Issue date: Jan 19, 1999

This patent is for a process to install a liner into a pipe of same diameter. With this process, a cylindrical pipe of high density polyethylene is formed into a smaller W-shaped cross-section to then insert into a pipe for lining. The liner is deformed into a W-shape cross section so external assistance or bindings does not have to be utilized to keep it into that shape. To deform, the cylindrical pipe is inserted into a series of three axially spaced rollers under a temperature of about 70˚C. Once the pipe is deformed, it is inserted into the pipe that is to be lined. Steam is flowed through and applied to the W-shaped pipe to deform back to the original cylindrical shape. The following figures illustrate the W-shaped cross-sectional area and the rollers in the deforming process:



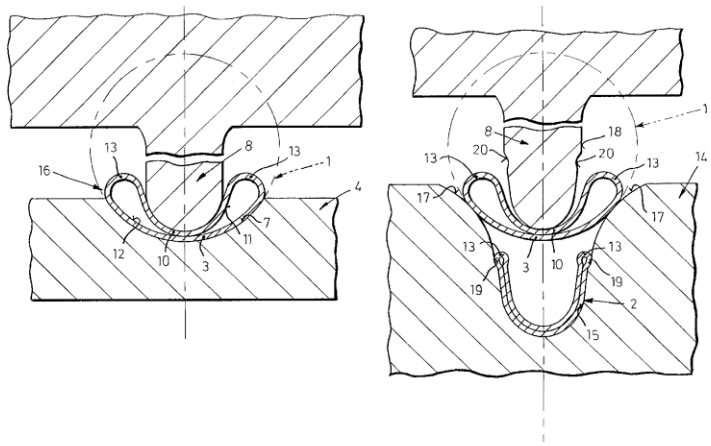


Patent number: 6119501 (Method of deforming an initial pipe having a circular cross-section into a U-shaped section and device for carrying out the method)

Filing date: May 7, 1999

Issue date: Sep 19, 2000

The relevance of this patent is it involves a process for making a circular shaped cross-sectional into a U-shaped cross-section. This pipe deformation process involves circular shaped cross-sectional being placed into dies to make a U-shaped cross-sectional. This patent does not mention what this pipe is used for and does not describe a process of reopening into its original circular cross-section. The following figures illustrate how the dies bend the pipe.



These patents are relevant because they involve forming circular pipe into a U-shaped cross section. This shape reduces the overall outer diameter for inserting the pipe into another pipe. This is done for the repair of underground sewer, water, gas and similar grounds. They involve heating the pipe to allow for deforming the pipe to proper shape. The forming is done through a multitude of rollers and dies. After the shape is obtained they are cooled back to help the pipe maintain the U-shape.

APPENDIX IV- Calculations

Force Required To Move Pipe Through System

Force Required to Move Pipe	Equation	Values	Units
Coefficient of Friction (c_f)	User Input	0.0024	
Angle of Force (θ)	User Input	33.56	degrees
Percent Change	User Input	84.56%	percent
Max Force	User Input	800	lb_f

Inputs for Design I

	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
Actual forces for each roller	1	321	lb_f	$f_{required} = 2 * f * c_f + f * \sin(\theta)$	178.993	lb_f
	2	505	lb_f		281.593	lb_f
	3	460	lb_f		256.501	lb_f
	4	421	lb_f		234.754	lb_f
	5	423	lb_f		235.869	lb_f
	6	427	lb_f		238.099	lb_f
	7	442	lb_f		246.464	lb_f
	8	455	lb_f		253.713	lb_f
	1-8	3454	lb_f		1925.985	**lb_f**

Design I Fast

	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
Actual forces for each roller	1	271	lb_f	$f_{required} = 2 * f * c_f + f * \sin(\theta)$	151	lb_f
	2	427	lb_f		238	lb_f
	3	389	lb_f		217	lb_f
	4	356	lb_f		199	lb_f
	5	358	lb_f		199	lb_f
	6	361	lb_f		201	lb_f
	7	374	lb_f		208	lb_f
	8	385	lb_f		215	lb_f
					1629	**Total**

Design I Slow

Force Required to Move Pipe	Equation	Values	Units
Coefficient of Friction (c_f)	User Input	0.0024	
Angle of Force (θ)	User Input	29	degrees
Percent Change	User Input	84.56%	percent
Max Force	User Input	800	lb_f

Inputs for Design II

	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
Actual forces for each roller	1	321	lb_f	$f_{required} = 2 * f * c_f + f * \sin(\theta)$	157.165	lb_f
	2	505	lb_f		247.253	lb_f
	3	460	lb_f		225.220	lb_f
	4	421	lb_f		206.126	lb_f
	5	423	lb_f		207.105	lb_f
	6	427	lb_f		209.063	lb_f
	7	442	lb_f		216.407	lb_f
	8	455	lb_f		222.772	lb_f
	1-8	3454	lb_f		1691.112	**lb_f**

Design II Fast

	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
Actual forces for each roller	1	271	lb_f	$f_{required} = 2 * f * c_f + f * \sin(\theta)$	133	lb_f
	2	427	lb_f		209	lb_f
	3	389	lb_f		190	lb_f
	4	356	lb_f		174	lb_f
	5	358	lb_f		175	lb_f
	6	361	lb_f		177	lb_f
	7	374	lb_f		183	lb_f
	8	385	lb_f		188	lb_f
					1430	**Total**

Design II Slow

Force required to move pipe through system					
Design	**Speed of system**	**Actual Force**		**Force with 1.5 Safety Factor**	
Split Design	Fast (25 fpm)	1691	in*lb_f	**2537**	in*lb_f
	Slow (10 fpm)	1430	in*lb_f	**2145**	in*lb_f
Solid Design	Fast (25 fpm)	1926	in*lb_f	**2889**	in*lb_f
	Slow (10 fpm)	1629	in*lb_f	**2443**	in*lb_f

Torque Required By Drive Motor

	Torque Required for Drive Motors	Equation	Values	Units
Solid Design	Diameter of Roller	User Input	1.5	in
	Coefficient of Friction [between drive roller and pipe] (c_f)	User Input	0.5	
	Angle of Force between drive roller and pipe (θ)	User Input	1	degrees
	Total force for equal max force on all rollers	From Force on Rollers Sheet	3569	lb_f
	Total force for actual forces for each roller	From Force on Rollers Sheet	1926	lb_f
	Total force for % of actual forces for each roller	From Force on Rollers Sheet	1629	lb_f
	Max Force	From Force on Rollers Sheet	800	lb_f
	Percent Change	From Force on Rollers Sheet	84.56%	Percent
	Normal Force exerted by roller (Max)	$f_n = \frac{f_{roller}}{\mu + \sin\theta}$	2011	lb_f
	Normal Force exerted by roller (Actual)		1085	lb_f
	Normal Force exerted by roller (% Actual)		918	lb_f
	Torque of motor to produce force required (Max)	$\tau = f_n * d/2$	**1508**	**in*lb_f**
	Torque of motor to produce force required (Fast)		**814**	**in*lb_f**
	Torque of motor to produce force required (Slow)		**688**	**in*lb_f**

Design I Fast and Slow

	Torque Required for Drive Motors	Equation	Values	Units
Solid Design	Diameter of Roller	User Input	1.5	in
	Coefficient of Friction [between drive roller and pipe] (c_f)	User Input	0.5	
	Angle of Force between drive roller and pipe (θ)	User Input	1	degrees
	Total force for equal max force on all rollers	From Force on Rollers Sheet	3134	lb_f
	Total force for actual forces for each roller	From Force on Rollers Sheet	1691	lb_f
	Total force for % of actual forces for each roller	From Force on Rollers Sheet	1430	lb_f
	Max Force	From Force on Rollers Sheet	800	lb_f
	Percent Change	From Force on Rollers Sheet	84.56%	Percent
	Normal Force exerted by roller (Max)	$f_n = \frac{f_{roller}}{\mu + \sin\theta}$	1766	lb_f
	Normal Force exerted by roller (Fast)		953	lb_f
	Normal Force exerted by roller (Slow)		806	lb_f
	Torque of motor to produce force required (Max)	$\tau = f_n * d/2$	**1325**	**in*lb_f**
	Torque of motor to produce force required (Fast)		**715**	**in*lb_f**
	Torque of motor to produce force required (Slow)		**604**	**in*lb_f**

Design II Fast and Slow

Torque of motor to produce force required					
Design	**Speed of system**	**Actual Torque**		**Torque with 1.5 Safety Factor**	
Split Design	Fast (25 fpm)	715	in*lb_f	**1072**	in*lb_f
	Slow (10 fpm)	604	in*lb_f	**907**	in*lb_f
Solid Design	Fast (25 fpm)	814	in*lb_f	**1221**	in*lb_f
	Slow (10 fpm)	688	in*lb_f	**1033**	in*lb_f

Shaft Design

Shaft Design	Equation	Values	Units
Distance from force to center of bearing	User Input	4.25	in
Force on shaft	User Input	800	lb_f
Diameter of shaft	User Input	1.25	in
To calculate stress (σ) for shaft			
Moment (M)	(Force on shaft) * Distance	3400	in*lb_f
Centroid (C)	(Diameter of shaft)/2	0.625	in
Moment of Inertia (I)	$\frac{\pi * diameter^4}{64}$	0.120	in^4
Bending Stress (σ)	$\frac{M * c}{I}$	**17731.643**	**psi**

Bearing Analysis

Bearing Analysis	Equation	Values	Units
Diameter of Roller	User Input	1.5	in
Expected life of Bearing	User Input	10	years
Force on shaft	User Input	800	lb_f
Velocity (given)	(10ft/min)*12	120	in/min
Radius of Roller	d/2	0.75	in
Circumference of Roller	2*pi()*r	4.712	in
Number of Revolutions per minute	Velocity/Circumference	25.465	rev/min
Number of hours operated per year	(# hour/week)*(# weeks/year)	124800	min/year
Revolutions per Life	(rev/min)*(# min operation/year)*(# years/life)	31780059	rev/life
Force on bearings	(Force on shaft)/(# bearings supporting shaft)	400	lb_f
To calculate C_{10} for bearing			
X_D	(revolutions/life)/(revolutions rated life)	31.780	
R_D	$(\text{reliability})^{.5}$	0.995	
F_D	(Force on shaft)/(2 bearings)	400	lb_f
x_0	Look up value for bearing type	0.02	
θ	Look up value for bearing type	4.459	
a	Look up value for bearing type	3	
b	Look up value for bearing type	1.483	
a_f	Assume value	1.2	
C_{10}	$C_{10} = a_f * F_D \left[\frac{x_D}{x_0 + (\theta - x_0) * (1 - R_D)^{-1/b}} \right]^a$	**2894.981**	

APPENDIX V-Proposed Budget

						Direct Drive				Gear or Chain Drive			
						Not Split		Split		Not Split		Split	
		Quantity	Type	Size	Cost	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast
Motors	Drive	2	Hydraulic	Depends on design and speed	Depends on Motor Size	$2,600.00	$2,600.00	$1,700.00	$1,600.00	$1,100.00	$800.00	$800.00	$1,700.00
	Grout Arm Lift	1	Hydraulic			$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
	Spool	1	Hydraulic			$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Cylinders	Die Set	4	Tie Rod Ends	2"x1" 2000 psi	$50.00	-	-	$200.00	$200.00	-	-	$200.00	$200.00
	Spool Lift	2	Tie Rod Ends	To Be Determined	$75.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00
	Press Split	4	Tie Rod Ends	To Be Determined	$50.00	-	-	$200.00	$200.00	-	-	$200.00	$200.00
Bearings	Die Set	16	4 bolt flange	1"	$42.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00
	Spools	24	4 bolt flange	1.25"	$51.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00
	Grout Lift	2	pillow block	2"	$110.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00
Fasteners	Nuts/Bolts	Estimated Here, All To Be Determined			$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00
Bander	Machine				$5,000.00	-	$5,000.00	-	$5,000.00	-	$5,000.00	-	$5,000.00
Hydraulics	Pump				$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00
	Hose and Fittings				$1,500.00	$750.00	$750.00	$1,500.00	$1,500.00	$750.00	$750.00	$1,500.00	$1,500.00
	Reservoir				$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00
	Heat Exchanger				$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00
Control Switches					$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00
Safety					$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00
Electronics					$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Gears/Sprockets					$15.00	-	-	-	-	$90.00	$90.00	$90.00	$90.00
Chain					$40.00	-	-	-	-	$40.00	$40.00	$40.00	$40.00
					Total	**$12,966.00**	**$17,966.00**	**$13,216.00**	**$18,116.00**	**$11,596.00**	**$16,296.00**	**$12,446.00**	**$18,346.00**

Material	Size	Length Needed		Price Per Foot	Price
		In inches	In Feet		
Round Stalk	1 inch	72	6	$4.00	$24.00
	1.25 inch	132	11	$4.00	$44.00
	5 inch	16	1.3	$166.90	$222.53
	6 inch	40	3.3	$276.37	$921.23
Flat Plate	1/4 inch	33 sq. ft.	33	$12.86	$424.38
	1/2 inch	2 sq. ft.	2	$27.56	$55.12
	1 inch	3.5 sq. ft.	3.5	$78.51	$274.79
Welded Round Pipe	3 inch	36	3	$9.41	$28.23
	5 inch	12	1	$17.85	$17.85
Square Tubing	2x2x.25	36	3	$6.51	$19.53
	4x2x.25	30	2.5	$14.31	$35.78
	4x4	288	24	$17.96	$431.04
C-Channel	6x2x.25	40 foot	7.24	$10.66	$77.18
Angle Iron	.5x.5x.125	160	13.3	$1.21	$16.13
				Total	**$2,591.79**

APPENDIX VI- Actual Budget

Machined Parts from Ditch Witch

Machined Part Table			
Part	**Quantity**	**Cost**	**Total**
Guard Plates	2	$45.00	$90.00
Split Bottom Final	2	$45.00	$90.00
Split Top final	2	$45.00	$90.00
Hydraulic Motor Mount	2	$12.00	$24.00
Cross Bar Mount	2	$5.00	$10.00
Die Box Mount	2	$5.00	$10.00
Driveroller Mount	4	$20.00	$80.00
4.5" Square	4	$6.00	$24.00
1.25" dia 24" shaft	4	$8.00	$32.00
1.25" dia 20" shaft	4	$8.00	$32.00
Modified Press Wheel	10	$30.00	$300.00
Collar for Die	10	$33.00	$330.00
Adjustable Shaft	24	$5.00	$120.00
Adjustable Saddle	28	$45.00	$1,260.00
Brace	40	$3.00	$120.00
		Total	$2,612.00

Material Cost

Metal Table				
Material	**Size**	**Length (ft)**	**Cost/Foot**	**Total**
SquareTubing	3x3x1/4"	63	$6.20	$390.60
C Channel	4"x7.25x.321"x1.721"	28	$5.25	$147.00
Angle	1.5 x 1.5 x 3/16"	16	$1.12	$17.92
Angle	1/4"x1/4"x3/16"	24	$0.99	$23.76
Flat Strap	1/4" x 1-1/2"	7	$1.08	$7.56
			Total	$586.84

Cost of Hydraulics

Hydraulics Table				
Part Number	Description	Quantity	Cost	Total
154-220	Adapter	4	$ 0.65	$ 2.60
154-323	Adapter	2	$ 3.40	$ 6.80
154-474	Adapter	1	$ 6.35	$ 6.35
154-401	Adapter	1	$ 6.24	$ 6.24
154-342	Adapter	2	$ 1.75	$ 3.50
154-471	Adapter	2	$ 7.18	$ 14.36
154-252	Adapter	1	$ 1.48	$ 1.48
154-474	Adapter	1	$ 6.35	$ 6.35
154-308	Adapter	2	$ 1.61	$ 3.22
154-783	Hose	4	$ 10.86	$ 43.44
515-750	Hose	2	$ 29.47	$ 58.94
515-739	Hose	2	$ 8.97	$ 17.94
153-274	Hose	2	$ 23.85	$ 47.70
500-736	Plug	1	$ 3.17	$ 3.17
155-130	Plug	2	$ 0.18	$ 0.36
159-350	Quick Disconnect	1	$ 16.43	$ 16.43
159-351	Quick Disconnect	1	$ 9.00	$ 9.00
155-171	Reducer	8	$ 2.32	$ 18.56
154-373	Reducer	4	$ 1.71	$ 6.84
155-254	Reducer	2	$ 0.89	$ 1.78
154-344	Tee	4	$ 3.24	$ 12.96
			Total Cost	$ 288.02

Geothermal Pipe Bending

Marshall Oldham
Ryan Turner
Sarah Reiss

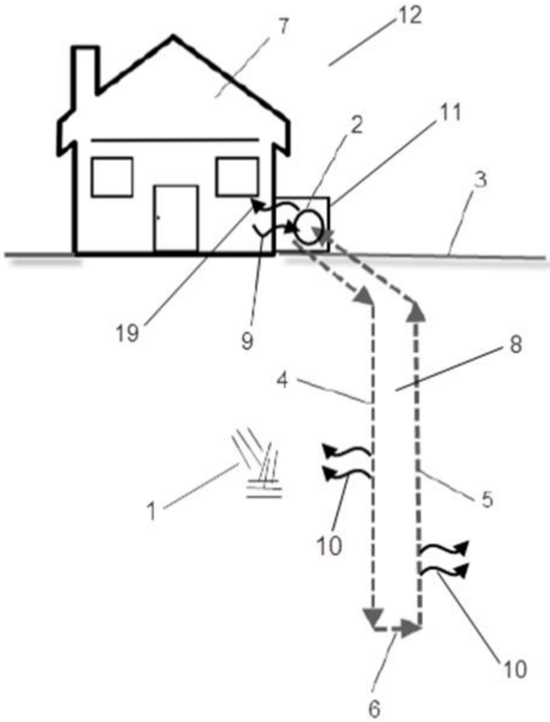
Prepared for Charles Machine Works, Inc.

Mission Statement

D.T.E. is dedicated to developing creative and innovative designs with our client’s satisfaction as our top priority. We are devoted to designing solutions that are cost efficient, reliable, and exceed all expectations. We promise to put our client’s needs first through the entirety of the project. Our innovation can make your engineering dreams come to life.

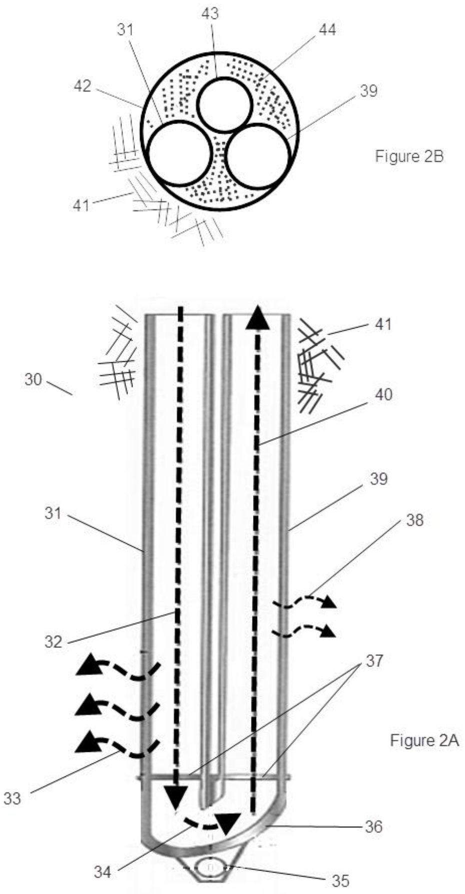
Problem Introduction

- Basic Ground Source Heat Pump System
- 250,000 systems installed each year worldwide
  - 50,000 in United States in 2010
- Geothermal energy falls under space heating and cooling, a 1.9 billion dollar industry.
- Growth rate expected to rise from 2.1% to 3.4% through 2016.



Problem Introduction

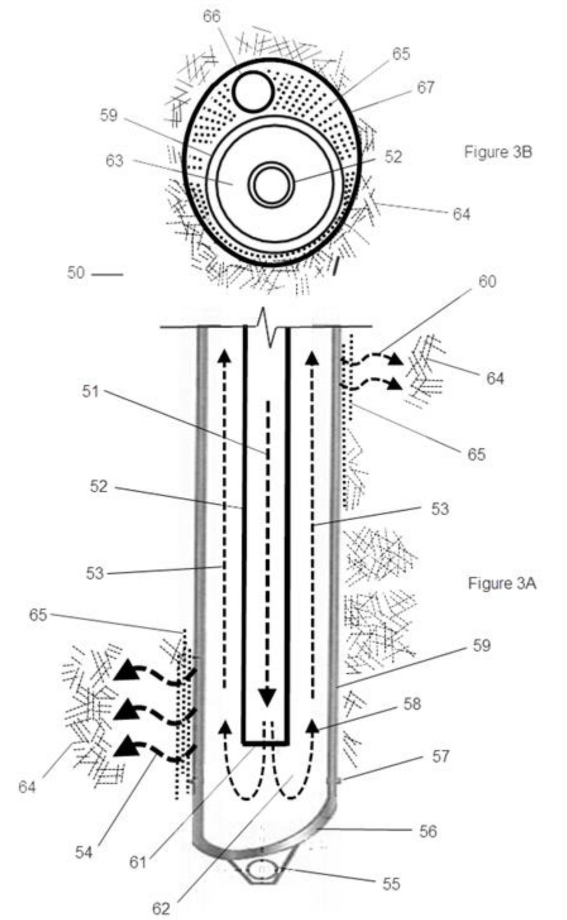
- Current Design
  - Single U-Loop
  - Packed with 240 gallons of grout
  - Grout is a poor heat conductor



“Technical Data: Geothermal Grout.” *CETCO*. Feb 2011. cetco.com/dpg. 29 Nov 2012.

Problem Introduction

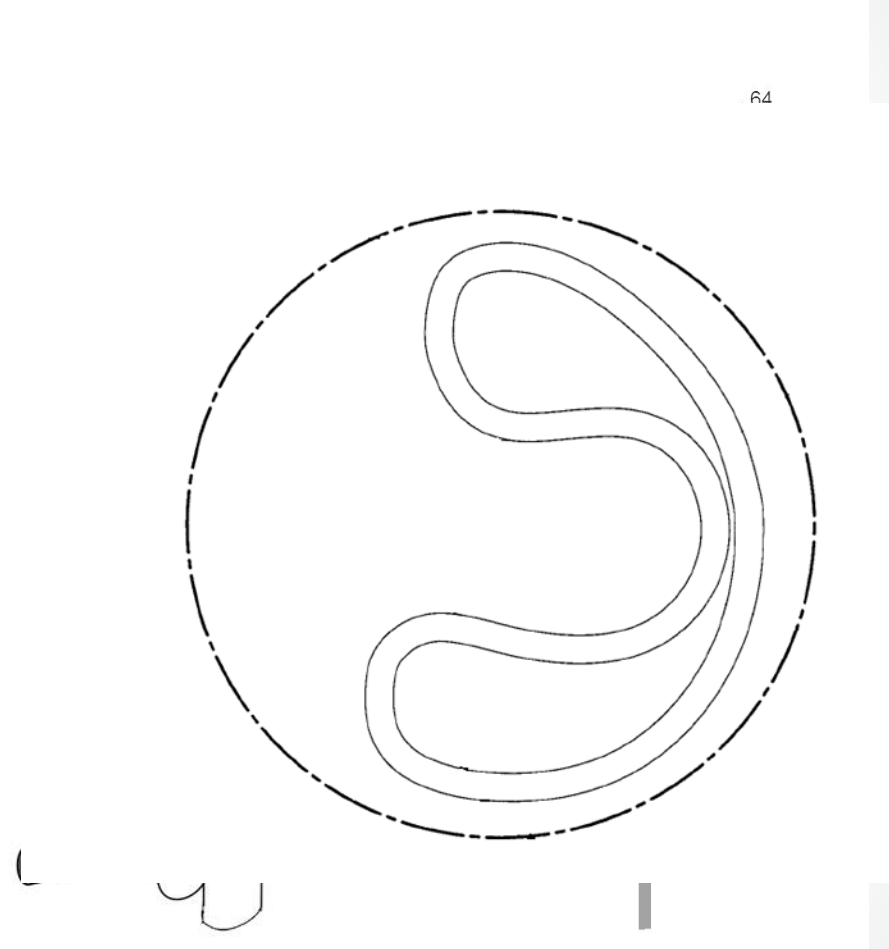
- Current Design
  - Single pipe with outer return
  - Packed with 200 gallons of Grout
  - 19% Reduction of grout from single U-Loop



"Technical Data: Geothermal Grout." *CETCO*. Feb 2011. cetco.com/dpg. 29 Nov 2012.

Problem Statement Introduction

- Reduce the outer diameter of the pipe
- Allows for smaller diameter drill holes (approximately 4.5 inch diameter hole)
- 88% reduction in grout from Single U-Loop
- Less grout=more efficient system



"Technical Data: Geothermal Grout." *CETCO*. Feb 2011. cetco.com/dpg. 29 Nov 2012.

