Automated Powder Coat Machine

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Bachelor of Science

in Mechanical Engineering Technology

by

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ABSTRACT

Although there are many types of powder coating machines out in industry today, there really weren't any that were tailored to the needs of Matdan Corporation. Matdan Corporation needed a machine that was flexible enough to cover their wide range of products without breaking the bank.

The following report covers the research, design, fabrication, and implementation of a machine deemed acceptable by the University of Cincinnati - Mechanical Engineering Technology professors to fulfill the requirements of the Senior Design project.

Keywords: Powder Coat Machine, Automation

INTRODUCTION

PROBLEM STATEMENT

There is a need to automate a manual powder coating process at a company I co-oped for. Currently it’s a two-step process, the operator will manually load parts onto racks, and then the operator will load the rack into the powder coat booth and manually paint the parts. This is where the problem lies, the manual painting of the parts is causing problems with quality. By designing a machine to do the actual painting, quality can be improved by not replacing the worker. The worker will still be needed to manually load the parts onto the racks and then load the racks into the machine.

NORDSON OSCILLATOR

Nordson makes a powder coat system that could have worked for this specific application, however it did not have a rotational axis to allow for 360 degree coverage. Also the system was extremely expensive. This system could have been plug and play into the current powder coat booth but the cost made it unattractive for the job.

Figure 1 - Nordson Oscillator

SURVEY ANALYSYS, CUSTOMER FEATURES, QFD

SURVEY ANALYSIS

Five surveys were administered to employees that either overlooked the painting process, or were project engineers, or in charge of quality control throughout the company. From the five surveys all were consistently “Somewhat Dissatisfied” when it came to the current painting operation. The next consensus was about machine efficiency, all applicants rated this as “Very Important”. Lastly all applicants thought machine safety was “Very Important”. There was also a section about key aspects required of the machine. This was a fill in section. Consensus shows a need for a machine with high efficiency, high quality in the parts, and the machine is safe for the operator. Below is a figure of the survey administered.

Customer Satisfaction Survey

1. **On a scale of 1-4 how satisfied are you with your current paintint operation?**
   - 4 - Completely satisfied
   - 3 - Somewhat satisfied
   - 2 - Somewhat dissatisfied
   - 1 - Completely dissatisfied
2. **How important is machine efficiency to you?**
   - Very important
   - Somewhat important
   - Not very important
   - Not important at all
3. **How important is a short cycle time to you?**
   - Very important
   - Somewhat important
   - Not very important
   - Not important at all
4. **How important is machine safety to you?**
   - Very important
   - Somewhat important
   - Not very important
   - Not important at all
5. **Overall what are few key aspects you are looking for in this new robot?**

Figure 2 - Customer Survey

House of Quality and Customer Features

From the information gathered from the surveys and an interview with the owner of the company, Dave Arand, the following customer requirements and engineering requirements were determined. It was decided that the machine be flexible enough to paint many different parts, it had to be intuitive for the operator, the machine had to be more efficient than a human operator, it had to cycle faster or equal to a human operator, it had to be safe for the operator, and lastly it had to be able to be implemented in the US or China facilities.

			Engineering Requirements (units)										
		Importance wt.	Number of steps to operate (# steps)	Efficiency (Good/Total %)	Cycle Time (S)	Reprogrammable (Yes/No)	Voltage (110 and 220)	Guards/Safety Stops in place (Yes/No)					
	Customer Requirements		1	2	3	4	5	6	7	8	9	10	11
1	System is flexible for different parts	0.20				9							
2	Intuitive for the operator	0.15	9			1							
3	More Efficient than Human operator	0.25	1	9									
4	Cycles faster than or equal to Human operato	0.20		1	9								
5	System is safe for the operator	0.15						9					
6	Can be used in China and USA	0.05					9						
7													
8													
9													
10													
	Total Importance	1.00	1.6	2.5	1.8	1.95	0.5	1.4					

Figure 3 - House of Quality

CONCEPT DESIGN

VERTICAL AXIS CONCEPT

The vertical axis concept below was created and approved. Since this is a precision machine, accuracy and control are key features of the vertical axis. This is why a stepper motor and XL timing belt are needed for the application. This combination will allow for the most control and precision without increasing the price by going with a servo motor. The vertical axis will need to cover the full length of the rack which is 23in. below is the concept design for the vertical axis.

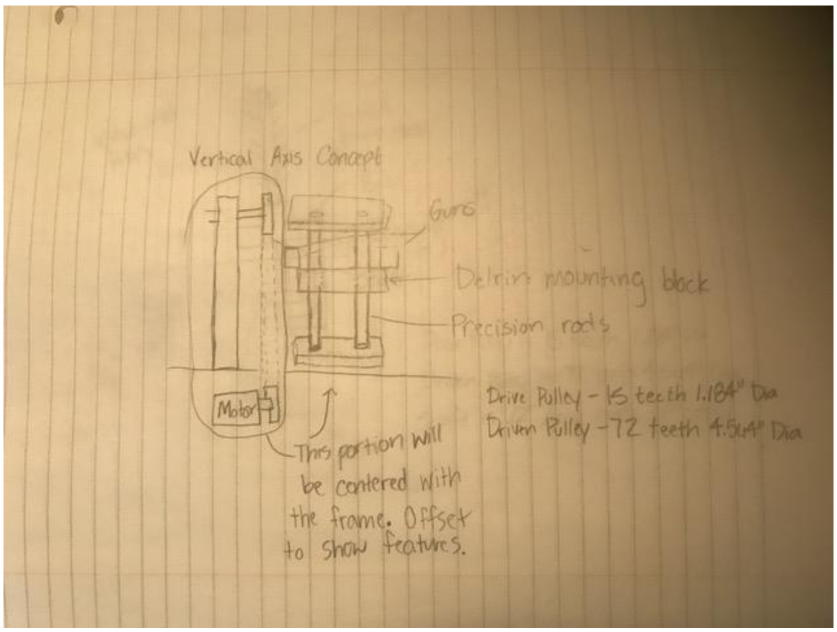


Figure 4 - Vertical Axis Concept Design

ROTATIONAL AXIS CONCEPT

The rotational axis needs to be able to rotate 360 degrees to allow for full paint coverage of the parts. This system will also use a 15 teeth timing pulley as the drive pulley and a 72 teeth timing pulley as the driven pulley. This ratio will allow for greater control and accuracy throughout the cycle. In this system the weight of the rack and base will be loaded axially which will cause the torque required to be minimal. Below is a picture detailing the concept drawn out.

