.decimal Proton Therapy Device Manager

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Submitted To:	Dr. Nikhil Gupta, Dr. Chiang Shih
Authors:	Micah Baxter, Morgan O'Rorke, Sarah Sweat
Faculty Advisor:	Dr. Jonathan Clark
Sponsor Contact:	Dr. Kevin Erhart

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1 Introduction

Proton therapy is currently being used as a cancer treatment when traditional radiation methods would cause too much damage. Proton therapy relies on a large cyclotron to accelerate protons to a desired speed, a 'snout' then directs those protons towards the patient's tumor. However, this beam of protons still has the potential to radiate a large region surrounding the tumor. To remedy this, .decimal manufactures brass apertures to focus and shape the proton beam in three dimensions. The current setup relies on a nurse to navigate through a maze of radiation shielding walls and exchange the final brass aperture which shapes the proton beam's cross section. These pieces weigh around 30 lbs and need to be changed five times per patient, for each position of the snout. This process increases strain on the technician and the patient as treatment time is delayed; as a result, the chance of patient movement increases which greatly affects the accuracy and effectiveness of the treatment. The goal for .decimal, and this senior design team, is to reduce treatment time and improve the accuracy of proton therapy treatment.

2 Project Definition

2.1 Background Research

Our specific project has not been executed by any other companies, universities, or individuals. The University of Florida is in the process of brainstorming a scaffolding device that will be used to load and unload the apertures. There is no literature on their research. The two systems will be developed in parallel in the coming year.

Much can be learned by observing automation devices and mechanisms that are currently on the market. Manufacturing factories utilize these types of technologies daily. Many of these ideas can be 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).[xx] 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! [1]

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. [2]

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.[3]

Figure 1. CD Sorting Robot

A 1962 Rockola Princess jukebox using a unique storage and sorting system, Figure 2. The system has 2 degrees of freedom.[4] 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.

Figure 2. 1962 Rockola Princess Jukebox

2.2 Need Statement

The sponsor for this project is .decimal. .decimal is a medical device manufacturing company in North Orlando. They manufacture patient specific devices for various types of cancer treatments including proton, photon, and electron beam treatment. The need that they have expressed to the senior design team has been that the apertures, or patient specific devices, take too long to load into a Mevion S250 Proton Therapy System. For the technician to come into the room, the machine must be off and then they have to navigate through a long hallway before getting to the treatment room. Also the apertures can be up to 25 pounds and the technicians have complained about having to lift the heavy apertures repeatedly throughout the therapy session.

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

2.3 Goal Statement & Objectives

Goal Statement: Provide proof of concept by developing a functioning scaled model of an automation device that will load and unload .decimal's apertures and range compensator relative to the nozzle of the Mevion S250.

Objectives:

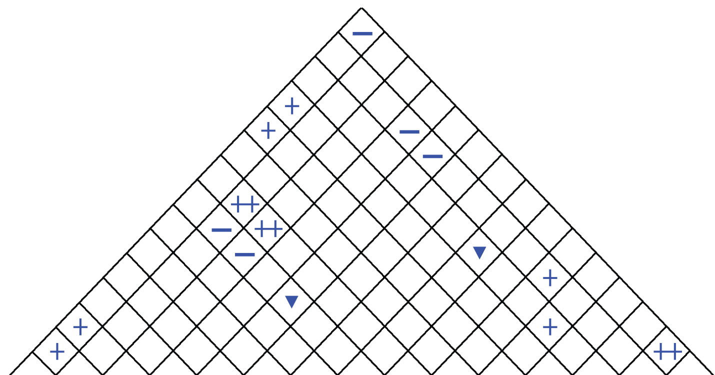
- Decrease the time a patient is in the treatment room
- Eliminate manual process for technician

2.4 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

Below in Table 1 is a House of Quality, which helped determined which customer requirements and engineering characteristics will be focused on when developing the design and final deliverables.