Problem Statement

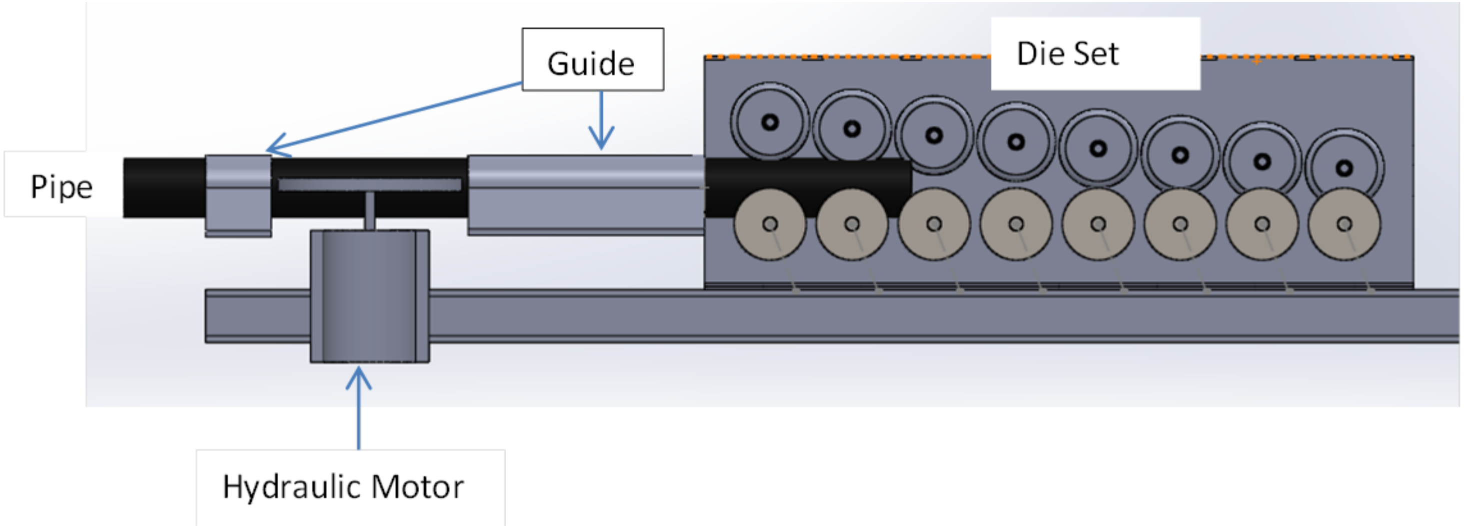
- Feasibility of Bending
  - 4.5 inch outer diameter high density polyethylene (HDPE) pipe in “U” shape

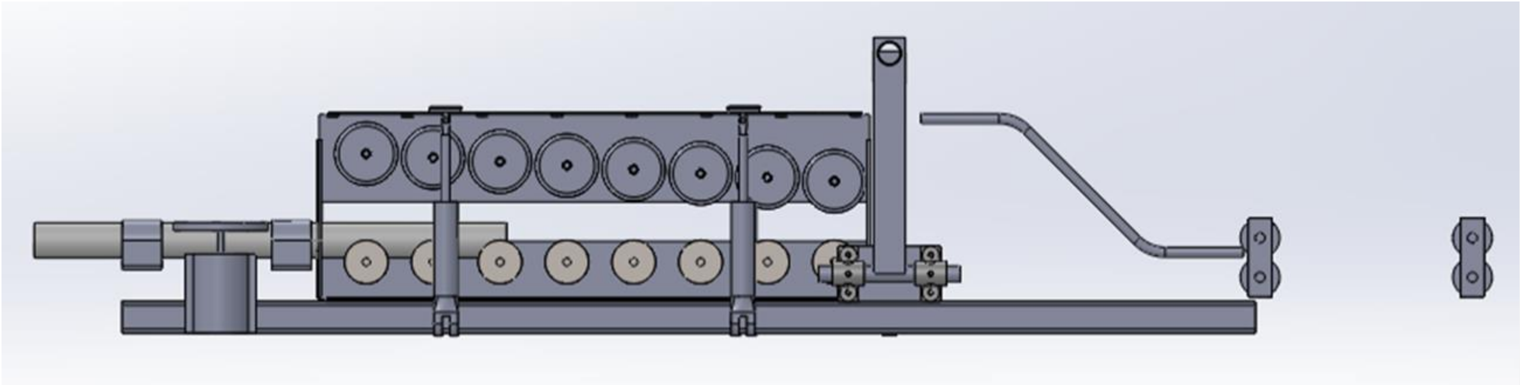
- Design and build a prototype machine that will:
  - Bend the HDPE pipe into “U” shape

Deliverables

- Geothermal Pipe Bending Prototype Machine
  - Fold HDPE SDR 21 pipe with a 4.5 inch outer diameter
  - Test data collected from prototype
  - Banding ideas

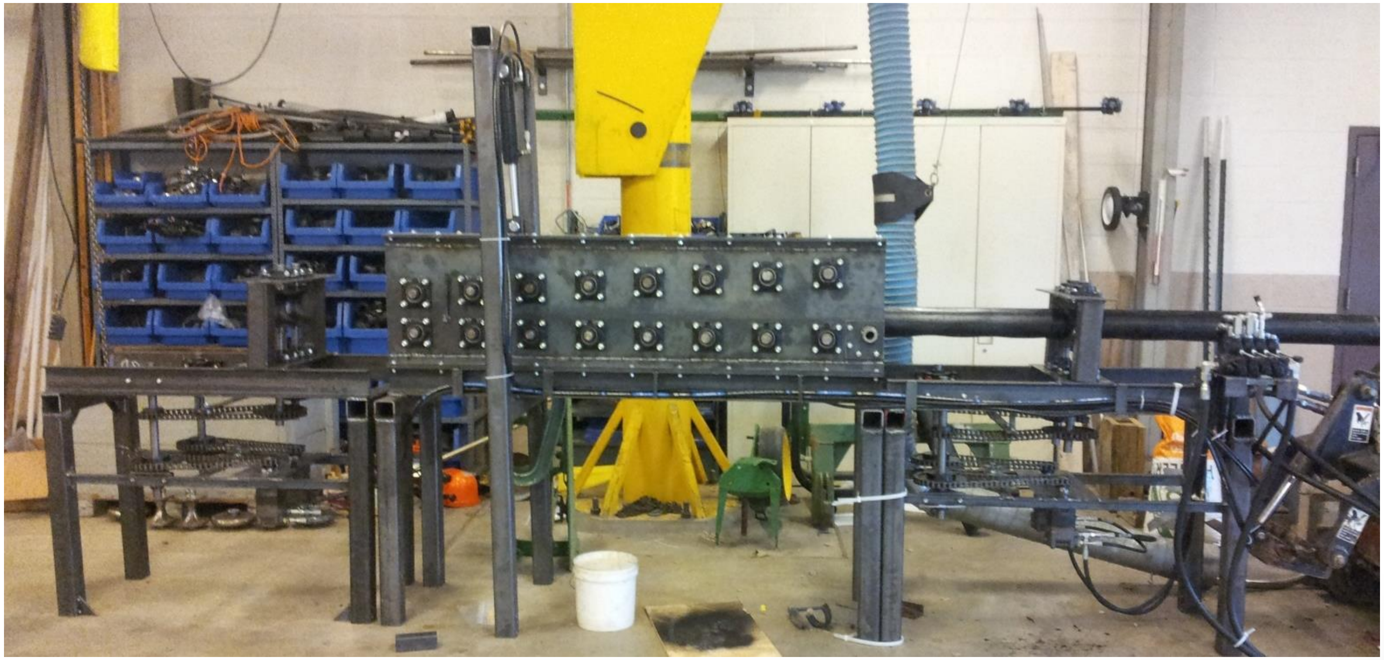
Old Designs





Design

- Hinged design
- Single cylinder to split the die sets
- Two drive systems (front and back)

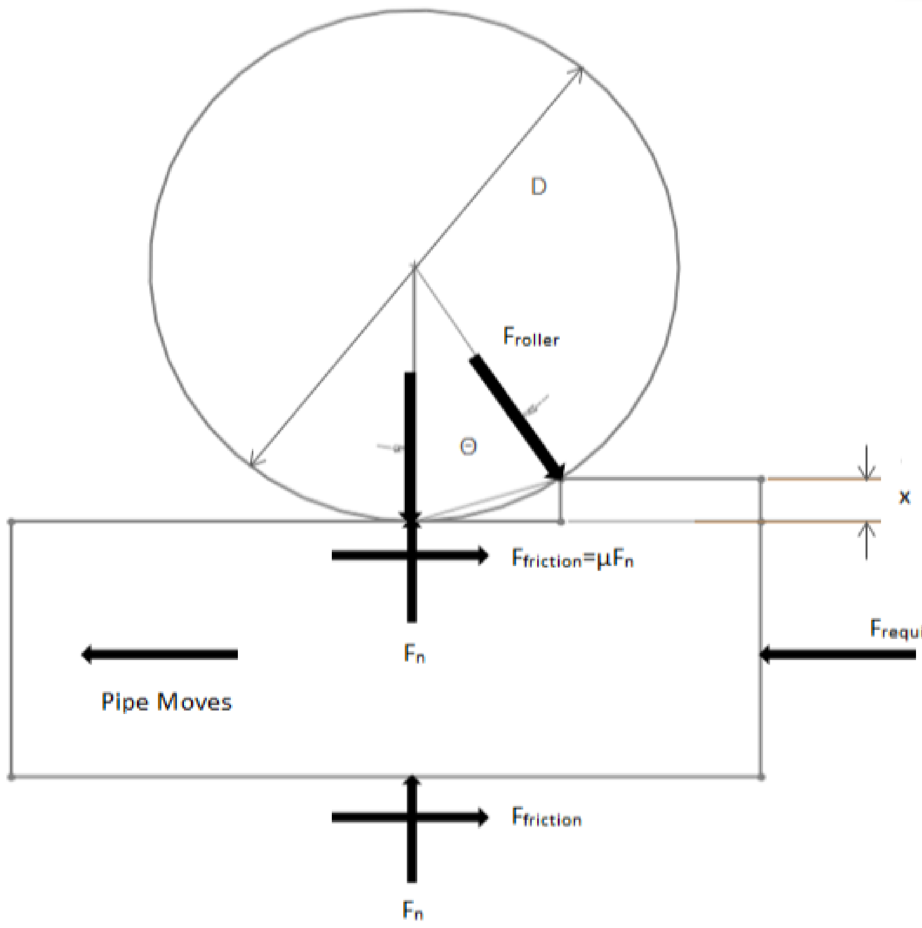


Dies

- ***Top Dies***
  - 8 dies
  - 1.25 inch wide
  - 8 inch diameter
  - Step down in increments of ½ inch for every 8.5 inches of linear travel
  - Reduces the height of the pipe by 3.75 inches (brings the top of the pipe in contact with the bottom)
- ***Bottom Dies***
  - A saddle for the 4.5 inch outer diameter pipe

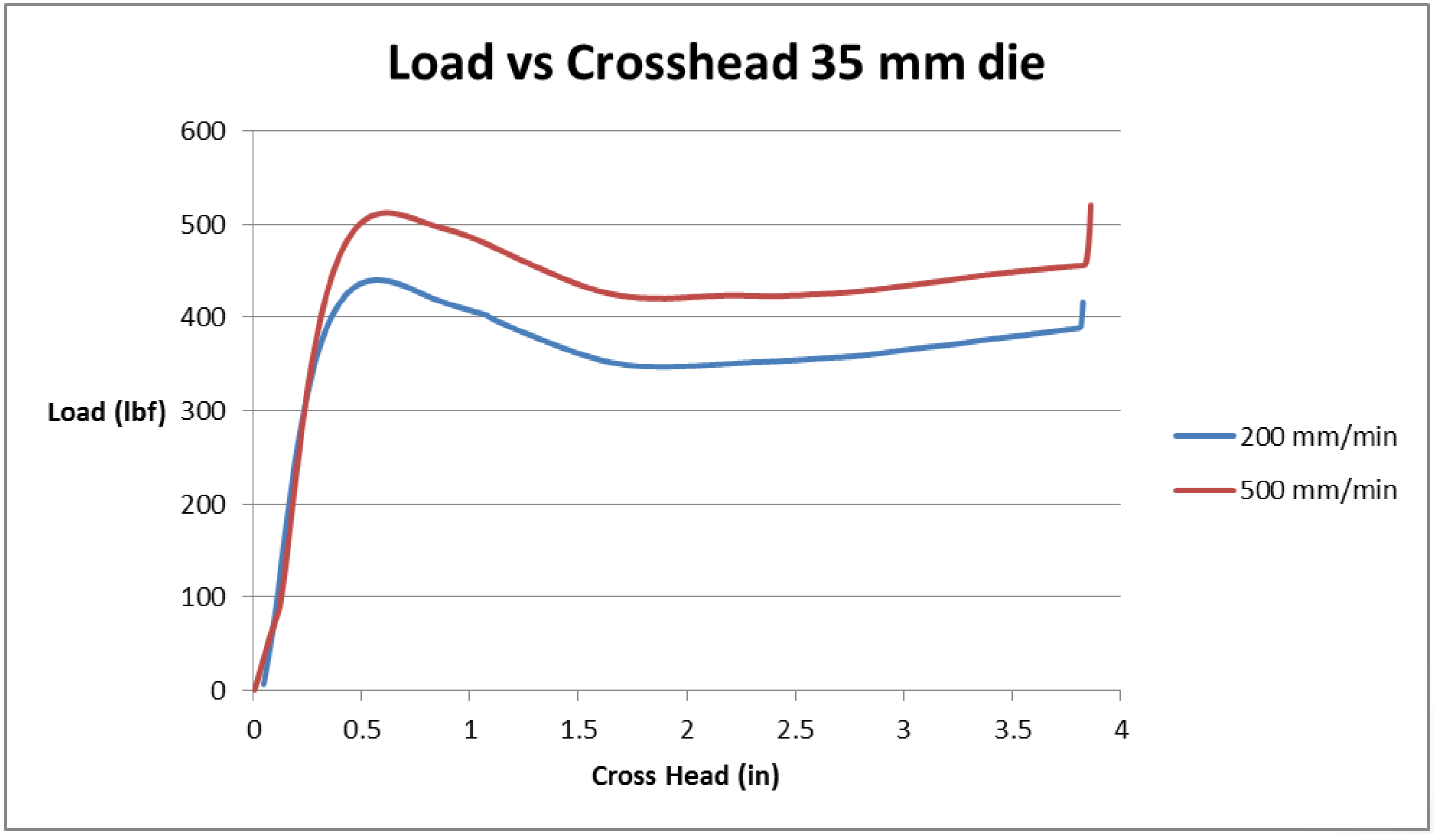
Calculate Forces Required to Move Pipe through System

- $F_{required} = 2 * F_n * \mu + F_{roller} \sin(\theta)$
- $F_{linear} = \sum F_{required}$



Calculate Forces Required to Move Pipe through System

- Test results from the Instron Machine
- Force to fold pipe



Calculate Forces Required to Move Pipe through System

Force Required to Move Pipe	Equation	Values	Units
Coefficient of Friction (c_f)	User Input	0.0024	
Angle of Force (θ)	User Input	29	degrees

Actual forces for each roller	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
	1	271	lb_f	$f_{required} = 2 * f * c_f + f * \sin(\theta)$	133	lb_f
	2	427	lb_f		209	lb_f
	3	389	lb_f		190	lb_f
	4	356	lb_f		174	lb_f
	5	358	lb_f		175	lb_f
	6	361	lb_f		177	lb_f
	7	374	lb_f		183	lb_f
	8	385	lb_f		188	lb_f
					1430	Total

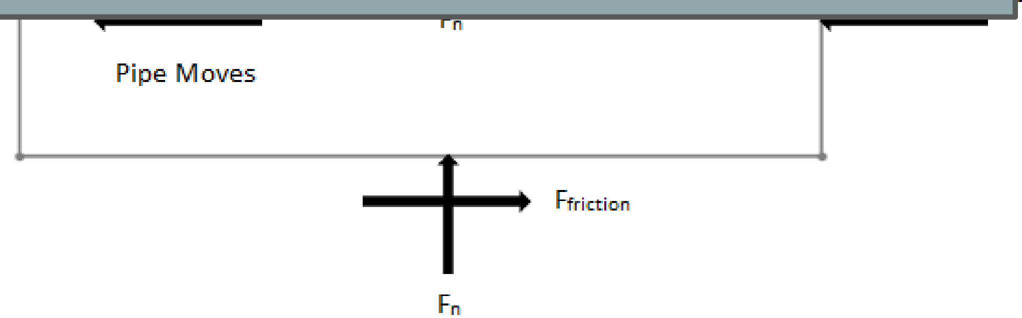
Drive System

- 2 Hydraulic Motors
  - Char-Lynn 2000 series
  - 11.9 cu in displacement
  - 2000 psi & 2 gpm
  - 26 rpm & 2880 in lbs
- Chain Driven
  - #60 chain
- 4 sprockets per motor
  - 1:6 gear ratio
- System
  - 4.3 rpm
  - 17,280 in lbs of torque

How To Calculate Torque

$$F_{roller} = \frac{F_{total}/2}{\mu + \sin(\theta)}$$

Torque Required for Drive Motors	Equation	Values	Units
Diameter of Roller	User Input	8	in
Coefficient of Friction [between drive roller and pipe] (c_f)	User Input	0.8	
Angle of Force between drive roller and pipe (θ)	User Input	5	degrees
Total force for actual forces for each roller	From Force on Rollers Sheet	1430	lb_f
Normal Force exerted by roller	$f_n = \frac{f_{required/4}}{\mu + \sin(\theta)}$	403	lb_f
Torque of motor to produce force required	$\tau = f_n * d$	1612	$in*lb_f$



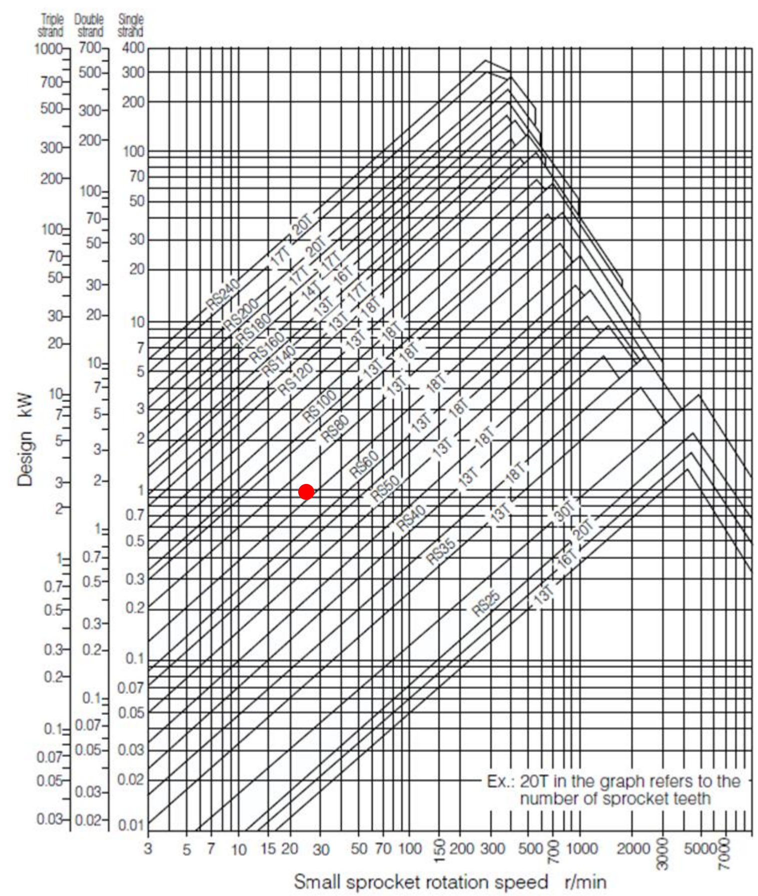
Drive Chain Calculations

n1*rpm1=n2*rpm2				
Gear Ratio	**n 1**	**rpm1**	**n2**	**rpm 2**
10-30	10	26	30	8.67
15-30	15	8.67	30	4.33

Torque1*rpm1=Torque2*rpm2				
Gear Ratio	**Torque 1**	**rpm 1**	**Torque 2**	**rpm 2**
10-30	2880	26	8640	8.67
15-30	8640	8.67	17280	4.33

17280	in lbs
1440	ft lbs
1.37	hp
1.07	kW

3. Roller Chain Provisional Selection Tables

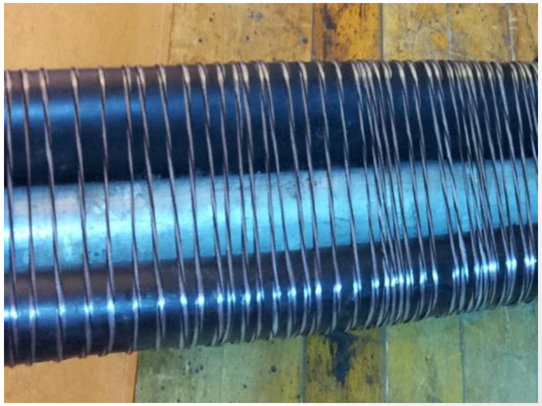


Testing

- Banding
  - Zip-ties
  - Twine
  - Duck-Tape®
- Prototype Machine
  - Come Along and Cylinder
  - Drive Motor Force

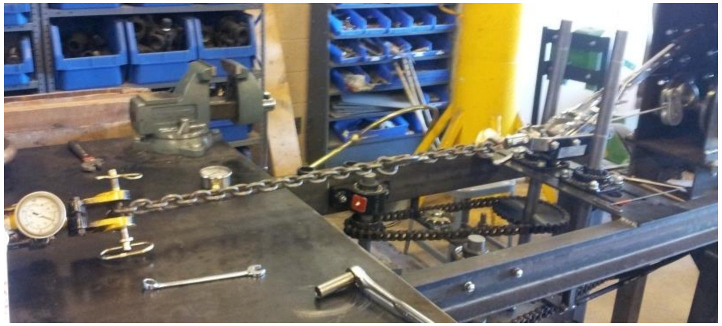
Testing (Banding)

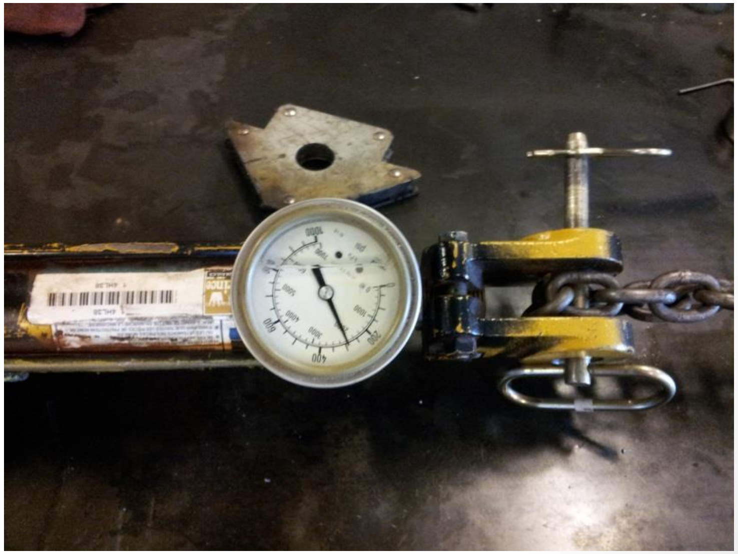
- Zip-ties
  - 50lb, 75lb, 125lb, 250lb
  - Max spacing with 250lb was 3in.
    - Not feasible
- Twine
  - 100lb tensile strength
  - Worked best with 2in. spaced spiral
- Duck-Tape®
  - Failed in all aspects, just stretched



Force Requirement

- Procedure
  - Cut pipe to length
  - Drill hole in pipe to insert bolt for pulling
  - Attach come-a-long
  - Attach cylinder with pressure gage to come-a-long
  - Crank come-a-long and take pressure readings
- Needed 1500 lbf to move pipe through system
- Drive system applies 1000 lbs per set





Difference in Budget

Comparison of Budgets			
Part	**Proposed**	**Actual**	**Difference**
Motors	2600	643.16	-$1,956.84
Cylinders	550	93.36	-$456.64
Bearings	2116	1178.4	-$937.60
Fasteners	500	94.05	-$405.95
Control Valve	750	431.32	-$318.68
Sprockets	90	329.52	$239.52
Chain	40	120.12	$80.12
Materials	2592	3198.84	$607.05
Hydraulics	1500	288.02	-$1,211.98
Other	4300	41.03	-$4,258.97
Total	**15037.79**	**6417.82**	**-$8,619.97**

Furthering the Project

- Alternative way to move pipe
  - Custom made push rollers
  - Powering the die box
- Banding suggestions
  - Twine wrap
  - Industrial packaging tape

Acknowledgements

- Kelvin Self
- Jarred Callaway
- Ditch Witch
- Wayne Kiner
- Dr. Paul Weckler
- Dr. Carol Jones
- Dr. Randy Taylor
- Dr. James Hardin
- Kevin Moore

Questions?

D.T.E.

You Dream It. We Build It.