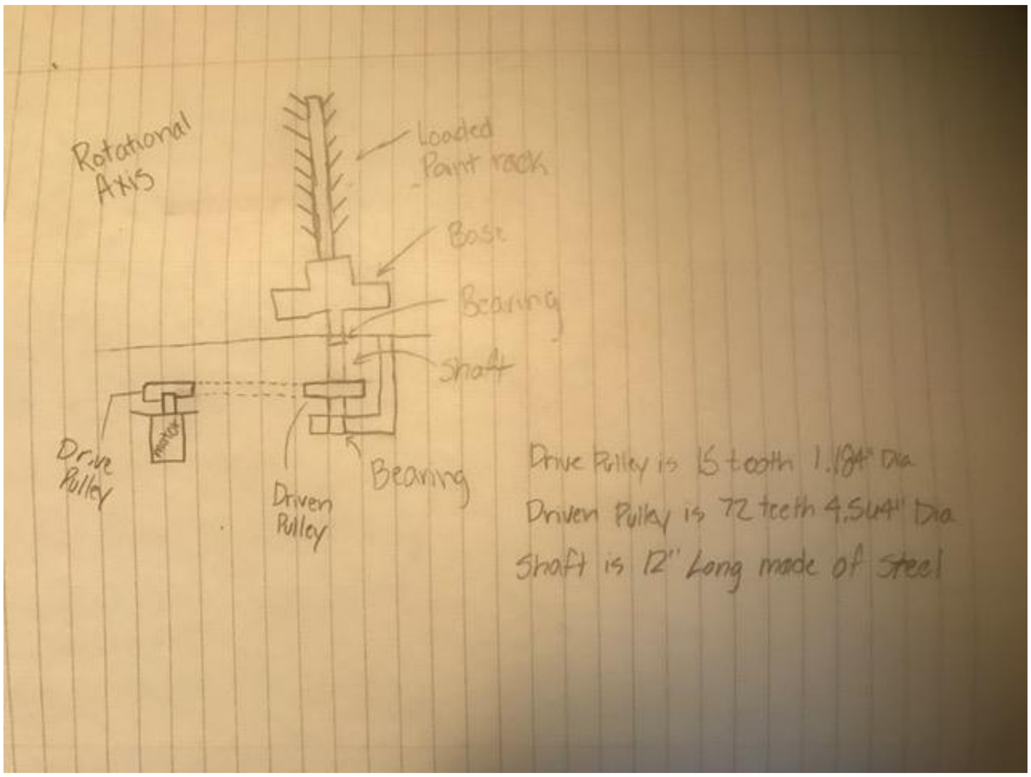
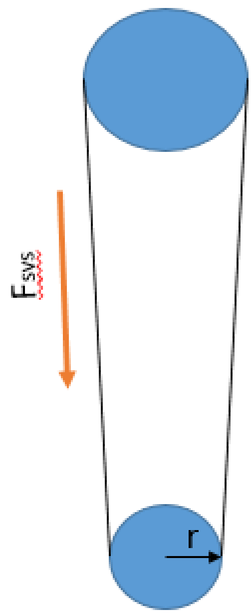


Figure 5 - Rotational Axis Concept Design

LOADING CALCULATIONS

VERTICAL AXIS LOAD CALCULATION

The loads in the vertical axis come from the weight of the Delrin slider block added to the weight of the two paint guns. These are the two forces acting downward on the belt. The motor must be able to provide enough torque to overcome these forces. Shown below is the torque calculation.



$W_{delrin} = 1.682 \text{ Lb}$

$W_{gun} = 1.575 \text{ Lb}$

$F_{sys} = W_{delrin} + 2*W_{gun}$

$F_{sys} = 1.682 \text{ Lb} + 2*(1.575\text{Lb})$

$F_{sys} = 2.861 \text{ Lb}$

$$\tau_{motor} = F * r$$

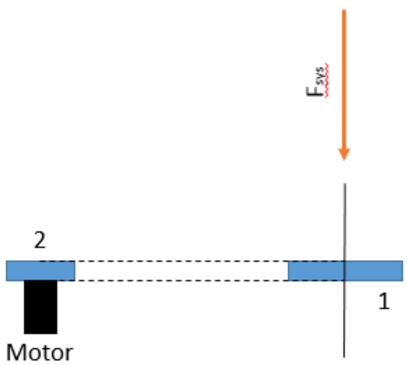
$$\tau_{motor} = 2.861Lb * \frac{1.184}{2} in$$

$$\tau_{motor} = 1.694 \text{ in - lb}$$

Figure 6 - Vertical Axis Load calculations

ROTATIONAL AXIS LOAD CALCULATION

The rotational axis has the weight of the rack loaded with parts to mimic worst case scenario, as well as the weight of the base piece already existing made out of Delrin, as well as the weight of the shaft to overcome. By using the weights of these pieces loaded axially to the driven pulley, the force can found on the belt which can then be used to find the torque required of the motor to overcome the combined inertia of these members. Shown below is the free body diagram with calculations.



$$F_{sys} = \sum W$$

$$F_{sys} = 7.606Lb + 1.706Lb + 0.3755Lb$$

$$F_{sys} = 9.6875\ Lb$$

$$m_{sys} = \frac{F_{sys}}{g}$$

$$m_{sys} = \frac{9.6875\ Lb}{32.2\ ft/s^2}$$

$$m_{sys} = 0.301\ \text{Slug}$$

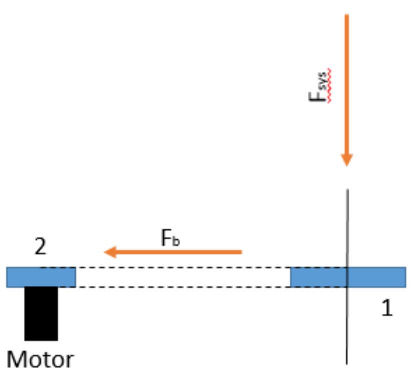
$$m_{sys} = 0.301\ Slug * 12\ in$$

$$m_{sys} = 3.612\ \frac{lb * s^2}{in}$$

$$I_{disk} = \frac{1}{2} m_{sys} * r_1^2$$

$$I_{disk} = \frac{1}{2} 3.612\ \frac{lb * s^2}{in} * 2.282\ in^2$$

$$I_{disk} = 9.4\ lb * s^2 * in$$



$$\alpha = \frac{\omega}{t}$$

$$\alpha = \frac{1 \frac{rad}{s}}{2s}$$

$$\alpha = 0.5\ \frac{rad}{s^2}$$

$$\tau_1 = I * \alpha$$

$$\tau_1 = 9.4\ lb * s^2 * in * 0.5\ \frac{rad}{s^2}$$

$$\tau_1 = 4.7\ \text{in lb}$$

$$F_b = \frac{\tau_1}{r_1}$$

$$F_b = \frac{4.7\ in * lb}{2.282\ in}$$

$$F_b = 2.059\ lb$$

$$\tau_2 = F_b * r_2$$

$$\tau_2 = 2.059 lb * 0.592\ in$$

$$\tau_2 = 1.21\ in\ lb$$

Figure 7 - Rotational Axis Load Calculations

FINITE ELEMENT ANALYSIS

VERTICAL AXIS FINITE ELEMENT ANALYSIS

The drive pulley in the vertical axis is made out of steel. It is a purchased standard part designed specifically for XL timing belts. After running finite element analysis on the part from the loads calculated the pulley will see a maximum stress of 76 psi. This comes out to a safety factor of 15 for steel.