Table 1- House of Quality for Proton Therpay Device Manager



Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Aperture loading time	Scanning Sensors	Mechanical Sensors	Installation Time	Energy usage	User Interface	Wear on proton therapy machine	Cost	Scanning	Weight	Structural Integrity	Gripping Device	Materials	Size	Motion Range	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	x	x	▼	▼	x	▼	▼	▲	▼	▲	x	x	▼	x						
1	9			Reliability of Loading	Θ		Θ				▲					Θ									
2	9			Cost Estimate								Θ					O	Θ							
3	9			Treatment Time	Θ				▲		▲								O						
4	1			Technician Effort	▲													▲	▲						
5	9			Scanning System		Θ				▲			Θ												
6	9			Reliability of Operation	O	Θ	Θ			▲	O					Θ									
7	9			Non-obtrusive				O	O		O			Θ				Θ							
8	3			Scalability								O			O			O	O						
9	9			Software		O	O			Θ			Θ												
10	9			Patient Safety	O	Θ	Θ						Θ		Θ	Θ	▲		▲						
				Target or Limit Value																					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)																					
				Max Relationship Value in Column	9	9	9	3	3	9	3	9	9	9	9	9	3	9	3						
				Weight / Importance																					

Competitive Analysis
(0=Worst, 5=Best)

Our Company, Competitor 1, Competitor 2, Competitor 3, Competitor 4, Competitor 5

0 1 2 3 4 5

3 Project Approach

The team spent a week or two brainstorming and narrowing down possibilities. Then, the team created a few rough prototypes made out of cardboard or foam, creating a general proof of concept before designing some of their ideas in CAD software. By December, the goal is to have an initial prototype. From there, further improvements and refinement can be made during the spring semester as the group prepares for the final deliverable.

3.1 Schedule and Work Breakdown

We have built our initial cardboard prototypes and we are moving towards creating our first major prototype to be built in November and December. This will allow the team to utilize the spring semester to refine the design and take the necessary measures to correct the design to make it the best it can be. Our schedule can be seen in the Gantt Chart in Figure 1. The work breakdown structure is in Table 2. The team will be referring to our defined roles when delegating who will do the tasks. Since the team is small, most aspects will be completed together.

Table 2 Work Breakdown Structure for Fall 2015

Task Name	Duration	Start	Finish
Brainstorming	**12 days**	**Sun 9/20/15**	**Sat 10/3/15**
Create many ideas	6 days	Sun 9/20/15	Fri 9/25/15
Narrow it down to 3	0 days	Fri 9/25/15	Fri 9/25/15
Select Initial idea to begin designing	2 days	Mon 9/28/15	Tue 9/29/15
Initial Prototype	**11 days**	**Wed 9/30/15**	**Wed 10/14/15**
Buy cheap supplies	3 days	Wed 9/30/15	Fri 10/2/15
Build very basic and cheap prototype	3 days	Mon 10/5/15	Wed 10/7/15
Evaluate if chosen design is a good concept	3 days	Thu 10/8/15	Mon 10/12/15
Design 2nd Prototype	**6 days**	**Thu 10/15/15**	**Thu 10/22/15**
Create CAD Files	3 days	Thu 10/15/15	Mon 10/19/15
Reasearch Parts for purchase	3 days	Tue 10/20/15	Thu 10/22/15
Build 2nd prototype	**29 days**	**Thu 10/22/15**	**Tue 12/1/15**
Order parts needed	4 days	Thu 10/22/15	Tue 10/27/15
Create Software to operate device manager	16 days	Mon 10/26/15	Mon 11/16/15
Assembly Prototype as parts are delivered	20 days	Mon 11/2/15	Fri 11/27/15
Evaluate quality of design and prototype	3 days	Fri 11/27/15	Tue 12/1/15

