

# .decimal Proton Therapy Device Manager

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# Abstract

A Proton Therapy Device Manager is a product which will automatically load and unload apertures into a Mevion S250 Proton Therapy machine in order to reduce time and human effort in the treatment process. The product specifically discussed in this report is 1:4 scaled version of the actual device that would be used in the treatment center. This product uses a linear railing system in order to move up and down and side to side. The user will operate this device through a computer and will communicate when the product should move and complete a loading or unloading function.

This report will explain in more detail how the product works, is assembled, how it operates, and how to properly maintain this device over time with some wear and tear. It will also discuss the development of this project throughout the year and how the team was managed. Things discussed also include the budget and other business aspects. This device is simple to make and easy assemble, and has been designed with the ease of operation in mind for the end user. This report also includes information on common failures and how to go about identifying and correcting these failures.

# 1 Introduction

Dot Decimal sponsored the 2015-2016 Florida State University Senior Design project: Proton Therapy Device Manager. Dot Decimal is a medical device manufacturing company in Sanford, Florida. They manufacture patient specific devices for various types of cancer treatments including proton, photon, and electron beam treatment. Dot decimal expressed the need to design an automated system that would load and unloaded two of their patient specific devices into a Mevion S250 proton therapy system: apertures and range compensators.

## 1.1 Need Statement

Currently, a technician manually loads and unloads the apertures into the nozzle of the Mevion S250 proton therapy system. Dot Decimal has determined the time it takes to complete this procedure too lengthy and therefore undesirable for the patient's proton therapy experience. A senior design team at Florida State University, in conjunction with Dot Decimal, is developing an automation system in order to reduce the amount of time it takes to complete the loading and unloading procedure. The optimal system will be faster and safer than current methods. By optimizing the loading and unloading procedure the manual effort of the technician will be reduced, more patients will be treated each year, and patients will have an improved proton therapy experience.

It takes too long and too much effort for a technician to load and unload apertures during a patient's treatment.

## 1.2 Goal Statement & Objectives

Goal Statement: Provide proof of concept by developing a functioning 1:4 scaled model of an automation device that will load and unload Dot Decimal's apertures and range compensator into the snout of the Mevion S250.

Objectives:

- Decrease the time a patient is in the treatment room
- Eliminate manual process for technician

## 1.3 Constraints

- Automation device must lift up to 25 lbs.
- Automation device must not interfere with proton beam or the patient couch
- Automation device must scan apertures to identify patient specific aperture
- Automation device must be installed in the same room as the Mevion S250
- Automation device must load apertures and range compensator
- Automation device must unload apertures and range compensator

## 2 Background Research

Proton therapy is a form of radiation treatment that allows physicians to precisely deliver a high dose of radiation to target specific tumors. If enough radiation is delivered to the tumor, all the cancer cells will die, inhibiting their ability to heal and propagate. Proton therapy can deliver higher doses of radiation with far more accuracy and controls cancer with fewer treatments than conventional photon treatment (x-ray). As a result, patients experience a higher post-treatment quality of life as compared to conventional methods. Currently there are 14 proton therapy centers operating in the U.S. and 12 more in development ([http://proton-therapy.org/dotmed\\_progress\\_sept\\_2014.html](http://proton-therapy.org/dotmed_progress_sept_2014.html)).<sup>2</sup> Of the 12 centers in development, 6 will be equipped with proton therapy systems developed by Mevion Medical Systems, Inc.

Mevion Medical Systems, Inc. is a Massachusetts based radiation therapy company. They are the developer and manufacturer of their flagship product, the Mevion S250 Proton Therapy System. The Mevion S250 is the world's smallest single room proton therapy system, Figure 1. With a price tag of \$25M, the device is one quarter the cost of previously available systems. The system is built around the world's first superconducting synchrocyclotron accelerator, allowing the device to deliver 250 MeV high-energy protons to localized tumors while sparing surrounding healthy tissues. This precise form of radiation is due to custom machined brass apertures that snugly fit on the nozzle of the S250. The apertures are designed to guide the radiation to affected area while blocking radiation from hitting healthy tissue.

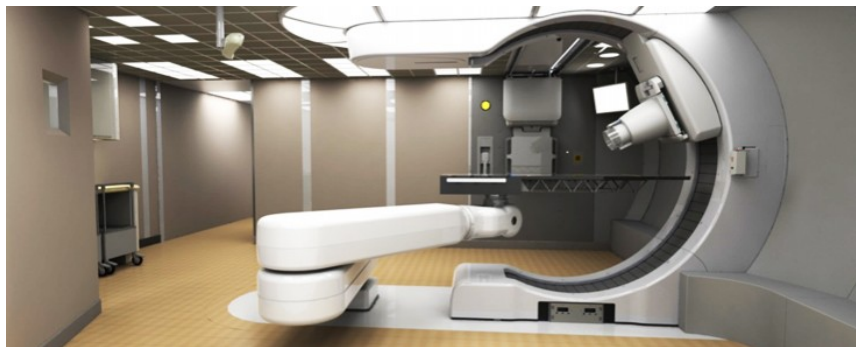


Figure 1. The Mevion S250 Proton Therapy System

Dot Decimal, a Florida based radiation therapy company, is the manufacturer of these patient specific apertures. The brass aperture cutouts are designed according to the Treatment Plan parameters designated by hospital personnel and then transmitted to Dot Decimal machining centers for custom manufacture and delivery back to the hospital ([http://www.accessdata.fda.gov/cdrh\\_docs/pdf12/K123893.pdf](http://www.accessdata.fda.gov/cdrh_docs/pdf12/K123893.pdf)).<sup>3</sup> Each aperture can weigh up to 30 lbs. due to the high lead content in the brass. Currently, technicians are manually lifting, inserting, and removing these heavy apertures into the correct position on the beam's nozzle. The process is physically strenuous and, more importantly, time consuming. More patients can be treated each year if this time consuming process can be eliminated from each therapy session. Additionally, speeding up the process will be a selling point for proton therapy treatments. All companies involved with proton radiation therapy will make more money if the technology is easier to sell.



Any other companies, universities, or individuals have not tried to execute this specific project. The University of Florida is in the process of brainstorming a scaffolding device that will be used to load and unload the apertures; however, there is no literature on their research. The two systems are being developed in parallel.

Observing automation devices and mechanisms that are currently on the market provided great insight. Manufacturing factories utilize these types of technologies daily. Many of these ideas were adapted to meet the needs of our project. SMD Machinery Inc. manufactures high end metal fabrication systems for a variety of applications. Their Astes4 is a plate sheet sorting, stacking, and labeling system for plasma and laser cutting machines (<http://smdmachinery.com/astes4>). It utilizes a 2.5 axis sorting system that uses geometric coordinates to locate and pick up sheet metal. Inductors turn a series of magnets “on” in order to pick up the sheet and turns the magnets “off” to stack the sheet. The machine can pick up plates as large as 15,000 kg!

ZenRobotics Recycler is the first robotic waste sorting system in the world (<http://zenrobotics.com/zenrobotics-recycler/zenrobotics-recycler/>). The robotic recycles also uses a 2.5 axis system to laser scan and locate scrap. Scrap garbage travels via a conveyor belt. Once the scrap has been located, a robotic claw lowers down on the z-axis and clasps the garbage. The scrap is then sorted into a bin. The process is then repeated.

CD labels are pressed using a 2 degree of freedom robotic arm, Figure 1. The nozzle of the robot is equipped with a vacuum system on the output link. A vacuum pump is cycled on and off in order to pickup and drop off the CDs. The crank arm pivots through 180 deg of motion and is powered by a servo motor.

A 1962 Rockola Princess jukebox uses a unique storage and sorting system. The system has 2 degrees of freedom. The vinyl records are stored in a vertical fashion on a rotating wheel. After the user selects their song, the wheel rotates until the correct album is selected. A mechanical clasp then grabs the record while rotating and spinning the record onto a turntable.

The solution developed over the course of the past two semesters utilizes some of the ideas in place in these systems, but overall it’s a novel system. Aside from the linear rail system, this system presents a unique solution to a unique problem; the platform designed by this senior design team is not based off anything currently on the market.

### 3 Concept Generation

The scope of our project focused on loading and unloading an aperture into a proton therapy machine. In September 2015, the team visited the Orlando Health Center to see the proton therapy machine and to understand how the apertures were loaded and unloaded into the proton therapy machine by the technician. Soon after, the team began generating concepts for the automation system.

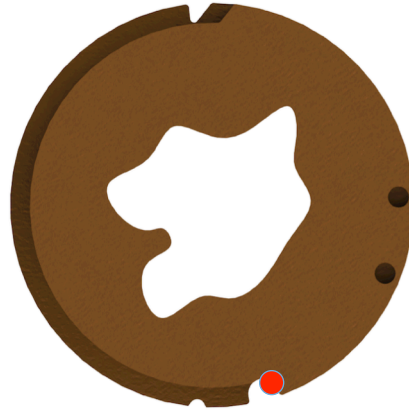


Figure 2 Aperture with instantaneous center indicated by red dot

Our designs were based around the fact that there was an instantaneous center of zero velocity about one point on the aperture when it was loaded into the therapy system as seen in Figure 2. During the conceptual design phase, cardboard prototypes were created to have a visual understanding of how the automated system would work.

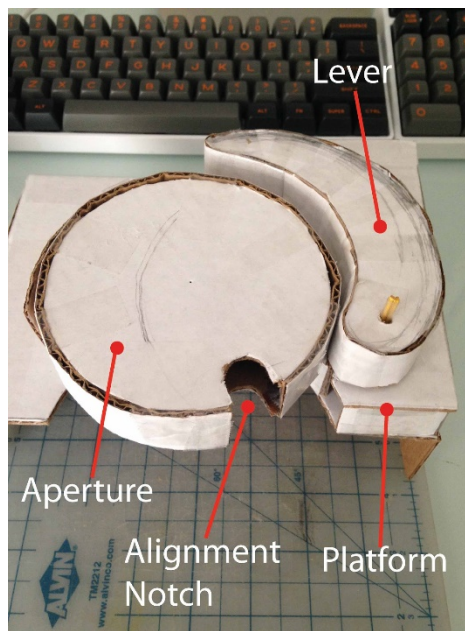


Figure 3 Prototype 1

The first prototype is shown in Figure 3. The cardboard medium was a cheap, fast, and effective rapid prototyping strategy. Concepts could be generated quickly, and modes of failure could be identified easily. This fail-safe approach allowed the team to monitor the system's weaknesses. After the basic design concepts were identified the team moved into the embodiment design phase. CAD models were created for the automated system's parts and subassemblies. The use of FDM (Fused Deposition Modeling) technology enabled the team to create its second prototype out of plastic like the CAD image seen in Figure 4. The plastic prototype was robust and used a simple mechanism to load and unload the apertures. Design for manufacturability, reliability, and safety were continually considered during the design phase. Safety was the team's main priority. Safety features such as a lock and automatic cutoff switches

were incorporated into the design. Potential dangers such as falling objects, electrical shock, power outages, fatigue, operator error, breakdown of lubrication, material corrosion, misalignment, sharp edges, stability, and vibration were considered in the design.

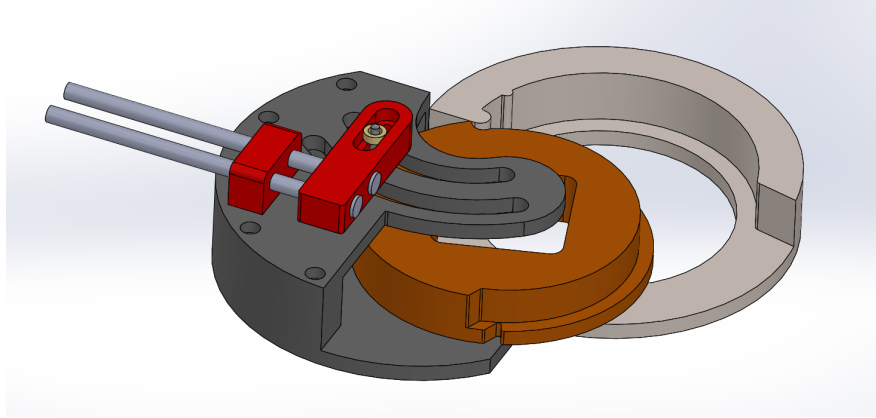


Figure 4 Prototype 2

Manufacturing methods and materials were not selected during the initial design phases. However, simple geometries for each part were constructed in order to aid in the manufacturing process. Additionally, these simple shapes strongly influenced reliability and reduced chances of error. Simple machines have simple problems. Complex machines have complex problems. Two of these simple geometries were analyzed using FEM (finite element modeling). The lock and the platform were analyzed to determine their constraints and the results can be seen in Section 6 of this report. The embodiment design phase continued into the Spring semester. A third prototype was created used the FDM process as seen in the CAD image in Figure 5. Additive manufacturing and computer aided engineering tools were beneficial technologies for concept generation and allowed the components to be subjected to a wide range of environmental conditions at a relatively low cost. Parts could be created and tested redundantly to determine optimal geometry, assembly, and integration.

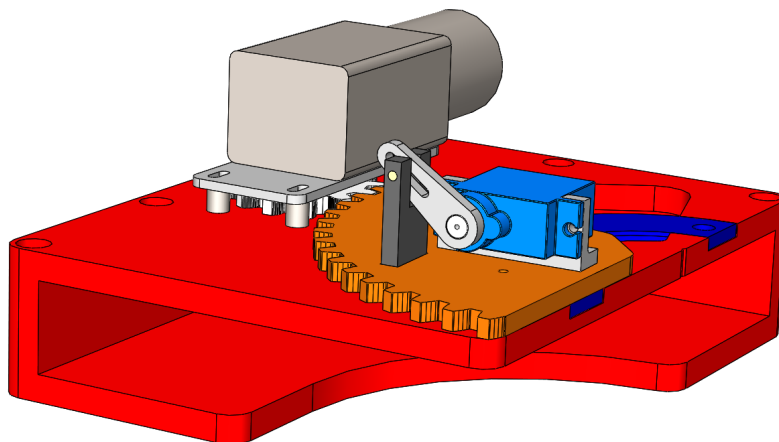


Figure 5 Prototype 3

The detailed design phase began after verifying the concepts generated from the third prototype. Materials, motors, and manufacturing methods were selected in order to progress to the production phase. Given the team's constraints on design, time, and budget the final automated system included parts that were designed and assembled in order to produce the highest quality product. Troubleshooting of software and electrical components ensured the mechanical design was functioning at an optimal state. There is still much room for improvement for the final design. More analysis and testing should be done in order to optimize the performance of the machine. The team's final prototype can be seen in Figure 6.

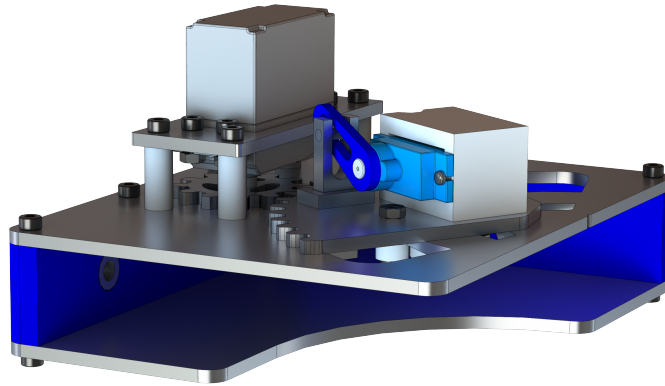


Figure 6 Final Product

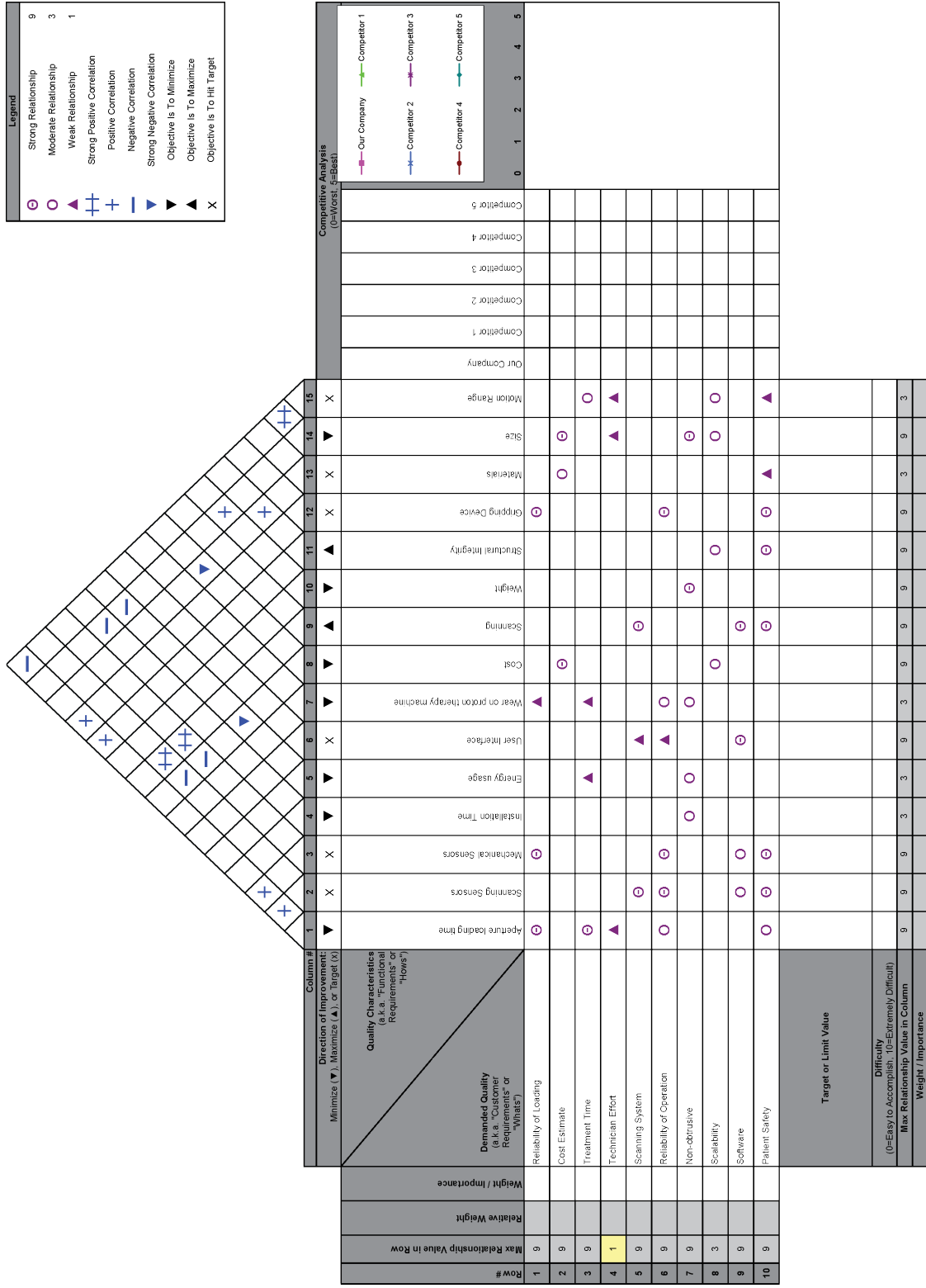


Figure 7. House of Quality

## 4 Final Concept

The final prototype is composed of two subassemblies: an aperture loading and unloading head and a linear rail system. The main focus of the project was on the aperture loading and unloading head. The head is proprietary hardware created for Dot Decimal by Team 14. The system is composed of 6 main components: platform, pinion, driven gear, guide, lock, and lock arm. An illustration of the loading process in Figure XXX shows how all of the components function in order to load and unload an aperture into the nozzle of the Mevion S250 proton therapy system.