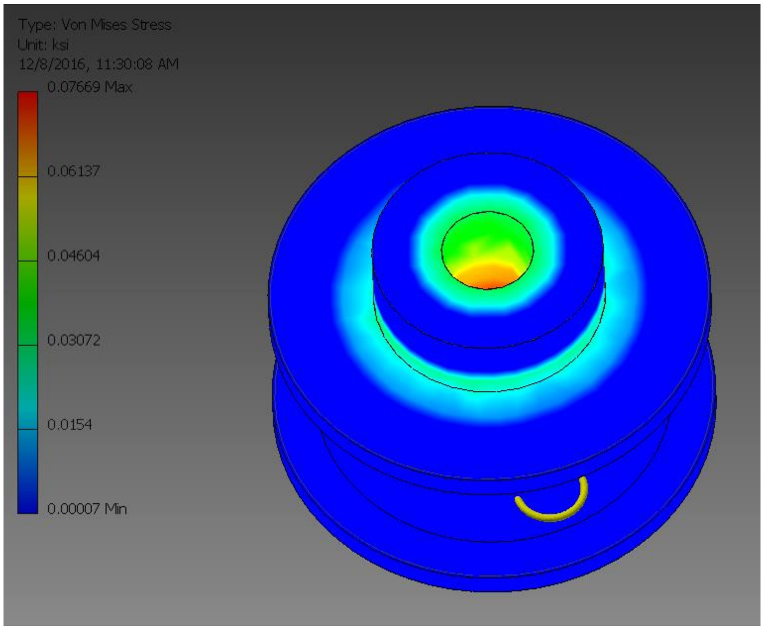


Figure 8 - FEA Analysis of Drive Pulley for Vertical Axis

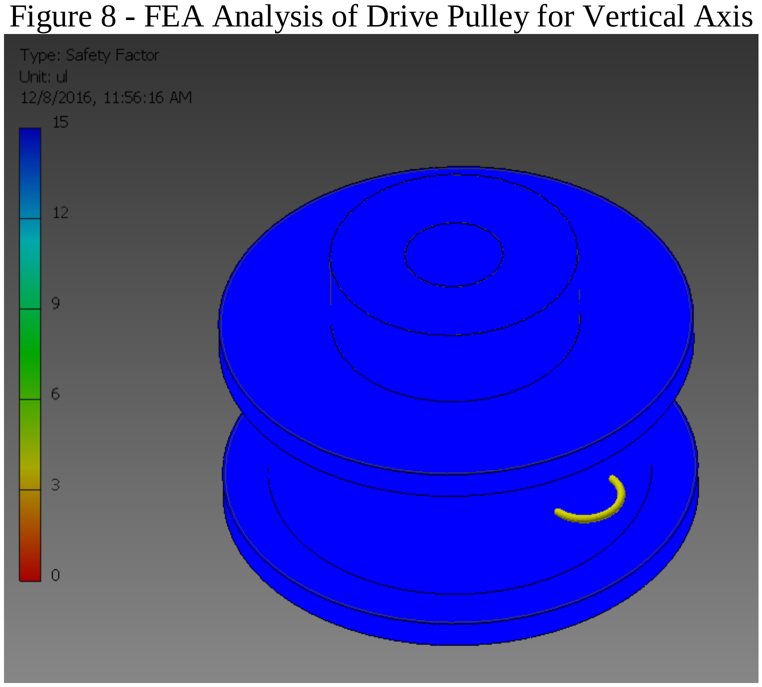


Figure 9 - Safety Factor of Drive Pulley for Vertical Axis

Rotational Axis Finite Element Analysis

The rotational axis has the same setup as the vertical axis. Both pulleys are made out of steel. The forces were applied each pulley using FEA analysis in Autodesk Inventor. Both the drive pulley and driven pulley had a safety factor of 15. The shaft was also tested and came out with a factor of safety of 15.