Geothermal Pipe Bending

Marshall Oldham

Ryan Turner

Sarah Reiss

2012 Fall Design Report

Prepared for Charles Machine Works, Inc.

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MISSION STATEMENT

D.T.E. is dedicated to coming up with creative and innovative designs with our client's satisfaction as our top priority. We are devoted to designing solutions that are cost efficient, reliable, and exceed all expectations. We promise to put our client's needs first through the entirety of the project. Our innovation can make your engineering dreams come to life.

INTRODUCTION TO PROBLEM

Ditch Witch has always been a leader and innovator of underground construction equipment. In recent years geothermal heat pump installation has become a large industry and many companies use Ditch Witch trenchless equipment for digging wells. Current methods for geothermal installation involve a large hole and multiple small loops sent down hole. The loops are secured with grout in the hole. One of the biggest problems in the process is adding the grout down hole to secure the pipe. Not only is it costly, but also reduces the efficiency of the geothermal system. Ditch Witch has set out to improve the installation process by reducing the amount of grout needed. To reduce the amount of needed grout, Ditch Witch has requested that D.T.E. design a prototype machine that can reduce the outer diameter of the pipe temporarily. By doing this a smaller diameter hole can be dug in the ground. This smaller hole will allow the pipe to create a tight fit once down hole and expanded back to its original shape. This will reduce the amount of grout needed to secure the pipe and also increase heat transfer efficiency.

PROBLEM STATEMENT

Charles Machine Works, Inc. has assigned the task of evaluating the feasibility of bending 4.5 inch outer diameter High Density Polyethylene (HDPE) pipe into a "U" shape cross sectional area reducing the outer diameter when folded. If bending the HDPE pipe into said shape is feasible, then D.T.E. will design and build a machine that can achieve this profile for the pipe.

STATEMENT OF WORK

a. SOW

DTE will design and develop a machine to address the problem statement. This machine will crease HDPE pipe, incorporate a 1 inch grout line into the "U" cross section and a banding mechanism to maintain the "U" shape with the inserted grout line until the pipe is inserted down hole. The purpose of bending the pipe is to reduce the outer diameter. This will allow for a smaller drill hole, tighter fit, and less cement to secure the pipe.

b. Location of Work

The work will take place at several locations. The prototype dies for testing the pipe will be assembled in the BAE lab. The testing will take place in the BAE lab also, using the BAE Instron Machine. The dies will be made at Ditch Witch. Ditch Witch has offered to make any pieces of our design that cannot be made at the BAE lab.

c. *Period of Performance*

The project will start in August 2012 and will be completed at the beginning of May 2013.

d. *Gantt Chart*

A Gantt Chart is used to outline what will take place during the completion of the project. This chart can be found in Appendix 1.

e. *Deliverable Requirements*

Ditch Witch has requested we build a machine to fold, band, and package HDPE pipe with the following specifications. The machine will be made to handle HDPE SDR 21 pipe with an outer diameter of 4.5 inches. The machine will need to handle 300 feet of pipe in a 30 minute time period. The pipe needs to be bent and banded into a "U" shape cross section with a 1 inch grout line in the center. The banding mechanism must be able to be broken once the pipe is inserted down hole; therefore the banding mechanism must break at 100 PSI. The machine should only take 1 person to properly and safely operate. All drive systems need to be powered by hydraulics.

f. *Work Breakdown Structure*

The work breakdown structure is a tabular representation of the tasks necessary to complete the project. The full work breakdown structure is located in Appendix II.

g. *Task List*

1.0 -Testing

- 1.1 Create test dies to test the pipe in the Instron machine
- 1.2 Test the pipe
- 1.3 Gather data and analyze to determine whether the dies are feasible
- 1.4 Analyze the forces observed by the frame

1.5 Test the amount of force required to push pipe
1.6 Develop a drive train to apply the required force to the pipe
1.7 Test pipe for forces required to keep in U-Shape
1.8 Design band to apply forces to keep the pipe in the U-Shape

2.0 - Pipe Bending Machine
2.1 Dies for bending pipe
2.2 Die driving mechanism
2.3 Design Frame
2.4 Drive mechanism
2.5 Grout line insert mechanism
2.6 Bands for holding the pip in “U” Shape
2.7 Banding mechanism
2.8 Mechanism for putting bent and banded pipe on reel

3.0 - Documentation
3.1 Drafting
3.2 Write design report
3.3 Gantt charts and MS Project
3.4 Solid Works drawings

4.0 - Engineering Review and Approval
4.1 Review and approve engineering
4.2 Review, approve, and finalize drawings

5.0 - Fabricate and Procure System Materials
5.1 Procure Materials
5.2 Fabricate frame and full assembly

6.0 - Integration of system
6.1 Deliver to Charles Machine Works
6.2 Functional checks

MARKET RESEARCH

CMW doesn’t have any market competition in the development of this machine. This is strictly a research and design task to check the feasibility of bending the HDPE pipe into a U shape. Further testing will have to be done with the pipe down hole to determine if the system will be improved over current methods. Once the method is proven, CMW will have to decide whether they want to sell the machine or the bent pipe. This will determine what portion of the market they will be in. economic analysis was done by OSU Ag Econ group consisting of Justin Anderson and Alan Smith. Their analysis can be found in Appendix V.

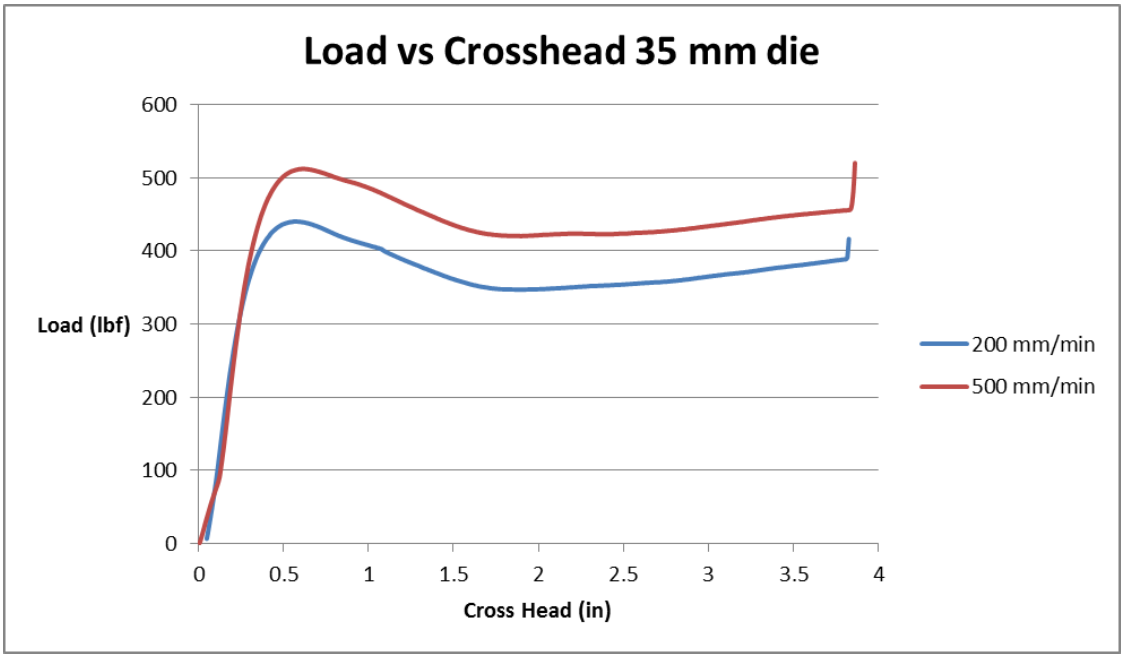
Technical Analysis

a. Customer Limitations

Limitations set forth by Charles Machine Works, Inc. include using a 4.5 inch outer diameter HDPE pipe, bending the pipe without the use of heat, and banding the pipe until it is down hole. The pipe chosen by CMW specifically chose the 4.5 inch HDPE pipe for two reasons. The first is the size requirement needed to properly heat or cool a building. The second is because this is the biggest diameter available in a continuous piece. Most patents we found use heat to help shape the pipe. CMW chose not to heat the pipe to ease the process of unfolding it once down hole. To reform the pipe it would need to be pressurized with a heated fluid and that would be difficult to do under the circumstances. Because no heat will be used to form the pipe; it will naturally want to unfold on its own. This is why bands will be necessary. The bands will maintain the U shape until the pipe is down hole. Once the pipe is down hole the bands will need to be released.

b. Testing

The first step in testing is to find the forces it takes to crush the pipe. The Instron Machine was used to find the maximum stresses when the pipe is crushed and bent. A custom die a set was made to fit the Instron machine. Using this die set the pipe was crushed at different speeds to determine the required forces. The following graph shows the results from the Instron machine at 10 feet per minute and 25 feet per minute.



The graph above shows that more force and speed are proportional to each other. The faster we want to crush the pipe, the more force we need to push the pipe through the system. Through testing it was also discovered that manipulating the shape of the pipe during crushing resulted in higher forces. This led us to redesign our dies so that the pipe could take the shape more naturally. This data is also useful in proper bracing and linear pushing force the machine will need to have.

At a later time we will test the pipe's structural properties. This will be necessary to make sure the pipe is not stressed to the point of yielding or failure at any point.

c. Material limitations

The limitations of the HDPE pipe are still unknown at this time. Testing at a later date will allow us to better understand the limits of the pipe. We will need to know the yielding and fracturing stresses to make sure nothing is done that will cause the pipe to fail. We do know the pipe is rated for 109 psi and that will limit our bands. They will have to be broke with less than 100 psi to make sure the pipe does not burst. The bend radius will be important for spooling the bent pipe for storage and delivery.

d. Similar design

Technical analysis of similar designs has resulted in a few patented ideas that we need to be careful not to infringe upon. All the current patents to date that involve bending pipe in said manner are for repairing or revamping underground pipe lines without disturbing the surface. The pipe for this is typically much larger than what we are working with and is made of a large variety of materials. Also, the patents' methods that were found used heat in a manner to soften the pipe so that it could be formed. It should be noted, that we will not be using heat to deform our pipe; therefore our design will differ drastically. The current patents did describe a multitude of different rollers and dies used to shape the pipe. Our design will include the similar idea of rollers and dies to shape our pipe. Other similar patents involved the use of U-shaped pipe in methods for repairing old pipe. This method described the use of the U-shaped pipe and not actually the process of bending the pipe.

e. Patents Searches

The patents that are relevant to the design process were obtained through Google Patent Search. The detailed summary of each of them can be found in Appendix III. Patents 4986951, 4863365, 4998871, 5091137, 5342570, 5861116, and 6119501 contain processes describing how to deform pipe liner. Each process deforms the liner from a circular cross section to a smaller diameter in the shape of a “U” or “W”. The processes are similar to our machine in the fact that rollers are used to decrease the outer diameter of pipe but differ in the application of heat. Heat will not be applied during the deformation process.

DESIGN CONCEPTS

a. Generation of Design Concepts

Two design concepts were developed to meet the following design criteria. Both designs will take the HDPE pipe from a circular cross sectional profile to a U shaped cross sectional profile. This profile will be achieved by means of bending by which the pipe is run through a series of dies. Secondly the grout line will need to be incorporated into the “U” shaped profile. Thirdly, design a temporary clamping mechanism that can be released once the pipe is secured down hole.

i. Design I

At the front of the machine there will be a set of hydraulic motors equipped with rubber disks to feed the pipe through the system. There will be a set of guides before and after the push motors to ensure the pipe stays in line with the dies (See Fig. A1, 2). There will also be a hydraulically driven spool at the end of the machine that will aid in pulling the pipe through the system once the pipe reaches the spooler. All motors will run so that the pipe travels through the system at either 10 feet per minute or 25 feet per minute, depending on CMW's preferences.

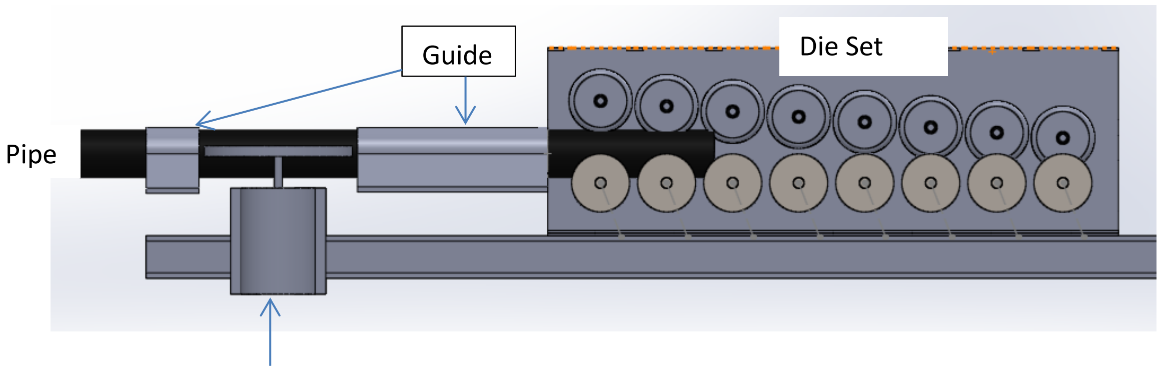


Fig. A

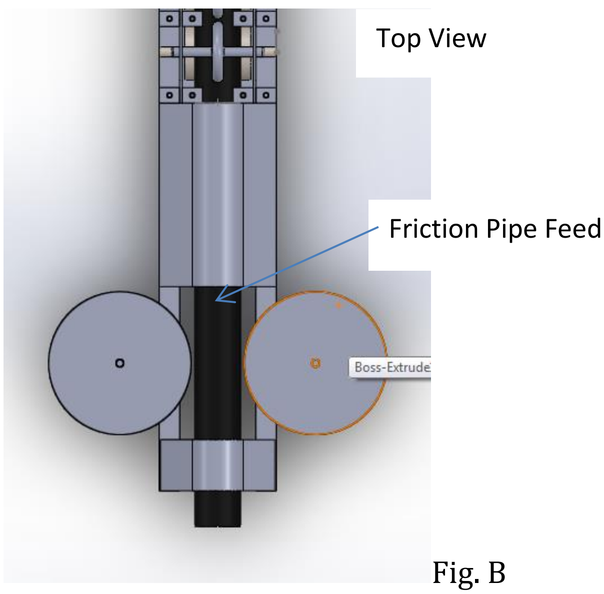
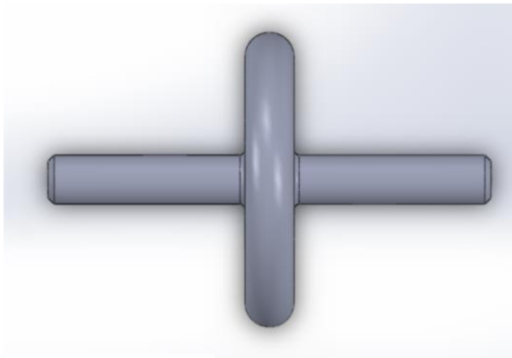


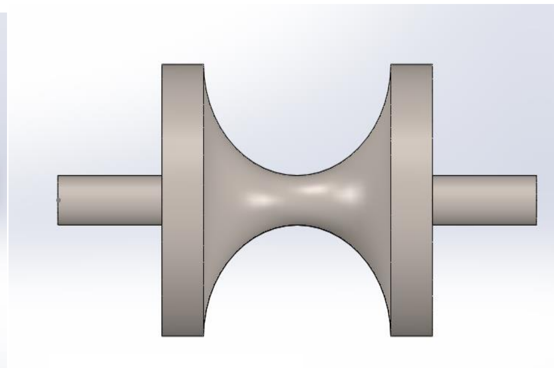
Fig. B

Once the pipe reaches the dies, there will need to be a significant amount of linear force on the pipe to feed through the dies. The dies will be 1 inch wide and have a diameter of 6 inches with a rounded edge (See Fig. C for die). The dies will step down in increments of a half inch for every 6.25 inches of linear travel (See Fig. D for die setup).   The pipe will see 8 dies that will reduce the height of the pipe by 3.75

inches total. The 3.75 inches will bring the top of the pipe in contact with the bottom giving the pipe the "U" shaped profile. (See Fig. E)



Upper Die



Lower Die

Fig. C

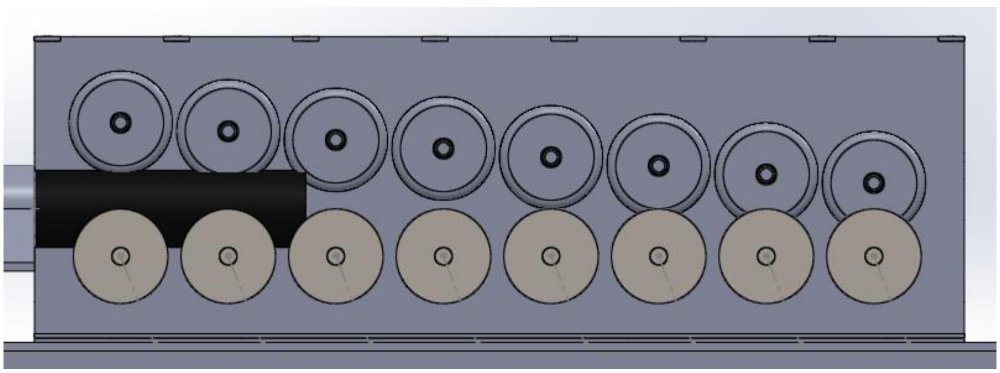


Fig. D

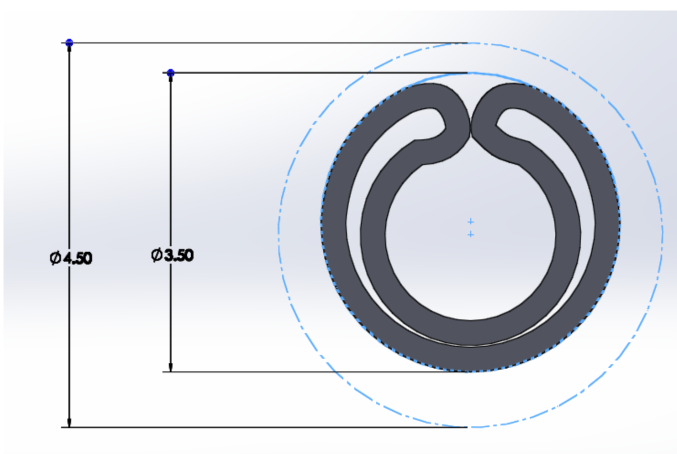


Fig. E

After the die set, the 1 inch grout line will be inserted into the fold of the HDPE pipe. The spool of grout line will be lifted above the machine via hydraulic lift (see figure

F). This will eliminate the need for multiple workers to lift the spool and reduce worker strain and injury. Once the beginning of the pipe has reached the grout line inserter, the machine will need to be stopped so that the operator can line up the grout line with the HDPE pipe. This will ensure the grout line is accessible once the pipe is in the ground. After the dies, the pipe will follow in a track that will ensure it does not unfold before it is banded. Immediately after the insertion of the grout line, the pipe will be compressed on the sides in the position it will need to stay in. While under this compression, the bands can be put on the pipe to ensure the pipe stays folded.

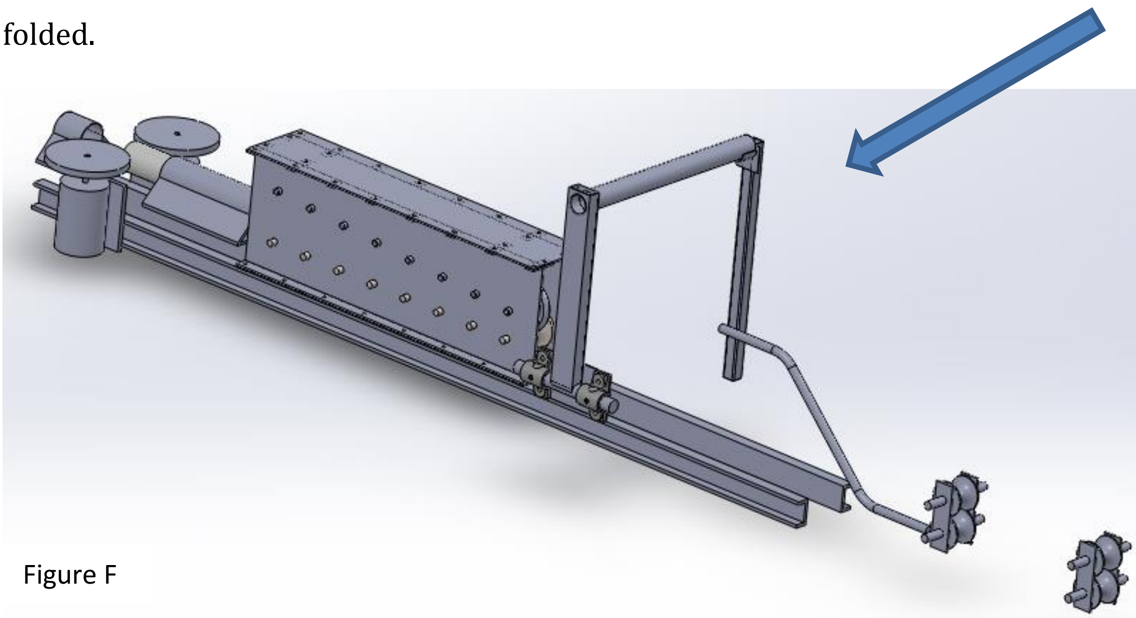
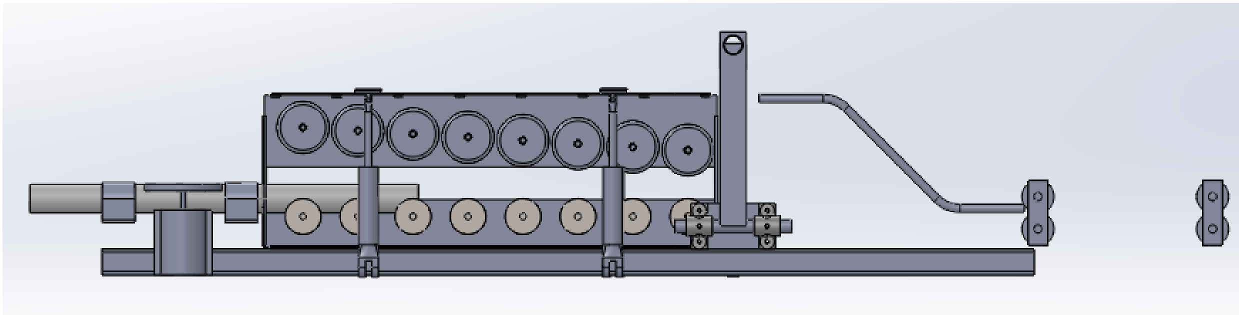


Figure F

ii. Design II

Design II is similar to Design I, but there will be vertical separation between the die sets. This design reduces the initial force it takes to push the pipe through the die set. Rather than waiting for the pipe to reach the hydraulically driven spool, at the end of the machine, the spooler can aid in pulling the pipe through the dies from the beginning. The following figure illustrates the vertical die separation.