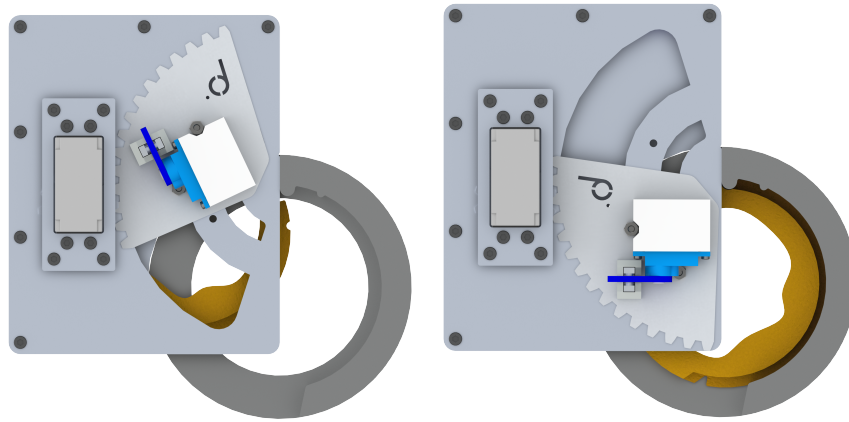


Figure 8 Starting position in A, End position in B

An aperture will be supported by the platform. A lock will be inserted into an alignment notch on the top surface of the brass aperture. The lock will aid in safely securing the aperture to the platform during rotational movement and it will accurately guide the aperture along its path to the nozzle. The lock will move along an axis perpendicular to the surface of the platform with the help of the lock arm and the guide. The lock is secured to the top surface of the driven gear. The lock arm will be driven by a micro servo motor allowing for its physical movement up and down. The guide will accurately and precisely align the lock into the surface of the aperture. Once the lock is secured, a pinion will be driven by a continuous rotation servo motor. The pinion will drive the driving gear. The driving gear is attached to the lock, enabling the aperture to rotate  $80^\circ$  about an instantaneous center of zero velocity until it is safely and securely in the nozzle of the proton therapy system. The unloading procedure will be very similar to the loading procedure as seen in Figure 8. Engineering drawings for the entire loading and unloading head can be found in Appendix C.

## 5 Operation Manual

### 5.1 Product/Project Specifications

This project consists of two distinct mechanical systems, the linear rail system and the platform assembly. The linear rail system is a two degree of freedom system that can move through approximately 150mm of motion in both the horizontal and vertical directions. Two Nema17 Stepper drivers, driven by Toshiba TB6560 motor drivers, operate the linear rail system. The motor drivers can output up to 3.5 A of current and microstep down to 1/16 of a step. Power is supplied via a 12V power supply which provides power to the entire system, including the arduino and platform. The power supply is capable of outputting up to 30A.

Two aluminum brackets were manufactured to connect the vertical linear rail system to the horizontal and to connect the platform to the vertical linear rail system. Additionally, ABS supports were cut to raise the assembly around 3 inches off the ground. This leaves a small area under the assembly to store the electronic components.

### 5.2 Product Assembly

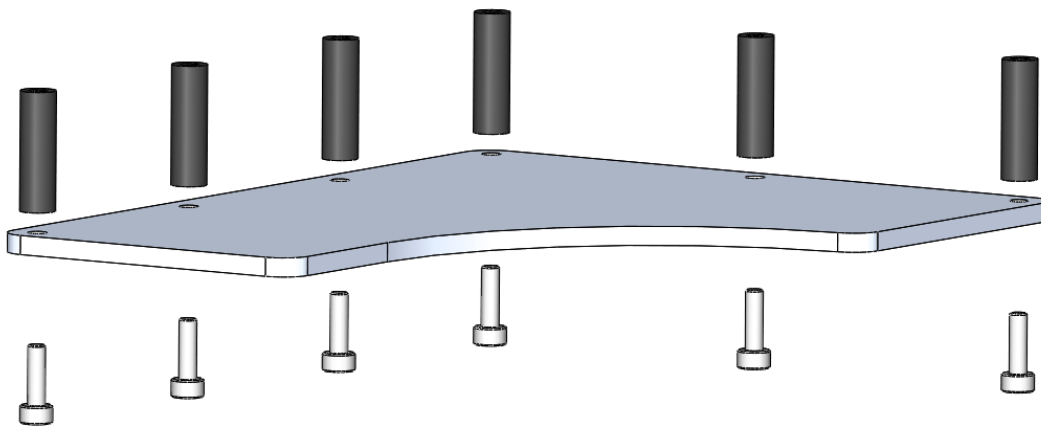


Figure 9. Step 1 of Assembly

Step 1:

Assembly of the bottom platform will occur first. Fasten the 20 mm spacers to the platform with 6 10 mm M3 screws.

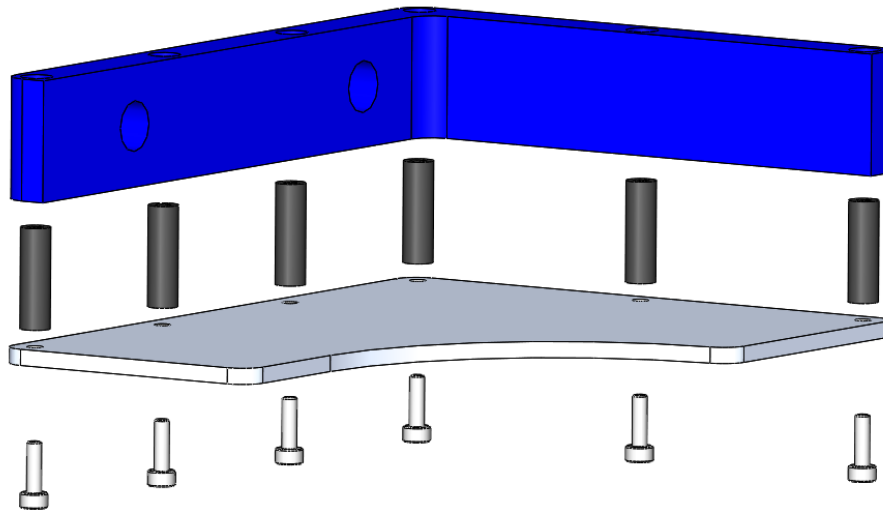


Figure 10. Step 2 of Assembly

Step 2:

Place the middle platform on top of the spacers. Use the holes on the middle platform for guides. This should be a press fit.

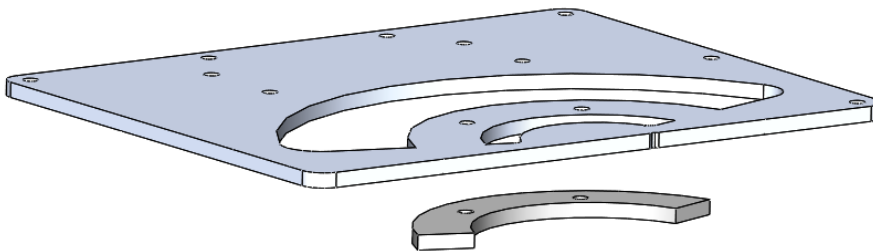


Figure 11. Step 3 of Assembly

Step 3:

Place the bottom platform to the side and assemble the top platform section. First, use epoxy to glue the bearing guide to the bottom side of the platform and allow 24 hours for the epoxy to cure. Use the registration keys to align the bearing guide with the platform using 2 M3 screws and nuts. Tighten the nuts after applying the epoxy.



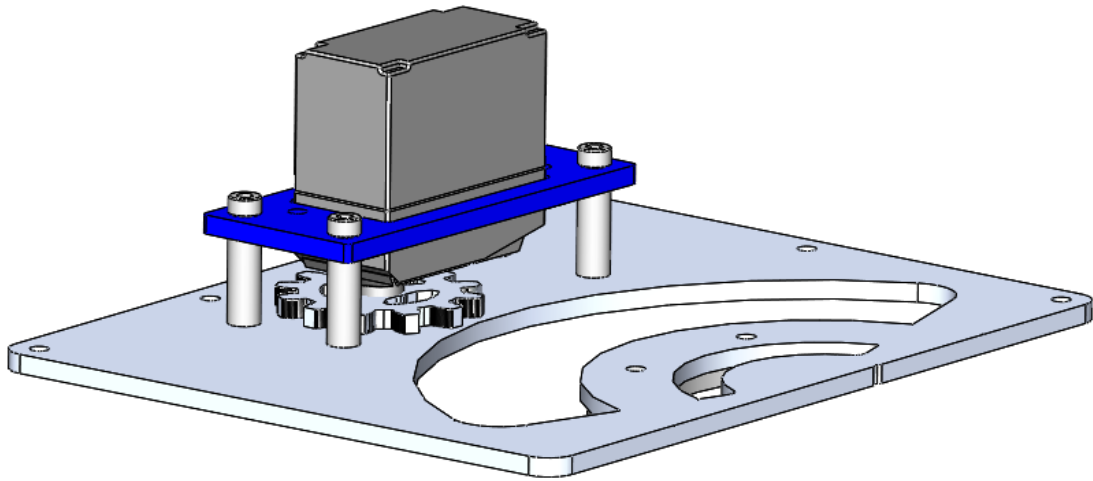


Figure 12. Step 4 of Assembly

Step 4:

Mount the large servo motor to the top of the platform using the 15 mm spacers. Place the large servo inside the large servo mount. Use 4 M3 screws and bolts to securely fasten the large servo to the large motor mount. Use 8 M3 screws to mount the large servo mount to the spacers and platform as shown in the image above.

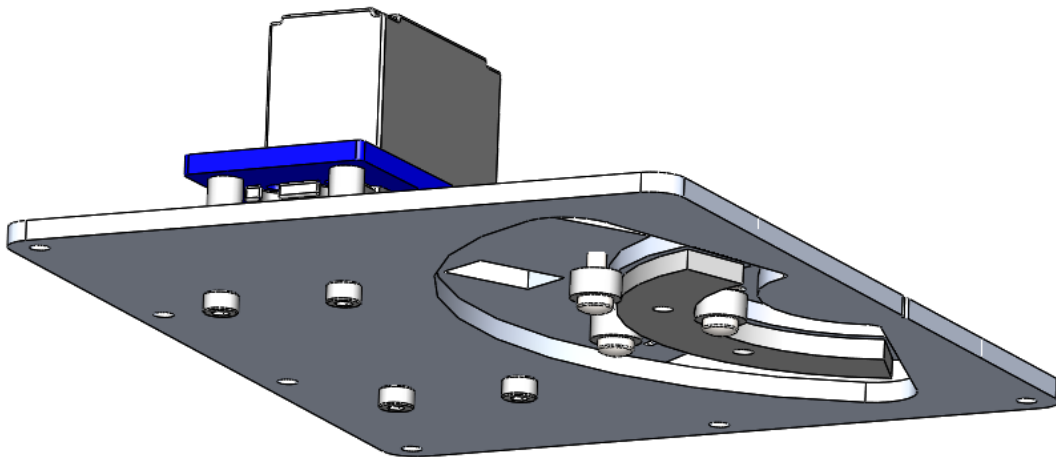


Figure 13. Step 5 of Assembly

Step 5:

Mount the 3 bearings using 3 M3 screws and bolts. Use the three alignment holes on the driven gear to align the bearings. The bearings should fit tangent to the bearing guide. Tighten the 3M nuts on top of the driven gear.

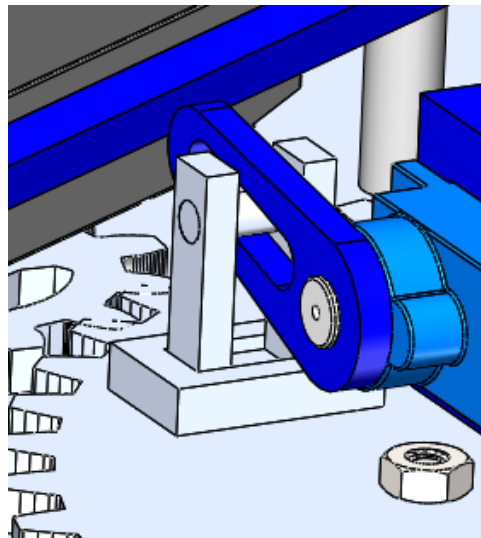


Figure 14. Step 6 of Assembly

Step 6:

Mount the locking servo mount to the top of the driven gear. Use 3 M2 screws to fasten the mount in place. Position the micro servo inside the locking servo mount. Fasten the micro servo with 2 M2 screws.

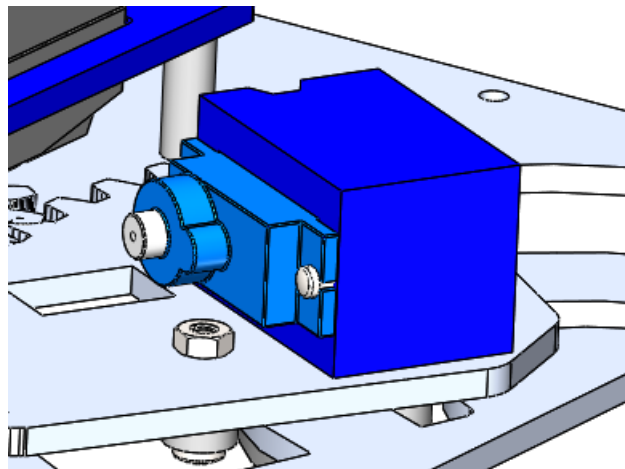


Figure 15. Step 7 of Assembly

Step 7:

Press fit the guide into the driven gear. Next, slide the lock into the guide. Press fit the servo arm onto the output shaft of the micro servo. Place the locking rod through the side of the lock, through the servo arm and through the other side of the lock. The servo arm should be able to move the lock up and down if properly assembled.

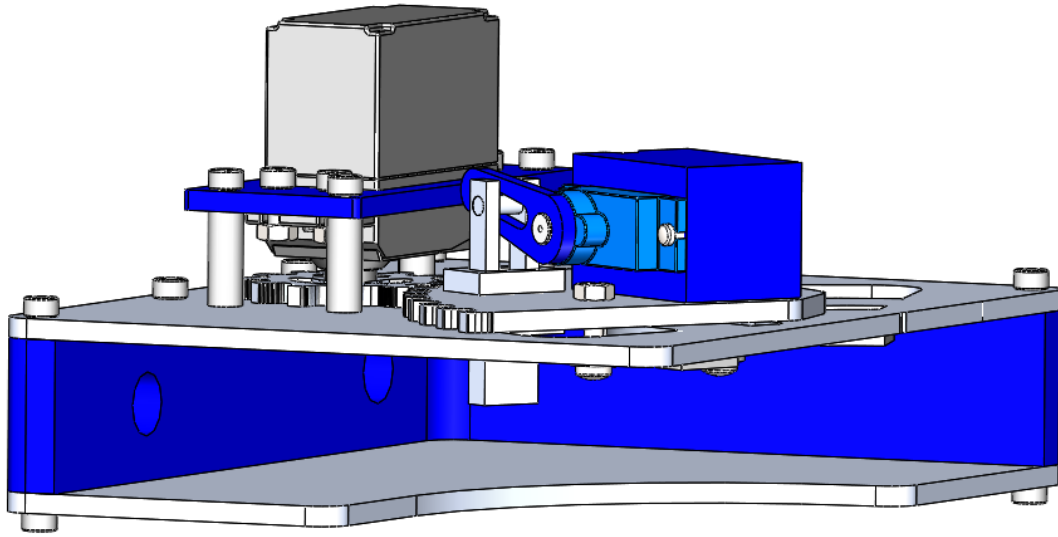


Figure 16. Step 3 of Assembly

Step 8:

Use 6 M3 screws to align the top platform to the top of the middle platform.

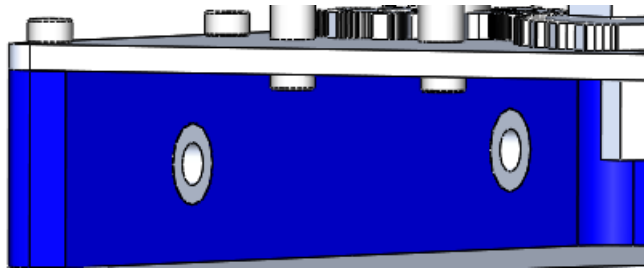


Figure 17. Step 9 of Assembly

Step 9:

Press fit the 10 mm spacers into the two 10 mm alignment holes on the middle platform as seen above.