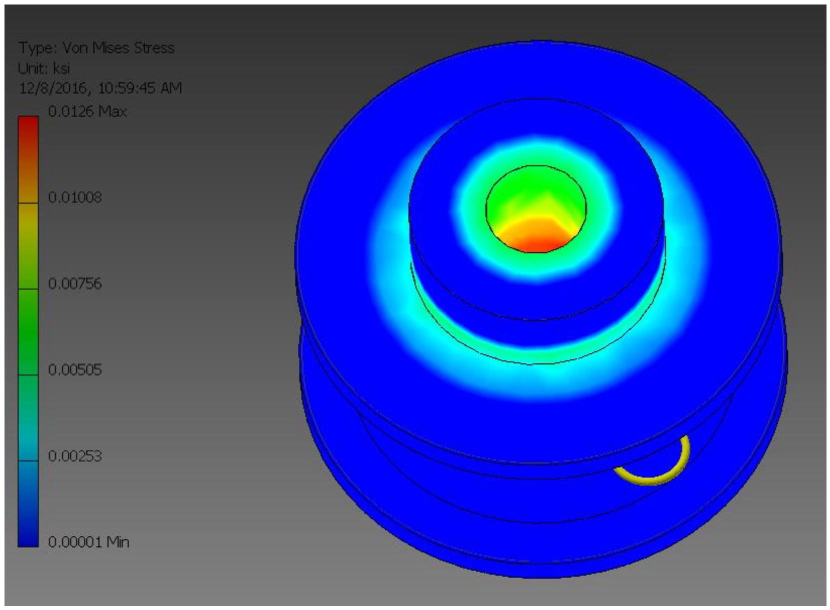


Figure 10 - FEA Analysis of Drive Pulley for Rotational Axis

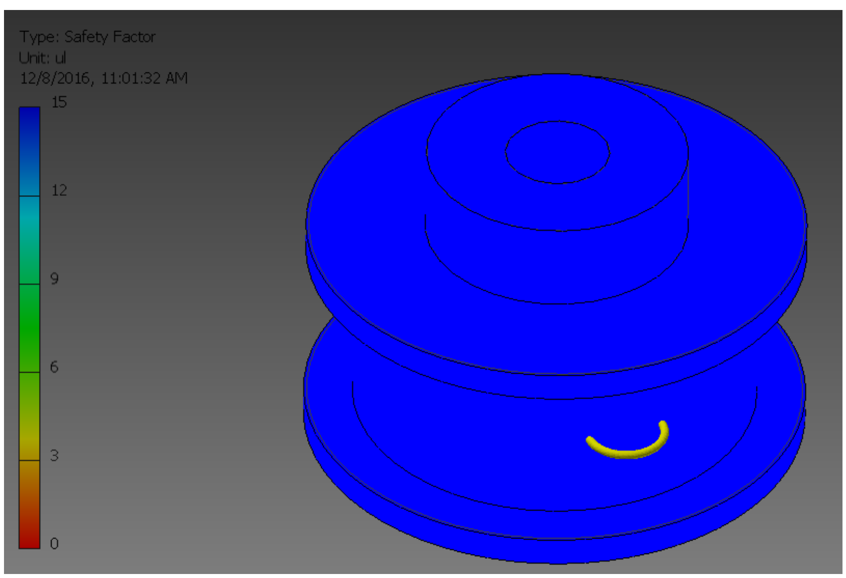


Figure 11- Safety Factor of Drive Pulley for Rotational Axis

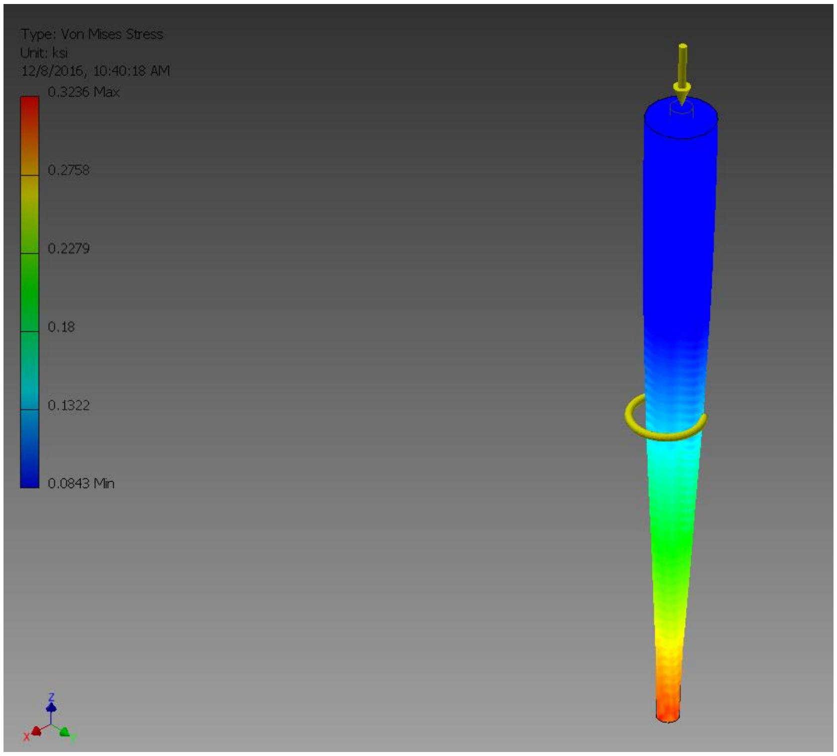


Figure 12 - FEA Analysis of Driven Shaft for Rotational Axis

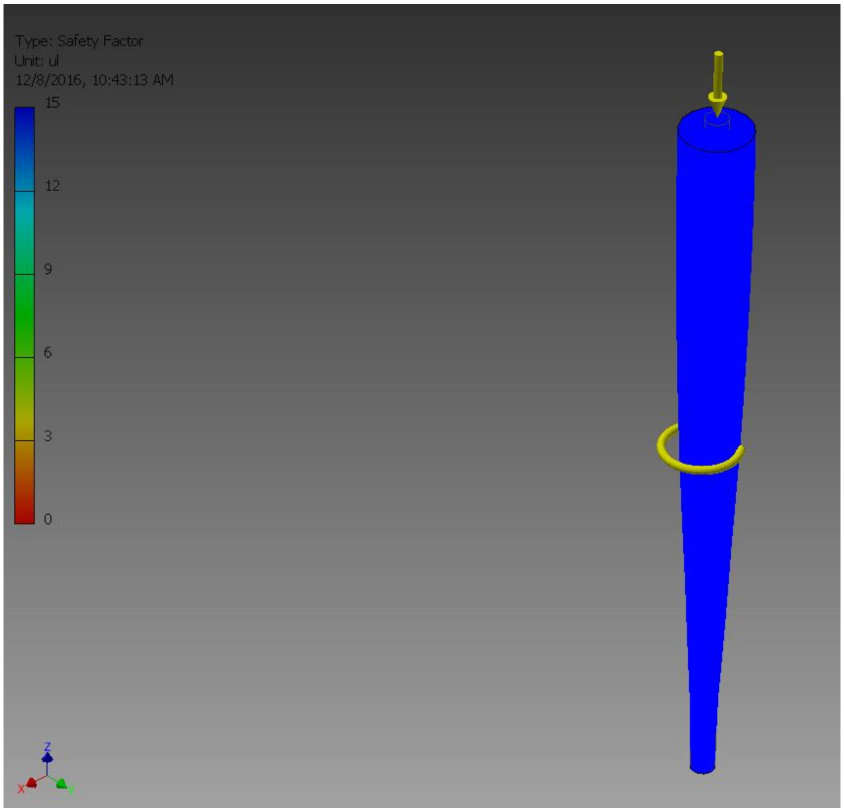


Figure 13 - Safety Factor of Driven Shaft for Rotational Axis

MATERIAL SELECTION

MOTORS

Based on the loading calculations a motor with at least 5 in-lbs. would suffice. A 5 in-lb. motor would give the system a safety factor of at least 2. However a Nema 23 motor was selected because of its low price, and high reliability. It also has a 23 in-lb. torque rating. This gives the system a safety factor of over 9.

Figure 14 - Stepper Motor

MOVING PARTS

All moving or sliding parts were created out of Delrin. This is because Delrin has a very low friction factor, especially when rubbing on itself. Delrin is also non-conductive so a charge cannot build up on the parts and cause powder to stick to it.

RESULTS

After running several test cycles a few averages were found. A 2 – stem rack could cycle at about 10 seconds. The 4-stem rack could cycle at about 15 seconds. This is much better than expected and could be optimized with further testing. It was also discovered that the belt alignment was a little off as the belt was running to one side of the pulley. A guide rail will need to be added to the top idler pulley to prevent the belt from slipping off. Lastly the Delrin pieces with eventually wear since they are rubbing a lot. Spare parts should be made to reduce downtime.

A productivity calculation was run and shows by implementing the powder coat machine production can increase approximately 22%.

Productivity without machine

$$60\ seconds\ to\ load\ rack + 30\ seconds\ to\ paint\ parts = 90\ \text{sec}\ total$$

$$\frac{24\ parts}{90\ seconds} * \frac{28800s}{shift} = 7680\ parts\ per\ shift$$

Productivity with machine

$$60\ seconds\ to\ load\ rack + 10\ seconds\ to\ load\ rack\ into\ machine = 70\ \text{sec}\ total$$

$$\frac{24\ parts}{70\ seconds} * \frac{28800s}{shift} = 9874\ parts\ per\ shift$$

$$\frac{9874 - 7680}{9874} * 100 = 22\%\ increase\ in\ productivity$$

Figure 15 - Productivity Calculation

RECOMMENDATIONS

If the project were to be re-done I would recommend giving yourself more time to fabricate. I think I did a decent job using my time efficiently however there is always room for improvement. With regards to my design, the long belt made for problematic alignment. The belt is definitely needed as a power transmitter, but I think if I did the project a second time, I would focus more on making sure the pulleys were perfectly in line.