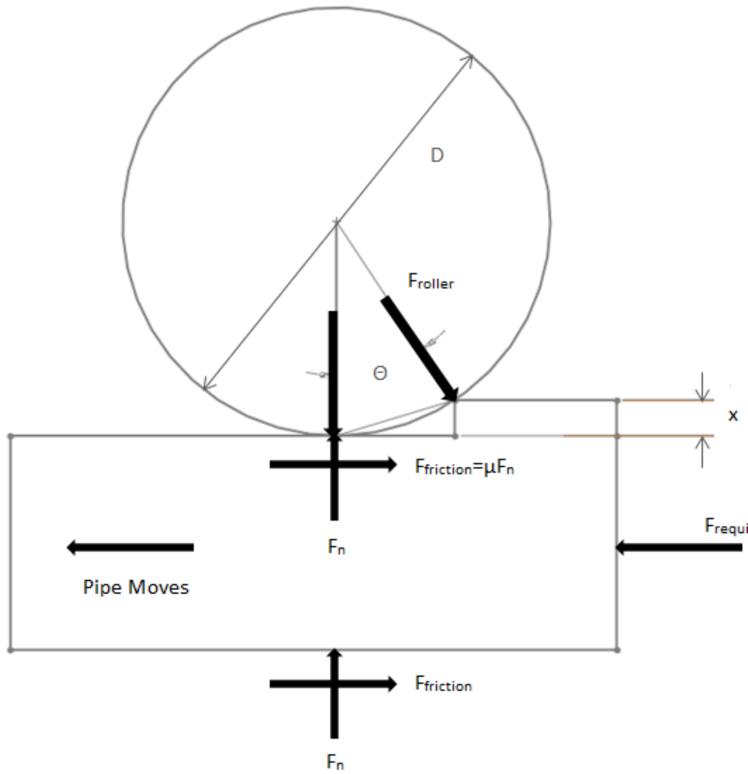
Design II also has the option of moving fast or slow and is equipped at the beginning with hydraulic motors to push the pipe. The dies will start in the separated position so the pipe can be inserted into the system. This will leave 6 feet of unbent pipe at the beginning. The unbent portion of the pipe will aid in attaching lines at the top of the hole to make expanding the pipe down hole easier. The dies will then crush the pipe and the pipe will continue through the process described in Design I.

iii. Calculations

The forces required to move the pipe through the system was calculated by using the following figure and equations.

$$F_{required} = 2 * F_n * \mu + F_{roller}\cos(\theta)$$

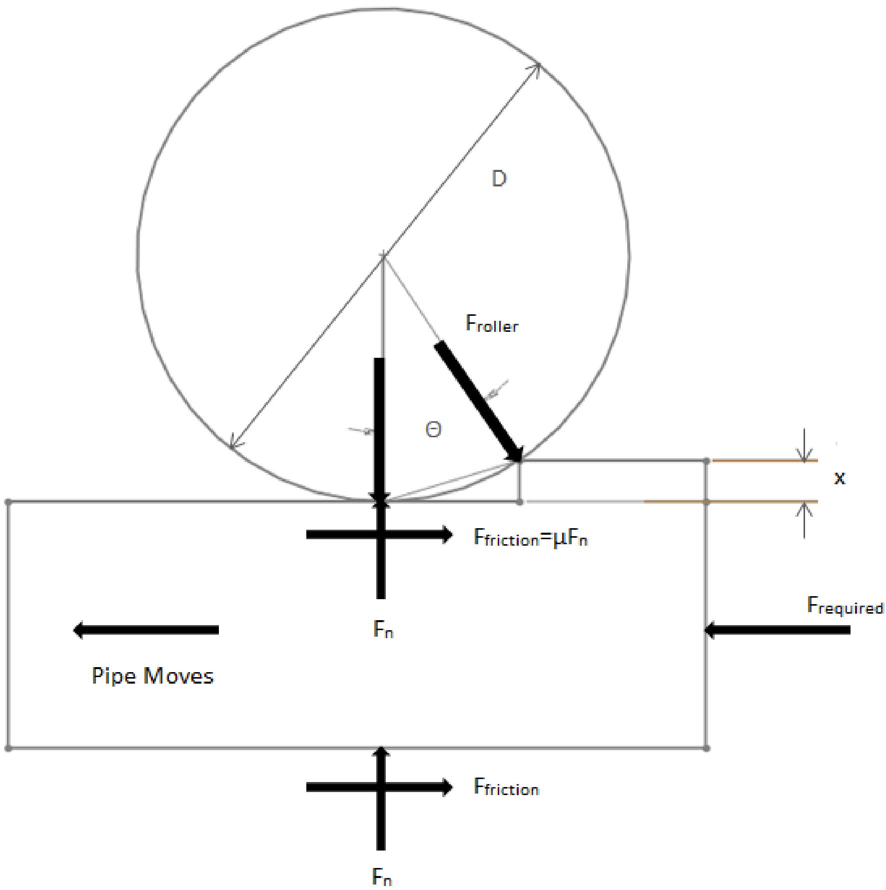
$$F_{total} = \sum F_{required}$$



Tables for each individual calculation can be found in Appendix IV. The following table displays the forces it would take to move the pipe through Design I and Design II and at the different speeds.

Force required to move pipe through system						
Design	Speed of system	Actual Force		Force with 1.5 Safety Factor		
Split Design	Fast (25 fpm)	5078.609	in*lb$_f$	**7617.913**	in*lb$_f$
	Slow (10 fpm)	4294.471	in*lb$_f$	**6441.707**	in*lb$_f$
Solid Design	Fast (25 fpm)	4950.644	in*lb$_f$	**7425.966**	in*lb$_f$
	Slow (10 fpm)	4186.264	in*lb$_f$	**6279.396**	in*lb$_f$

The next thing calculated is the torque required for each system. The following equations and illustration was used to determine the torque required.



$$\text{Design Concept 1:}\ F_{roller} = \frac{F_{total}/2}{\mu+\cos(\theta)}$$

$$\text{Design Concept 2:}\ F_{roller} = \frac{F_{total}/4}{\mu+\cos(\theta)}$$

$$\tau = F_{roller} * \frac{d}{2}$$

Design 1 and Design 2 equation differs because of the difference in the initial force required by the system. Tables are provided to demonstrate the calculations in Appendix IV, but the overall torque required for each design concept at 10 fpm and 25 fpm is provided in the following table.

Torque of motor to produce force required					
Design	**Speed of system**	**Actual Torque**		**Torque with 1.5 Safety Factor**	
Split Design	Fast (25 fpm)	2827.427	$in*lb_f$	**4241.140**	$in*lb_f$
	Slow (10 fpm)	2390.872	$in*lb_f$	**3586.308**	$in*lb_f$
Solid Design	Fast (25 fpm)	5512.369	$in*lb_f$	**8268.554**	$in*lb_f$
	Slow (10 fpm)	4661.259	$in*lb_f$	**6991.889**	$in*lb_f$

iv. Drive systems

Given the previous calculations, there are three options for the drive system for either design concept. Direct drive, gear driven, and chain driven are all available options to pursue. The following table shows the comparison between the three options and the price of hydraulic motors for each of the options.

Drive System	Design	Speed of System	Pump Series	Displacement (in^3)	Torque of Pump ($in*lb_f$)	RPM	PSI	Ratio	Final Torque (in*lbf)	Price
Direct Drive	Split	Fast (25 fpm)	4000	12.5	3860	12	2500	1:1	3860	$800.00
		Slow (10 fpm)	4000	30	3825	5	1000	1:1	3825	$850.00
	Solid	Fast (25 fpm)	6000	49	12539	12	2000	1:1	12539	$1,300.00
		Slow (10 fpm)	6000	45	11121	5	2000	1:1	11121	$1,300.00
Gear Drive or Chain Driven	Split	Fast (25 fpm)	4000	24	6000	14	2000	6:5	7200	$850.00
		Slow (10 fpm)	2000	11.9	2720	7	2000	3:4	3808	$400.00
	Solid	Fast (25 fpm)	4000	30	8375	19	2000	3:2	13260	$800.00
		Slow (10 fpm)	2000	24	5880	6	2000	6:5	7056	$550.00

v. Banding

The pipe will be banded prior to exiting the machine. There are multiple options to do this that depend upon the speed that the machine is operating at. If the machine is operating at 10 fpm, then it will be slow enough for an operator to be placing industrial zip ties approximately every three feet. These zip ties would be rated to break at 100 psi. This method however, would be difficult if the machine was operating at 25 fpm. Therefore, another method such as a banding machine will have to be utilized. The Dynaric D2400 automatic strapping machine would be ideal for this application (see figure G). This machine could be used to strap bands to the bent pipe as it travels through the system.

Figure G

b. Safety

The designed machine will need to follow all safety standards outlined by OSHA. Proper guards will need to be in place at any moving part or pinch point. Moving parts will be guarded against inadvertent contact. The dies will be under a great amount of force and all hands and fingers shall be guarded against contact to prevent injury. All hydraulic systems will follow OSHA specifications for pressure requirements. To prevent strain to the worker all heavy lifting over 50 pounds will be assisted by hydraulics. The operator station will require the operator be at a safe position to minimize the possibility of injury. Multiple safety kill switches will be strategically placed along the machine so the operator can always shut down the machine from any position in the event of an emergency. Lock out switches will be incorporated on the machine to prevent it from running while the operator is making adjustments or repairs.

DESIGN EVALUATION

a. *Feasibility Evaluation of Possible Designs*

The first design differs from the second because it is rigid at the die housing where the second is split in two. The reason for the split is to reduce the force needed, by a single motor, to feed the pipe through the system. Without the split the push motors will have to apply all the force to get the pipe to the spool. Once the pipe reaches the spooler, it can assist in pulling the pipe. This reduces the power requirements by half for each push motor. To eliminate the high initial force requirements, we came up with design two. This design is split at the dies so that the push motors are always assisted by the spooler. This allows us to design the push motors for a smaller torque and that reduces the cost. However, the split design will have an added cost from the hydraulic cylinders needed to split the housing. Design two will have some structural integrity that will need to be addressed such as the split in the die housing causing a bending issue on the side plates. Both designs are feasible and backed up by engineering. There is no definite reason at this point to choose one design over the other.

The bands will be nothing more than pressure rated zip ties for the time being. They can be put on manually. Once the entire idea is verified and a final design is made an automated banding machine can be incorporated into the design to make the process faster.

The entire machine will be powered by hydraulics. CMW suggested hydraulics because most all their machines in the manufacturing plant are ran off hydraulics. The hydraulics also allows us to incorporate all moving parts into the same power system. This will eliminate cluster and reduce the complexity of the machine as a whole.

PROJECT BUDGET

Since the project at hand is a prototype and part of research and design there was no set budget. The main purpose is to have the bent pipe to check the rest of the feasibility of the idea at hand. If reducing the diameter of the pipe can result in a tighter fit down hole, then less grout needs to be used. Less grout will allow this method to be superior to other designs and bring CMW into the geothermal market. We did however form a cost analysis to construct the prototype.

The cost of this machine can vary significantly depending on which design and speed we chose to run the machine at. This change in cost can mostly be contributed to the different motor requirements to feed the pipe. Another large portion of the change comes from the automated bander needed to run at higher speeds. The cost of all materials can be found in the spreadsheet below.

						Direct Drive				Gear or Chain Drive			
						Not Split		Split		Not Split		Split	
		Quantity	Type	Size	Cost	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast
Motors	Drive	2	Hydraulic	Depends on design and speed	Depends on Motor Size	$2,600.00	$2,600.00	$1,700.00	$1,600.00	$1,100.00	$800.00	$800.00	$1,700.00
	Grout Arm Lift	1	Hydraulic			$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
	Spool	1	Hydraulic			$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Cylinders	Die Set	4	Tie Rod Ends	2"x1" 2000 psi	$50.00	-	-	$200.00	$200.00	-	-	$200.00	$200.00
	Spool Lift	2	Tie Rod Ends	To Be Determined	$75.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00
	Press Split	4	Tie Rod Ends	To Be Determined	$50.00	-	-	$200.00	$200.00	-	-	$200.00	$200.00
Bearings	Die Set	16	4 bolt flange	1"	$42.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00
	Spools	24	4 bolt flange	1.25"	$51.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00
	Grout Lift	2	pillow block	2"	$110.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00
Fasteners	Nuts/Bolts	Estimated Here, All To Be Determined			$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00
Bander	Machine				$5,000.00	-	$5,000.00	-	$5,000.00	-	$5,000.00	-	$5,000.00
Hydraulics	Pump				$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00
	Hose and Fittings				$1,500.00	$750.00	$750.00	$1,500.00	$1,500.00	$750.00	$750.00	$1,500.00	$1,500.00
	Reservoir				$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00
	Heat Exchanger				$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00
Control Switches					$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00
Safety					$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00
Electronics					$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Gears/Sprockets					$15.00	-	-	-	-	$90.00	$90.00	$90.00	$90.00
Chain					$40.00	-	-	-	-	$40.00	$40.00	$40.00	$40.00
					Total	$12,966.00	$17,966.00	$13,216.00	$18,116.00	$11,596.00	$16,296.00	$12,446.00	$18,346.00

In the spreadsheet above are prices for all purchase components. The hydraulic motors will vary in price due to the needed size per design. The cheapest option for motors is to use design II and gear up the motors to the proper speed and torque. This allows us to choose a smaller, cheaper motor. There will be an added cost for chain and gears. Design II will also need more hydraulic cylinders to split the die set apart. This cost will not be seen in design I. A large price difference in the designs will come from the automated banding machine. This will be used at faster production speeds and will add approximately 5,000 dollars to the cost. Since this machine is a prototype it is most likely we will keep a slower speed to reduce the cost. Other cost will include bearings, fasteners, hydraulic components, control switches, safety, and electronics. We estimate that these costs will be relatively the same no matter which design we choose.

Material	Size	Length Needed		Price Per Foot	Price
		In inches	In Feet		
Round Stalk	1 inch	72	6	$4.00	$24.00
	1.25 inch	132	11	$4.00	$44.00
	5 inch	16	1.3	$166.90	$222.53
	6 inch	40	3.3	$276.37	$921.23
Flat Plate	1/4 inch	33 sq. ft.	33	$12.86	$424.38
	1/2 inch	2 sq. ft.	2	$27.56	$55.12
	1 inch	3.5 sq. ft.	3.5	$78.51	$274.79
Welded Round Pipe	3 inch	36	3	$9.41	$28.23
	5 inch	12	1	$17.85	$17.85
Square Tubing	2x2x.25	36	3	$6.51	$19.53
	4x2x.25	30	2.5	$14.31	$35.78
	4x4	288	24	$17.96	$431.04
C-Channel	6x2x.25	40 foot	7.24	$10.66	$77.18
Angle Iron	.5x.5x.125	160	13.3	$1.21	$16.13
				Total	**$2,591.79**

The above spreadsheet covers most of the material cost to construct the machine. These costs will vary little between designs. The total cost will be approximately 2,600 dollars for materials.

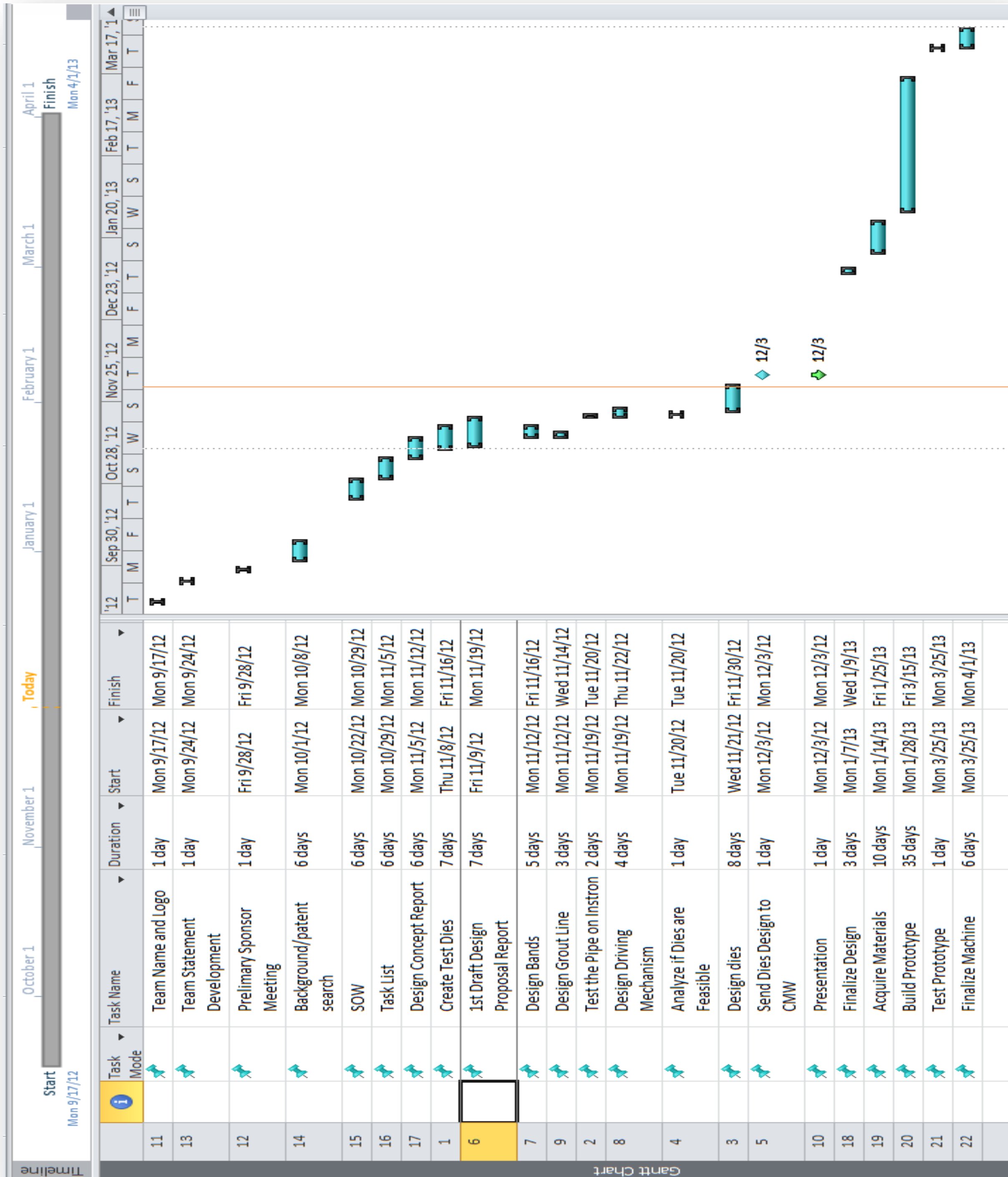
Drive System	Design	Speed of System	Total Cost
Direct Drive	Split	Fast (25 fpm)	**$20,707.79**
		Slow (10 fpm)	**$15,807.79**
	Solid	Fast (25 fpm)	**$20,557.79**
		Slow (10 fpm)	**$15,557.79**
Gear Drive or Chain Driven	Split	Fast (25 fpm)	**$20,937.79**
		Slow (10 fpm)	**$15,037.79**
	Solid	Fast (25 fpm)	**$18,887.79**
		Slow (10 fpm)	**$14,187.79**

The above spreadsheet will be the total estimated cost for each design. The most feasible idea that stands out on cost alone is to move the machine at a slow speed (10ft/min). Looking at only the slow speed design it could be estimated the machine will cost around 15,000 dollars. There is no one design that is significantly cheaper than the other to choose based on cost.

APPENDIX

I. Gantt Chart
II. Work Breakdown Structure
III. Patents
IV. Calculations
V. Economic Analysis

APPENDIX I



	Task Mode	Task Name	Duration	Start	Finish
11		Team Name and Logo	1 day	Mon 9/17/12	Mon 9/17/12
13		Team Statement Development	1 day	Mon 9/24/12	Mon 9/24/12
12		Prelimary Sponsor Meeting	1 day	Fri 9/28/12	Fri 9/28/12
14		Background/patent search	6 days	Mon 10/1/12	Mon 10/8/12
15		SOW	6 days	Mon 10/22/12	Mon 10/29/12
16		Task List	6 days	Mon 10/29/12	Mon 11/5/12
17		Design Concept Report	6 days	Mon 11/5/12	Mon 11/12/12
1		Create Test Dies	7 days	Thu 11/8/12	Fri 11/16/12
6		1st Draft Design Proposal Report	7 days	Fri 11/9/12	Mon 11/19/12
7		Design Bands	5 days	Mon 11/12/12	Fri 11/16/12
9		Design Grout Line	3 days	Mon 11/12/12	Wed 11/14/12
2		Test the Pipe on Instron	2 days	Mon 11/19/12	Tue 11/20/12
8		Design Driving Mechanism	4 days	Mon 11/19/12	Thu 11/22/12
4		Analyze if Dies are Feasible	1 day	Tue 11/20/12	Tue 11/20/12
3		Design dies	8 days	Wed 11/21/12	Fri 11/30/12
5		Send Dies Design to CMW	1 day	Mon 12/3/12	Mon 12/3/12
10		Presentation	1 day	Mon 12/3/12	Mon 12/3/12
18		Finalize Design	3 days	Mon 1/7/13	Wed 1/9/13
19		Acquire Materials	10 days	Mon 1/14/13	Fri 1/25/13
20		Build Prototype	35 days	Mon 1/28/13	Fri 3/15/13
21		Test Prototype	1 day	Mon 3/25/13	Mon 3/25/13
22		Finalize Machine	6 days	Mon 3/25/13	Mon 4/1/13

APPENDIX II

WBS	Task	Element	Definition
1	**0**	**Geothermal Pipe Bender**	**All work to develop a machine that will bend Geothermal pipe into a U-shaped cross section**
2	**0**	**Initiation**	**Work that starts the project**
	1	Sponsor Assignments	Instructor assigns the project and sponsors
	2	Team Name and Logo development	Team members are to develop the team name and logo for their group and deliver to instructor
	3	Preliminary meeting with Sponsor	Team meets with a representative of Charles Machine Works, Inc. to understand the problem and requirements for the final product
3	**0**	**Planning**	**Work that plans the process of design**
	1	Team statement development	The development of the problem statement for the problem set forth by Ditch Witch
	2	Gather Background	Team gathers background on the problem and conducts research on potential solutions. This also includes patent searches.
	3	Statement of Work	The development of the a narrow definition of the problem and a definition of what the final machine will consist of
	4	Task list	Development of a list of deliverables
	5	Business Plan	Agriculture Economic Team develops a financial analysis and business plan for the project
	6	Project Website	Develop a website that displays the project in its entirety
	7	Design Concept Report	Development of preliminary design concepts for the machine
	8	Testing	Test the HDPE pipe to make sure that the preliminary design concept if feasible and adjust design if needed
	9	Design Proposal Report	Deliver a compiled analysis that includes SOW, Task List, Business Plan, and Design Concepts that will be presented to the sponsor
	10	Design Proposal Oral	Team will present an oral presentation

		Presentation	to sponsor, instructors, and department head that will show the proposal of the project
4	**0**	**Execution**	**The actual execution of the project**
	1	Finalization of design proposal	Team works with sponsor to make final adjustments to proposed machine so assembly can begin
	2	Acquire Materials	Gather all materials to build machine. This includes hardware and facility. Ditch Witch has offered to help in the building of things such as the dies that would be difficult to do in the BAE lab
	3	Development of Prototype	Involves the actual development of the geothermal pipe bender
	4	Testing	Evaluate the prototype and test for defects
	5	Final Prototype Development	Finalization of prototype so it can be delivered to client
	6	Final Report	Deliver final report that includes revised design proposal report and final design of machine
	7	Demonstration	Final prototype is demonstrated and presented to sponsor, instructors, peers, and department head

APPENDIX III

Patents

BEFORE 1992: These patents are out of date but are relevant to our project and a good source of ideas.

The following patents are either in relation or a continuation of each other. They describe a method for bending circular shaped cross-sectional thermoplastic pipe liner into U-shaped cross-sectional liner temporarily, to then be placed into the pipe and reformed into its original circular cross-sectional shape. The pipe liner is deformed through a process involving rollers and heat. After the liner is placed inside the desired pipe it goes through a pressure and heating process. The following figures illustrate the process for the patents below.

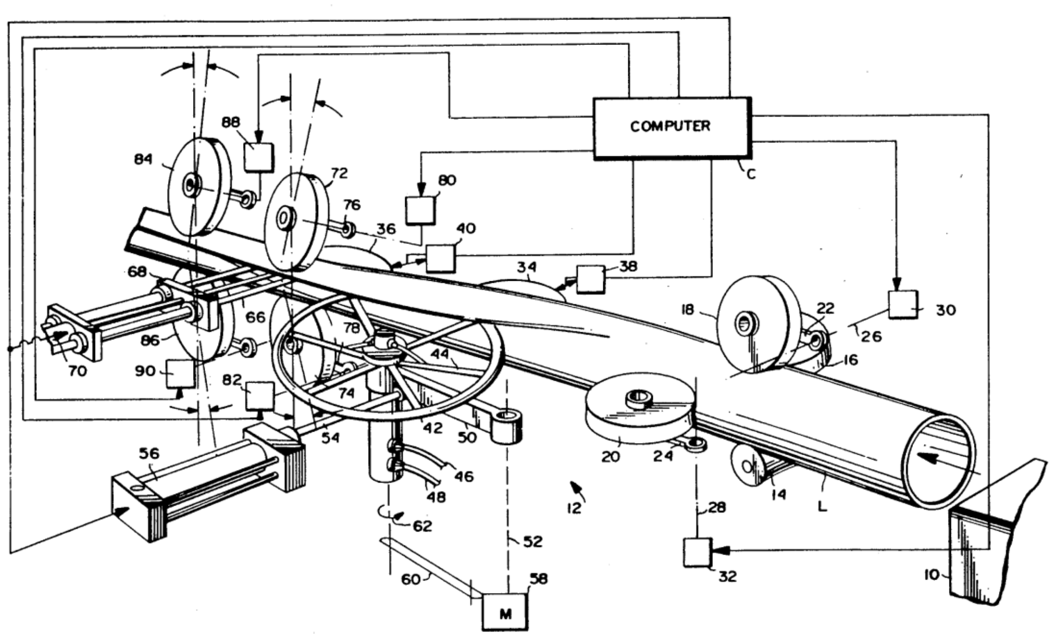


FIG. 1

Patent number: 4986951 (Pipe Liner Process)

Filing date: Apr 29, 1988

Issue date: Jan 22, 1991

Patent number: 4863365 (Method and apparatus for deforming reformable tubular pipe liners)

Filing date: Jul 27, 1987

Issue date: Sep 5, 1989

Patent number: 4998871 (Apparatus for deforming plastic tubing for lining pipe)

Filing date: Jan 19, 1989

Issue date: Mar 12, 1991

Patent number: 5091137 (Pipe lining process)

Filing date: Nov 21, 1990

Issue date: Feb 25, 1992

AFTER 1992: These patents are still to date and need to be taken into account when designing.