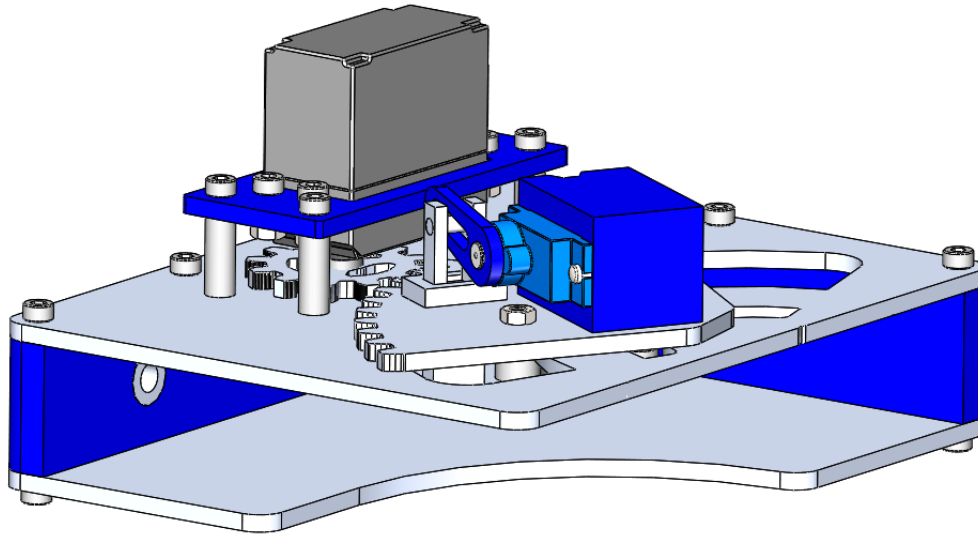


Figure 18. Step 10 of Assembly

Step 10:

The assembly is now complete. The loading and unloading system can now be mounted to a linear rail system using 2 M5 screws, 2 M5 bolts, and 2 washers.

The linear rail system simply bolts together using a combination of bolts and spacers. A flexible coupler connects the Nema 17 stepper motors to the lead screws. Bearings are pressed into the end brackets to support the lead screw. Due to a loose tolerance on this press fit, vibrations will produce noise unless the brackets are carefully aligned. The gantrys are guided along the aluminum rails via four wheels. The spacing between these wheels can be very slightly adjusted using eccentric spacers to allow for smooth motion.

## 5.3 Operation Instructions

Prior to operation, inspect all components to ensure that everything is properly assembled and that no possible collisions occur during the course of operation. Prototype operation is limited due to the scope of the project and lack of a proper testing setup. Manufacturing the Mevion S250's nozzle, even at a scaled size, is far too costly given this project's budget.

Additionally, the scope of this project is to provide a proof of concept, a scaled Mevion nozzle is not necessary to do this.

### 5.3.1 Prototype operation

1. Connect device to a power source
2. Use buttons to select the loading or unloading sequence. The device will run through a simplified routine to provide a proof of concept for the device's loading/unloading capabilities.
3. Disconnect device from power source after use.

### 5.3.2 Full Scale Operation

See Appendix: Figure 2 Full-Scale Operation

## 5.4 Troubleshooting

This design uses a combination of both mechanical and electrical components. Potential hazards may include things like broken mechanical parts and faulty wiring. Before any troubleshooting is carried out, the user/repairer must ensure that proper safety precautions are taken. The state of the machine must always be reported and the problems described in as much detail as possible to facilitate the troubleshooting process.

### Platform

The platform is constructed out of aluminum and is structurally sound, no material failure is expected. The platform does contain the lock component which will be experiencing varied shearing forces in addition to constant wear from friction, because of its small size and frequent usage it is a possible source of failure. Additionally, the servo setup that operates this lock to ensure that it is functioning properly.

Table 1. Troubleshooting

| <b><i>Problem</i></b> | <b><i>Steps to Fix</i></b>   |
|-----------------------|--|
| Alignment             | Recalibration of linear rail system<br>Ensure the motor drivers are set to the correct microstepping routine and that the motors are receiving adequate power. Additionally, the condition of the lead screws and lock nuts should be examined for any signs of wear or failure.   |
| Electrical            | Ensure the device is not connected to a source of power. Inspect all the wiring to make sure there are no loose wires and that the connections are correct. If there is no obvious problem then the state of the motor driver, arduino, and power supply should be checked. These components will have LED lights lit up when receiving power. |

## 5.5 Maintenance

The components of this device are rather standard and are of good quality and are low maintenance. No supplies have to be regularly in stock or provided other than a reliable power source.

This product will however require routine calibrations to ensure that the motors are driving the platform to the correct position every single time. The room for error is little to none so this device needs to be as accurate as possible. Along with this, the device needs to be maintained on a flat surface with a sturdy foundation. This will require goes back to the constant calibration checks to make sure the results are consistent and repeatable.

The wiring must also be secure and checked on a regular basis. The electronics must be kept in a dry and cool location. If not secure, then they should be secured and tested before utilizing the product on a patient.

The lock will experience the most stress of all the components. Due to alignment issues from the servo arm and the guide, the lock will have to be routinely checked to ensure proper alignment with the aperture, guide, and micro servo. Additionally, the lock rod should be checked to ensure that it is not bent or misaligned.

## 6 Design for Reliability

Our system is designed to be run intermittently on X-minute cycles. The prototype we have constructed makes use of two linear rail systems to position a platform for loading and unloading of the apertures. The platform is responsible for loading/unloading the apertures and relies on a very tight tolerance nozzle. We do not have a nozzle to load/unload the apertures so current testing involves loading the apertures into a low tolerance, 3D printed loading bay. Because tolerances are so low with our current platform/nozzle setup, the reliability of this part of our design cannot accurately represent the reliability of the final system's platform/nozzle. With our current setup, the prototype can perform any number of cycles barring unexpected catastrophic failure.

However, we can make claims to the reliability of our linear rail system. In the final design, the proper indexing of the platform depends almost entirely on the accuracy of the linear rails. Our current linear rail system can accurately position the platform with an accuracy of 5  $\mu\text{m}$ . We've achieved this by reducing the backlash within the lead screw/threaded nut mating on the rail system and by microstepping the Nema 17 motors to decrease the step size.

While we've taken steps to ensure the accuracy of our linear rail system, we have not implemented a means of automatic calibration. This is necessary to remedy misalignment from events like power loss, unexpected contact, or missed stepping. This is something that will have to be included in a final design, but it is beyond the scope of this project.

### 6.1.1 Finite Element Analysis of the Tool

When the motor is activated the loading arm that will exert a uniformly distributed load on the tool shaft when as the aperture is guided into the applicator. The force must be large enough to move the 16 kg aperture from the resting position. A free body diagram was made to determine the force of the loading arm  $F_{LA}$  acting on the aperture, Figure 7. A force of 160 N is needed to overcome the force of static friction  $F_{fr}$ .

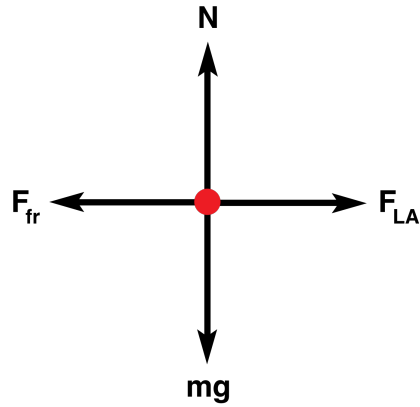


Figure 19. Free body diagram of the forces acting on the aperture.

The load exerted on the tool will be uniformly distributed, in the transverse direction, over a 10 mm section of the tool. The thickness of the loading arm will determine how the load is distributed over the surface of the tool. The system can be modeled as a cantilever beam, as seen in Figure 8.

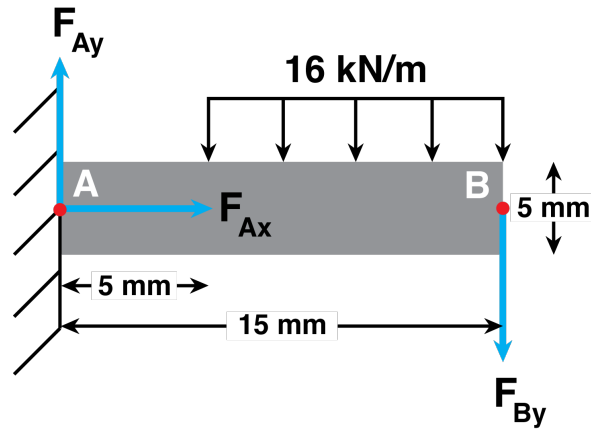


Figure 20. Free body diagram of the tool shaft modeled as a cantilever beam.

The tool must be designed to withstand the maximum stresses induced by loads, which the, requires determination of the maximum shear  $V$ . The governing equation for shear stress is defined as

$$\tau = \frac{F_{Ay}}{A_c} \quad (1)$$

where  $A_c$  is the cross-sectional area of the tool shaft and  $F_{Ay}$  is the shear force acting in the y-direction at point A, as seen in Figure 5. A maximum shear stress of approximately 13.6 MPa is exerted at point A. The yield strength for AISI 4130 steel is 435 MPa and Young's modulus is 205 GPA (ASM.com).

The deflection of the tool shaft must be limited in order to provide stability and integrity of the loading mechanism. To secure the aperture safely, the tool must not deflect severely. The

maximum displacement will occur at point B, when  $x=0$ . The governing equation for maximum displacement  $v$  is defined as (Hibbeler, 2014)

$$v = -\frac{F_B y L^3}{3EI} \quad (2)$$

where  $L$  is the length of the beam,  $E$  is the elastic modulus for the material, and  $I$  is the moment of inertia about the neutral axis. The moment of inertia about the neutral axis for a thin rod is defined as

$$I = \frac{mr^2}{2} \quad (3)$$

where  $m$  is the mass of the rod, and  $r$  is the radius. The maximum deflection for the tool shaft is  $1.22 \times 10^{-7}$  m in the negative  $y$ -direction.

A finite element model was created in order to verify the theoretical model. It is assumed that the system can be modeled using the Euler-Bernoulli beam theory. The thickness of the rod is relatively small compared to the overall length. There are no loading forces about the neutral axis, and the body of the rod does not vary in thickness. The rod is made of a linearly elastic material, steel. Solutions were created with this model using two nodes over one element as 160 N is applied as a concentrated point load at node 2.

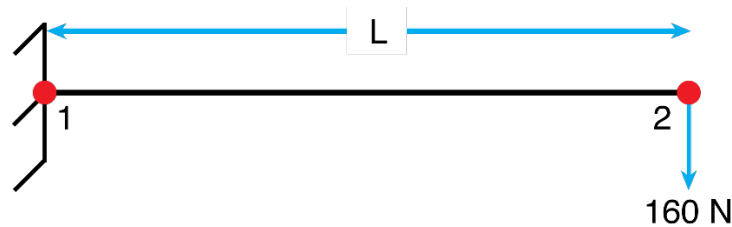


Figure 21. Beam modeled as one element in Abaqus.

In this theory, bending moment  $M$  and transverse deflection  $w$  in a beam are related by

$$-EI \frac{d^2 w}{dx^2} = M(x) \quad (4)$$

where  $M(x)$  is a known function of  $x$  (Reddy, 2006). The maximum deflection can be determined by using the finite element model. The FEM is given by

$$[K^e]\{w^e\} = \{f^e\} + \{Q^e\} \quad (5)$$

Abaqus approximated the maximum displacement at node 2 to be 0.0022 mm, Figure 10. The displacement for the theoretical model was 0.0001 mm. A uniformly distributed load was analyzed in the theoretical model, and a concentrated point load was modeled in the FEM model and approximated in Abaqus. Analysis for the different type loads may have resulted in the variance in displacement. The displacement for the theoretical model and the finite element



model was extremely small. The 5mm diameter steel tool shaft will remain rigid enough to safely and securely guide the aperture into the applicator. Further analysis of the system would include lifecycle calculations to determine when the tool will require maintenance or replacement.

### 6.1.2 Finite Element Analysis of the Platform

Dot decimal has tasked our senior design team with designing a loading/unloading mechanism for brass apertures used in proton therapy treatments. The solution that our team has designed involves the use of a platform to support the large mass of these brass apertures as they are being exchanged from the machine. Preliminary modeling uses a critical cross-section of this platform to model bending. This cross-section is taken where the platform supports the aperture at the greatest distance from its anchoring point, where the largest moment will occur.

Modeling of this system is done using Euler-Bernoulli beam theory where vertical displacement is a function of horizontal displacement over the platform's length, given by equation 1.

$$\frac{d^2}{dx^2} \left( EI \frac{d^2w}{dx^2} \right) = q(x) \quad \text{for } 0 < x < L \tag{1}$$

Where E is elastic modulus, I is the moment of inertia, w is displacement, and q is the distributed load along the section. Steel is chosen as the material for preliminary modeling.

The supporting wall is the location where the platform will be fixed to the rest of the system, thus it is given a constraint of zero displacement. The load, q, is 0 from 0 < x < 1cm. The load from 1 cm < x < L is taken to be the weight of the plate equally distributed along the beam's length. The end of the beam is left free.

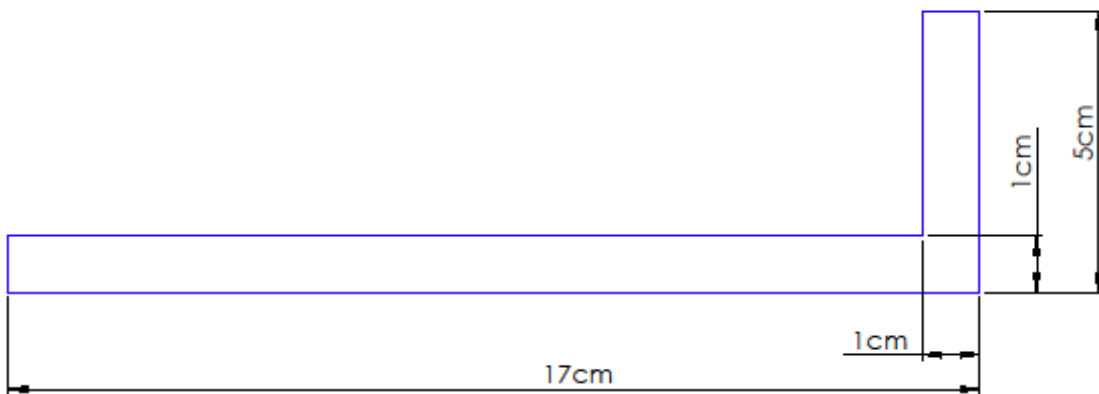


Figure 22. Critical cross-section of platform

Table 2. Device Dimensions

|          |        |       |
|----------|--------|-------|
| Aperture | Mass   | 15 kg |
| Platform | Length | 17 cm |

|              |                       |
|--------------|-----------------------|
| Thickness    | 1 cm                  |
| Wall length  | 1 cm                  |
| Wall height  | 5 cm                  |
| Support area | 164.5 cm <sup>2</sup> |

Table 3. Material Properties of A36 Steel

|                 |                        |
|-----------------|------------------------|
| Density         | 7850 kg/m <sup>3</sup> |
| Elastic Modulus | 200e9 Pa               |
| Poisson's Ratio | 0.33                   |

For ease of calculation and validation, the critical cross-section used for this analysis will be given a thickness and width of 1 cm. Additionally, the curve of the wall will be assumed to be linear to simplify the problem even further.

The deflection at the end of the platform can be easily calculated using theory. To further simplify the calculations, both sides of the wall are assumed to have a deflection of 0 cm. With this, the deflection at the end of the platform can be modeled by.

$$\delta = \frac{Fl^3}{8EI} \quad (2)$$

Where F is the load acting on cross-sectioned platform of width = 1cm, l is the length of the platform's base, E is the elastic modulus, and I is the section moment of inertia given by

$$I = \frac{wh^3}{12} \quad (3)$$

Assuming that the weight of the plate is evenly distributed across the platform's area, the force, F, acting on the modeled section is calculated by multiplying the aperture's weight by the fraction of area the model occupies on the entire platform. It follows that

$$F = (15kg) \left(9.81 \frac{m}{s^2}\right) \left(\frac{(16cm)(1cm)}{164.5 cm^2}\right) = 14.31 N \quad (4)$$

$$I = \frac{(1cm)(1cm)^3}{12} = 0.0833 cm^4 \quad (5)$$

$$\delta = \frac{(14.31 N)(16 cm)^3}{8(200e9 Pa)(0.0833 cm^4)} = 4.4e - 3 cm \quad (6)$$

In order to more accurately model this system, the platform's entire geometry was looked at in 3 dimensions. The assumption was made that the weight of the aperture was distributed equally along the platform's surface as a total force. This is not what actually happens in due to the aperture only being supported along a portion of its surface; however, the approximation is sufficient for this analysis. Additionally, the platform is fixed at its mounting surface along the

back wall of the aperture. The mounting surface can be seen at the far end of the x-axis contacting the y-z plane's grid in figure xx.

## 6.2 Design for Manufacturing

Design for Manufacturability (DFM) guidelines are structured to help reduce cost. DFM was used in conjunction with concurrent engineering practices to develop a product that is cost effective, reliable, and maintainable. Various design concepts were considered early in the development process to ensure optimal product design. The use of computer aided engineering (CAE) tools such as computer aided design (CAD), finite element analysis (FEA), and rapid prototyping technologies aided in the DFM process. Solid modeling helped visualize the individual parts in order to understand part relationships, orientation, scale, and geometric dimensions and tolerances. All parts were designed in accordance with ASME 14.5-2009 dimensioning and tolerancing standards. Errors could more easily be identified when the parts were placed into an assembly. FEA was used in the conceptual design phase to verify the geometry of two critically loaded components. Constraints such as tooling and machinery were considered as the design was developed from the conceptual phase to the detailed phase.

Parts for the Proton Therapy Device Manager were created using three manufacturing processes: Waterjet cutting, CNC machining, and additive manufacturing. Reducing the number of manufacturing operations was an attempt to simplify the design, reduced overall cost, and to save time. One part was milled using a CNC machine, and three parts were 3D printed. The lock had to be milled due to its geometry. 3D printing technology was used in order to reduce cost, part complexity, and time. However, it should be noted that the product can be further optimized by leveraging other manufacturing technologies such as CNC machining and injection molding processes. These processes could not be justified for the current prototype. The system is mainly designed in order to be cut on a waterjet machine. Waterjetting was the simplest way to achieve product efficiency. Waterjet technology was suitable because tight tolerances can still be achieved without the high cost of manufacturing. Additionally, a robust design was achieved to compensate for the uncertainty of the products testing and end use. Simple patterns were cut on the waterjet machine in approximately one hour. These simple shapes reduced material waste. The waterjetting process keeps the overhead low if parts need to be reproduced. The material was standardized to 0.125" aluminum.