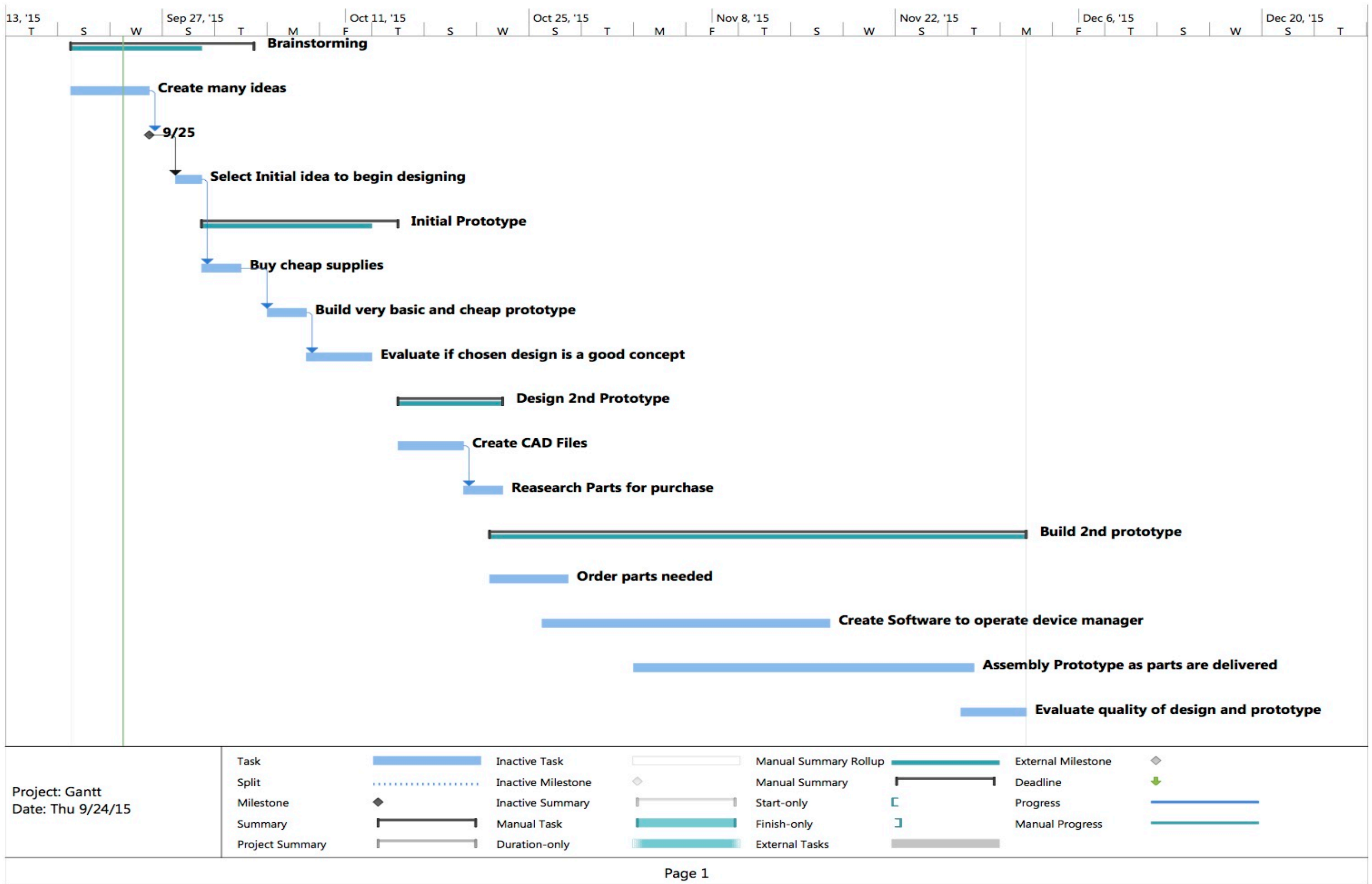


Figure 3. Gantt Chart for Fall 2015

3.2 Risk Analysis and Safety

3.2.1 Human Risk

The most important aspect of any project is ensuring human safety. Due to the nature of proton therapy treatments with the Mevion S250, the potential for harmful accidents is present. The heavy brass apertures can be directly positioned above the patients during treatment, and if the aperture is not locked in place it has the potential to fall on the patient. Additionally, during the loading/unloading process and indexing, the aperture will be moved around and must avoid the patient. If the gripper were to fail to secure the aperture during movement or loading/unloading, the aperture could fall and seriously injure the patient.