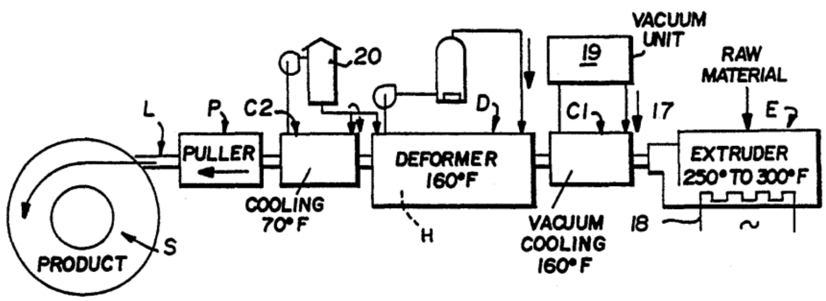
Patent number: 5342570 (Method and apparatus for deforming reformable tubular pipe liners)

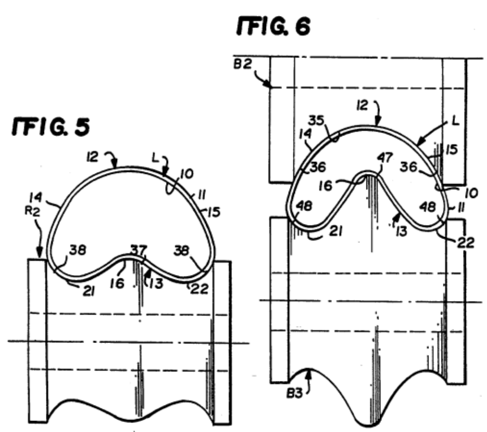
Filing date: Aug 9, 1990

Issue date: Aug 30, 1994

This patent is for a process to deform pipe liners to line new and old pipe into a U-shape to be placed and then unfolded within the pipe that is needed to be lined, so the fit is tight.

Our project shares similar ideas with the use of rollers, although the main difference with this patent and our project is the use of heat and the use of unusually shaped rollers. The pipe is continuously extruded and heated then cooled during the process of deformation using rollers and guidance rollers. The following figures show the overall process and the guidance rollers.



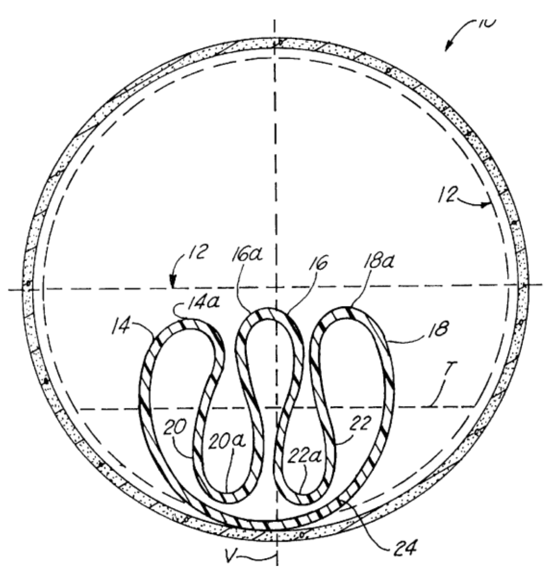


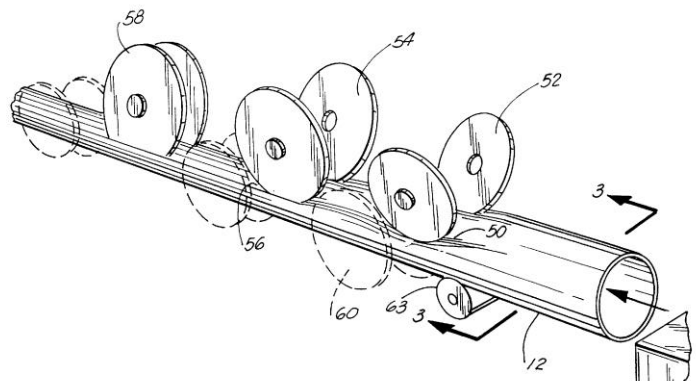
Patent number: 5861116 (Process for installing a pipe liner)

Filing date: Sep 17, 1996

Issue date: Jan 19, 1999

This patent is for a process to install a liner into a pipe of same diameter. With this process, a cylindrical pipe of high density polyethylene is formed into a smaller W-shaped cross-section to then insert into a pipe for lining. The liner is deformed into a W-shape cross section so external assistance or bindings does not have to be utilized to keep it into that shape. To deform, the cylindrical pipe is inserted into a series of three axially spaced rollers under a temperature of about 70˚C. Once the pipe is deformed, it is inserted into the pipe that is to be lined. Steam is flowed through and applied to the W-shaped pipe to deform back to the original cylindrical shape. The following figures illustrate the W-shaped cross-sectional area and the rollers in the deforming process:



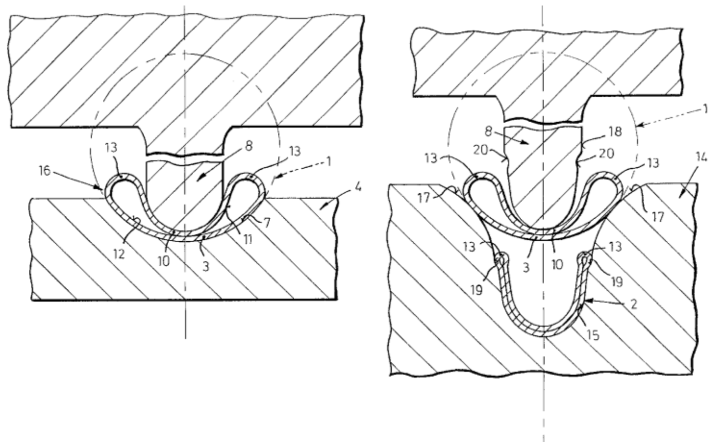


Patent number: 6119501 (Method of deforming an initial pipe having a circular cross-section into a U-shaped section and device for carrying out the method)

Filing date: May 7, 1999

Issue date: Sep 19, 2000

The relevance of this patent is it involves a process for making a circular shaped cross-sectional into a U-shaped cross-section. This pipe deformation process involves circular shaped cross-sectional being placed into dies to make a U-shaped cross-sectional. This patent does not mention what this pipe is used for and does not describe a process of reopening into its original circular cross-section. The following figures illustrate how the dies bend the pipe.



These patents are relevant because they involve forming circular pipe into a U-shaped cross section. This shape reduces the overall outer diameter for inserting the pipe into another pipe. This is done for the repair of underground sewer, water, gas and similar grounds. They involve heating the pipe to allow for deforming the pipe to proper shape. The forming is done through a multitude of rollers and dies. After the shape is obtained they are cooled back to help the pipe maintain the U-shape.

APPENDIX IV- Calculations

Die Assembly Weight

Die Support	Length (in)	Height (in)	Area (in^2)	Weight .25" Steel Plate (lb/ft^2)	Weight (lb)
Bottom Plate	70	11.5	805	10.2	57.021
Top Plate	70	11.5	805	10.2	57.021
Right Side Plate (Top)	70	11.13	779.1	10.2	55.186
Right Side Plate (Bottom)	70	7.38	516.6	10.2	36.593
Left Side Plate (Top)	70	11.13	779.1	10.2	55.186
Left Side Plate (Bottom)	70	7.38	516.6	10.2	36.593
				Top Total Weight	**167.393**
				Bottom Total Weight	**130.206**
				Total Weight of Die Support	**297.599**

Die	Die				
	$Radius_1$ (in)	$Radius_2$ (in)	Diameter of Saddle (in)	Thickness (in)	Volume (in^3)
Top	7.5	1.25	---	1	42.951
Bottom	6	1.25	4.5	2.5	39.810
Shaft	Shaft				
	Shaft Diameter (in)		Shaft length (in)	Shaft Volume (in^3)	
Top	1.25		10	12.272	
Bottom	1.25		10	12.272	
Assembly	Die and Shaft				
	Volume (in^3)		Density (lb/in^3)	Total Weight 1 Die (lb)	
Top	55.223		0.284	**15.661**	
Bottom	52.082		0.284	**14.770**	

Total Die Assembly	Total Weight of 1 Die (lb)	Number of Dies	Total Weight of Dies (lb)	Total Weight of Die Support (lb)	Total Weight (lb)
Top	15.66128839	8	125.290	167.393	292.684
Bottom	14.7703351	8	118.163	130.206	248.369
Assembly	---	16	243.453	297.599	**541.052**

Force Required To Move Pipe Through System

Force Required to Move Pipe	Equation	Values	Units
Coefficient of Friction (c_f)	User Input	0.3	
Angle of Force (θ)	User Input	33.56	degrees
Percent Change	User Input	84.56%	percent
Max Force	User Input	800	lb_f

Inputs for Design I

	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
Actual forces for each roller (Fast)	1	321	lb_f	$f_{required} = 2 * f * c_f + f * \cos(\theta)$	460.092	lb_f
	2	505	lb_f		723.820	lb_f
	3	460	lb_f		659.321	lb_f
	4	421	lb_f		603.422	lb_f
	5	423	lb_f		606.289	lb_f
	6	427	lb_f		612.022	lb_f
	7	442	lb_f		633.522	lb_f
	8	455	lb_f		652.155	lb_f
	1-8	3454	lb_f		**4950.644**	**lb_f**

Design I Fast

	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
% of actual forces for each roller (Slow)	1	271.4376	lb_f	$f_{required} = 2 * f * c_f + f * \cos(\theta)$	389.054	lb_f
	2	427.028	lb_f		612.062	lb_f
	3	388.976	lb_f		557.522	lb_f
	4	355.9976	lb_f		510.254	lb_f
	5	357.6888	lb_f		512.678	lb_f
	6	361.0712	lb_f		517.526	lb_f
	7	373.7552	lb_f		535.706	lb_f
	8	384.748	lb_f		551.462	lb_f
	1-8	2920.702	lb_f		**4186.264**	**lb_f**

Design I Slow

Force Required to Move Pipe	Equation	Values	Units
Coefficient of Friction (c_f)	User Input	0.3	
Angle of Force (θ)	User Input	29.5	degrees
Percent Change	User Input	84.56%	percent
Max Force	User Input	800	lb_f

Inputs for Design II

Actual forces for each roller (Fast)	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
	1	321	lb_f	$f_{required} = 2 * f * c_f + f * \cos(\theta)$	471.984	lb_f
	2	505	lb_f		742.530	lb_f
	3	460	lb_f		676.364	lb_f
	4	421	lb_f		619.020	lb_f
	5	423	lb_f		621.960	lb_f
	6	427	lb_f		627.842	lb_f
	7	442	lb_f		649.897	lb_f
	8	455	lb_f		669.012	lb_f
	1-8	3454	lb_f		**5078.609**	**lb_f**

Design II Fast

% of actual forces for each roller (Slow)	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
	1	271.4376	lb_f	$f_{required} = 2 * f * c_f + f * \cos(\theta)$	399.110	lb_f
	2	427.028	lb_f		627.883	lb_f
	3	388.976	lb_f		571.933	lb_f
	4	355.9976	lb_f		523.443	lb_f
	5	357.6888	lb_f		525.930	lb_f
	6	361.0712	lb_f		530.903	lb_f
	7	373.7552	lb_f		549.553	lb_f
	8	384.748	lb_f		565.716	lb_f
	1-8	2920.702	lb_f		**4294.471**	**lb_f**

Design II Slow

Force required to move pipe through system					
Design	**Speed of system**	**Actual Force**		**Force with 1.5 Safety Factor**	
Split Design	Fast (25 fpm)	5078.609	in*lb_f	**7617.913**	in*lb_f
	Slow (10 fpm)	4294.471	in*lb_f	**6441.707**	in*lb_f
Solid Design	Fast (25 fpm)	4950.644	in*lb_f	**7425.966**	in*lb_f
	Slow (10 fpm)	4186.264	in*lb_f	**6279.396**	in*lb_f

Torque Required By Drive Motor

	Torque Required for Drive Motors	Equation	Values	Units	
Solid Design	Diameter of Roller	User Input	8	in	
	Coefficient of Friction [between drive roller and pipe] (c_f)	User Input	0.5		
	Angle of Force between drive roller and pipe (θ)	User Input	1	degrees	
	Total force for equal max force on all rollers	From Force on Rollers Sheet	9173.167	lb_f	
	Total force for actual forces for each roller	From Force on Rollers Sheet	4950.644	lb_f	
	Total force for % of actual forces for each roller	From Force on Rollers Sheet	4186.264	lb_f	
	Max Force	From Force on Rollers Sheet	800	lb_f	
	Percent Change	From Force on Rollers Sheet	84.56%	Percent	
	Normal Force exerted by roller (Max)	$f_n = \frac{f_{roller}}{\mu + \cos\theta}$	2553.500	lb_f	
	Normal Force exerted by roller (Actual)		1378.092	lb_f	
	Normal Force exerted by roller (% Actual)		1165.315	lb_f	
	Torque of motor to produce force required (Max)	$\tau = f_n * d$	**10214.001**	**in*lb_f**	
	Torque of motor to produce force required (Actual)		**5512.369**	**in*lb_f**	Fast
	Torque of motor to produce force required (% Actual)		**4661.259**	**in*lb_f**	Slow

Design I Fast and Slow

	Torque Required for Drive Motors	Equation	Values	Units	
Split Design	Diameter of Roller	User Input	8	in	
	Coefficient of Friction [between drive roller and pipe] (c_f)	User Input	0.8		
	Angle of Force between drive roller and pipe (θ)	User Input	5	degrees	
	Total force for equal max force on all rollers	From Force on Rollers Sheet	9410.276	lb_f	
	Total force for actual forces for each roller	From Force on Rollers Sheet	5078.609	lb_f	
	Total force for % of actual forces for each roller	From Force on Rollers Sheet	4294.471	lb_f	
	Max Force	From Force on Rollers Sheet	800	lb_f	
	Percent Change	From Force on Rollers Sheet	84.56%	Percent	
	Normal Force exerted by roller (Max)	$f_n = \frac{f_{roller}}{\mu + \cos\theta}$	1309.752	lb_f	
	Normal Force exerted by roller (Actual)		706.857	lb_f	
	Normal Force exerted by roller (% Actual)		597.718	lb_f	
	Torque of motor to produce force required (Max)	$\tau = f_n * d$	**5239.007**	**in*lb_f**	
	Torque of motor to produce force required (Actual)		**2827.427**	**in*lb_f**	Fast
	Torque of motor to produce force required (% Actual)		**2390.872**	**in*lb_f**	Slow

Design II Fast and Slow

Torque of motor to produce force required					
Design	**Speed of system**	**Actual Torque**		**Torque with 1.5 Safety Factor**	
Split Design	Fast (25 fpm)	2827.427	in*lb_f	**4241.140**	in*lb_f
	Slow (10 fpm)	2390.872	in*lb_f	**3586.308**	in*lb_f
Solid Design	Fast (25 fpm)	5512.369	in*lb_f	**8268.554**	in*lb_f
	Slow (10 fpm)	4661.259	in*lb_f	**6991.889**	in*lb_f

Shaft Design

Shaft Design	Equation	Values	Units
Distance from force to center of bearing	User Input	4.25	in
Force on shaft	User Input	800	lb_f
Diameter of shaft	User Input	1.25	in
To calculate stress (σ) for shaft			
Moment (M)	(Force on shaft) * Distance	3400	in*lb_f
Centroid (C)	(Diameter of shaft)/2	0.625	in
Moment of Inertia (I)	$\frac{\pi * diameter^4}{64}$	0.120	in^4
Bending Stress (σ)	$\frac{M * c}{I}$	**17731.643**	**psi**

Bearing Analysis

Bearing Analysis	Equation	Values	Units
Diameter of Roller	User Input	1.5	in
Expected life of Bearing	User Input	10	years
Force on shaft	User Input	800	lb_f
Velocity (given)	(10ft/min)*12	120	in/min
Radius of Roller	d/2	0.75	in
Circumference of Roller	2*pi()*r	4.712	in
Number of Revolutions per minute	Velocity/Circumference	25.465	rev/min
Number of hours operated per year	(# hour/week)*(# weeks/year)	124800	min/year
Revolutions per Life	(rev/min)*(# min operation/year)*(# years/life)	31780059	rev/life
Force on bearings	(Force on shaft)/(# bearings supporting shaft)	400	lb_f
To calculate C_{10} for bearing			
X_D	(revolutions/life)/(revolutions rated life)	31.780	
R_D	$(reliability)^{.5}$	0.995	
F_D	(Force on shaft)/(2 bearings)	400	lb_f
x_0	Look up value for bearing type	0.02	
θ	Look up value for bearing type	4.459	
a	Look up value for bearing type	3	
b	Look up value for bearing type	1.483	
a_f	Assume value	1.2	
C_{10}	$C_{10} = a_f * F_D \left[\frac{x_D}{x_0 + (\theta - x_0) * (1 - R_D)^{-1/b}}\right]^a$	**2894.981**	

APPENDIX V- Economic Analysis

GeoFold Premium Geothermal Well Product Business Plan

I. Executive Summary

The Concept

Charles Machine Works, Inc. is developing an new geothermal well casing design that has the potential to decrease home owner utility costs by up to four times the savings already realized with geothermal heating and cooling systems. This new well casing, GeoFold, will decrease the amount of geothermal wells needed to achieve the same efficiency the current systems exhibit. GeoFold may also decrease the amount of time needed to install these geothermal wells. GeoFold will do this by being much more efficient than the conventional geothermal wells, thus needing fewer wells for each system installed.

Background

Vertical geothermal wells today utilize a u-loop design which allows water to pass through them and release or absorb heat depending on the time of year. This process is much more efficient than HVAC units, but it could be improved. GeoFold will eliminate much of the grout, which hinders the u-loop system's efficiency. The u-loop systems normally require three wells for a residential home where GeoFold may reduce that number to only two wells or possibly one. GeoFold will do this while maintaining, if not increasing, the efficiency geothermal systems currently exhibit.

The Company and Management Team

Charles Machine Works, Inc., also known as CMW, began in the late 1940's by Ed Malzhan in Perry, Oklahoma with the creation of a new trenching machine. CMW is an industry leader in the trenching, compact utility machines, trenchless directional drilling, vacuum excavation, and underground utility location areas. CMW is still located in Perry, Oklahoma where their world headquarters and manufacturing facilities are housed. Their products are marketed at Ditch Witch products through their dealer network. CMW has been at the forefront of innovation in their field, twice being named "one of the best American-made products in the world" by Fortune magazine. CMW is currently under the direction of Tiffany Sewell-Howard as CEO and Edwin Malzahn as Chairman and President. GeoFold is currently being developed under Mr. Kelvin Self.

The Industry

The geothermal industry falls under the space heating and cooling industry umbrella. This industry has seen near 2.5% growth over the last ten years and is expected to increase that growth to over 3% in by 2017. GeoFold will build on the latest technological advances in geothermal pipe by creating a more efficient well casing design which will increase the thermal conductivity of each well resulting in a more efficient overall system and greater savings to the homeowner. Retail trade, education, and government account for the majority of the purchases in the industry with plastic pipe and heat exchanger manufacturers accounting for most inputs.

The Market

The target market for the GeoFold is primarily the geothermal well installers, but also the end-users or homeowners and business owners. GeoFold could be easier to install than the u-loop system because of the requirement of fewer wells. It will also be much more efficient allowing the end-user to recover the investment must quicker and realize greater savings through the life of the system.

The Competition

While the only current competition for GeoFold is the current u-loop method, GeoFold will be a premium geothermal pipe as a result of the greater efficiency of systems using GeoFold and will warrant a higher price. Given this higher initial price GeoFold will likely only attract 1% of the target market in the first full year of production. Even the 1% is enough to realize a gross profit of over $2 million from 7,500 wells installed. There are several unknown variables that could alter than profit number, but none to the point of eliminating it. GeoFold will slowly grow its market share into single digit growth after 3-5 years once consumers can see the added benefits of this premium product.

Competitive Position

Charles Machine Works, Inc. has an impeccable reputation in the underground construction industry. This reputation and their attention to the consumer will not go away once in the geothermal industry. The developers of GeoFold will make certain the premium product is as advertised prior to market entry and the network of Ditch Witch dealers will insure the customers are satisfied once the product leaves their dealership. GeoFold will be marketed as a premium geothermal well product. Initially the product will be distributed through the Ditch Witch network throughout the United States. CMW will also join with two well known entities in the geothermal industry. The first of these is the International Ground Source Heat Pump Association which is located on the Oklahoma State University campus in Stillwater, Oklahoma and has access to the most current advancements in the geothermal industry. A partnership with this industry association would prove invaluable. The second of these partnerships is with the world's largest and most progressive manufacturer of geothermal heat pumps which is ClimateMaster who is headquartered in Oklahoma City, Oklahoma. The pairing of the most advanced geothermal well product with the largest heat pump manufacturer could propel the sales of GeoFold past expectations and allow CMW to realize a much higher return on their investment in GeoFold.

Operations

GeoFold will be manufactured and shipped from the CMW manufacturing facility in Perry, Oklahoma initially. Manufacturing the product at the headquarters will allow the research and development team to closely monitor the process and insure that no GeoFold pipe leaves Perry unless it is of the highest quality. Once the process is perfected the manufacturing may be expanded by the sale of creasing devices to Ditch Witch dealerships or even geothermal well installers.

Charles Machine Works already has organizational technology in place to assist in the GeoFold process and the company's years of manufacturing will prove invaluable in creating the highest quality product possible.

The Future

GeoFold is predicted to harness 1% of the target market which would total 7,500 geothermal wells and over 2 million feet of GeoFold pipe. This market share is expected to rise slowly for the first few years until the market share growth realizes yearly single digit gains. GeoFold will continually be monitored and improved as needed to keep up with the industry. GeoFold technology will be protected by the issuance of a United States Patent in the near future.

Financials

GeoFold will realize a pre-tax gross margin of $2,214,450 in the first year and each year thereafter with only a 1% market share. The investment in GeoFold is currently worth $13,748,538 to Charles Machine Works when considering 10 years of GeoFold sales. These numbers could rise once the increased cost savings of systems utilizing GeoFold are realized and advertised.

Sales Projections

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
GeoFold	unit	7,500	7,500	7,500	7,500	7,575	7,651	7,727	7,805	7,883	7,961

Gross Sales Projection

This sheet summaries the volume and price and sales growth information from the input page. There is no input on this page.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
GeoFold										
Total Volume	7,500	7,500	7,500	7,500	7,575	7,651	7,727	7,805	7,883	7,961
Price/Unit	$ 1,279.46	$ 1,292.25	$ 1,305.18	$ 1,318.23	$ 1,331.41	$ 1,344.73	$ 1,358.17	$ 1,371.75	$ 1,385.47	$ 1,399.33
Gross Sales	$ 9,595,950	$ 9,691,910	$ 9,788,829	$ 9,886,717	$ 10,085,440	$ 10,288,157	$ 10,494,949	$ 10,705,898	$ 10,921,086	$ 11,140,600
TOTAL GROSS SALES	$9,595,950	$9,691,910	$9,788,829	$9,886,717	$10,085,440	$10,288,157	$10,494,949	$10,705,898	$10,921,086	$11,140,600
Production Expense										
Cost/unit	$ 984.20	$ 994.04	$ 1,003.98	$ 1,014.02	$ 1,024.16	$ 1,034.40	$ 1,044.75	$ 1,055.20	$ 1,065.75	$ 1,076.41
TOTAL VARIABLE EXP.	$ 7,381,500	$ 7,455,315	$ 7,529,868	$ 7,605,167	$ 7,758,031	$ 7,913,967	$ 8,073,038	$ 8,235,306	$ 8,400,836	$ 8,569,692

These figures are calculated with an initial cost of each GeoFold geothermal well equal to $984.20 and a selling price of $1,279.46. The cost only accounts for the cost of the raw pipe needed to construct the GeoFold pipe. It does not take into consideration any processing, shipping, fixed costs, or additional parts needed to complete the GeoFold pipe. It also does not consider any labor or additional pipe to join the well with the heat pump unit. This is simply a calculation of raw pipe for a 300' GeoFold well.

This sheet summaries income, expenses and net profit. There are no inputs on this sheet

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Gross Sales											
GeoFold	$0	$ 9,595,950	$ 9,691,910	$ 9,788,829	$ 9,886,717	$ 10,085,440	$ 10,288,157	$ 10,494,949	$ 10,705,898	$ 10,921,086	$ 11,140,600
Total	**$0**	**$ 9,595,950**	**$ 9,691,910**	**$ 9,788,829**	**$ 9,886,717**	**$ 10,085,440**	**$ 10,288,157**	**$ 10,494,949**	**$ 10,705,898**	**$ 10,921,086**	**$ 11,140,600**
Expenses											
Variable	$0	$7,381,500	$7,455,315	$7,529,868	$7,605,167	$7,758,031	$7,913,967	$8,073,038	$8,235,306	$8,400,836	$8,569,692
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Expenses	**$0**	**$7,381,500**	**$7,455,315**	**$7,529,868**	**$7,605,167**	**$7,758,031**	**$7,913,967**	**$8,073,038**	**$8,235,306**	**$8,400,836**	**$8,569,692**
Pre-Tax Gross Margin	**$ -**	**$ 2,214,450**	**$ 2,236,595**	**$ 2,258,960**	**$ 2,281,550**	**$ 2,327,409**	**$ 2,374,190**	**$ 2,421,911**	**$ 2,470,592**	**$ 2,520,251**	**$ 2,570,908**

These figures are calculated with an initial cost of each GeoFold geothermal well equal to $984.20 and a selling price of $1,279.46. The cost only accounts for the cost of the raw pipe needed to construct the GeoFold pipe. It does not take into consideration any processing, shipping, fixed costs, or additional parts needed to complete the GeoFold pipe. It also does not consider any labor or additional pipe to join the well with the heat pump unit. This is simply a calculation of raw pipe for a 300' GeoFold well.