Each part was designed to be versatile and can easily be redesigned and fabricated with the manufacturing techniques used. Each part has a clear function, interface, and interaction. These aspects were considered in order to maximize ease of assembly. Undercuts and thin wall features were avoided. Parts were designed to be multifunctional. For example, the loading gear acts as a guiding tool, provides structural support to the lock's motor, and transfers power from the driving gear. Some parts do require an adequate amount of post processing due to the waterjet manufacturing process. Post processing procedures mainly consist of drilling, tapping, countersinking, grinding, and sanding. Many fasteners such as nut, bolts, washers, and spacers were used to assemble the product. The use of these fasteners increased assembly time. Much time was invested into ensuring each hole was properly aligned, drilled, and tapped. However, it was worth the time investment in order to verify the alignment of the other assembly components.

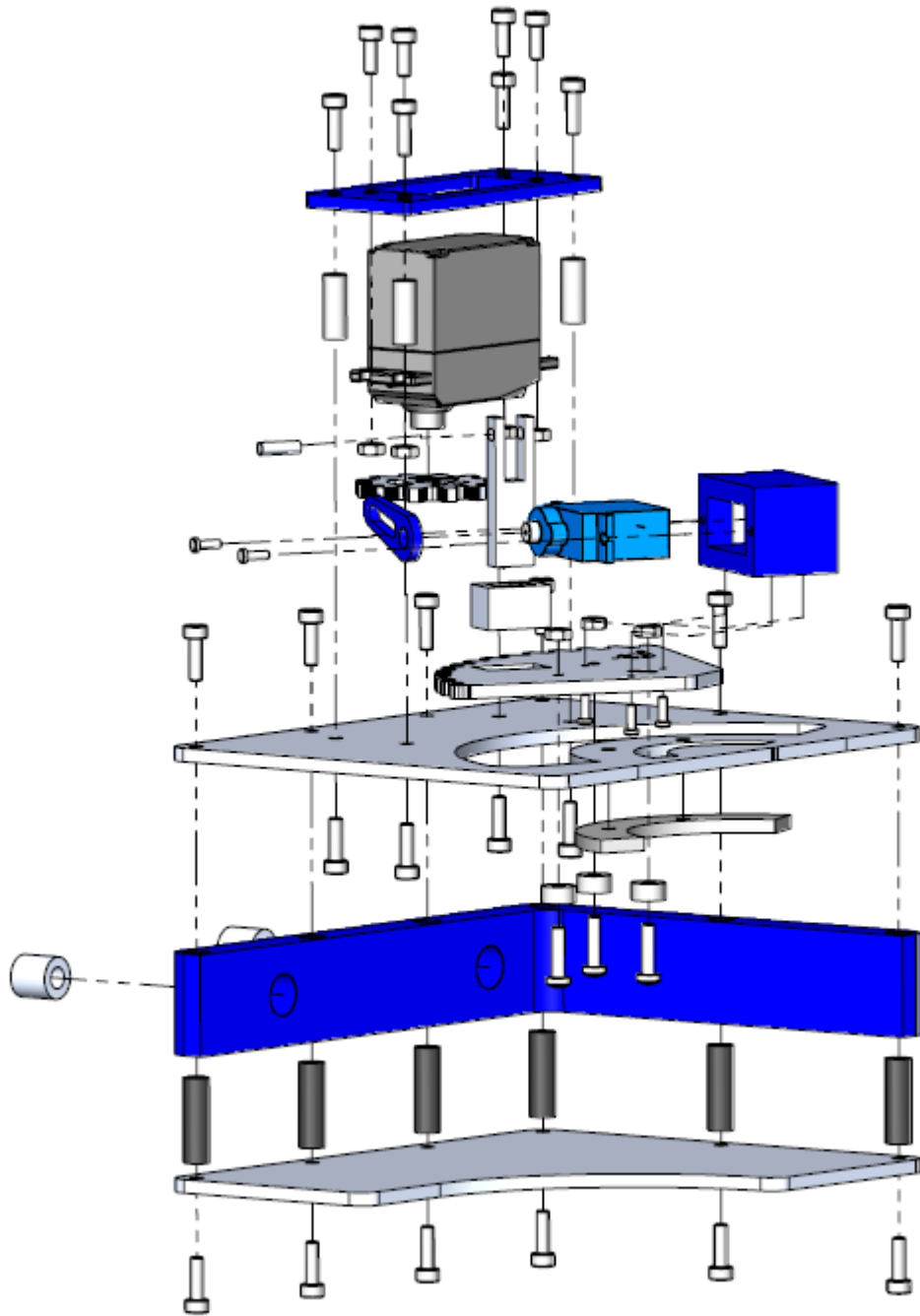


Figure 23 Exploded view of Platform

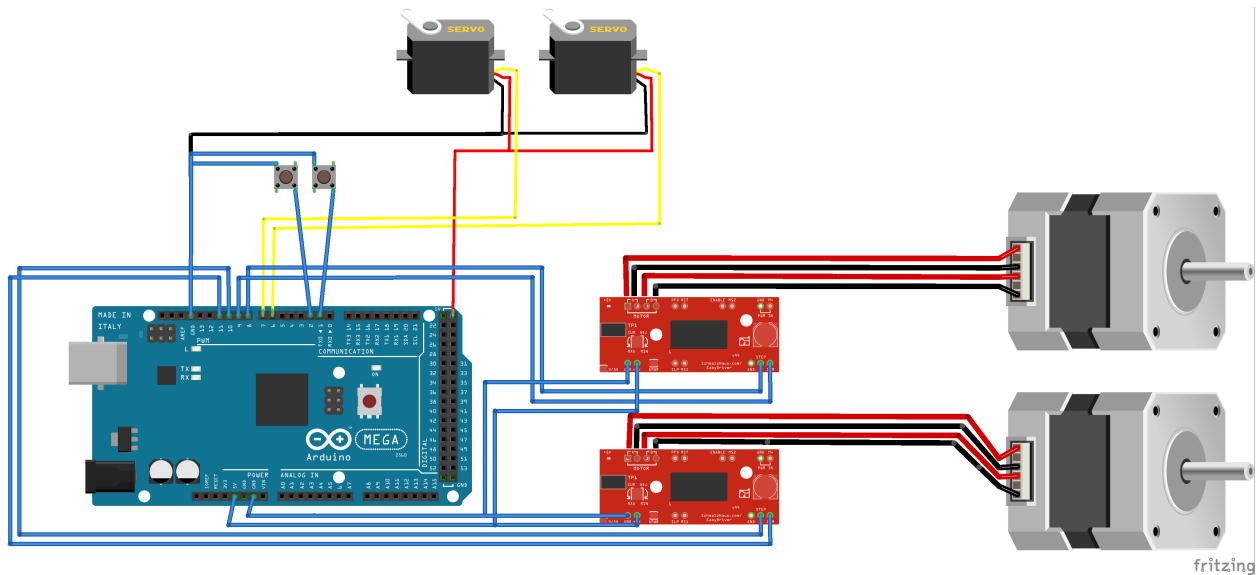


Figure 24 Wiring Diagram

## 6.3 Design for Economics

In all, to complete our project, we spent \$1,424.14 of our \$2,000 budget. We have yet to use \$575.86. Some of the items we bought were only sold in larger quantities than we needed, so we do have some spare parts which can be used to repair or add onto our prototype. All measures were taken to find the cheapest yet, still reliable components. We did not want to sacrifice quality for quantity, but instead searched for the best value for our money. A breakdown of our total cost, budget and remaining funds can be found in table 3.

Most of the money in our budget went to to the electrical components at a total of \$924.43. Our team also chose to develop a few 3D printed prototypes as we were finalizing the design of the grabbing mechanism, and also our final version of this element. This cost the team \$200 in plastic for the 3D printer. The remaining mechanical parts were purchased or manufactured via CNC machining and/or water jet and is reflected in the Mechanical total of \$149.90. Misc. tools and supplies were purchased to aid in the assembly process and overall structural reliability of the final prototype. We also factored in the cost of shipping on some of our orders, thankfully some sites had free shipping. Power supplies and cords were also an expense at \$60.37. In Table 4 it is noted how much money was spent on each category of items needed for the completion of this project.

A comprehensive list of all of the components purchased can be found in Appendix A.

Table 4. Budget Spending Figures

|                        |            |
|------------------------|------------|
| <b>Total Budget</b>    | \$2,000.00 |
| <b>Total Spent</b>     | \$1,424.14 |
| <b>Total Remaining</b> | \$575.86   |

Table 5. Budget Broken Down by Category

| Category     | Total Spent |
|--------------|-------------|
| 3-D printing | \$200.00    |
| Electronic   | \$924.43    |
| Mechanical   | \$149.40    |
| Misc.        | \$44.90     |
| Power        | \$60.37     |
| Shipping     | \$45.04     |

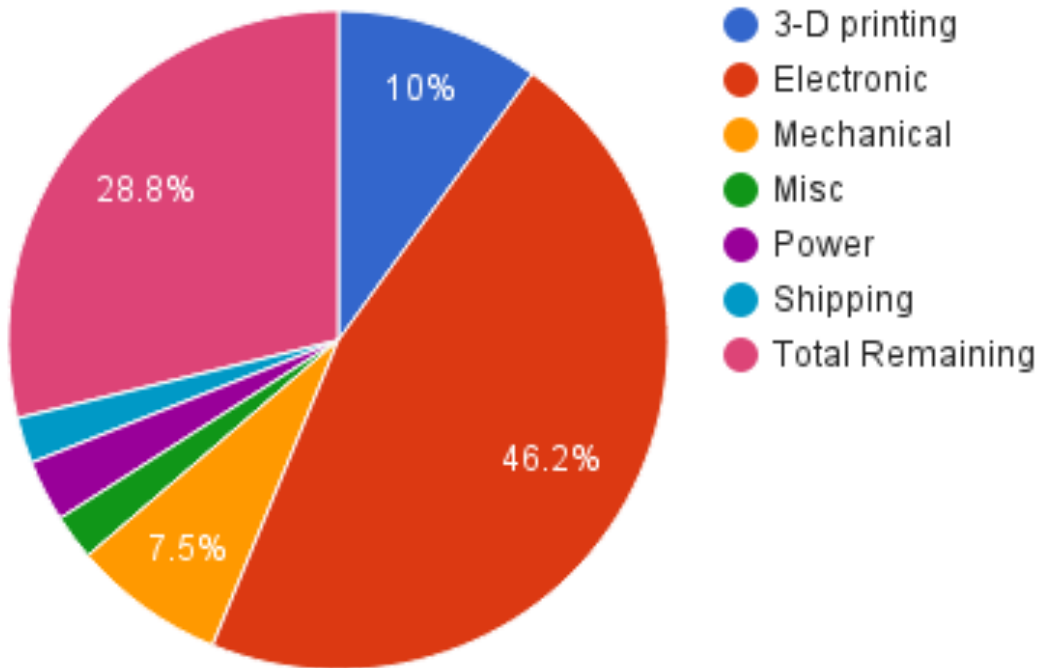


Figure 25 Pie Chart of Categorical Budget Breakdown

There are no similar products currently on the market to the Proton Therapy Device Manager. This product is very unique and is designed for the specific use in proton therapy at cancer centers. The majority of the work this team designed is in the grabbing mechanism which directly loads/unloads the apertures. Specific elements of the design however are similar to others on the market. Below in Table 4, is the price difference of various metals. As seen, Aluminum is the cheapest and yet still has a high enough strength in order to perform the duties required.

This product would be replacing the utilization of a technician’s manual effort of loading and unloading the apertures. The purchase of this product’s one time build doesn’t necessarily save the customer money directly, but it greatly improves the quality of life and reduces the physical work effort - both of the patient and technician - which in turn will allow the cancer center to make more money as they treat more patients.

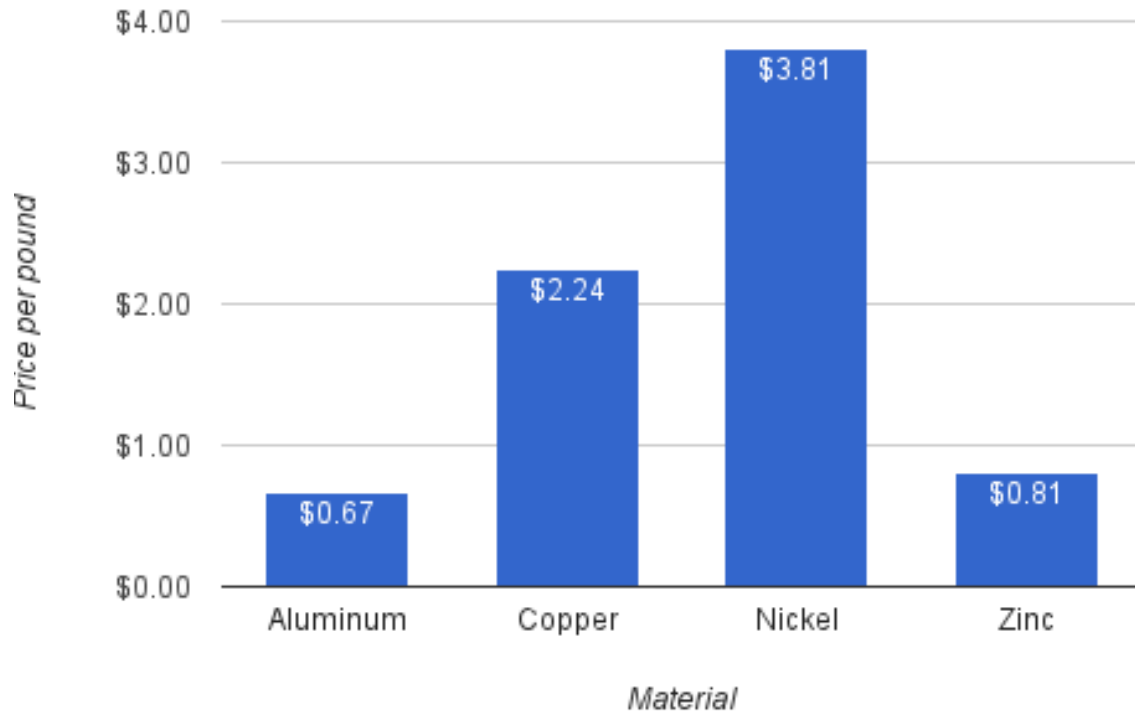


Figure 26 Material Selection by Price

## 7 Design of Experiment

The Parallax Fubata continuous rotation servo requires some calibration. The position of this servo must be controlled by a delay, and the speed must be controlled by a pulse rate. Every 120V outlet will send a different signal to the servo, therefore, the servo must be calibrated before any loading and unloading cycles can be completed. The servo will need to be calibrated for its stop pulse and its operating range of motion. The operating range of motion will have two limits: front and back. The front limit can be calibrated by first aligning the edge of the driven gear with the score mark on the top of the platform as seen in Figure XXX. The back limit can be calibrated by aligning the back edge of the gear with the score mark on the platform as seen in

Figure XXX. The pulse for each limit will need to be adjusted in the code in order to move the aperture through its full range of motion.

The locking arm is driven by a micro servo. The micro servo's position can be controlled in degrees. The range of motion is programmed into the code. Adjust the range of the degrees in order to get either a higher or lower range of motion. The ability of this servo to plunge the lock to different depths allows for the platform to handle different sized apertures, as well as the thicker range compensator.

The linear rail systems, driven by NEMA17 stepper motors, have a calibration function built into the operation program. When the system is powered, the rails will calibrate themselves by traversing to their limits. Once this calibration is complete, the platform will home to a known position and any desired locations can be reached using the accuracy of the stepper motors to move the platform a certain distance. If miscalibration is suspected, or a recalibration desired, the technician can manually run the calibration procedures.

In addition to these safeguards for ensuring smooth operation, the prototype will be tested using a nozzle manufactured using fused deposition modeling. Due to budget constraints, this nozzle will be limited to two aperture slots and relatively loose tolerances. Additionally, the nozzle's aperture security lock will be designed to allow for ease of testing.

## 8 Considerations for Environment, Safety, and Ethics

This project does not really affect the environment, as it is a robotic system located within a hospital. It does consume energy though, and so the team plans to design a system with a low power requirement, but the team also realizes that lifting the heavy apertures requires a relatively large amount of power. We have also selected motors and other components for their small size, and low noise levels.

When it comes to safety of the design team, considerations for electrical components and sharp points will need to be handled with precaution during the assembly phase. Also the team must be cognizant of the patient's safety. Where this is relevant is when the apertures are being loaded and it needs to be ensured that the correct aperture is being loaded for the right treatment session, and then the system also needs to be strong enough to carry the aperture and make sure it does not drop it on the patient



## 9 Project Management

Overall, things went fairly smoothly in the planning and execution of this project. The majority of the management of this project was carried out by the Team Leader, but was also a team effort at all times.

### 9.1 Schedule

Team 14 completed the initial prototypes and all work in a timely manner. By winter break, the team had created the initial head mount for loading and unloading the apertures. By the end of February the team had a working linear rail system assembled and had finalized all designs in CAD software. The team met with their sponsor to ensure things were moving along at the desired pace and that results were on track with what they had envisioned. The Gantt charts developed were respected and the team stayed on track meet the deadlines set by the team and advisors.

### 9.2 Resources

In order to complete this project, the team utilized a wide variety of resources. Many of the initial prototypes were 3D printed by Micah Baxter at Function 3D. This facility has multiple printers, and since Micah worked there we were able to use their equipment at any time and only paid for the material. Team members had many tools of their own that were used to assemble various elements and test the project. A few extra tools and components were purchased with the team's budget and will be of good use to the following team. Morgan O'Rorke works at HPMI and was able to utilize the water jet at that facility to manufacture several of out aluminum pieces at no cost. We made appointments and completed everything in a timely manner with the guidance of HPMI staff members.