Lastly with regards to design I would have added a small capacitive sensor at the top and bottom of the cycle. This would be used as an added safety measure in case the motors somehow got off count, this way the capacitive sensors would act as limit switches.

WORKS CITED

1. **DuPont.** Delrin Design Information. *DuPont.* [Online]
http://www2.dupont.com/Plastics/en_US/assets/downloads/design/DELDGe.pdf.

APPENDIX A – PROPOSED BUDGET

Below is the proposed budget for the project. While coming up with concepts the idea was to keep it under $2000.00. The proposed budget meets these requirements.

Item	Proposed Price	Actual Price	Qty
Stepper Motor	$200.00	$59.00	2
Controller	$200.00	$100.00	2
PLC	-	-	1
Drive Pulley	$15.21	$15.21	1
Driven Pulley	$49.87	$49.87	1
Vertical Belt	$20.00	$13.43	1
Precision Rods	$50.00	$21.20	2
Drive Shaft	$10.00	-	1
Delrin Material	$50.00	$35.71	1
Base Plate	$30.00	-	1
Rod Supports	$25.00	$19.45	2
Fasteners	$5.00	$5.00	1
Total	$655.08	$518.52	

Table 1 - Proposed Budget vs Actual Price

APPENDIX B – PROJECT TIMELINE

Below is the project timeline. The timeline highlights major accomplishments or tasks that are to be completed. The leftover time will be used for error proofing.

Task Name	Start	End
Automated Powder Coat Machine	8/22/2016	4/27/2017
Design 1		
Start Design 1	8/22/2016	10/10/2016
Final Design Report	11/11/2016	11/11/2016
Design 1 Complete	11/11/2016	11/11/2016
Design 2		
Start Design 2	11/14/2016	12/10/2016
Conceptual Sketches	11/23/2016	11/30/2016
Equation Analysis	11/30/2016	12/10/2016
Design 2 Complete	12/10/2016	12/10/2016
Design 3		
Start Design 3	1/9/2017	4/27/2017
Fabrication	1/9/2017	3/24/2017
Testing	3/27/2017	3/31/2017
Tech Expo	4/6/2017	4/6/2017
Project Presentation	4/14/2017	4/14/2017
Submit to Library	4/27/2017	4/27/2017
Design 3 Complete	4/27/2017	4/27/2017

Table 2 - Proposed Project Timeline

APPENDIX C – MANUFACTURING DRAWINGS

Below are the drawings for all critical components to the design. Drawings for screws and small mounting brackets were omitted.