This sheet summaries the feasibility of the project. It provides net present value, benefit cost ratio and internal rate of return
The only input is the discount rate.

Discount Rate 12.00%

Year	0	1	2	3	4	5	6	7	8	9	10
Gross Margin		$9,595,950	$9,691,910	$9,788,829	$9,886,717	$10,085,440	$10,288,157	$10,494,949	$10,705,898	$10,921,086	$11,140,600
Discount Factor	1	0.892857143	0.797193878	0.711780248	0.635518078	0.567426856	0.506631121	0.452349215	0.403883228	0.360610025	0.321973237
PV of Income	$0	$8,567,813	$7,726,331	$6,967,495	$6,283,187	$5,722,749	$5,212,301	$4,747,382	$4,323,933	$3,938,253	$3,586,975
Total Expense	$0	$7,381,500	$7,381,500	$7,455,315	$7,529,868	$7,605,167	$7,758,031	$7,913,967	$8,073,038	$8,235,306	$8,400,836
Less Depreciation and Term Interest		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Expenses	$0	$7,381,500	$7,381,500	$7,455,315	$7,529,868	$7,605,167	$7,758,031	$7,913,967	$8,073,038	$8,235,306	$8,400,836
Discount Factor	1	0.892857143	0.797193878	0.711780248	0.635518078	0.567426856	0.506631121	0.452349215	0.403883228	0.360610025	0.321973237
PV of Expenses	$0	$6,590,625	$5,884,487	$5,306,546	$4,785,367	$4,315,376	$3,930,460	$3,579,877	$3,260,565	$2,969,734	$2,704,844.21
Benefits Less Costs	$0	$2,214,450	$2,310,410	$2,333,514	$2,356,849	$2,480,273	$2,530,127	$2,580,982	$2,632,860	$2,685,780	$2,739,764
PV Benefits Less PV Costs	$0	$1,977,188	$1,841,844	$1,660,949	$1,497,820	$1,407,374	$1,281,841	$1,167,505	$1,063,368	$968,519	$882,131

Total PV of Income	$57,076,418
Total PV of Expenses	$43,327,880
Net Present Value	$13,748,538

These figures are calculated with an initial cost of each GeoFold geothermal well equal to $984.20 and a selling price of $1,279.46. The cost only accounts for the cost of the raw pipe needed to construct the GeoFold pipe. It does not take into consideration any processing, shipping, fixed costs, or additional parts needed to complete the GeoFold pipe. It also does not consider any labor or additional pipe to join the well with the heat pump unit. This is simply a calculation of raw pipe for a 300' GeoFold well.

This is for a traditional HVAC Unit that costs $10,000 to install. It is also estimated that the yearly utility bill will be $3,900 . The 2% Discount Rate is the estimated average interest rate.

Discount Rate 2.00%

Year	0	1	2	3	4	5	6	7	8	9	10
Utility Bill	$0	$3,900	$3,900	$3,900	$3,900	$3,900	$3,900	$3,900	$3,900	$3,900	$3,900
Discount Factor	1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Utilities	$0	$3,824	$3,749	$3,675	$3,603	$3,532	$3,463	$3,395	$3,329	$3,263	$3,199

Total PV of Utilities	$35,032
Total Initial Cost	$10,000
Net Present Value	$45,032

This is for a traditional Geothermal Unit that costs $30,000 to install with a 30% tax credit and $375/ton OG&E rebate applied for a total initial cost of $19,125. It is also estimated that the yearly utility bill will be $2,460 . The 2% Discount Rate is the estimated average interest rate.

Discount Rate 2.00%

Year	0	1	2	3	4	5	6	7	8	9	10
Utility Bill	$0	$2,460	$2,460	$2,460	$2,460	$2,460	$2,460	$2,460	$2,460	$2,460	$2,460
Discount Factor	1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Utilities	$0	$2,412	$2,364	$2,318	$2,273	$2,228	$2,184	$2,142	$2,100	$2,058	$2,018

Total PV of Utilities	$22,097
Total Initial Cost	$19,125
Net Present Value	$41,222

This is for a 5 ton Geothermal Unit with 2 wells that costs $35,000 to install with a 30% tax credit and $375/ton OG&E rebate applied for a total initial savings of $12,375. It is also estimated that the yearly utility savings will be $1,440 with three holes cased with GeoFold. The 2% Discount Rate is the estimated average interest rate if the money was not invested in a geothermal system.

Discount Rate	**2.00%**											
Year		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Savings		$12,375	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Savings		$12,375	$1,412	$1,384	$1,357	$1,330	$1,304	$1,279	$1,254	$1,229	$1,205	$1,181
Total Expense of Installation		$22,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Less Depreciation and Term Interest			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Expenses		$22,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Expenses		$22,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0.00
Savings Less Initial Costs		($10,250)	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440
PV Savings Less PV Initial Costs		($10,250)	$1,412	$1,384	$1,357	$1,330	$1,304	$1,279	$1,254	$1,229	$1,205	$1,181
Total PV of Savings	$25,310											
Total Initial Cost	$22,625											
Net Present Value	$2,685											
Running Total		$12,375.00	$13,786.76	$15,170.85	$16,527.79	$17,858.13	$19,162.38	$20,441.06	$21,694.67	**$22,923.69**	$24,128.62	$25,309.92

This is for a 5 ton Geothermal Unit with 2 wells that costs $25,000 to install with a 30% tax credit and $375/ton OG&E rebate applied for a total initial savings of $9,375. It is also estimated that the yearly utility savings will be $1,440 with three holes cased with GeoFold. The 2% Discount Rate is the estimated average interest rate if the money was not invested in a geothermal system.

Discount Rate	**2.00%**											
Year		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Savings		$9,375	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Savings		$9,375	$1,412	$1,384	$1,357	$1,330	$1,304	$1,279	$1,254	$1,229	$1,205	$1,181
Total Expense of Installation		$15,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Less Depreciation and Term Interest			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Expenses		$15,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Expenses		$15,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0.00
Savings Less Initial Costs		($6,250)	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440
PV Savings Less PV Initial Costs		($6,250)	$1,412	$1,384	$1,357	$1,330	$1,304	$1,279	$1,254	$1,229	$1,205	$1,181
Total PV of Savings	$22,310											
Total Initial Cost	$15,625											
Net Present Value	$6,685											
Running Total		$9,375.00	$10,786.76	$12,170.85	$13,527.79	$14,858.13	**$16,162.38**	$17,441.06	$18,694.67	$19,923.69	$21,128.62	$22,309.92

This is for a 5 ton Geothermal Unit with 3 wells that costs $35,000 to install with a 30% tax credit and $375/ton OG&E rebate applied for a total initial savings of $12,375. It is also estimated that the yearly utility savings will be $2,160 with three holes cased with GeoFold. The 2% Discount Rate is the estimated average interest rate if the money was not invested in a geothermal system.

Discount Rate	**2.00%**											
Year		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Savings		$12,375	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Savings		$12,375	$2,118	$2,076	$2,035	$1,996	$1,956	$1,918	$1,880	$1,844	$1,807	$1,772
Total Expense of Installation		$22,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Less Depreciation and Term Interest			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Expenses		$22,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Expenses		$22,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0.00
Savings Less Initial Costs		($10,250)	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160
PV Savings Less PV Initial Costs		($10,250)	$2,118	$2,076	$2,035	$1,996	$1,956	$1,918	$1,880	$1,844	$1,807	$1,772
Total PV of Savings	$31,777											
Total Initial Cost	$22,625											
Net Present Value	$9,152											
Running Total		$12,375.00	$14,492.65	$16,568.77	$18,604.19	$20,599.69	$22,556.07	**$24,474.09**	$26,354.50	$28,198.04	$30,005.43	$31,777.38

This is for a 5 ton Geothermal Unit with 2 wells that costs $30,000 to install with a 30% tax credit and $375/ton OG&E rebate applied for a total initial savings of $10,875. It is also estimated that the yearly utility savings will be $1,440 with three holes cased with GeoFold. The 2% Discount Rate is the estimated average interest rate if the money was not invested in a geothermal system.

Discount Rate	**2.00%**											
Year		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Savings		$10,875	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Savings		$10,875	$1,412	$1,384	$1,357	$1,330	$1,304	$1,279	$1,254	$1,229	$1,205	$1,181
Total Expense of Installation		$19,125	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Less Depreciation and Term Interest			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Expenses		$19,125	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Expenses		$19,125	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0.00
Savings Less Initial Costs		($8,250)	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440	$1,440
PV Savings Less PV Initial Costs		($8,250)	$1,412	$1,384	$1,357	$1,330	$1,304	$1,279	$1,254	$1,229	$1,205	$1,181
Total PV of Savings	$23,810											
Total Initial Cost	$19,125											
Net Present Value	$4,685											
Running Total		$10,875.00	$12,286.76	$13,670.85	$15,027.79	$16,358.13	$17,662.38	$18,941.06	**$20,194.67**	$21,423.69	$22,628.62	$23,809.92

This is for a 5 ton Geothermal Unit with 3 wells that costs $30,000 to install with a 30% tax credit and $375/ton OG&E rebate applied for a total initial savings of $10,875. It is also estimated that the yearly utility savings will be $2,160 with three holes cased with GeoFold. The 2% Discount Rate is the estimated average interest rate if the money was not invested in a geothermal system.

Discount Rate	**2.00%**											
Year		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Savings		$10,875	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Savings		$10,875	$2,118	$2,076	$2,035	$1,996	$1,956	$1,918	$1,880	$1,844	$1,807	$1,772
Total Expense of Installation		$19,125	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Less Depreciation and Term Interest			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Expenses		$19,125	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Expenses		$19,125	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0.00
Savings Less Initial Costs		($8,250)	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160
PV Savings Less PV Initial Costs		($8,250)	$2,118	$2,076	$2,035	$1,996	$1,956	$1,918	$1,880	$1,844	$1,807	$1,772
Total PV of Savings	$30,277											
Total Initial Cost	$19,125											
Net Present Value	$11,152											
Running Total		$10,875.00	$12,992.65	$15,068.77	$17,104.19	$19,099.69	**$21,056.07**	$22,974.09	$24,854.50	$26,698.04	$28,505.43	$30,277.38

This is for a 5 ton Geothermal Unit with 3 wells that costs $25,000 to install with a 30% tax credit and $375/ton OG&E rebate applied for a total initial savings of $9,375. It is also estimated that the yearly utility savings will be $2,160 with three holes cased with GeoFold. The 2% Discount Rate is the estimated average interest rate if the money was not invested in a geothermal system.

Discount Rate	**2.00%**											
Year		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Savings		$9,375	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Savings		$9,375	$2,118	$2,076	$2,035	$1,996	$1,956	$1,918	$1,880	$1,844	$1,807	$1,772
Total Expense of Installation		$15,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Less Depreciation and Term Interest			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Expenses		$15,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Discount Factor		1	0.980392157	0.961168781	0.942322335	0.923845426	0.90573081	0.887971382	0.870560179	0.853490371	0.836755266	0.8203483
PV of Expenses		$15,625	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0.00
Savings Less Initial Costs		($6,250)	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160	$2,160
PV Savings Less PV Initial Costs		($6,250)	$2,118	$2,076	$2,035	$1,996	$1,956	$1,918	$1,880	$1,844	$1,807	$1,772
Total PV of Savings	$28,777											
Total Initial Cost	$15,625											
Net Present Value	$13,152											
Running Total		$9,375.00	$11,492.65	$13,568.77	**$15,604.19**	$17,599.69	$19,556.07	$21,474.09	$23,354.50	$25,198.04	$27,005.43	$28,777.38

Geothermal Well Materials Cost Estimate

U-Loop versus GeoFold

Cost is on a per well basis. Assumed mark-up at both the distributor and contractor level is 15%. It is also assumed that the grout will only be marked up once at 15%. Cost is shown for pipe materials and grout for both a 1" and 1-1/4" U-loop geothermal well compared to a 4" GeoFold pipe with an inlet pipe of 1-1/2." A 1" line of 305' is attached to both systems for the line which will transport the grout downhole. Additional value-added actions on the pipe is not considered such as creasing, cutting, adding centralizers, binding material, or fusing to the above ground geothermal components. It is assumed that this cost will be relatively consistent between both methods.

	U-Loop Geothermal Casing		1" Grout	GeoFold	
Casing Size	1"	1-1/4"	Line	4"	1-1/2"
Length	610	610	305	305	305
Cost per Foot	$0.28	$0.38	$0.24	$1.77	$0.43
Distributor Cost	$170.80	$231.80	$73.20	$539.85	$131.15
Distibutor Mark-up	$25.62	$34.77	$10.98	$80.98	$19.67
Contractor Cost	$196.42	$266.57	$84.18	$620.83	$150.82
Contractor Mark-up	$29.46	$39.99	$12.63	$93.12	$22.62
Cost to Consumer	$225.88	$306.56	$96.81	$713.95	$173.45
Total Pipe Cost	$322.69	$403.36	$96.81 is applied to both methods.		$984.20
Grout Cost per Bag	$12.68	$12.68			$12.68
Number of Bags	50	50			2
Grout Cost	$634.00	$634.00			$25.36
Grout Mark-up	$95.10	$95.10			$3.80
Total Consumer Cost	$729.10	$729.10			$29.16
Consumer Cost per Geothermal Well Installed	$1,051.79	$1,132.46			$1,013.37
1-Well Cost	$1,051.79	$1,132.46			$1,013.37
2-Well Cost	$2,103.58	$2,264.93			$2,026.74
3-Well Cost	$3,155.37	$3,397.39			$3,040.11

Geothermal Pipe Bending

Marshall Oldham
Ryan Turner
Sarah Reiss

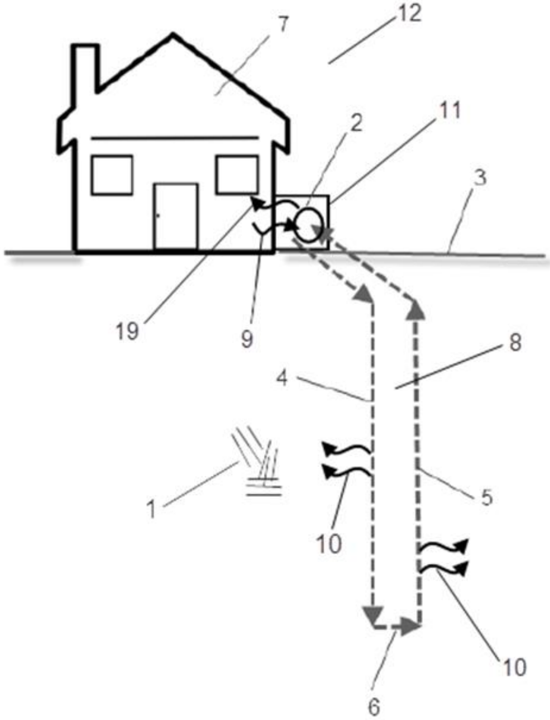
Prepared for Charles Machine Works, Inc.

Mission Statement

D.T.E. is dedicated to coming up with creative and innovative designs with our client's satisfaction as our top priority. We are devoted to designing solutions that are cost efficient, reliable, and exceed all expectations. We promise to put our client's needs first through the entirety of the project. Our innovation can make your engineering dreams come to life.

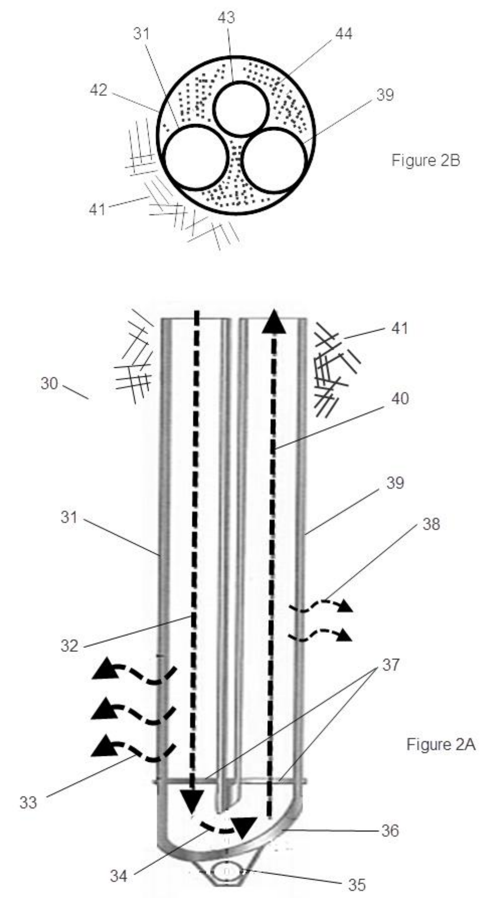
Problem Introduction

- Basic Ground Source Heat Pump System
- 250,000 systems installed each year worldwide
  - 50,000 in United States in 2010
- Geothermal energy falls under space heating and cooling, a 1.9 billion dollar industry.
- Growth rate expected to rise from 2.1% to 3.4% through 2016.



Problem Introduction

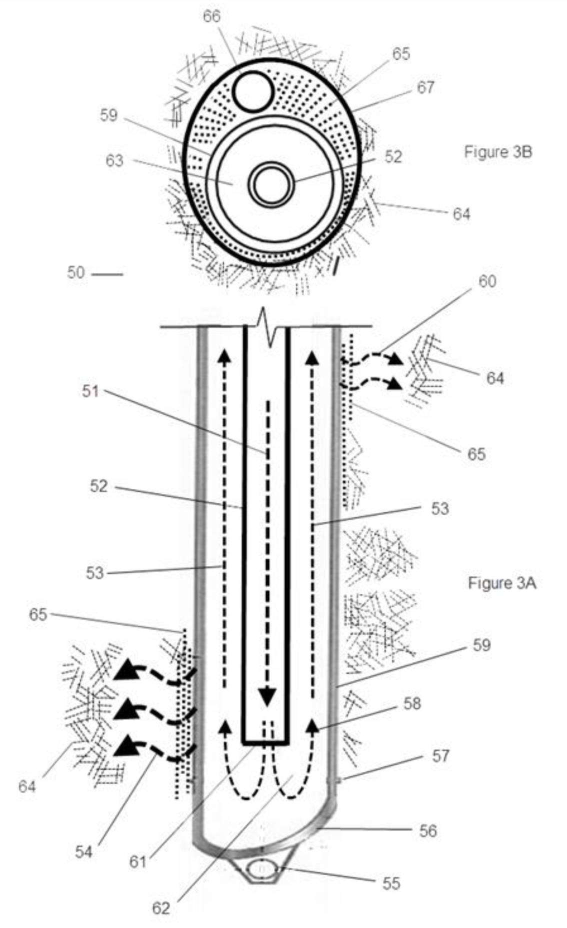
- Current Design
  - Single U-Loop
  - Packed with 240 gallons of grout
  - Grout is a poor heat conductor



"Technical Data: Geothermal Grout." *CETCO*. Feb 2011. cetco.com/dpg. 29 Nov 2012.

Problem Introduction

- Current Design
  - Single pipe with outer return
  - Packed with 200 gallons of Grout
  - 19% Reduction of grout from single U-Loop



“Technical Data: Geothermal Grout.” *CETCO*. Feb 2011. cetco.com/dpg. 29 Nov 2012.

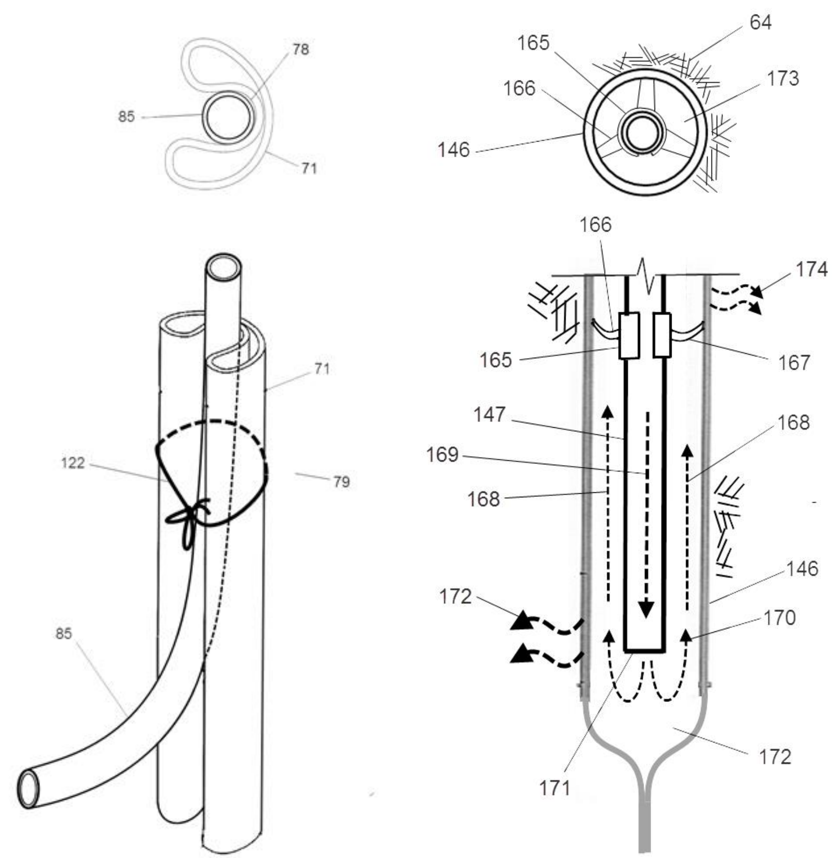
Problem Statement

- Feasibility of Bending
  - 4.5 inch outer diameter HDPE pipe in “U” shape

- Design and build a machine that will:
  - Bend the HDPE pipe
  - Insert a 1 inch grout line into the “U” of the bend
  - Band the bent pipe and grout line for spooling

Problem Statement Introduction

- Reduce the outer diameter of the pipe
- Allows for smaller diameter holes (approximately 4.5 inch diameter hole)
- Reduces the amount of grout used to 30 gallons
- 88% reduction from Single U-Loop
- Less grout=better efficiency



"Technical Data: Geothermal Grout." *CETCO*. Feb 2011. cetco.com/dpg. 29 Nov 2012.

Deliverables

- Geothermal Pipe Bending Machine
  - Fold HDPE SDR 21 pipe with a 4.5 inch outer diameter
  - 300 feet of pipe in approximately 30 minutes
  - Finished pipe will be banded in a “U” shape with a 1” grout line
  - Bands must break at 100 PSI
  - Operable by one person

Task List

- 1.0 -Testing
  - 1.1 Create test dies to test the pipe in the Instron machine
  - 1.2 Test the pipe
  - 1.3 Gather data and analyze to determine whether the dies are feasible
  - 1.4 Analyze the forces observed by the frame
  - 1.5 Test the amount of force required to push pipe
  - 1.6 Develop a drive train to apply the required force to the pipe
  - 1.7 Test pipe for forces required to keep in U-Shape
  - 1.8 Design band to apply forces to keep the pipe in the U-Shape

Task List

- 2.0 - Pipe Bending Machine
  - 2.1 Dies for bending pipe
  - 2.2 Die driving mechanism
  - 2.3 Design Frame
  - 2.4 Drive mechanism
  - 2.5 Grout line insert mechanism
  - 2.6 Bands for holding the pipe in "U" Shape
  - 2.7 Banding mechanism
  - 2.8 Mechanism for putting bent and banded pipe on reel

Task List

- 3.0 - Documentation
  - 3.1 Drafting
  - 3.2 Write design report
  - 3.3 Gantt charts and MS Project
  - 3.4 SolidWorks drawings

- 4.0 - Engineering Review and Approval
  - 4.1 Review and approve engineering
  - 4.2 Review, approve, and finalize drawings

- 5.0 - Fabricate and Procure System Materials
  - 5.1 Procure Materials
  - 5.2 Fabricate frame and full assembly

- 6.0 - Integration of system
  - 6.1 Deliver to Charles Machine Works
  - 6.2 Functional checks

Market Research

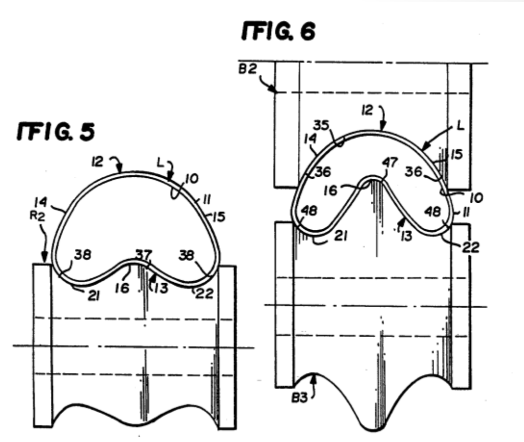
- 250,000 systems installed each year worldwide
  - 50,000 in United States in 2010
    - Potentially 45,000,000 feet of geothermal casing in U.S.
- Primary customers will be commercial heating and cooling contractors.
- Secondary customers will be end-users or home-owners/builders.