### 9.3 Procurement

In all, to complete our project, we spent \$1,424.14 of our \$2,000 budget. We have yet to use \$575.86. Some of the items we bought were only sold in larger quantities than we needed, so we do have some spare parts, which can be used to repair or add onto our prototype. All measures were taken to find the cheapest yet, still reliable components. We did not want to sacrifice quality for quantity, but instead searched for the best value for our money. We felt the budget was an appropriate amount and the team did their best to manage the budget responsibly. Parts were purchased from a variety of places in order to get the best parts and to pay the least amount for them. A full Bill of Materials can be found in Appendix C.

### 9.4 Communications

The team communicated on a minimum weekly basis, usually daily and discussed all ongoing part of the projects and their status. The group maintained an online to do list that all members could view and update the status of each task so the team was always aware of what was going on. The team met with advisors and their sponsor regularly to ensure the project was developing in a positive way. Since the sponsor was located in Central Florida, the team made a visit to their facility and the proton therapy center at the beginning of the year. Then as the year

and project progressed the team communicated with their sponsor via an online meeting website capable of screen-sharing and video chat.

## 10 Conclusion

Senior design Team 14, has created a device that will automatically load and unload apertures from a Proton Therapy treatment system. It is relatively simple device which is easy to assemble as well as easy for the user to operate. The device does not require much maintenance as it has very sturdy components and does not require any additional supplies as it runs. The only thing that must be provided is power. This device was made with the budget of the consumer in mind, therefore decisions were made to pick the best parts at the best price. This device has also undergone testing to ensure that the product performs correctly and repeatedly. However, frequent calibration is necessary to ensure that the device is navigating to the correct height to meet the nozzle every time. This team has worked to make the most user friendly, as well as budget friendly, product as possible.

### 10.1 Future Work

This project has enormous potential for future work and more elements to be designed. The product created this year simply approached the challenges of loading and unloading the apertures directly into the nozzle. It can only move up and down, side-to-side, and then the holding platform to insert and remove the actual aperture.

This system does not account for the changing of apertures based on what the patient's treatment plan is or initially pick up the apertures. Creating a rotational element of some sort could do this and then a rack or table where the technician could store each patient's devices before treatment begins. A barcoding system could be created as well to double check the right apertures are being placed in at the right time in the right positions. Each aperture would have a barcode that stored all of the correct data and the technician could control this information from their user interface in the control room. This project could also be improved by creating a more user friendly and professional looking interface for the technician to use. The current system is very basic and is directly linked to the code. Another very important element not addressed in this year's project was the latching and unlatching of the safety lock that is on the nozzle.

# 11 Acknowledgement

Team 14 would like to thank the sponsor, Dot Decimal, for providing us with sample parts, answering questions, brainstorming ideas, and bringing us to their facility in Orlando and the proton therapy center. Thank you to our advisors, Dr. Jonathan Clark, Dr. Nikhil Gupta, and Dr. Chiang Shih for providing administrative support as well as technical advice.

# Appendix A

| Category    | Product  | Price    | Quantity | Total    | Vendor      | Number Input |
|-------------|--|----------|----------|----------|-------------|--------------|
| Electronic  | V-Slot™ Nema 17 Linear Actuator Bundle (Lead Screw)<br>(Length: 250mm, V-Slot Color: Black, Motor Included? Include Motor) | \$117.85 | 2        | \$235.70 | OpenBuilds  | 29           |
| 3D Printing | 3-D Printing Rolls of Plastic  | \$40.00  | 5        | \$200.00 | Function 3D | 54           |
| Electronic  | L12 50mm 100:1 Linear Actuator [Firgelli]  | \$90.00  | 2        | \$180.00 | Robot Geek  | 1            |
| Electronic  | Big Easy Driver  | \$19.95  | 4        | \$79.80  | Sparkfun    | 50           |
| Mechanical  | Xtreme Solid V Wheel™ Kit<br>(Quantity: Qty. 1)  | \$6.75   | 8        | \$54.00  | OpenBuilds  | 30           |
| Electronic  | SunFounder New Uno R3 Project Super Starter Kit For Arduino UNO R3 Mega2560 Mega328 Nano                                   | \$52.99  | 1        | \$52.99  | Amazon      | 55           |
| Misc.       | Tool Kit - Beginner  | \$34.95  | 1        | \$34.95  | Sparkfun    | 52           |
| Electronic  | FS90MG Micro Metal Gear Servo [RobotGeek]  | \$14.90  | 2        | \$29.80  | Robot Geek  | 10           |
| Shipping    | SparkFun Shipping  | \$26.71  | 1        | \$26.71  | Sparkfun    | 53           |
| Electronic  | Arduino Compatible Mega 2560 Atmega2560 Mega2560 R3 Board + USB Cable  | \$24.99  | 1        | \$24.99  | Amazon      | 58           |
| Power       | 12v 30a Dc Universal Regulated Switching Power Supply 360w for CCTV, Radio, Computer Project                               | \$23.97  | 1        | \$23.97  | Amazon      | 64           |
| Electronic  | Servo - Generic Continuous Rotation (Micro Size)   | \$11.95  | 2        | \$23.90  | Sparkfun    | 49           |
| Electronic  | RobotGeek Geekduino [RobotGeek]  | \$22.50  | 1        | \$22.50  | Robot Geek  | 4            |
| Power       | NEWSTYLE 12v 30a Dc Universal Regulated Switching Power Supply 360w  | \$21.49  | 1        | \$21.49  | Amazon      | 35           |
| Electronic  | RobotGeek Slider [RobotGeek]   | \$6.95   | 3        | \$20.85  | Robot Geek  | 6            |
| Mechanical  | 8mm Metric Acme Lead Screw   | \$20.75  | 1        | \$20.75  | OpenBuilds  | 12           |
| Shipping    | Robot Geek Shipping  | \$18.33  | 1        | \$18.33  | Robot Geek  | 11           |
| Electronic  | SainSmart CNC Router Single 1 Axis 3.5A TB6560 Stepper Stepping Motor Driver Board   | \$17.99  | 1        | \$17.99  | Amazon      | 62           |
| Electronic  | SainSmart CNC Router Single 1 Axis 3.5A TB6560 Stepper Stepping Motor Driver Board   | \$17.99  | 1        | \$17.99  | Amazon      | 66           |
| Electronic  | DC 12V 15RPM 6mm Shaft High  | \$16.29  | 1        | \$16.29  | Amazon      | 38           |

|            |   |         |    |         |            |    |
|------------|---|---------|----|---------|------------|----|
|            | Torque Turbine Worm Geared Motor  |         |    |         |            |    |
| Electronic | RobotGeek Sensor Shield ( Version 2 ) [RobotGeek]   | \$7.95  | 2  | \$15.90 | Robot Geek | 2  |
| Electronic | Mini Microswitch - SPDT (Lever, 2-pack)   | \$3.95  | 4  | \$15.80 | Sparkfun   | 42 |
| Electronic | SainSmart CNC Router Single 1 Axis 3.5A TB6560 Stepper Stepping Motor Driver Board WL   | \$14.99 | 1  | \$14.99 | Amazon     | 34 |
| Electronic | RobotGeek Pushbutton [RobotGeek]  | \$2.95  | 5  | \$14.75 | Robot Geek | 5  |
| Electronic | Stepper Motor Nema 17 Bipolar 40mm 64oz.in(45Ncm) 2A 4 Lead 3D Printer Hobby CNC  | \$13.99 | 1  | \$13.99 | Amazon     | 65 |
| Mechanical | Nut Block for 8mm Metric Acme Lead Screw  | \$6.95  | 2  | \$13.90 | OpenBuilds | 23 |
| Electronic | Kimdrox Mini 12V DC 30RMP High Torque Gear Box Motor Diameter 37mm  | \$12.99 | 1  | \$12.99 | Amazon     | 37 |
| Electronic | SainSmart UNO R3 ATmega328P Development Board + Free USB Cable Compatible With Arduino  | \$12.99 | 1  | \$12.99 | Amazon     | 57 |
| Power      | Power Supply 6VDC 2.0A - US [Top Power Co]  | \$9.95  | 1  | \$9.95  | Robot Geek | 7  |
| Misc.      | Third Hand  | \$9.95  | 1  | \$9.95  | Sparkfun   | 51 |
| Mechanical | Cast Corner Bracket   | \$1.50  | 6  | \$9.00  | OpenBuilds | 17 |
| Electronic | 6pcs Addicore nRF24L01+ Wireless Transceiver in Antistatic Foam Arduino Compatible+ 2.4GHz  | \$8.45  | 1  | \$8.45  | Amazon     | 60 |
| Electronic | DROK □ L298N Motor Drive Controller Board DC Dual H-Bridge Robot Stepper Motor Control & Drives Module for Arduino Smart Car Power UNO MEGA R3 Mega | \$7.99  | 1  | \$7.99  | Amazon     | 63 |
| Electronic | Heat Shrink Kit   | \$7.95  | 1  | \$7.95  | Sparkfun   | 47 |
| Mechanical | Drop In Tee Nuts  | \$0.75  | 10 | \$7.50  | OpenBuilds | 18 |
| Electronic | Mihappy 3pcs Ultrasonic Module Hcsr04 Distance Measuring Transducer Sensor for Arduino  | \$7.25  | 1  | \$7.25  | Amazon     | 61 |
| Electronic | DROK □ L298N Motor Drive Controller Board DC Dual H-Bridge Robot Stepper Motor Control & Drives Module for Arduino Smart Car Power UNO MEGA R3 Mega | \$6.99  | 1  | \$6.99  | Amazon     | 36 |
| Mechanical | V-Slot™ Linear Rail (Size: 20mm x 40mm, Length: 500mm, Color: Silver)   | \$6.50  | 1  | \$6.50  | OpenBuilds | 28 |
| Mechanical | Ball Bearing 625 2RS 5x16x5   | \$1.00  | 6  | \$6.00  | OpenBuilds | 15 |

|            |  |        |    |        |            |    |
|------------|--|--------|----|--------|------------|----|
| Electronic | 30Pcs 2 Pole 5mm Pitch PCB Mount Screw Terminal Block 8A 250V  | \$5.95 | 1  | \$5.95 | Amazon     | 39 |
| Electronic | Pwr+ 6ft Ac Wall Cable Power Cord for Led Lcd Tv, Samsung, Apple Tv, Lg, Sharp; Canon Pixma, Hp Brother Epson Lexmark Printer, Ps2, Ps3 Slim, Ps4; Del | \$5.80 | 1  | \$5.80 | Amazon     | 59 |
| Electronic | Cooler Master Rifle Bearing 80mm Silent Cooling Fan for Computer Cases and CPU Coolers   | \$5.76 | 1  | \$5.76 | Amazon     | 31 |
| Electronic | Medium Bread Board [Seed Studio]   | \$5.50 | 1  | \$5.50 | Robot Geek | 9  |
| Electronic | Cooler Master Rifle Bearing 80mm Silent Cooling Fan for Computer Cases and CPU Coolers   | \$5.25 | 1  | \$5.25 | Amazon     | 32 |
| Mechanical | V-Slot™ Linear Rail<br>(Size: 20mm x 20mm, Length: 500mm, Color: Silver)   | \$5.00 | 1  | \$5.00 | OpenBuilds | 27 |
| Power      | ZJchao 9V 1A Power Adapter for Arduino (2-Flat-Pin Plug / 100CM Cable)   | \$4.96 | 1  | \$4.96 | Amazon     | 56 |
| Electronic | RobotGeek 300mm 3-pin Sensor Cable 10 pack [RobotGeek]   | \$4.95 | 1  | \$4.95 | Robot Geek | 3  |
| Electronic | Jumper Wires Premium 6" M/M - 20 AWG (10 Pack)   | \$4.95 | 1  | \$4.95 | Sparkfun   | 48 |
| Mechanical | Low Profile Screws M5<br>(Length: 40mm, Quantity: Qty. 25)   | \$4.90 | 1  | \$4.90 | OpenBuilds | 22 |
| Electronic | microtivity IM206 6x6x6mm Tact Switch (Pack of 12)   | \$4.33 | 1  | \$4.33 | Amazon     | 33 |
| Mechanical | Ball Bearing 688Z 8x16x5   | \$1.00 | 4  | \$4.00 | OpenBuilds | 16 |
| Electronic | Toggle Switch  | \$1.95 | 2  | \$3.90 | Sparkfun   | 40 |
| Electronic | Screw Terminals 3.5mm Pitch (2-Pin)  | \$0.95 | 4  | \$3.80 | Sparkfun   | 45 |
| Mechanical | Low Profile Screws M5<br>(Length: 25mm, Quantity: Qty. 25)   | \$3.50 | 1  | \$3.50 | OpenBuilds | 21 |
| Mechanical | Low Profile Screws M5<br>(Length: 8mm, Quantity: Qty. 25)  | \$3.15 | 1  | \$3.15 | OpenBuilds | 20 |
| Electronic | Alligator Clip with Pigtail (4 Pack) [SparkFun]  | \$2.95 | 1  | \$2.95 | Robot Geek | 8  |
| Electronic | Hook-up Stranded Wire - White (22 AWG)   | \$2.95 | 1  | \$2.95 | Sparkfun   | 46 |
| Mechanical | Low Profile Screws M5<br>(Length: 6mm, Quantity: Qty. 25)  | \$2.80 | 1  | \$2.80 | OpenBuilds | 19 |
| Mechanical | Precision Shim - 10x5x1mm  | \$0.25 | 10 | \$2.50 | OpenBuilds | 24 |
| Electronic | Hook-up Wire - Black (22 AWG)  | \$2.50 | 1  | \$2.50 | Sparkfun   | 43 |

|            |                              |        |    |        |            |    |
|------------|------------------------------|--------|----|--------|------------|----|
| Electronic | Hook-up Wire - Red (22 AWG)  | \$2.50 | 1  | \$2.50 | Sparkfun   | 44 |
| Mechanical | Self Tapping Screw           | \$0.25 | 8  | \$2.00 | OpenBuilds | 25 |
| Mechanical | Aluminum Spacers (Size: 3mm) | \$0.20 | 8  | \$1.60 | OpenBuilds | 13 |
| Mechanical | Aluminum Spacers (Size: 6mm) | \$0.20 | 8  | \$1.60 | OpenBuilds | 14 |
| Mechanical | Set Screw                    | \$0.07 | 10 | \$0.70 | OpenBuilds | 26 |
| Electronic | Rocker Switch - SPST (round) | \$0.50 | 1  | \$0.50 | Sparkfun   | 41 |



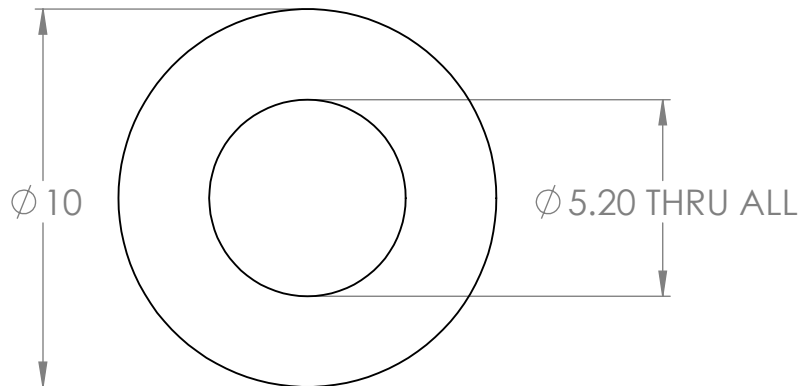
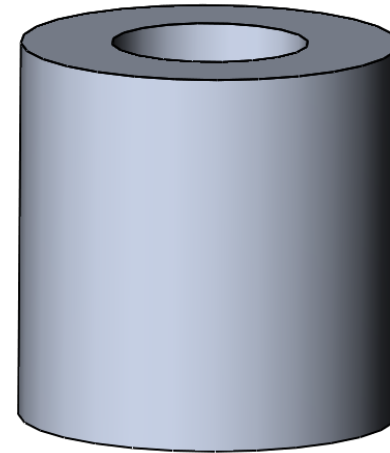
# Appendix B

2

1

B

B



A

A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X  $\pm$  0.1  
 X.XX  $\pm$  0.01  
 X.XXX  $\pm$  0.001  
 ANGLES  $\pm$  0.5°

FINISH:  
 N/A

PART NAME:  
 PLATFORM MIDDLE

DRAWN BY:  
 MICAH BAXTER

SCALE:  
 5:1

PROJECT:  
 PROTON THERAPY DEVICE MANAGER

DATE:  
 04/01/2016

SHEET NUMBER:  
 1 OF 1

MATERIAL:  
 ALUMINUM

PART NUMBER:  
 S16-PTDM-P-00

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2

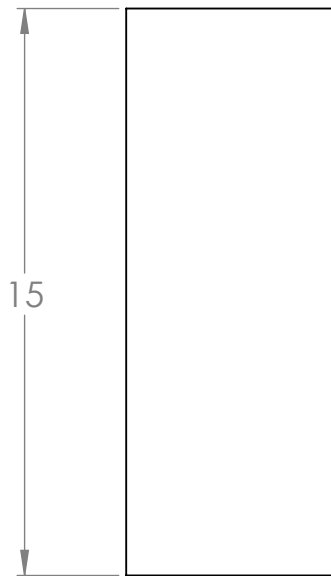
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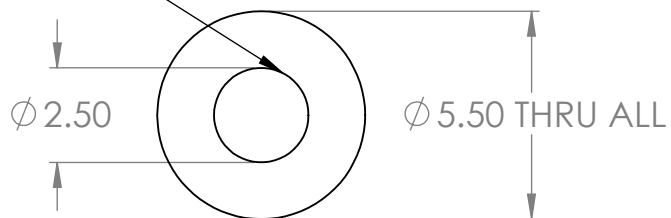
1