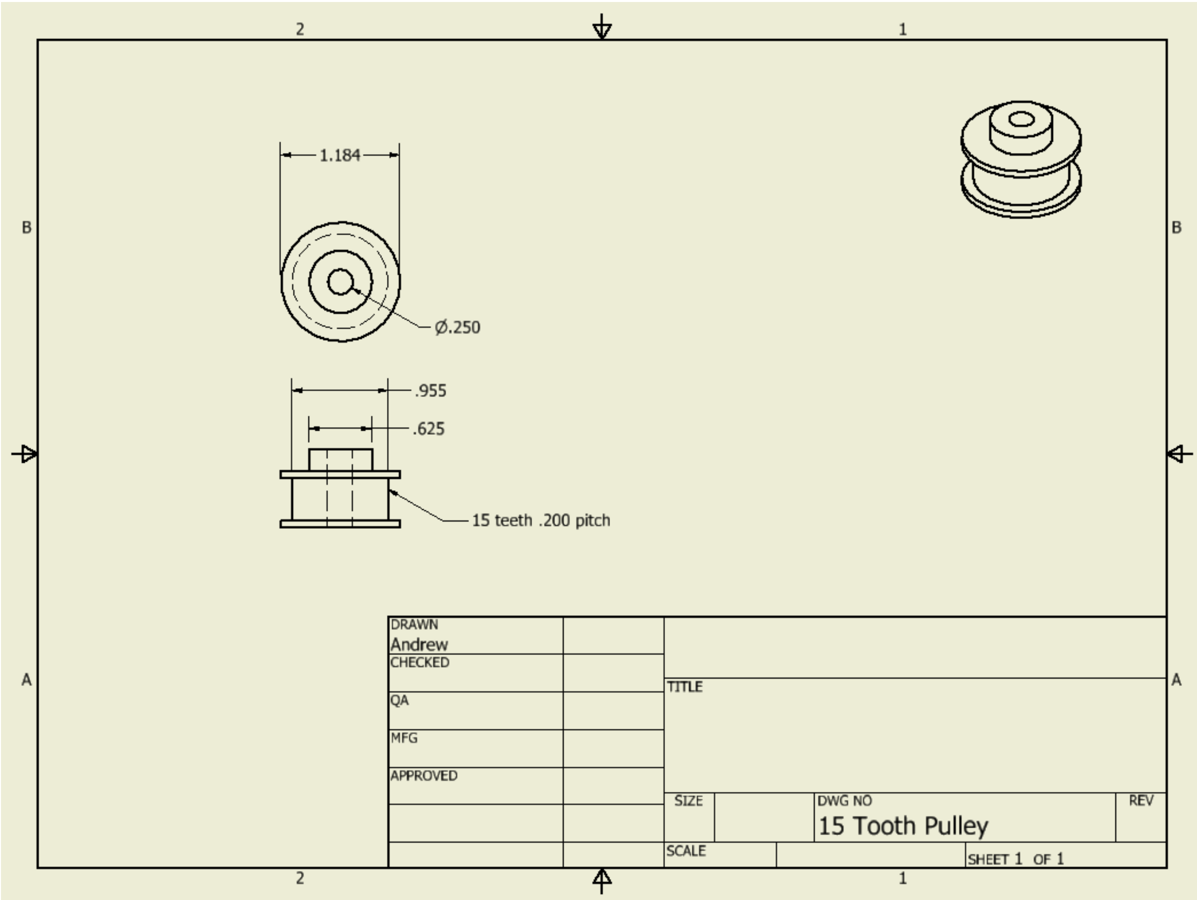


Figure 16 - Drawing for 15 Tooth Drive Pulley

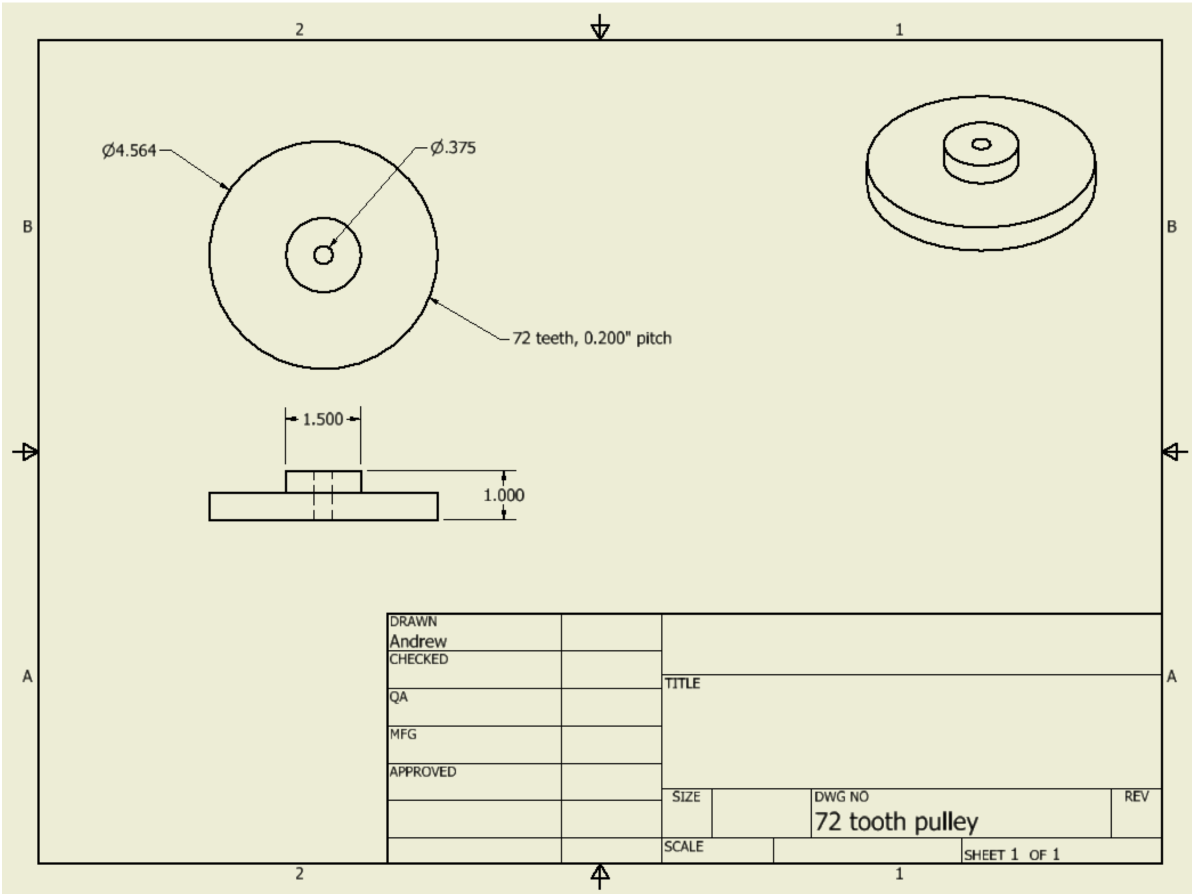


Figure 17 - Drawing for 72 Tooth Driven Pulley

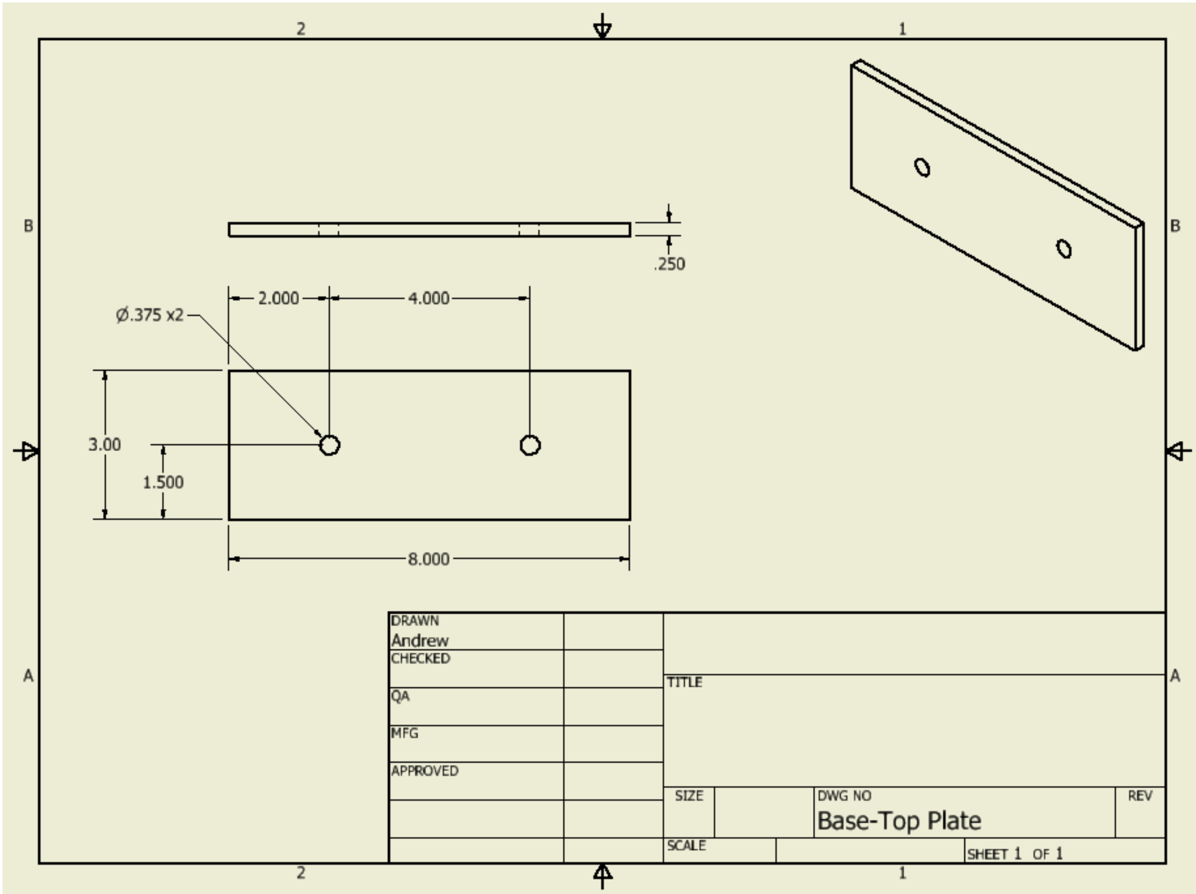


Figure 18 - Top and Bottom Support Plates

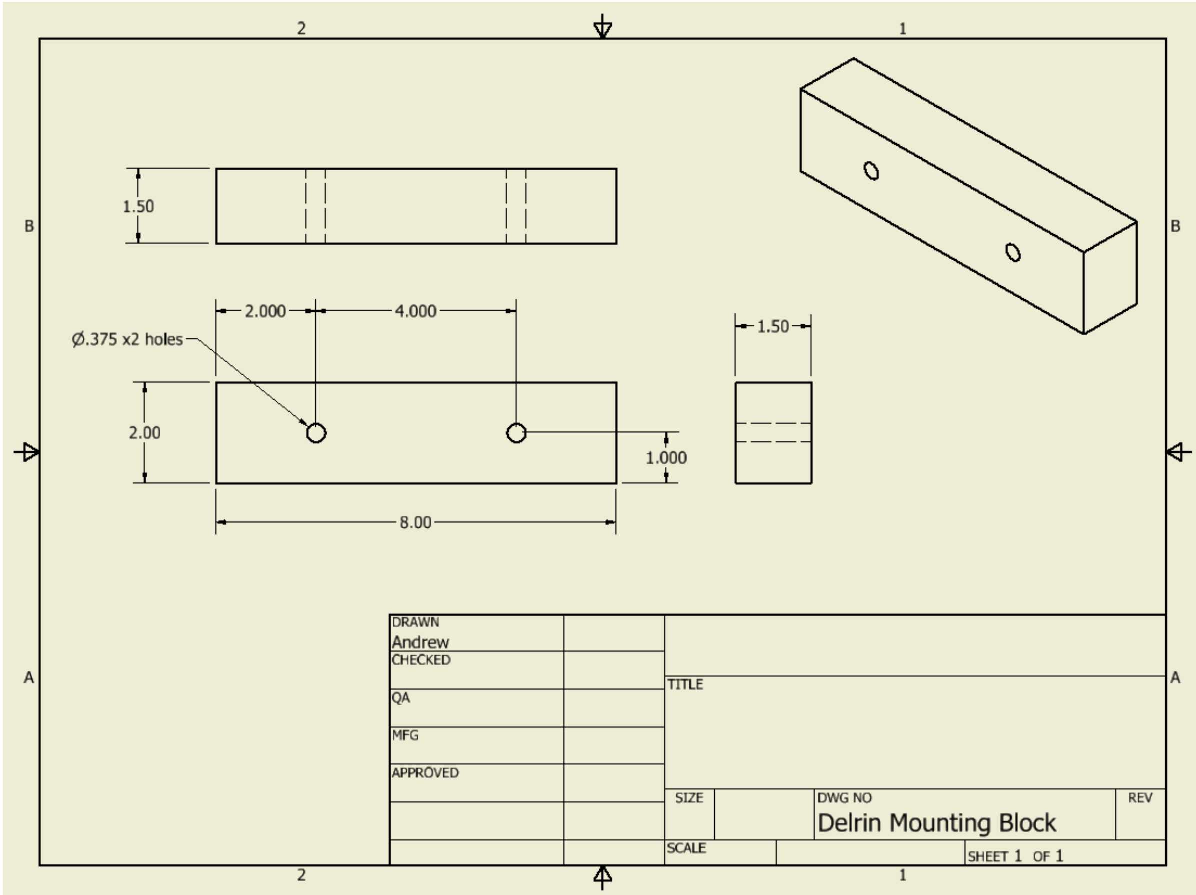


Figure 19 - Delrin Mounting Block

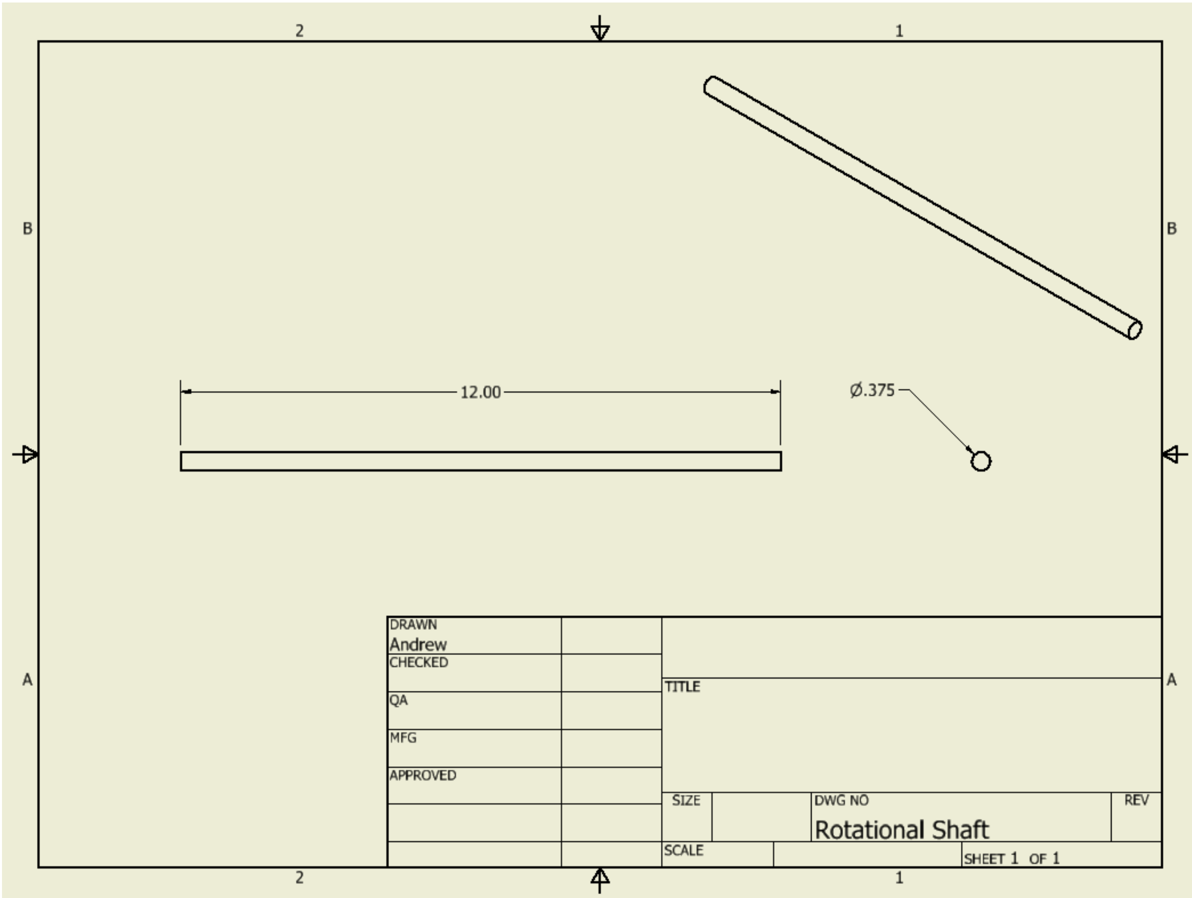


Figure 20 - Shaft for Rotational Axis

APPENDIX D – FABRICATION

VERTICAL AXIS

The idea was to create the fabrication from the ground up. That way this would minimalize alignment and mating issues. The base plates for the vertical tower were created out of steel first using a CNC Vertical Mill. The plates were milled to the correct overall dimensions. Then the two rod holes were programmed in and cut. The mounting holes were cut and threaded as well using the CNC programming. CNC programming is great for laying out hole locations.