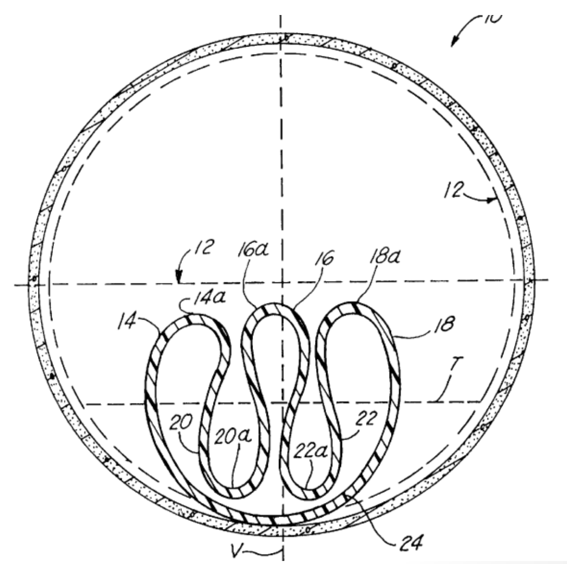
Patents

- ***Before 1992:*** **4986951, 4863365, 4998871, 5091137**
  - Relation or continuation of each other
  - Describes a method for bending circular cross sectional shaped pipe liner
  - Pipe liner is deformed through a process involving rollers and heat
  - Then placed in pipe for lining and is pressurized and heated to re-expand

Patents

- ***After 1992*: 5342570, 5861116, 6119501**
  - **5342570 , 6119501**
    - Describes a process to deform pipe liners to line new and old pipe into U-shape
    - Main differences include unusual shaped rollers and application of heat and cooling during the deformation process
  - **5861116**
    - Similar process that is described above but pipe liner is deformed into a “W” shape



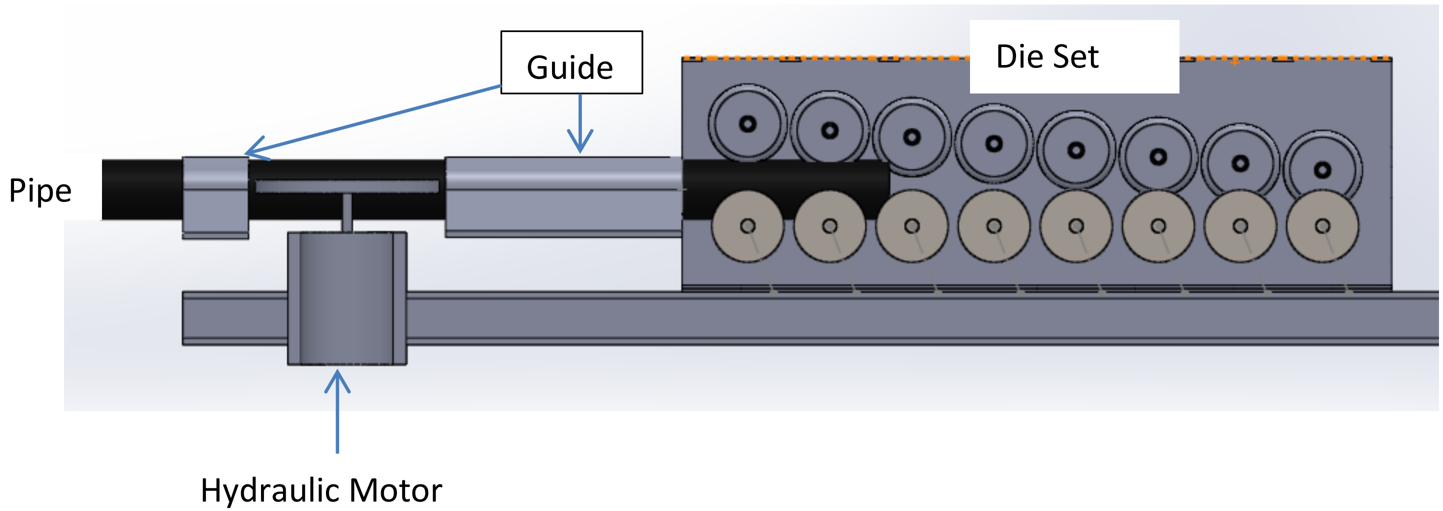


Design Concepts

- Design I
- Design II
- Both designs include:
  - Bending Geothermal HDPE pipe into “U”
  - Grout Line Incorporation
  - Banding Mechanism

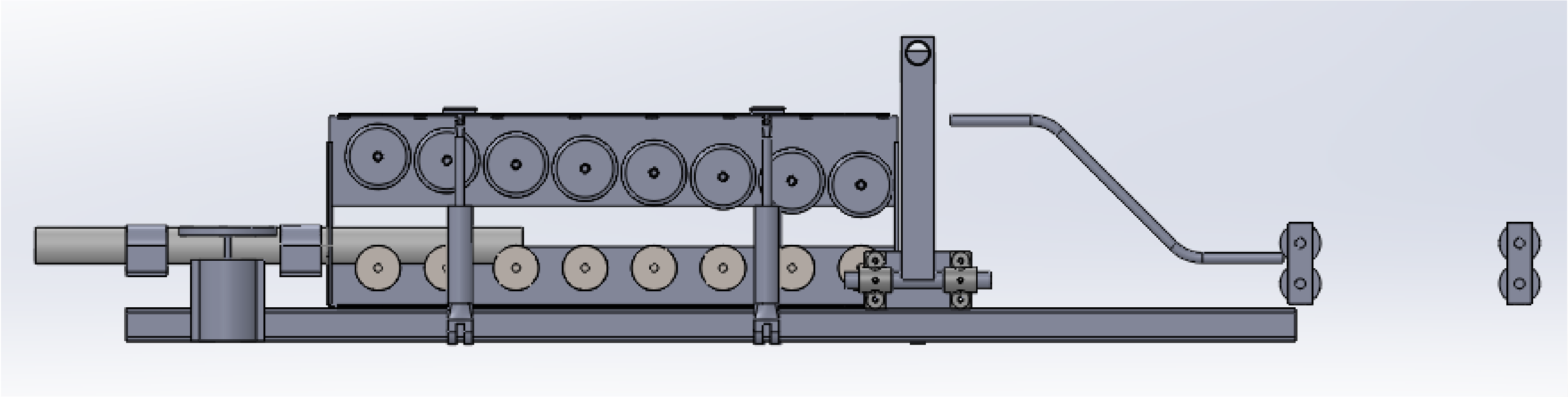
Design Concept I:

- Bending Geothermal HDPE pipe into “U”
- No vertical separation between the die sets



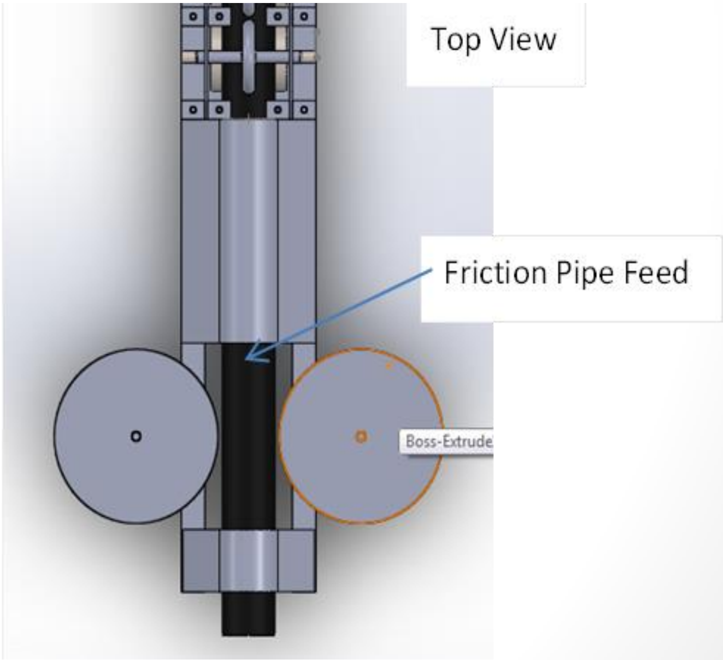
Design Concept II:

- Vertical separation between the die sets
- The pipe reel will assist in pulling the pipe through the die set
- Added cost of hydraulic cylinders



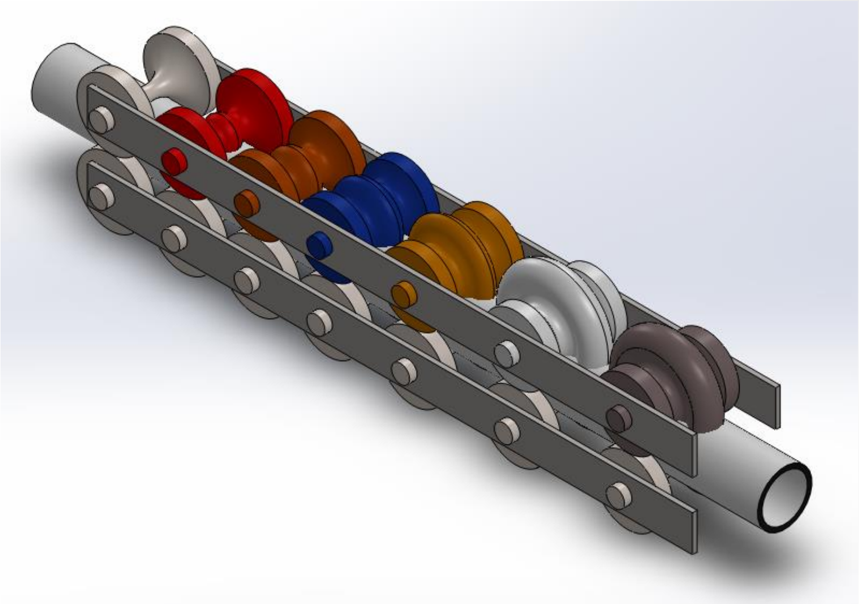
Hydraulic Motors

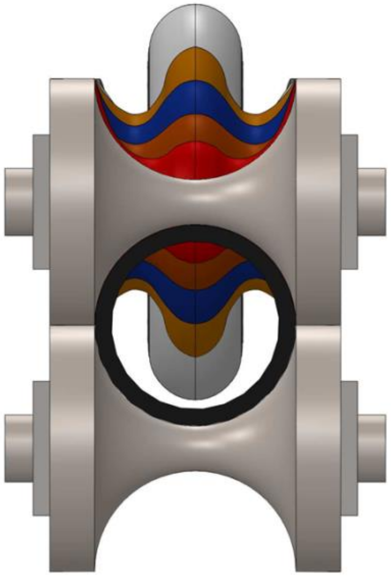
- Placed at the beginning of the machine to push the pipe into the dies
- Equipped with rubber disk to create friction
- 4 Options:
  - Design Concept 1: Slow or Fast
  - Design Concept 2: Slow or Fast



Dies

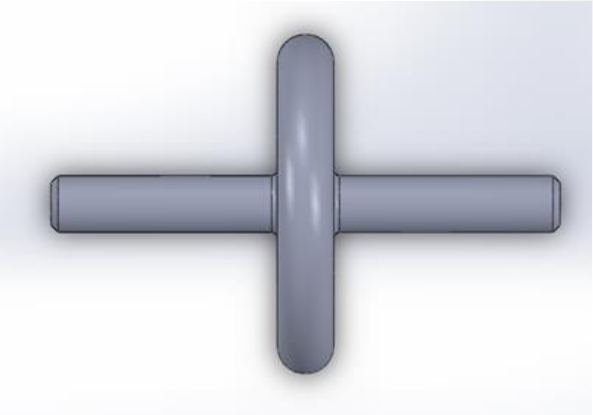
- **Initial Die Assembly**
  - 8 dies
  - 1 inch wide
  - 6 inch diameter

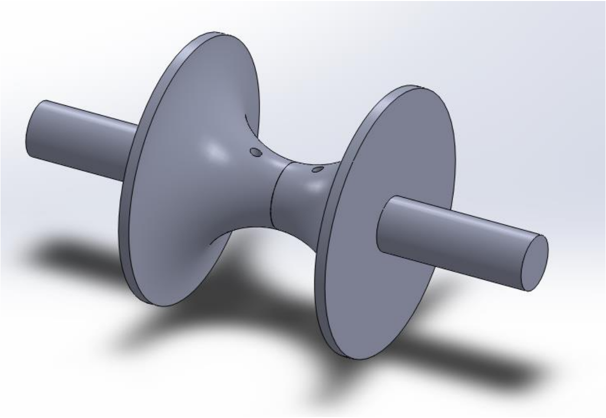




Dies

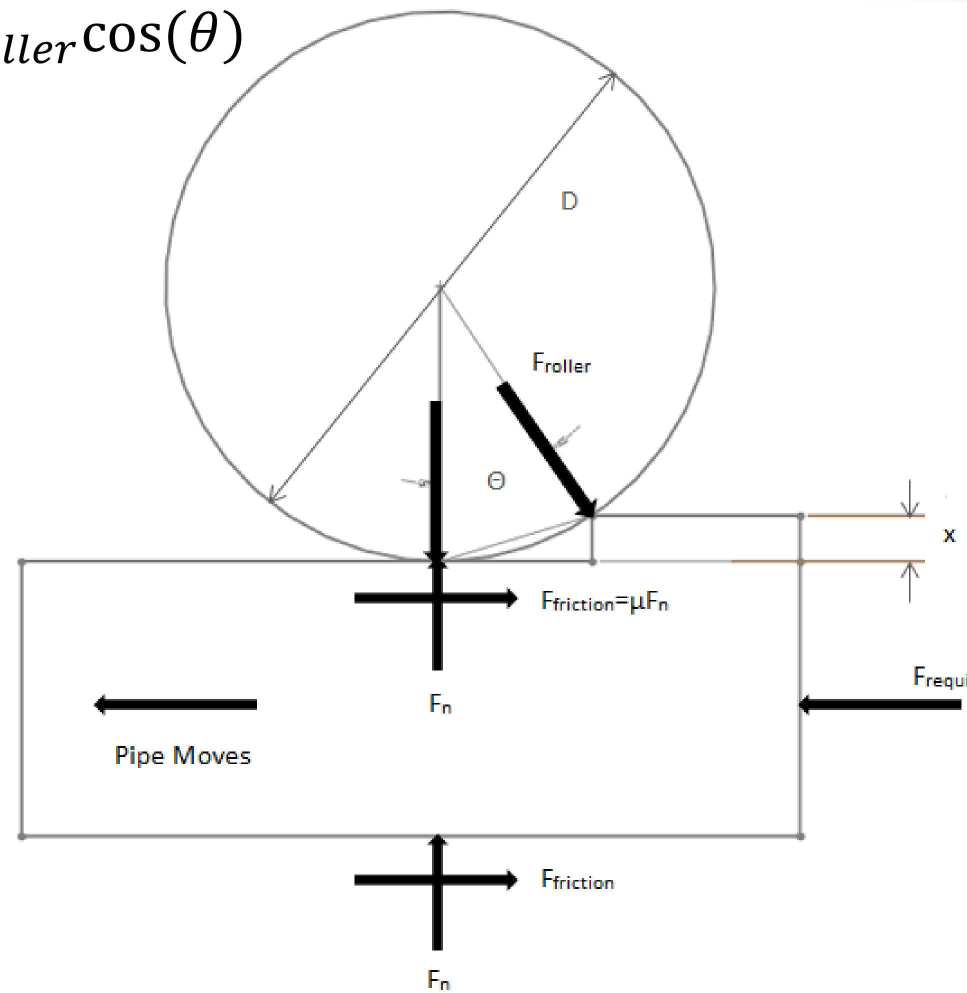
- ***Top Dies***
  - 8 dies
  - 1 inch wide
  - 7.5 or 6.0 inch diameter
  - Step down in increments of ½ inch for every 8.5 inches of linear travel
  - Reduces the height of the pipe by 3.75 inches (brings the top of the pipe in contact with the bottom)
- ***Bottom Dies***
  - A saddle for the 4.5 outer diameter pipe
  - Adjustable





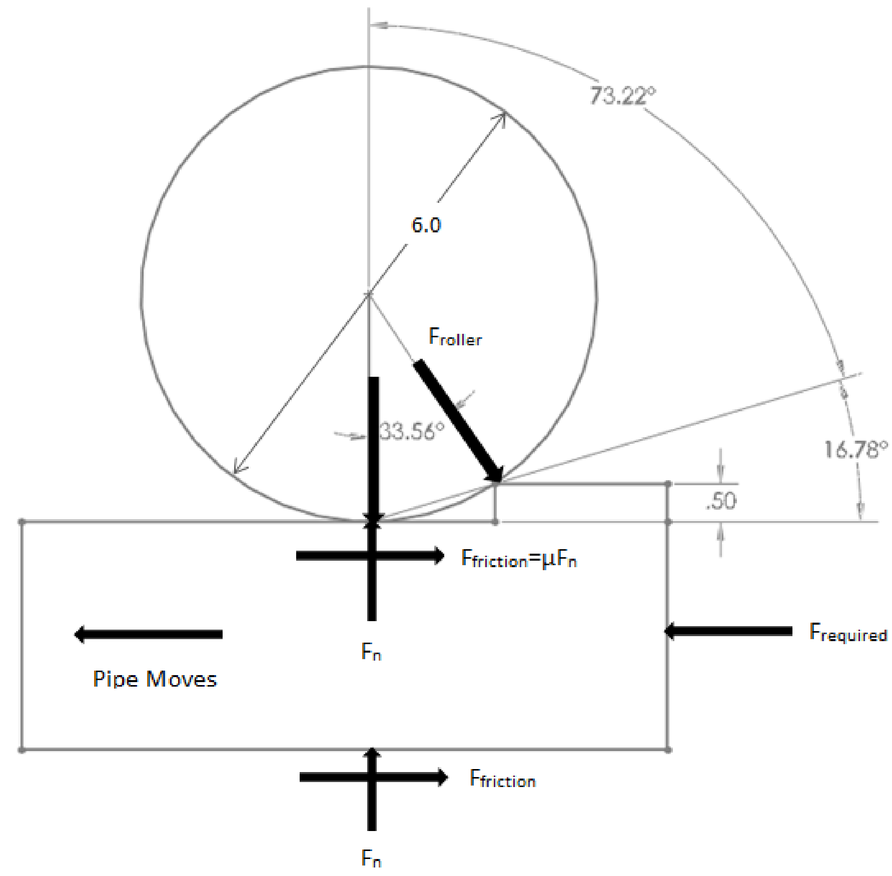
How to Calculate Forces Required to Move Pipe through System

- $F_{required} = 2 * F_n * \mu + F_{roller}\cos(\theta)$
- $F_{total} = \sum F_{required}$

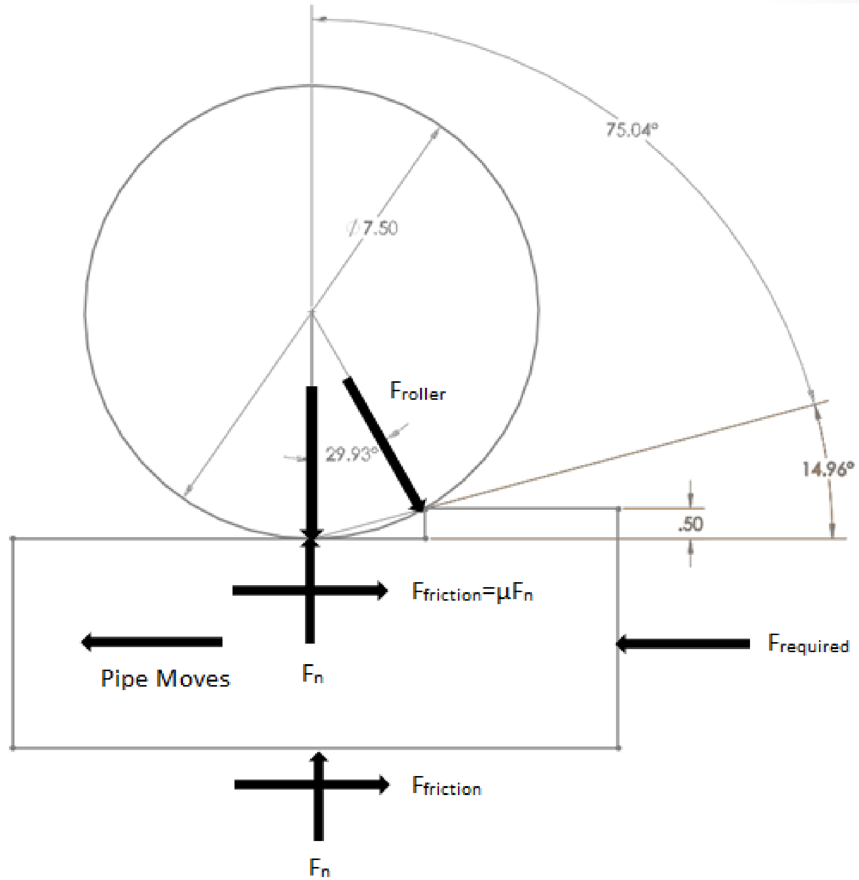


How to Calculate Forces Required to Move Pipe through System

- Design Concept I:

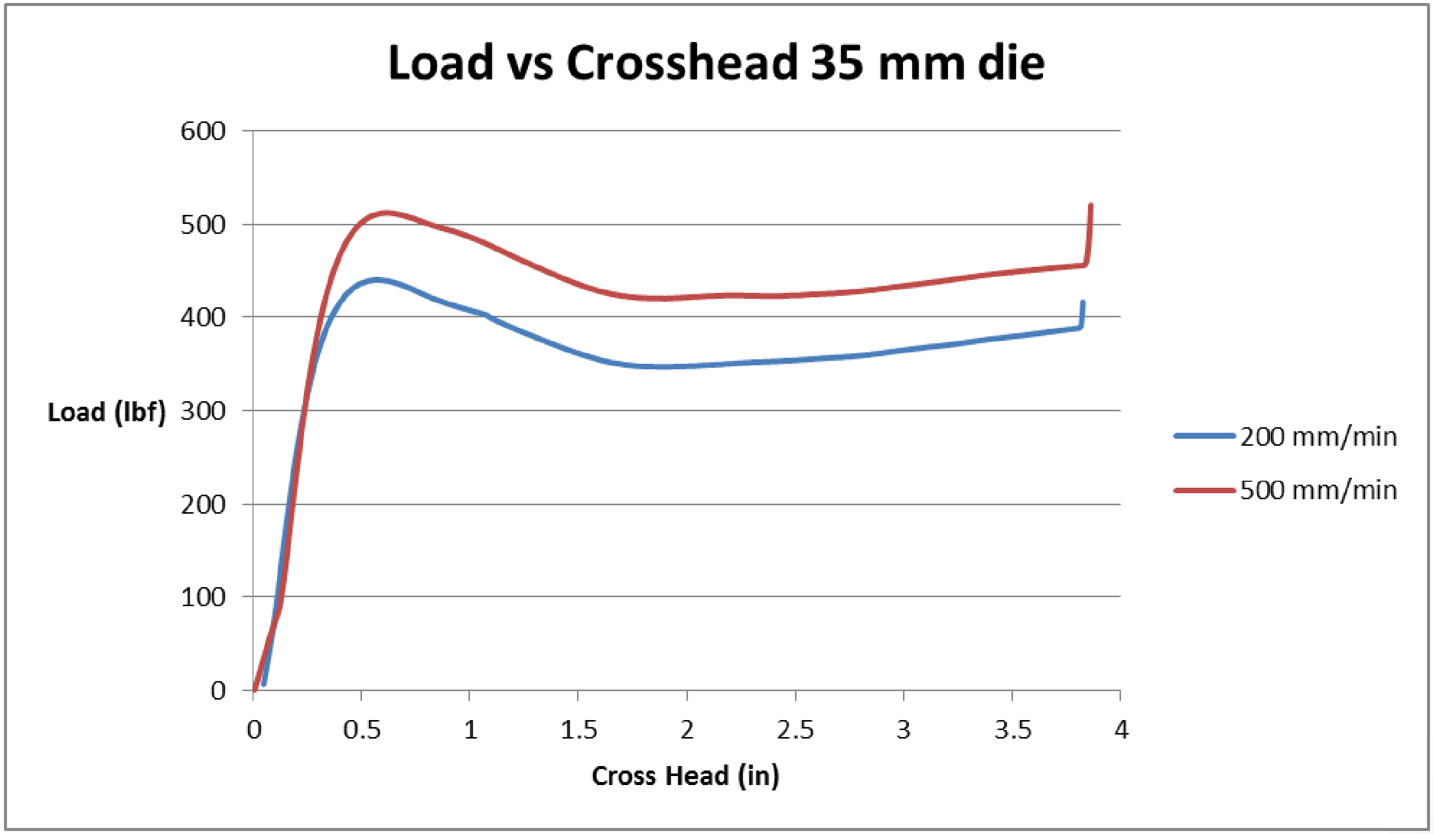


- Design Concept II:



How to Calculate Forces Required to Move Pipe through System

- Testing on the Instron Machine



How to Calculate Forces Required to Move Pipe through System

Force Required to Move Pipe	Equation	Values	Units
Coefficient of Friction (c_f)	User Input	0.3	
Angle of Force (θ)	User Input	33.56	degrees
Percent Change	User Input	84.56%	percent
Max Force	User Input	800	lb_f

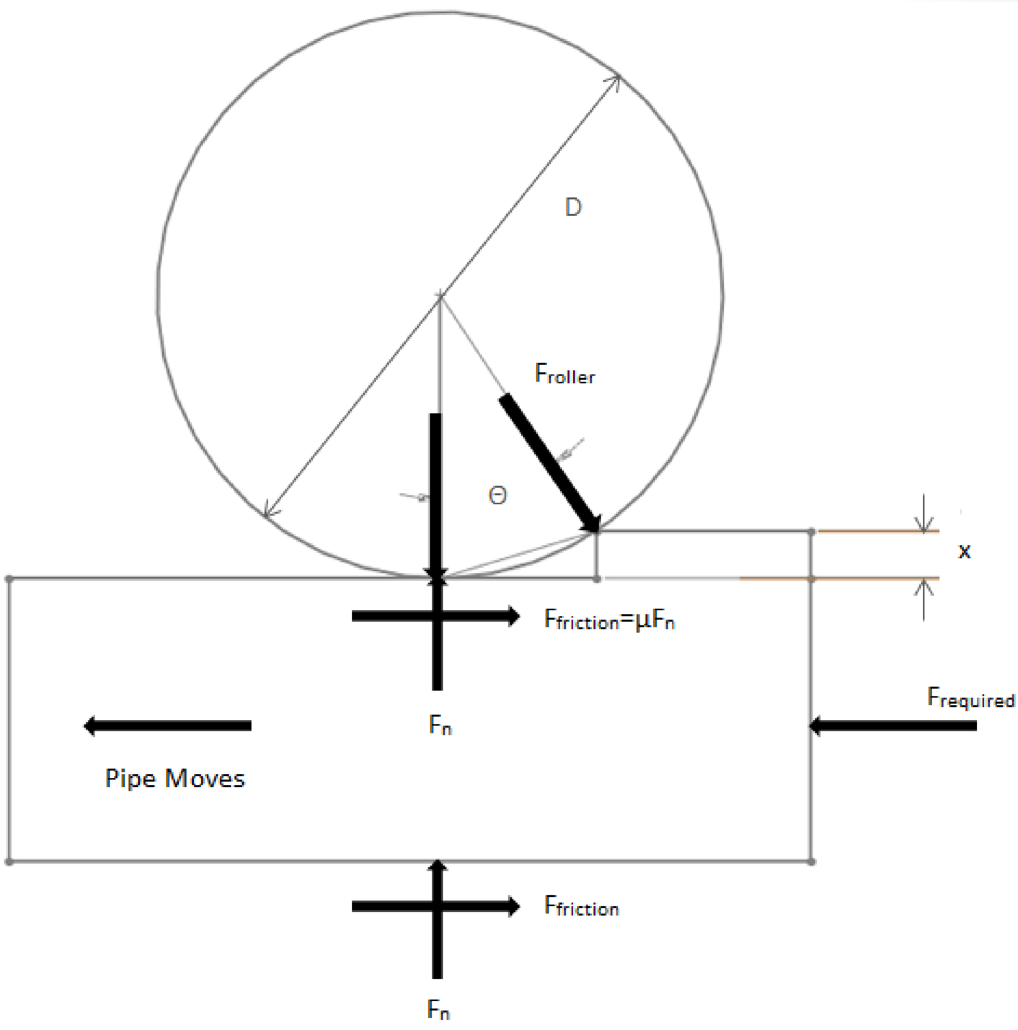
	Roller	Force (f)	Units	Equation	Force Required ($f_{required}$)	Units
Actual forces for each roller	1	321	lb_f	$f_{required} = 2 * f * c_f + f * \cos(\theta)$	460.092	lb_f
	2	505	lb_f		723.820	lb_f
	3	460	lb_f		659.321	lb_f
	4	421	lb_f		603.422	lb_f
	5	423	lb_f		606.289	lb_f
	6	427	lb_f		612.022	lb_f
	7	442	lb_f		633.522	lb_f
	8	455	lb_f		652.155	lb_f
	1-8	3454	lb_f		**4950.644**	**lb_f**

Force Required to Move Pipe through System

Force required to move pipe through system					
Design	**Speed of system**	**Actual Force**		**Force with 1.5 Safety Factor**	
Split Design	Fast (25 fpm)	5078.609	in*lb$_f$	**7617.913**	in*lb$_f$
	Slow (10 fpm)	4294.471	in*lb$_f$	**6441.707**	in*lb$_f$
Solid Design	Fast (25 fpm)	4950.644	in*lb$_f$	**7425.966**	in*lb$_f$
	Slow (10 fpm)	4186.264	in*lb$_f$	**6279.396**	in*lb$_f$

How To Calculate Torque

- Design Concept 1:
  - $F_{roller} = \frac{F_{total}/2}{\mu + \cos(\theta)}$
- Design Concept 2:
  - $F_{roller} = \frac{F_{total}/4}{\mu + \cos(\theta)}$
- $\tau = F_{roller} * \frac{d}{2}$



How to Calculate Torque

	Torque Required for Drive Motors	Equation	Values	Units
Split Design	Diameter of Roller	User Input	8	in
	Coefficient of Friction [between drive roller and pipe] (c_f)	User Input	0.8	
	Angle of Force between drive roller and pipe (θ)	User Input	5	degrees
	Total force for equal max force on all rollers	From Force on Rollers Sheet	9173.167	lb_f
	Total force for actual forces for each roller	From Force on Rollers Sheet	4950.644	lb_f
	Total force for % of actual forces for each roller	From Force on Rollers Sheet	4186.264	lb_f
	Max Force	From Force on Rollers Sheet	800	lb_f
	Percent Change	From Force on Rollers Sheet	84.56%	Percent
	Normal Force exerted by roller (Max)	$f_n = \frac{f_{roller}}{\mu + \cos\theta}$	1276.750	lb_f
	Normal Force exerted by roller (Actual)		689.046	lb_f
	Normal Force exerted by roller (% Actual)		582.657	lb_f
	Torque of motor to produce force required (Max)	$\tau = f_n * d$	**5107.000**	**in*lb_f**
	Torque of motor to produce force required (Actual)		**2756.184**	**in*lb_f**
	Torque of motor to produce force required (% Actual)		**2330.629**	**in*lb_f**

Torque Required for Drive Motor

Torque of motor to produce force required					
Design	**Speed of system**	**Actual Torque**		**Torque with 1.5 Safety Factor**	
Split Design	Fast (25 fpm)	2827.427	in*lb_f	**4241.140**	in*lb_f
	Slow (10 fpm)	2390.872	in*lb_f	**3586.308**	in*lb_f
Solid Design	Fast (25 fpm)	5512.369	in*lb_f	**8268.554**	in*lb_f
	Slow (10 fpm)	4661.259	in*lb_f	**6991.889**	in*lb_f

Drive System

- Three Options
  - Direct Drive
  - Gear Driven
  - Chain Driven

Drive System

Drive System	Design	Speed of System	Pump Series	Displacement (in^3)	Torque of Pump ($in*lb_f$)	RPM	PSI	Ratio	Final Torque (in*lbf)	Price
Direct Drive	Split	Fast (25 fpm)	4000	12.5	3860	12	2500	1:1	3860	$800.00
		Slow (10 fpm)	4000	30	3825	5	1000	1:1	3825	$850.00
	Solid	Fast (25 fpm)	6000	49	12539	12	2000	1:1	12539	$1,300.00
		Slow (10 fpm)	6000	45	11121	5	2000	1:1	11121	$1,300.00
Gear Drive or Chain Driven	Split	Fast (25 fpm)	4000	24	6000	14	2000	6:5	7200	$850.00
		Slow (10 fpm)	2000	11.9	2720	7	2000	3:4	3808	$400.00
	Solid	Fast (25 fpm)	4000	30	8375	19	2000	3:2	13260	$800.00
		Slow (10 fpm)	2000	24	5880	6	2000	6:5	7056	$550.00

Die Assembly Weight

Die Support	Length (in)	Height (in)	Area (in^2)	Weight .25" Steel Plate (lb/ft^2)	Weight (lb)
Bottom Plate	70	11.5	805	10.2	57.021
Top Plate	70	11.5	805	10.2	57.021
Right Side Plate (Top)	70	11.13	779.1	10.2	55.186
Right Side Plate (Bottom)	70	7.38	516.6	10.2	36.593
Left Side Plate (Top)	70	11.13	779.1	10.2	55.186
Left Side Plate (Bottom)	70	7.38	516.6	10.2	36.593
				Top Total Weight	**167.393**
				Bottom Total Weight	**130.206**
				Total Weight of Die Support	**297.599**

Die	Die				
	Radius$_1$ (in)	Radius$_2$ (in)	Diameter of Saddle (in)	Thickness (in)	Volume (in^3)
Top	7.5	1.25	---	1	42.951
Bottom	6	1.25	4.5	2.5	39.810

Shaft	Shaft		
	Shaft Diameter (in)	Shaft length (in)	Shaft Volume (in^3)
Top	1.25	10	12.272
Bottom	1.25	10	12.272

Assembly	Die and Shaft		
	Volume (in^3)	Density (lb/in^3)	Total Weight 1 Die (lb)
Top	55.223	0.284	**15.661**
Bottom	52.082	0.284	**14.770**

Die Assembly Weight –Total

Total Die Assembly	Total Weight of 1 Die (lb)	Number of Dies	Total Weight of Dies (lb)	Total Weight of Die Support (lb)	Total Weight (lb)
Top	15.66128839	8	125.290	167.393	292.684
Bottom	14.7703351	8	118.163	130.206	248.369
Assembly	---	16	243.453	297.599	**541.052**

Shaft Design

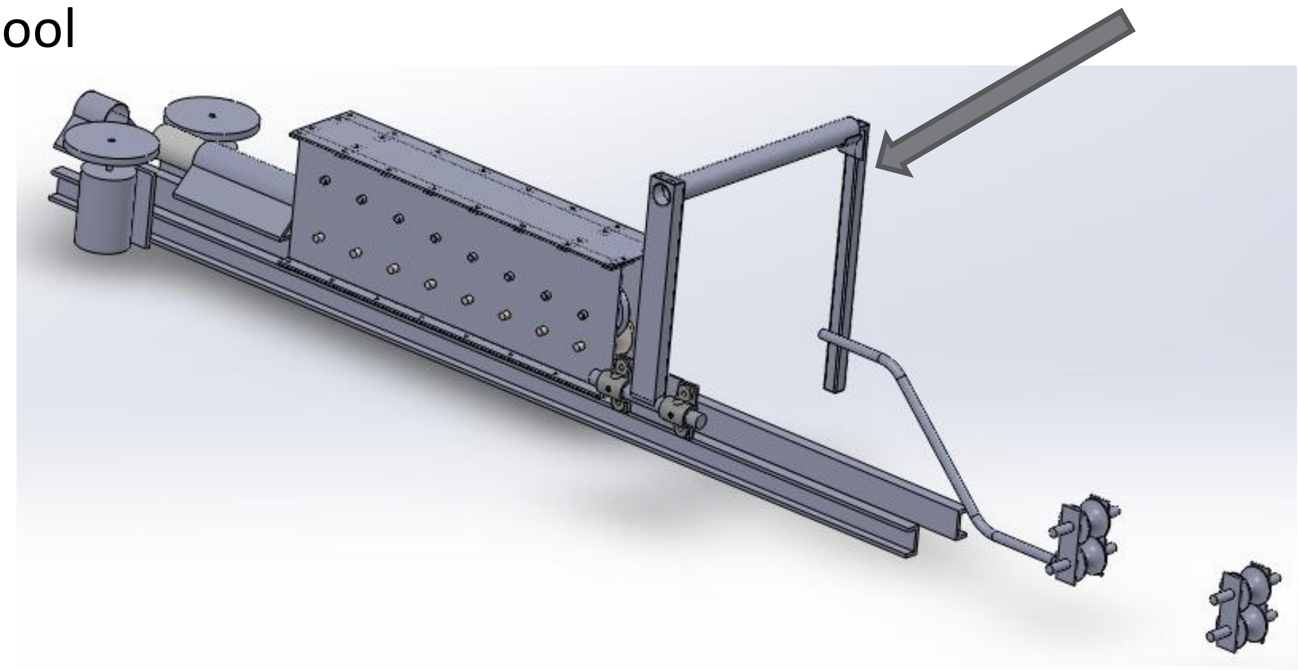
Shaft Design	Equation	Values	Units
Distance from force to center of bearing	User Input	4.25	in
Force on shaft	User Input	800	lb_f
Diameter of shaft	User Input	1.25	in
To calculate stress (σ) for shaft			
Moment (M)	(Force on shaft) * Distance	3400	$in*lb_f$
Centroid (C)	(Diameter of shaft)/2	0.625	in
Moment of Inertia (I)	$\frac{\pi * diameter^4}{64}$	0.120	in^4
Bending Stress (σ)	$\frac{M * c}{I}$	**17731.643**	**psi**

Bearing Analysis

Bearing Analysis	Equation	Values	Units
Diameter of Roller	User Input	1.5	in
Expected life of Bearing	User Input	10	years
Force on shaft	User Input	800	lb_f
Velocity (given)	(10ft/min)*12	120	in/min
Radius of Roller	d/2	0.75	in
Circumference of Roller	2*pi()*r	4.712	in
Number of Revolutions per minute	Velocity/Circumference	25.465	rev/min
Number of hours operated per year	(# hour/week)*(# weeks/year)	124800	min/year
Revolutions per Life	(rev/min)*(# min operation/year)*(# years/life)	31780059	rev/life
Force on bearings	(Force on shaft)/(# bearings supporting shaft)	400	lb_f
To calculate C_{10} for bearing			
X_D	(revolutions/life)/(revolutions rated life)	31.780	
R_D	$(\text{reliability})^{.5}$	0.995	
F_D	(Force on shaft)/(2 bearings)	400	lb_f
x_0	Look up value for bearing type	0.02	
θ	Look up value for bearing type	4.459	
a	Look up value for bearing type	3	
b	Look up value for bearing type	1.483	
a_f	Assume value	1.2	
C_{10}	$C_{10} = a_f * F_D \left[\frac{x_D}{x_0 + (\theta - x_0) * (1 - R_D)^{-1/b}} \right]^a$	**2894.981**	

Grout Line

- After the pipe travels through the dies, a 1 inch grout line will be inserted
- Spool will be lifted above the machine via hydraulic lift or wench
- Further analysis will be done once we acquire a diameter of a spool



Banding Mechanism

- Bands will be incorporated to ensure that the “U” shape is maintained
- Bands must break at 100 psi
- Several Options
  - Slow: Hand zip ties applied manually
  - Fast: Dynaric D2400 Automatic Strapping Machine
  - Slow or Fast: continuous spiral

Safety

- OSHA regulations
  - 1910.212(a)(4): Barrels, containers, and drums. Revolving drums, barrels, and containers shall be guarded by an enclosure which is interlocked with the drive mechanism, so that the barrel, drum, or container cannot revolve unless the guard enclosure is in place.
  - 1910.212(a)(1): Types of guarding. One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks. Examples of guarding methods are-barrier guards, two-hand tripping devices, electronic safety devices, etc.

Safety

- To comply with OSHA standards:
  - Emergency kill switches
  - Hydraulic line shielding
  - Guards on moving parts
  - Power lockout switch

Proposed Budget

						Direct Drive				Gear or Chain Drive			
						Not Split		Split		Not Split		Split	
		Quantity	Type	Size	Cost	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast
Motors	Drive	2	Hydraulic	Depends on design and speed	Depends on Motor Size	$2,600.00	$2,600.00	$1,700.00	$1,600.00	$1,100.00	$800.00	$800.00	$1,700.00
	Grout Arm Lift	1	Hydraulic			$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
	Spool	1	Hydraulic			$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Cylinders	Die Set	4	Tie Rod Ends	2"x1" 2000 psi	$50.00	-	-	$200.00	$200.00	-	-	$200.00	$200.00
	Spool Lift	2	Tie Rod Ends	To Be Determined	$75.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00
	Press Split	4	Tie Rod Ends	To Be Determined	$50.00	-	-	$200.00	$200.00	-	-	$200.00	$200.00
Bearings	Die Set	16	4 bolt flange	1"	$42.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00	$672.00
	Spools	24	4 bolt flange	1.25"	$51.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00	$1,224.00
	Grout Lift	2	pillow block	2"	$110.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00	$220.00
Fasteners	Nuts/Bolts				$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00
Bander	Machine				$5,000.00	-	$5,000.00	-	$5,000.00	-	$5,000.00	-	$5,000.00
Hydraulics	Pump				$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00
	Hose and Fittings				$1,500.00	$750.00	$750.00	$1,500.00	$1,500.00	$750.00	$750.00	$1,500.00	$1,500.00
	Reservoir				$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00
	Heat Exchanger	Estimated Here, All To Be Determined			$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00
Control Switches					$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00
Safety					$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00	$500.00
Electronics					$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Gears/Sprockets					$15.00	-	-	-	-	$90.00	$90.00	$90.00	$90.00
Chain					$40.00	-	-	-	-	$40.00	$40.00	$40.00	$40.00
					Total	**$12,966.00**	**$17,966.00**	**$13,216.00**	**$18,116.00**	**$11,596.00**	**$16,296.00**	**$12,446.00**	**$18,346.00**

Proposed Budget

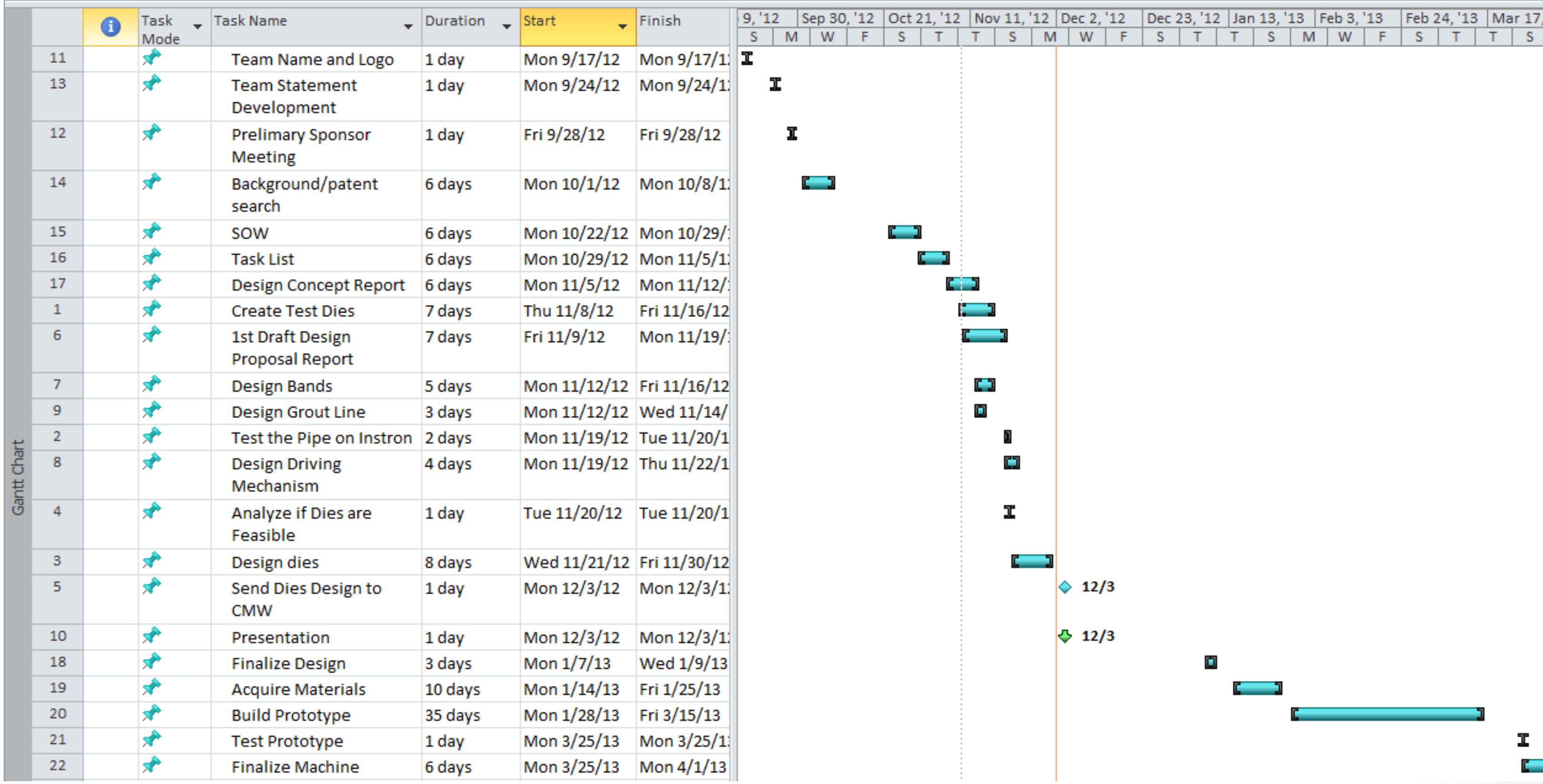
Material	Size	Length Needed		Price Per Foot	Price
		In inches	In Feet		
Round Stalk	1 inch	72	6	$4.00	$24.00
	1.25 inch	132	11	$4.00	$44.00
	5 inch	16	1.3	$166.90	$222.53
	6 inch	40	3.3	$276.37	$921.23
Flat Plate	1/4 inch	33 sq. ft.	33	$12.86	$424.38
	1/2 inch	2 sq. ft.	2	$27.56	$55.12
	1 inch	3.5 sq. ft.	3.5	$78.51	$274.79
Welded Round Pipe	3 inch	36	3	$9.41	$28.23
	5 inch	12	1	$17.85	$17.85
Square Tubing	2x2x.25	36	3	$6.51	$19.53
	4x2x.25	30	2.5	$14.31	$35.78
	4x4	288	24	$17.96	$431.04
C-Channel	6x2x.25	40 foot	7.24	$10.66	$77.18
Angle Iron	.5x.5x.125	160	13.3	$1.21	$16.13
				Total	**$2,591.79**

Proposed Budget

Drive System	Design	Speed of System	Total Cost
Direct Drive	Split	Fast (25 fpm)	**$20,707.79**
		Slow (10 fpm)	**$15,807.79**
	Solid	Fast (25 fpm)	**$20,557.79**
		Slow (10 fpm)	**$15,557.79**
Gear Drive or Chain Driven	Split	Fast (25 fpm)	**$20,937.79**
		Slow (10 fpm)	**$15,037.79**
	Solid	Fast (25 fpm)	**$18,887.79**
		Slow (10 fpm)	**$14,187.79**

Project Timeline

	Task Mode	Task Name	Duration	Start	Finish
11		Team Name and Logo	1 day	Mon 9/17/12	Mon 9/17/1
13		Team Statement Development	1 day	Mon 9/24/12	Mon 9/24/1
12		Prelimary Sponsor Meeting	1 day	Fri 9/28/12	Fri 9/28/12
14		Background/patent search	6 days	Mon 10/1/12	Mon 10/8/1
15		SOW	6 days	Mon 10/22/12	Mon 10/29/
16		Task List	6 days	Mon 10/29/12	Mon 11/5/1
17		Design Concept Report	6 days	Mon 11/5/12	Mon 11/12/
1		Create Test Dies	7 days	Thu 11/8/12	Fri 11/16/12
6		1st Draft Design Proposal Report	7 days	Fri 11/9/12	Mon 11/19/
7		Design Bands	5 days	Mon 11/12/12	Fri 11/16/12
9		Design Grout Line	3 days	Mon 11/12/12	Wed 11/14/
2		Test the Pipe on Instron	2 days	Mon 11/19/12	Tue 11/20/1
8		Design Driving Mechanism	4 days	Mon 11/19/12	Thu 11/22/1
4		Analyze if Dies are Feasible	1 day	Tue 11/20/12	Tue 11/20/1
3		Design dies	8 days	Wed 11/21/12	Fri 11/30/12
5		Send Dies Design to CMW	1 day	Mon 12/3/12	Mon 12/3/1
10		Presentation	1 day	Mon 12/3/12	Mon 12/3/1
18		Finalize Design	3 days	Mon 1/7/13	Wed 1/9/13
19		Acquire Materials	10 days	Mon 1/14/13	Fri 1/25/13
20		Build Prototype	35 days	Mon 1/28/13	Fri 3/15/13
21		Test Prototype	1 day	Mon 3/25/13	Mon 3/25/1
22		Finalize Machine	6 days	Mon 3/25/13	Mon 4/1/13



Questions?