B

B



THREADED PITCH 0.5



A

A

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|  |                            |   |                               |
|--|----------------------------|---|-------------------------------|
| UNLESS OTHERWISE SPECIFIED:<br>DIMENSIONS ARE IN MM<br>TOLERANCES:<br>X.X ± 0.1<br>X.XX ± 0.01<br>X.XXX ± 0.001<br>ANGLES ± 0.5°<br>FINISH:<br>N/A | PART NAME:<br>15 mm SPACER | PROJECT:<br>PROTON THERAPY DEVICE MANAGER |                               |
|  | DRAWN BY:<br>MICAH BAXTER  | DATE:<br>04/01/2016                       | MATERIAL:<br>ABS              |
|  | SCALE:<br>5:1              | SHEET NUMBER:<br>1 OF 1                   | PART NUMBER:<br>S16-PTDM-P-00 |
|  |                            |   |                               |

2

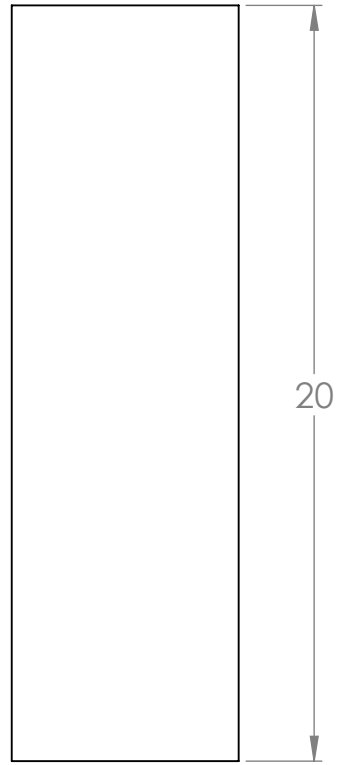
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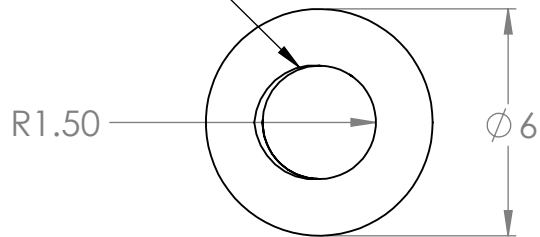
1

B

B



THREADED PITCH 0.5



A

A

UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X  $\pm$  0.1  
 X.XX  $\pm$  0.01  
 X.XXX  $\pm$  0.001  
 ANGLES  $\pm$  0.5°  
 FINISH:  
 N/A

PART NAME:  
 20 mm SPACER

PROJECT:  
 PROTON THERAPY DEVICE MANAGER

DRAWN BY:  
 MICAH BAXTER

DATE:  
 04/01/2016

MATERIAL:  
 ABS

SCALE:  
 2:1

SHEET NUMBER:  
 1 OF 1

PART NUMBER:  
 S16-PTDM-P-00

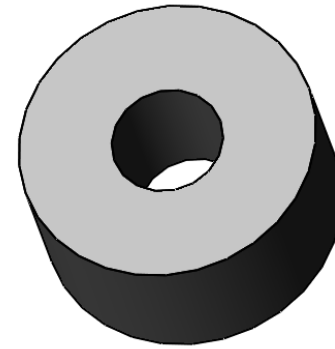
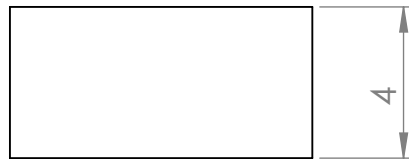
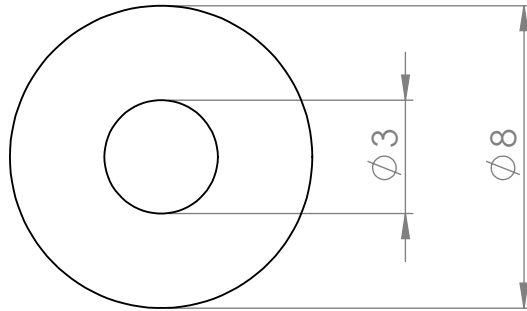
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2

1

2

1



B

B

A

A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM

TOLERANCES:

X.X ± 0.1

X.XX ± 0.01

X.XXX ± 0.001

ANGLES ± 0.5°

FINISH:

N/A

PART NAME:

BEARING

DRAWN BY:

MICAH BAXTER

SCALE:

5:1

PROJECT:

PROTON THERAPY DEVICE MANAGER

DATE:

04/01/2016

SHEET NUMBER:

1 OF 1

MATERIAL:

ALUMINUM

PART NUMBER:

S16-PTDM-P-00

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2

1

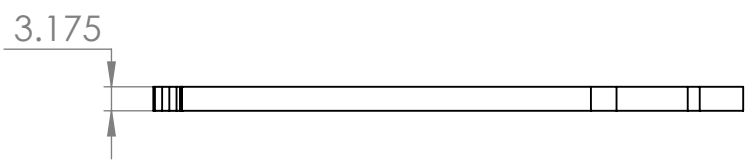
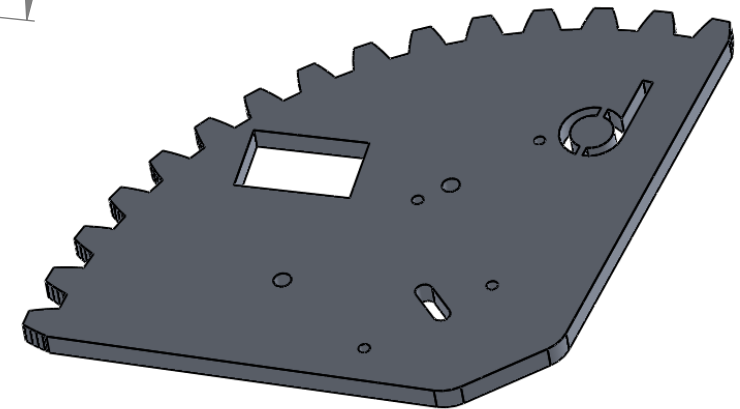
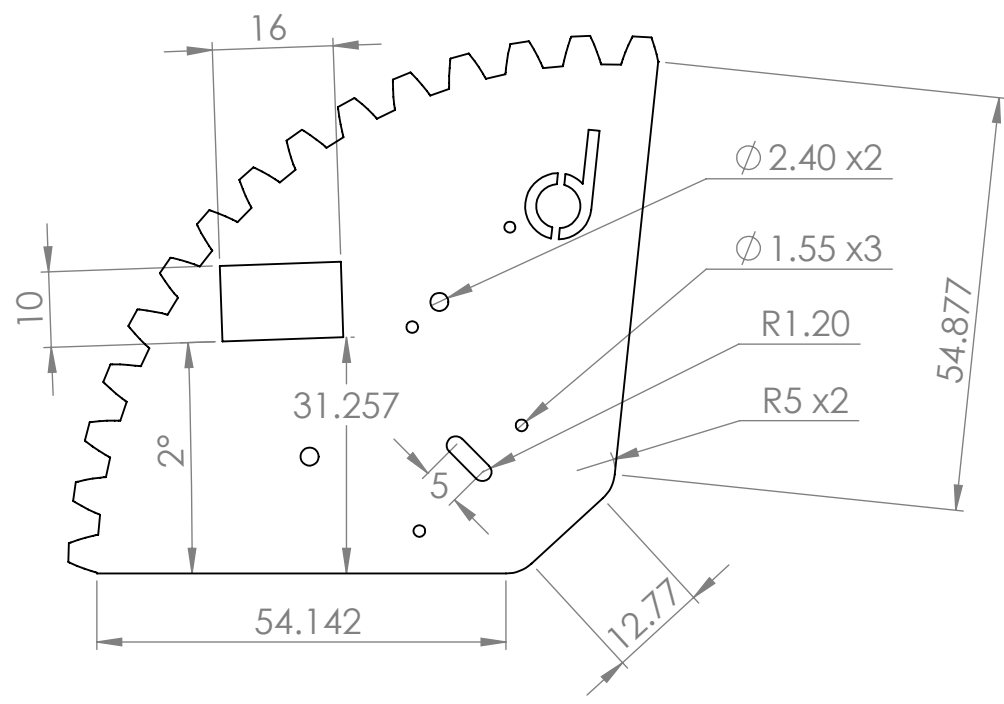
2

1

B

B

Notes: Spur Gear  
 54 teeth  
 270 mm pitch diameter  
 277.34 overall diameter  
 0.25 mm addendum  
 20° contact angle



A

A

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|--|---------------------------|---|-------------------------------|
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|  | DRAWN BY:<br>MICAH BAXTER | DATE:<br>04/01/2016                       | MATERIAL:<br>ALUMINUM         |
|  | SCALE:<br>1:1             | SHEET NUMBER:<br>1 OF 1                   | PART NUMBER:<br>S16-PTDM-P-00 |
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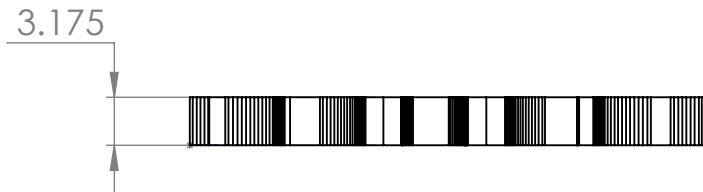
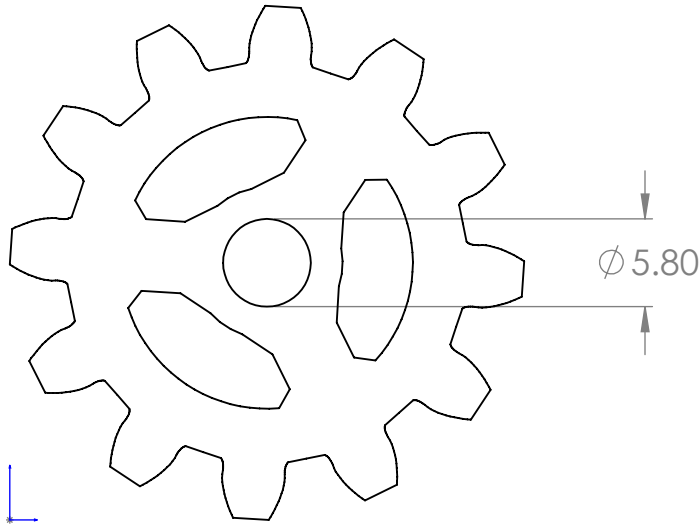
2

1

2

1

Notes: Spur Gear  
 12 teeth  
 60 mm pitch diameter  
 67.34 overall diameter  
 0.25 mm addendum  
 20° contact angle



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 DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X ± 0.1  
 X.XX ± 0.01  
 X.XXX ± 0.001  
 ANGLES ± 0.5°  
 FINISH:  
 N/A

PART NAME:  
 DRIVING GEAR

DRAWN BY:  
 MICAH BAXTER

SCALE:  
 2:1

PROJECT:  
 PROTON THERAPY DEVICE MANAGER

DATE:  
 04/01/2016

SHEET NUMBER:  
 1 OF 1

MATERIAL:  
 ALUMINUM

PART NUMBER:  
 S16-PTDM-P-00

2

1

B

B

A

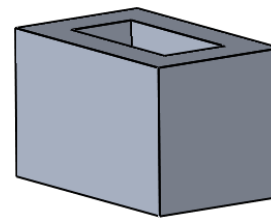
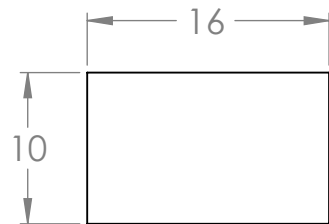
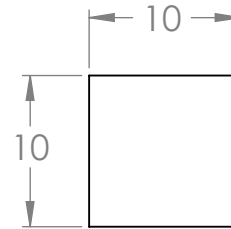
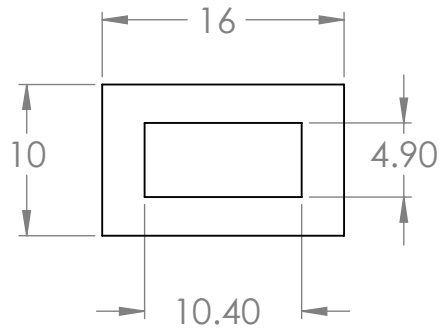
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B

B



A

A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X ± 0.1  
 X.XX ± 0.01  
 X.XXX ± 0.001  
 ANGLES ± 0.5°

FINISH:  
 N/A

PART NAME:

GUIDE

DRAWN BY:

MICAH BAXTER

SCALE:

2:1

PROJECT:

PROTON THERAPY DEVICE MANAGER

DATE:

04/01/2016

SHEET NUMBER:

1 OF 1

MATERIAL:

ALUMINUM

PART NUMBER:

S16-PTDM-P-00

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2

1

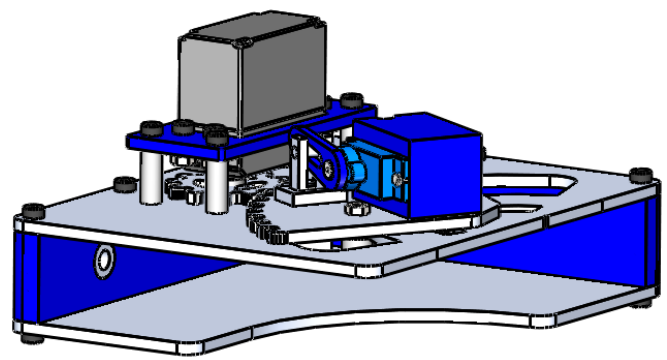
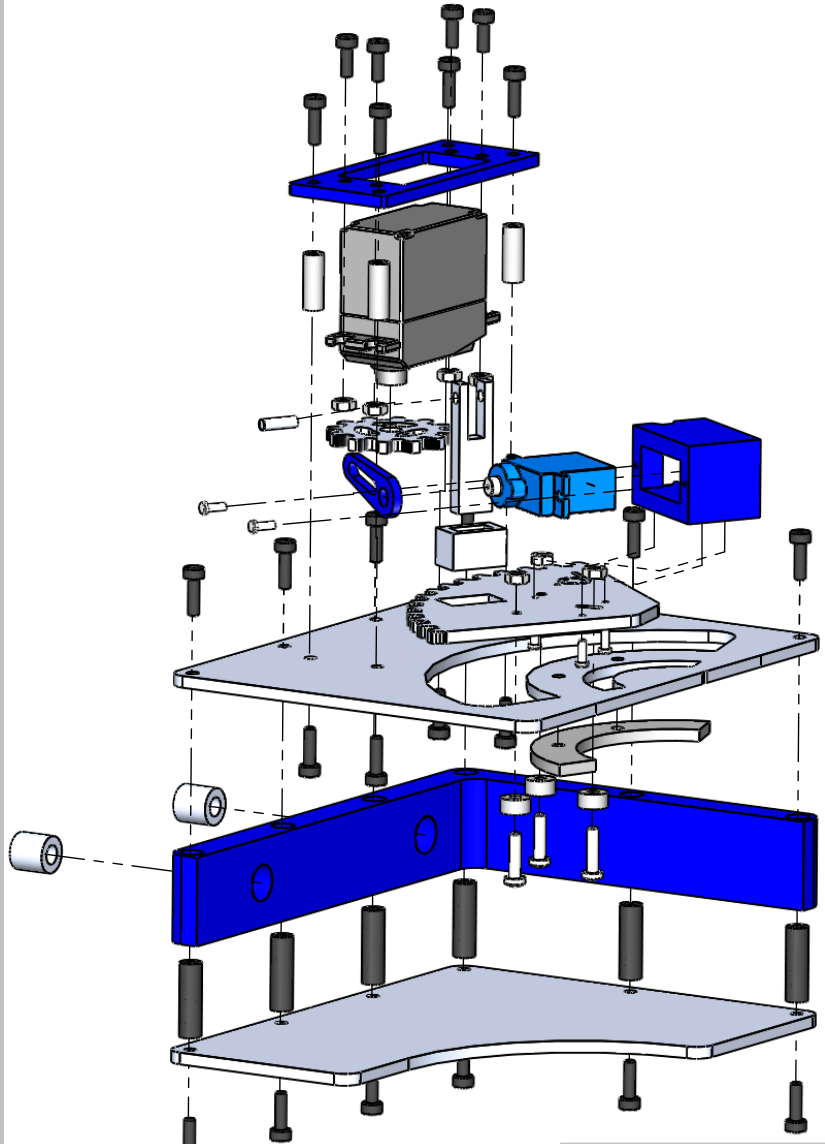


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B



A

A

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 DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X ± 0.1  
 X.XX ± 0.01  
 X.XXX ± 0.001  
 ANGLES ± 0.5°  
 FINISH:  
 N/A