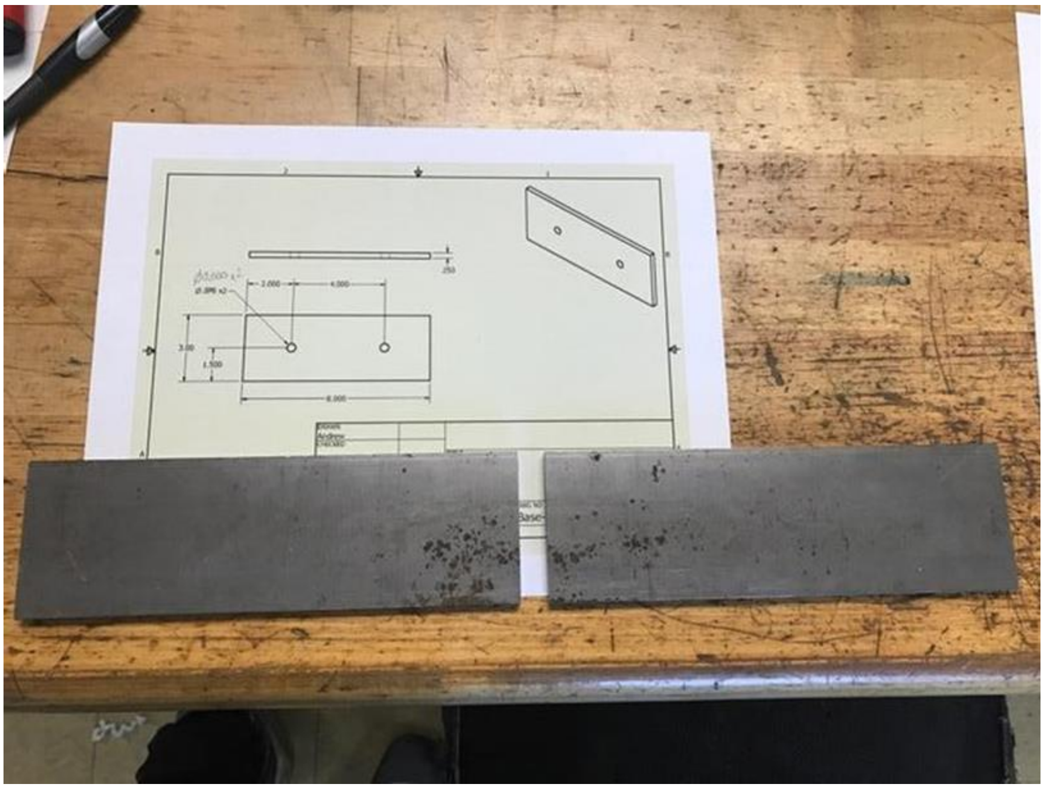


Figure 21 - Base Plate Material

Next the Delrin mounting block was created. Once this was created the vertical tower could be assembled since the precision rods and mounting feet were purchases parts. This was also fabricated in a CNC Bridgeport Mill.

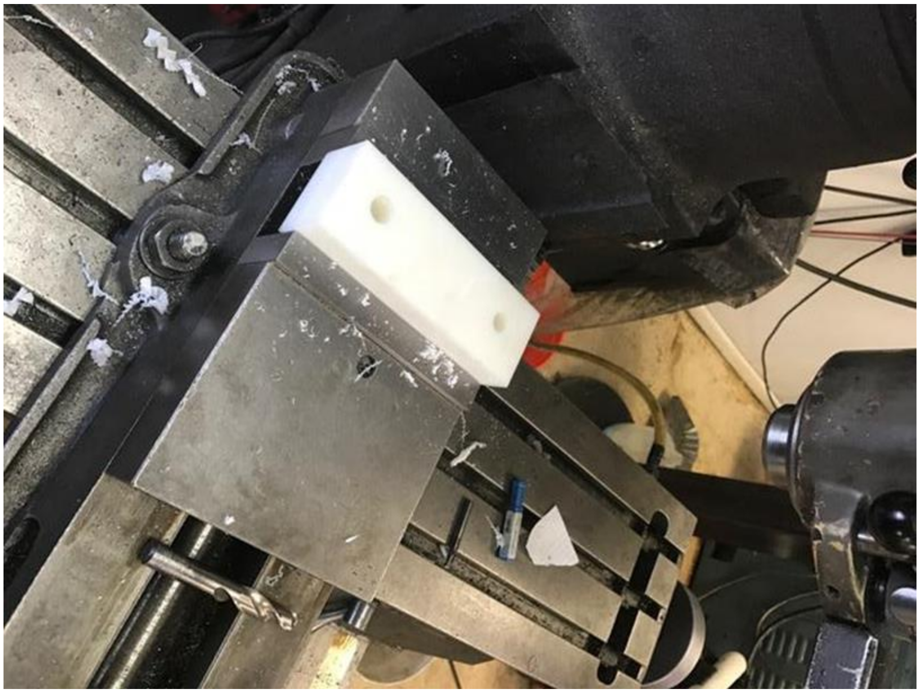


Figure 22 - Delrin Mounting Block

Once the two plates were cut and tapped, and the Delrin sliding block was created. The vertical tower assembly could be put together. Shaft supports were used to mount the rods to the base plates. The final vertical tower assembly is as shown below.

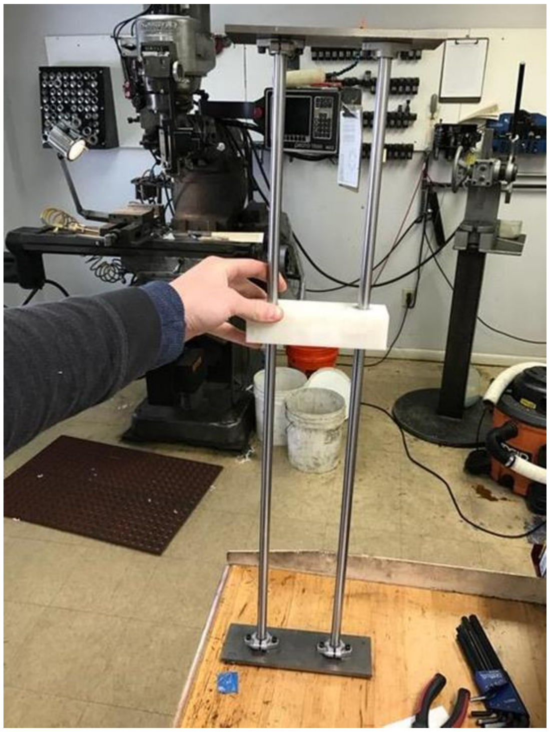


Figure 23 - Vertical Tower Assembly

ROTATIONAL AXIS

The first piece made was the large ½" thick steel grounding plate. This is what everything is going to be mounted to. Next the two Delrin sliding blocks were made shown in the center of the picture below. The top Delrin piece has a slot for the rack to be painted to lock in to. Both the plate and the Delrin blocks were fabricated on a CNC Bridgeport Mill. The aluminum spacers below the grounding plate that provide clearance for the motor shaft were fabricated using a CNC Lathe. The spacers were center drilled to allow clearance for a bolt, then they were cut and faced to length so that all four pieces were exactly the same length.

Figure 24 - Rotational Axis Assembly

FINAL ASSEMBLY

The final assembly is shown below. The vertical tower is mounted to the grounding plate so that the drive belt is parallel to the vertical tower. This allows for linear movement without stretching the belt.

Figure 25 - Final Assembly