PART NAME:  
 ASSEMBLY

DRAWN BY:  
 MICAH BAXTER

SCALE:  
 1:2

PROJECT:  
 PROTON THERAPY DEVICE MANAGER

DATE:  
 04/01/2016

SHEET NUMBER:  
 1 OF 2

MATERIAL:  
 N/A

PART NUMBER:  
 S16-PTDM-P-00

2

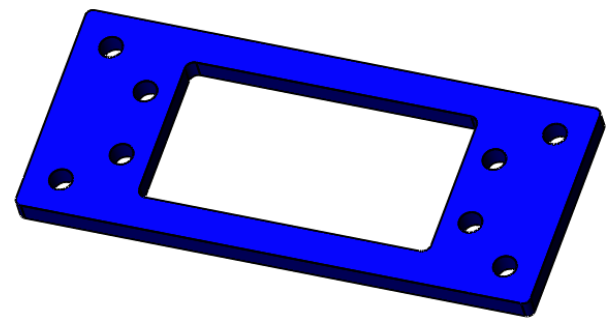
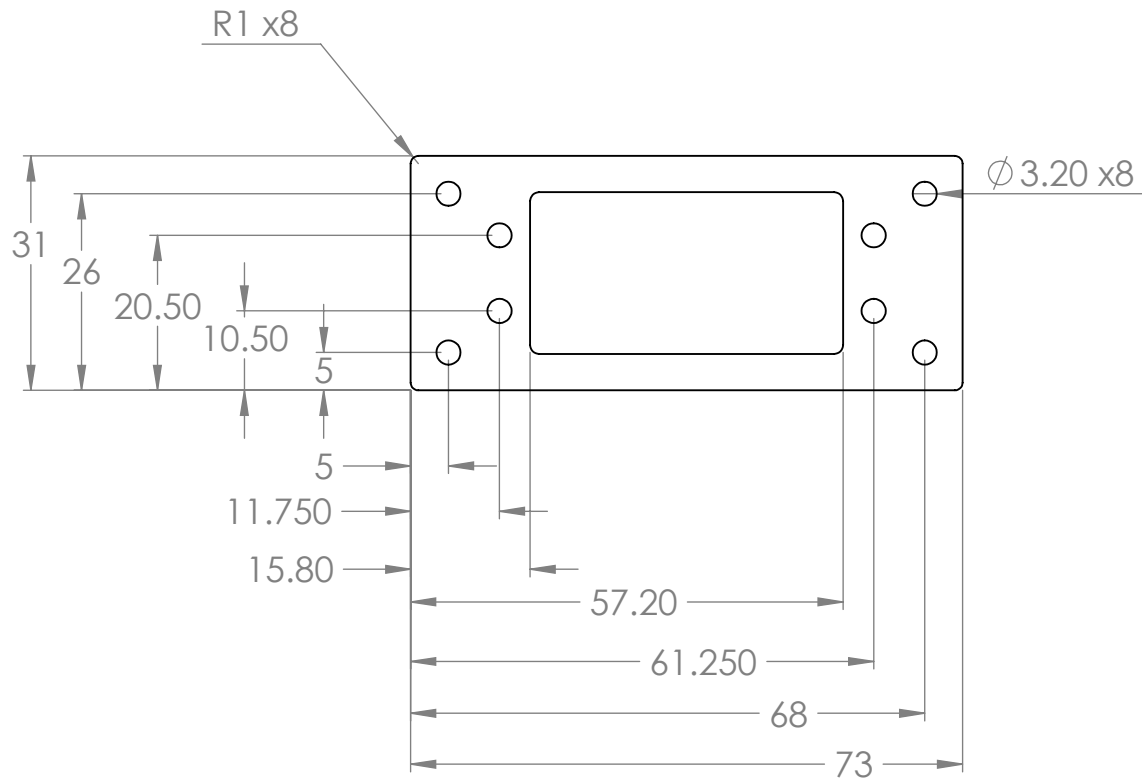
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B

B



A

A

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|--|---------------------------------|---|-------------------------------|
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|  | DRAWN BY:<br>MICAH BAXTER       | DATE:<br>04/01/2016                       | MATERIAL:<br>ALUMINUM         |
|  | SCALE:<br>1:1                   | SHEET NUMBER:<br>1 OF 1                   | PART NUMBER:<br>S16-PTDM-P-00 |
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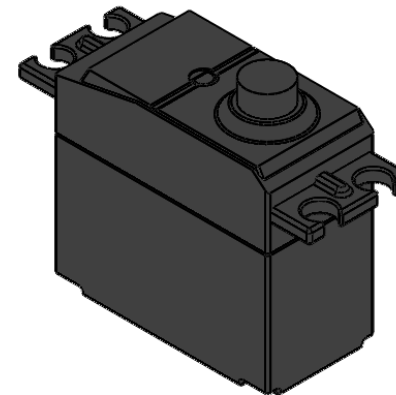
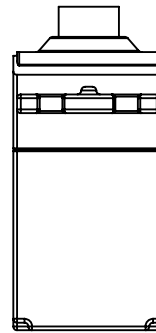
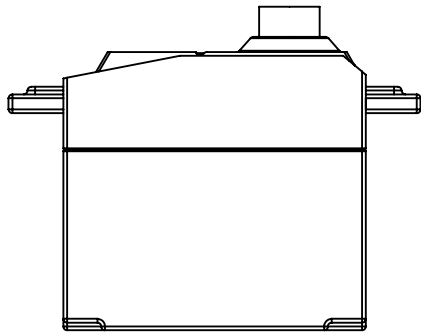
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DIMENSIONS ARE IN MM

TOLERANCES:

X.X ± 0.1

X.XX ± 0.01

X.XXX ± 0.001

ANGLES ± 0.5°

FINISH:

N/A

PART NAME:

FUTABA S3003  
 SERVO MOTOR

DRAWN BY:

MICAH BAXTER

SCALE:

1:1

PROJECT:

PROTON THERAPY DEVICE MANAGER

DATE:

04/01/2016

SHEET NUMBER:

1 OF 1

MATERIAL:

N/A

PART NUMBER:

S16-PTDM-P-00

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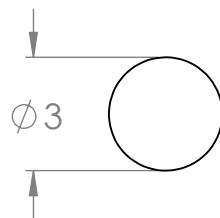
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 DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X ± 0.1  
 X.XX ± 0.01  
 X.XXX ± 0.001  
 ANGLES ± 0.5°  
 FINISH:  
 N/A

PART NAME:  
 LOCK ROD

DRAWN BY:  
 MICAH BAXTER

SCALE:  
 5:1

PROJECT:  
 PROTON THERAPY DEVICE MANAGER

DATE:  
 04/01/2016

SHEET NUMBER:  
 1 OF 1

MATERIAL:  
 ALUMINUM

PART NUMBER:  
 S16-PTDM-P-00

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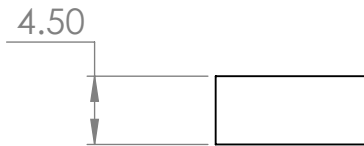
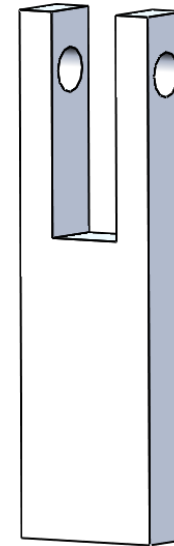
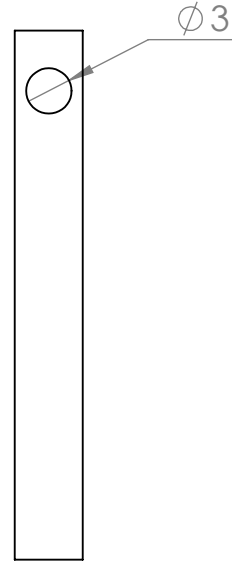
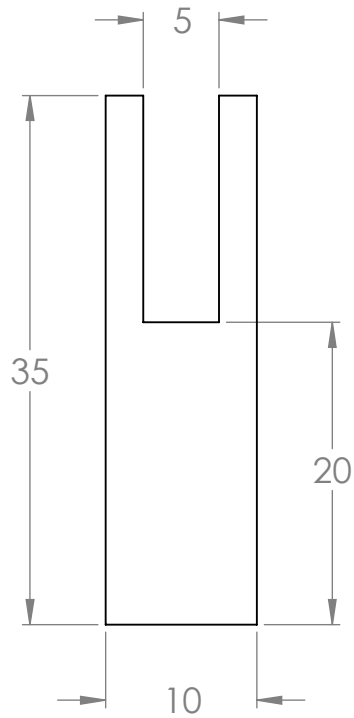
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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM  
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 X.XX  $\pm$  0.01  
 X.XXX  $\pm$  0.001  
 ANGLES  $\pm$  0.5°

FINISH:  
 N/A

PART NAME:

LOCK

DRAWN BY:

MICAH BAXTER

SCALE:

2:1

PROJECT:

PROTON THERAPY DEVICE MANAGER

DATE:

04/01/2016

SHEET NUMBER:

1 OF 1

MATERIAL:

ALUMINUM

PART NUMBER:

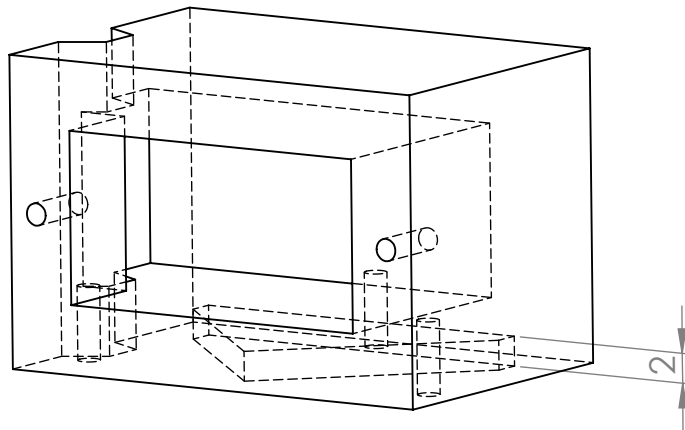
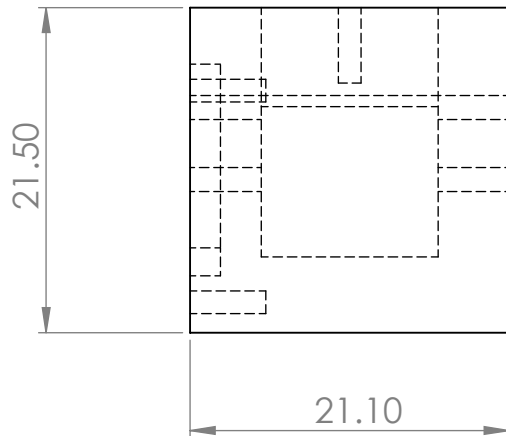
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2

1

B



A

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM  
TOLERANCES:  
X.X ± 0.1  
X.XX ± 0.01  
X.XXX ± 0.001  
ANGLES ± 0.5°

FINISH:  
N/A

PART NAME:  
LOCKING SERVO MOUNT

DRAWN BY:  
MICAH BAXTER

SCALE:  
2:1

PROJECT:  
PROTON THERAPY DEVICE MANAGER

DATE:  
04/01/2016

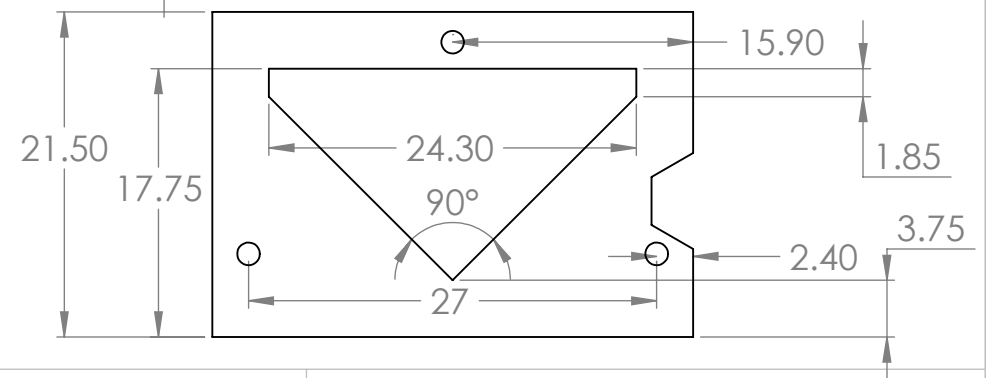
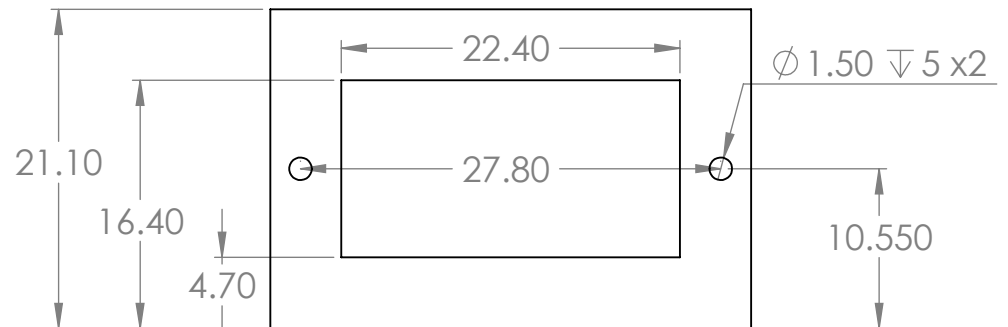
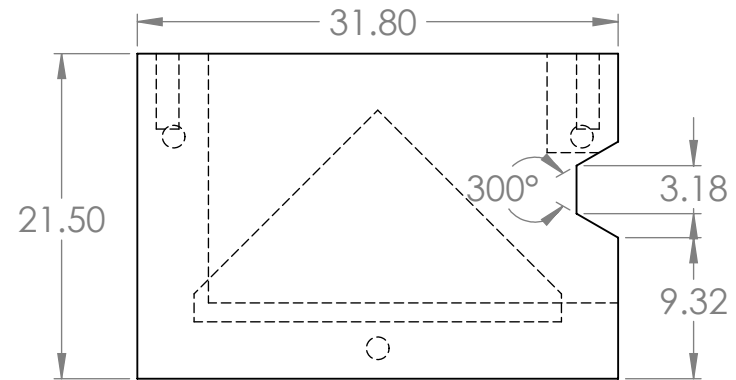
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1 OF 1

MATERIAL:  
ABS  
PART NUMBER:  
S16-PTDM-P-00

2

1

B



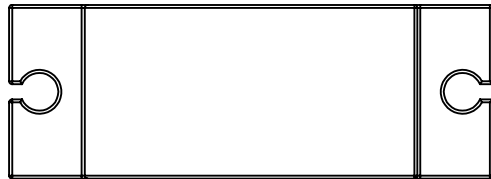
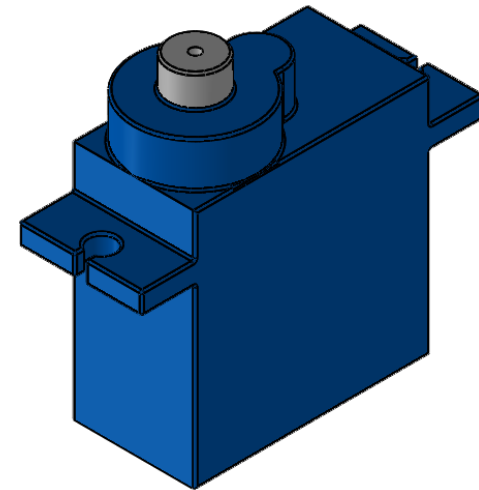
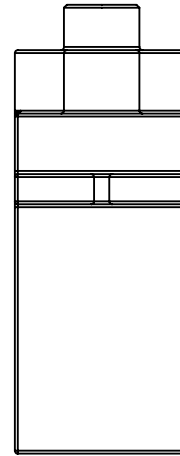
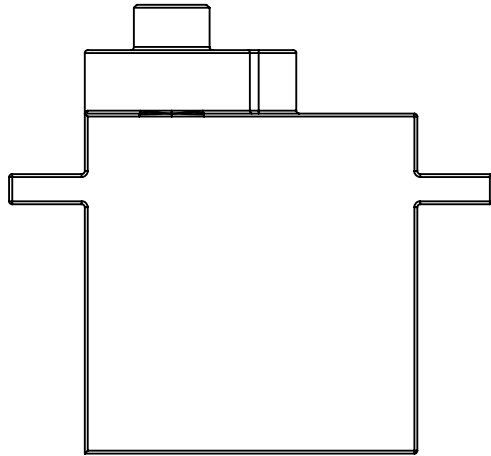
A

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B

B



A

A

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM

TOLERANCES:

X.X ± 0.1

X.XX ± 0.01

X.XXX ± 0.001

ANGLES ± 0.5°

FINISH:

N/A

PART NAME:

FS90MG MICRO METAL  
 GEAR SERVO

DRAWN BY:

MICAH BAXTER

SCALE:

2:1

PROJECT:

PROTON THERAPY DEVICE MANAGER

DATE:

04/01/2016

SHEET NUMBER:

1 OF 1

MATERIAL:

N/A

PART NUMBER:

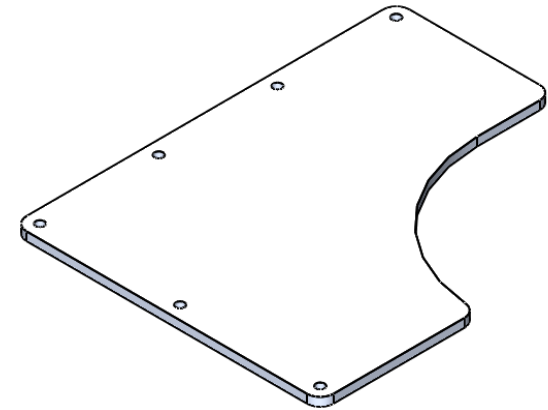
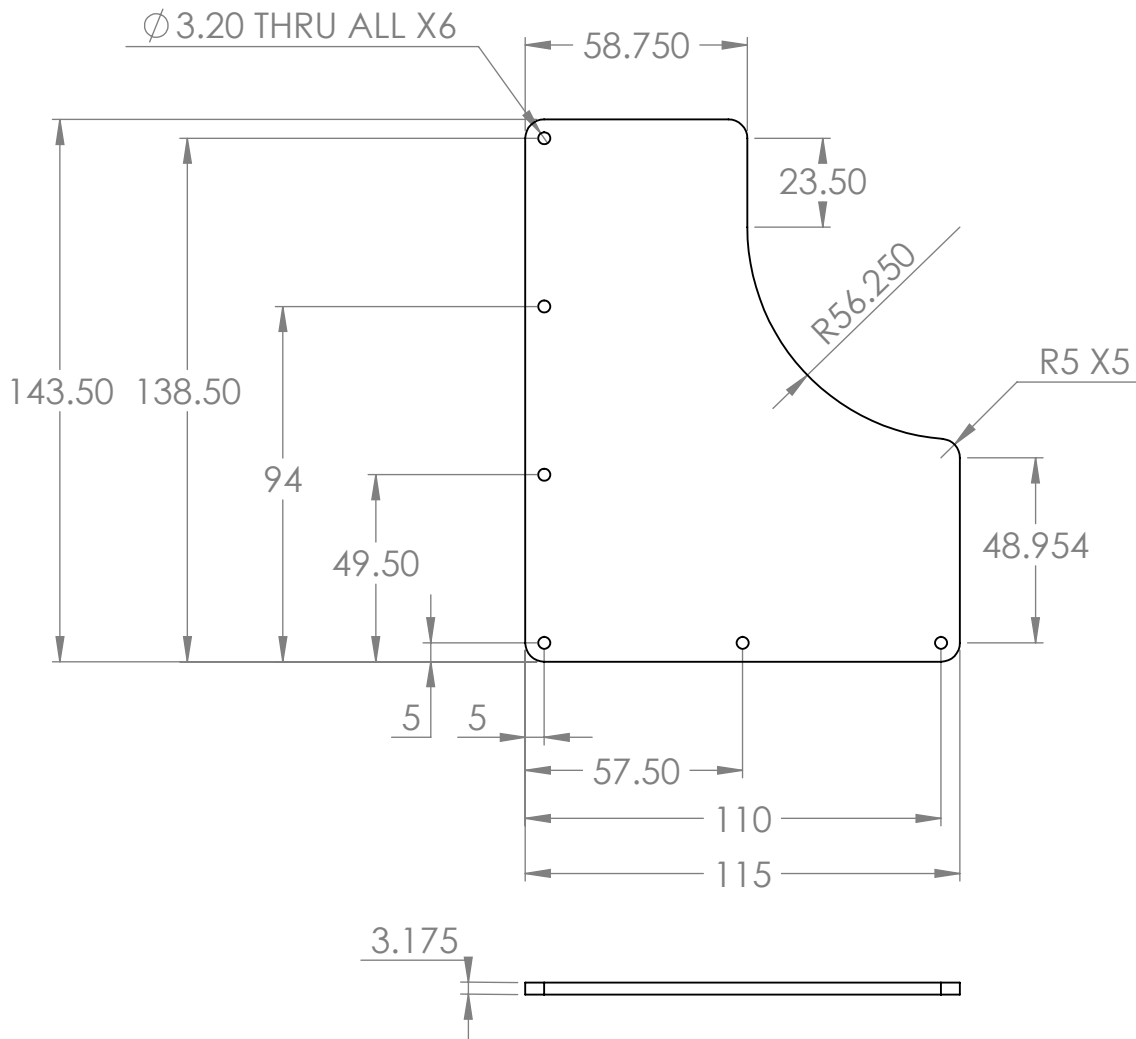
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2

1



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DIMENSIONS ARE IN MM

TOLERANCES:

X.X ± 0.1

X.XX ± 0.01

X.XXX ± 0.001

ANGLES ± 0.5°

FINISH:

N/A

PART NAME:

PLATFORM BASE

DRAWN BY:

MICAH BAXTER

SCALE:

1:2

PROJECT:

PROTON THERAPY DEVICE MANAGER

DATE:

04/01/2016

SHEET NUMBER:

1 OF 1

MATERIAL:

ALUMINUM

PART NUMBER:

S16-PTDM-P-00

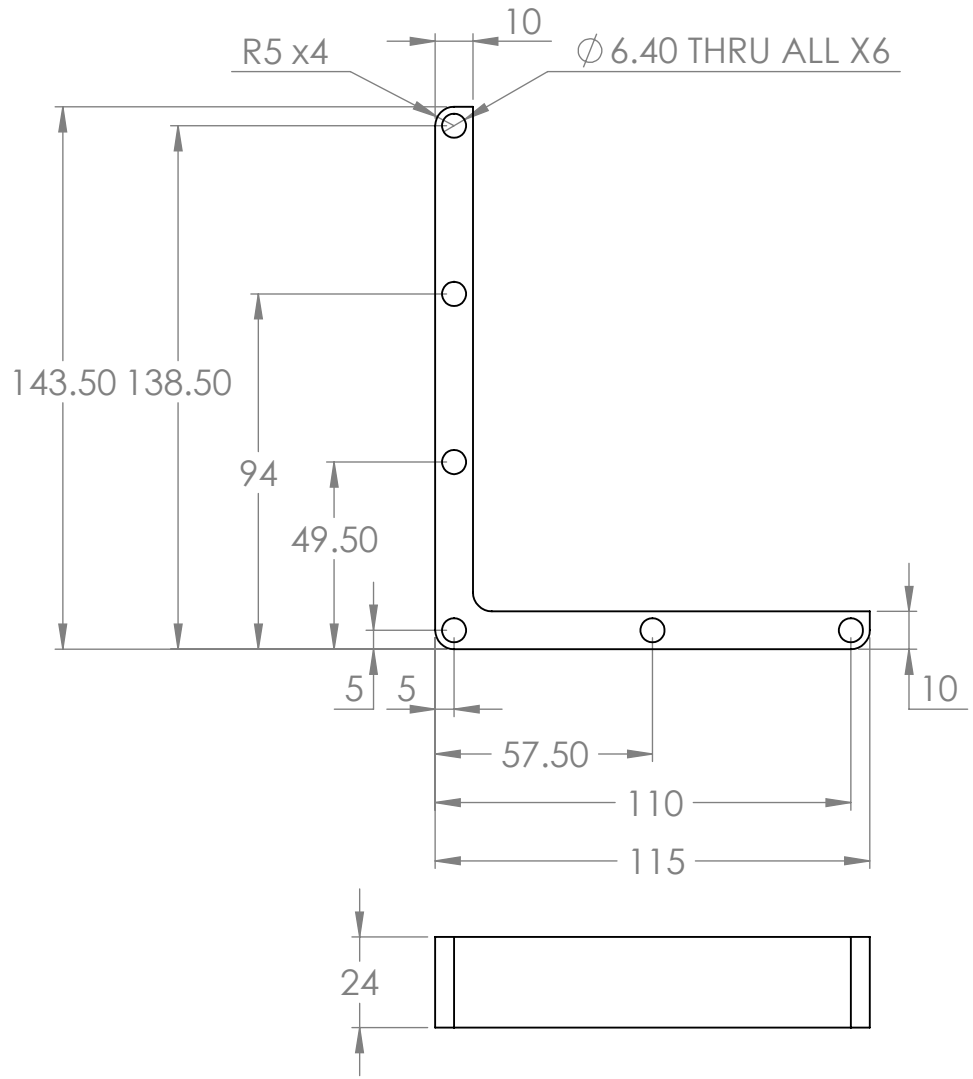
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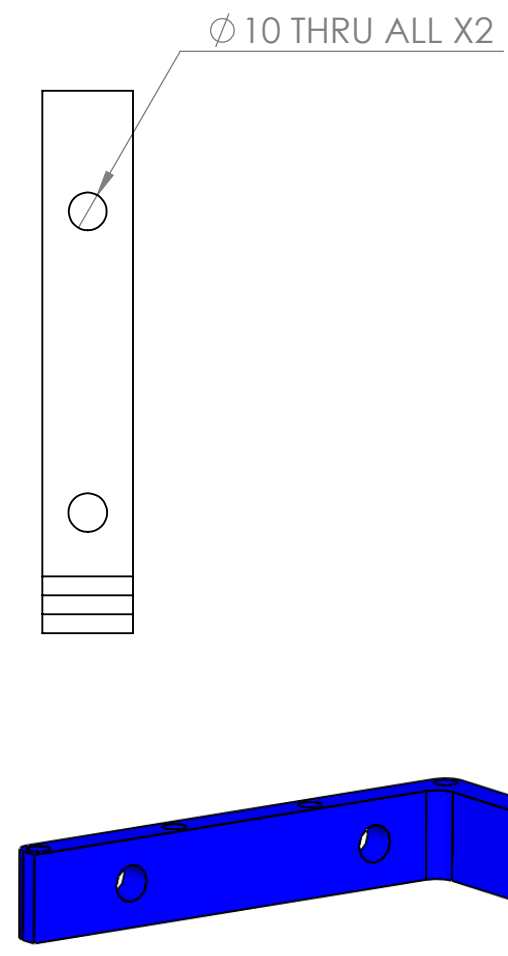


B

B



1



A

A

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 DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X ± 0.1  
 X.XX ± 0.01  
 X.XXX ± 0.001  
 ANGLES ± 0.5°  
 FINISH:  
 N/A

PART NAME:  
 PLATFORM MIDDLE  
 DRAWN BY:  
 MICAH BAXTER  
 SCALE:  
 1:2

PROJECT:  
 PROTON THERAPY DEVICE MANAGER  
 DATE:  
 04/01/2016  
 SHEET NUMBER:  
 1 OF 1  
 MATERIAL:  
 ABS  
 PART NUMBER:  
 S16-PTDM-P-00

2

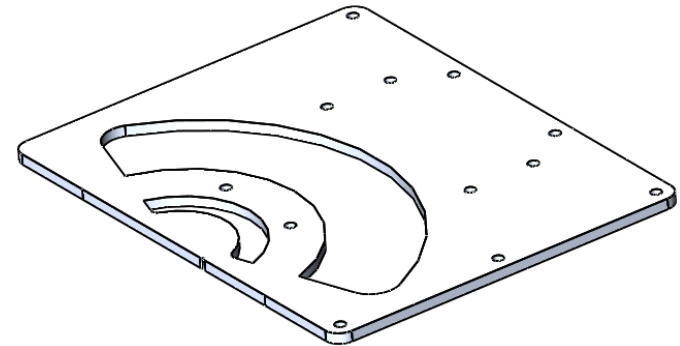
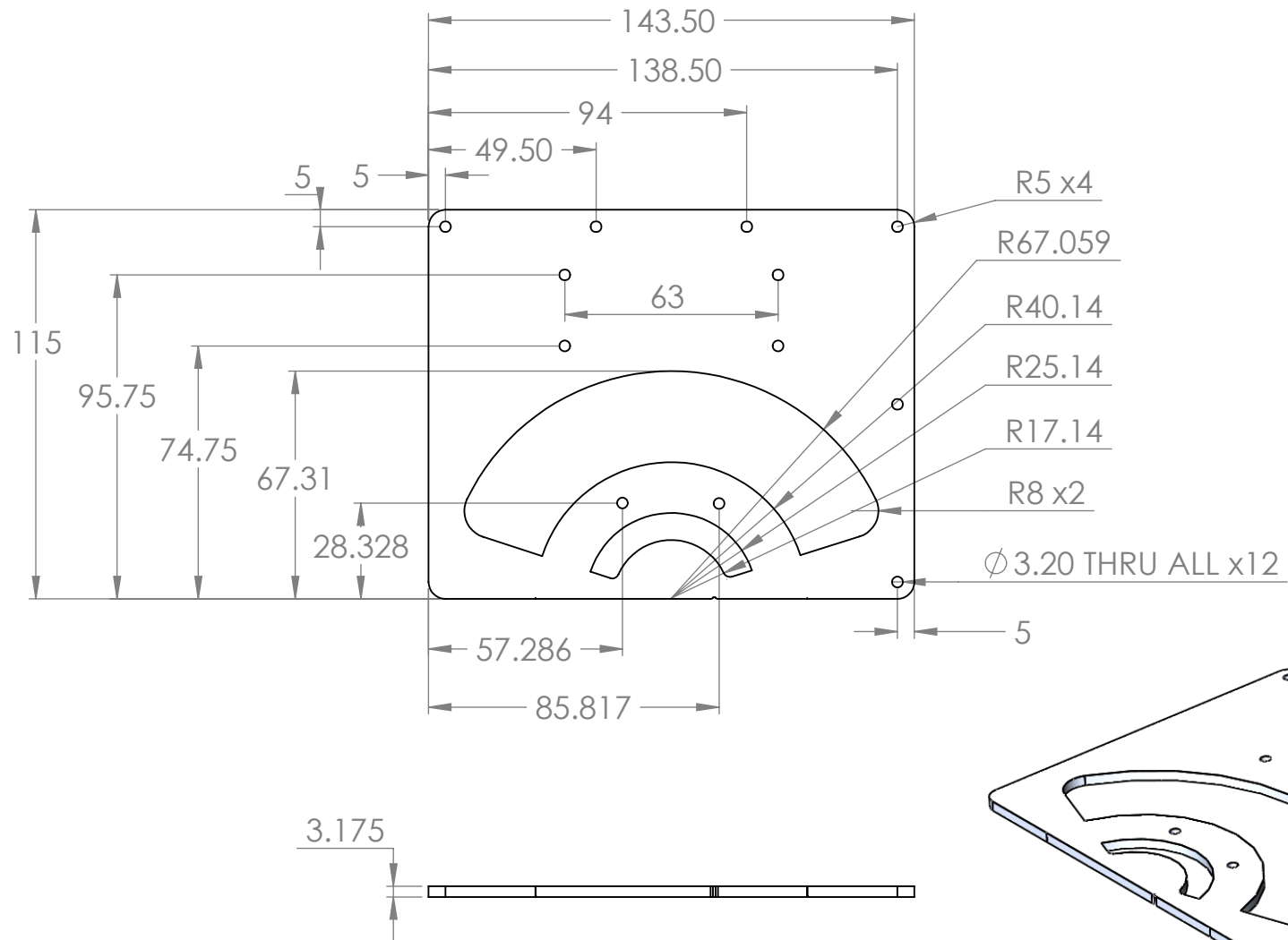
1

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B

B



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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X ± 0.1  
 X.XX ± 0.01  
 X.XXX ± 0.001  
 ANGLES ± 0.5°

FINISH:  
 N/A

PART NAME:

PLATFORM TOP

DRAWN BY:

MICAH BAXTER

SCALE:

1:2

PROJECT:

PROTON THERAPY DEVICE MANAGER

DATE:

04/01/2016

SHEET NUMBER:

1 OF 1

MATERIAL:

ALUMINUM

PART NUMBER:

S16-PTDM-P-00

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2

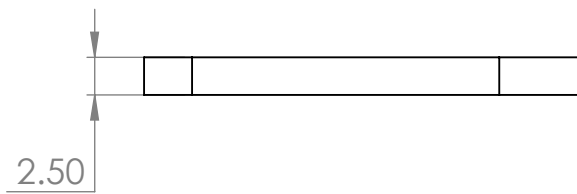
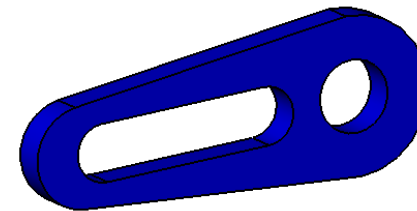
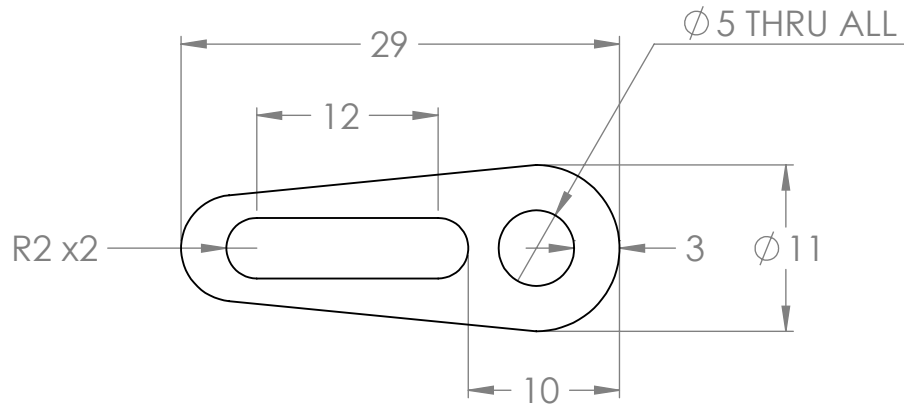
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2

1

B

B



A

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|  |              |               |                               |           |
|--|--------------|---------------|-------------------------------|-----------|
| UNLESS OTHERWISE SPECIFIED:<br>DIMENSIONS ARE IN MM<br>TOLERANCES:<br>X.X ± 0.1<br>X.XX ± 0.01<br>X.XXX ± 0.001<br>ANGLES ± 0.5°<br>FINISH:<br>N/A | PART NAME:   |               | PROJECT:                      |           |
|  | SERVO ARM    |               | PROTON THERAPY DEVICE MANAGER |           |
|  | DRAWN BY:    |               | DATE:                         | MATERIAL: |
|  | MICAH BAXTER |               | 04/01/2016                    | ABS       |
| SCALE:   |              | SHEET NUMBER: | PART NUMBER:                  |           |
| 2:1  |              | 1 OF 1        | S16-PTDM-P-00                 |           |

2

1

| ITEM NO. | PART NAME                | MATERIAL | QTY. |
|----------|--------------------------|----------|------|
| 1        | DRIVEN GEAR              | ALUMINUM | 1    |
| 2        | LOCK                     | ALUMINUM | 1    |
| 3        | DRIVING GEAR             | ALUMINUM | 1    |
| 4        | LARGE SERVO              | N/A      | 1    |
| 5        | LOCK ROD                 | ALUMINUM | 1    |
| 6        | SERVO ARM                | ABS      | 1    |
| 7        | MICRO SERVO              | N/A      | 1    |
| 8        | LARGE SERVO MOUNT        | ALUMINUM | 1    |
| 9        | 15 MM SPACER             | ABS      | 4    |
| 10       | TOP PLATFORM             | ALUMINUM | 1    |
| 11       | MIDDLE PLATFORM          | ALUMINUM | 1    |
| 12       | BOTTOM PLATFORM          | ALUMINUM | 1    |
| 13       | GUIDE                    | ALUMINUM | 1    |
| 14       | BEARING                  | ALUMINUM | 3    |
| 15       | BEARING GUIDE            | ALUMINUM | 1    |
| 16       | LOCKING SERVO MOUNT      | ABS      | 1    |
| 17       | 20 MM SPACER             | ABS      | 6    |
| 18       | M3 10mm Hex Bolt         | ALUMINUM | 20   |
| 19       | M3 8mm Hex Bolt          | ALUMINUM | 4    |
| 20       | M3 X 10mm Phillips Screw | ALUMINUM | 3    |
| 21       | M3 NUT                   | ALUMINUM | 7    |
| 22       | M2 X 6mm Phillips Screw  | ALUMINUM | 5    |
| 23       | 10 MM SPACER             | ALUMINUM | 2    |

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM  
 TOLERANCES:  
 X.X ± 0.1  
 X.XX ± 0.01  
 X.XXX ± 0.001  
 ANGLES ± 0.5°

FINISH:  
N/A

PART NAME:

ASSEMBLY

DRAWN BY:

MICAH BAXTER

SCALE:

1:5

PROJECT:

PROTON THERAPY DEVICE MANAGER

DATE:

04/01/2016

SHEET NUMBER:

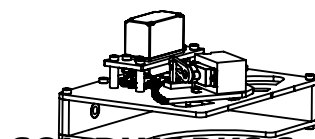
2 OF 2

MATERIAL:

ABS

PART NUMBER:

S16-PTDM-P-00



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