Risk also comes into play during the construction of the prototypes. The team must be careful when machining any necessary parts and when using the tools to complete the assembly. Also when the system is built, it will be lifting heaving objects, rotating and moving vertically. These motions could lead to a pinching/crushing injury if a human is in the way of the system.

3.2.2 System Risk

This device must be integrated with the Mevion S250 system, a $60 million setup. The device will interface with the Mevion S250 and has the potential to damage it. Additionally, the device cannot come in contact with the machine, other than at the nozzle. The proton therapy machine gives off high levels of radiation so the device manager could be damaged by these particles, thus making it unusable. The machine that controls the couch that the patient lays on takes about a week to calibrate, and the system itself takes up to two months to calibrate. If the device manager jeopardized this, the customer would be very displeased.

3.3 Product Specifications

3.3.1Design Specifications

The design must be fully automated and fit inside the proton therapy room. It must not interfere with the 6 degree of freedom robotic couch, which positions the patient for treatment. The automation device must not interfere with the movement of the electron therapy system's nozzle. The device must repeatedly and reliably be able to identify, pick up, and load an aperture. The design must incorporate a device that releases a spring-loaded safety latch. The purpose of this is to enable the aperture to be unloaded from the nozzle of the Mevion S250. Preliminary discussion with Dot Decimal has established that a secondary device can be designed to perform this operation. An integrated safety system for identifying the order of each aperture should be created. The system must return to its original position after a full cycle of loading and unloading has occurred. After unloading, the cycle must repeat. . A life cycle will need to be developed to ensure a re-design is in line with the latest market requirements of the Mevion S250. Design for manufacturability must be considered. One Mevion S250 Proton Therapy System is clinically active and 6 are under installation and architectural planning in the United States.

3.3.2Performance Specifications

The system must perform the loading and unloading process faster than a human technician. The goal for operation time of one complete cycle (unloading and loading) is under one minute. Patient safety is of utmost importance. The apertures must be rigidly secured to the automation device during loading and unloading. The system should be able to lift up to 25 lbs. The device's deflection under load must be minimized and accounted for to ensure the aperture is able to be secured in the nozzle. Failure mode analysis must be performed on all components of the system in order to identify any safety concerns. Safety factors should be considered to ensure failure does not occur during operation. Additionally, the automation device must be manufactured from materials that are anticorrosive. Additionally, the cycle progress and state will be continuously monitored and outputted to the technician. Data transmission will be wired and should not affect the room.

4 Design Concepts

Functionality requirements were the team's main concern when brainstorming design concepts. Designs were based on the fact that nozzle would be moved to its lowest position on the proton therapy system. The nozzle would be facing upwards, and the apertures would be parallel with the ground. A top-down design approach was used. Every subsystem was broken down and analyzed. Consequently, each subsystem was not fully developed in order to realistically validate the final design concept. As a result, a decision matrix was used to in order to correlate each design with the customer's requirements as seen in Table 3. The design criteria was ranked with weighting factors and they were scored using a 5-point scale.

Table 3 Weighted Decision Matrix for Device Manager

Design Criterion	**Weight Factor**	**Concept 1** Score Rating		**Concept 2** Score Rating		**Concept 3** Score Rating		**Concept 4** Score Rating	
Material Cost	0.1	1	0.1	1	0.1	1	0.1	1	0.1
Repeatability	0.2	2	0.4	1	0.2	3	0.6	4	0.8
Reliability	0.2	2	0.4	2	0.4	3	0.6	3	0.6
Time to (un)Load	0.3	0	0.0	0	0.0	2	0.6	3	0.9
Complexity	0.2	3	0.6	2	0.4	3	0.6	3	0.6

4.1 Design Concept 1

The first design concept utilized a gripping mechanism that would grab the aperture around its perimeter, about its symmetric axis, with the use of two pegs. The pegs would apply a constant force while the arm moved forwards and backwards in order to load and unload the aperture, respectively. After analyzing the design, the pegs proved to be unreliable. They would continually collide with the nozzle during the loading and unloading procedures. Design Concept 1 is labeled in Figure 4.

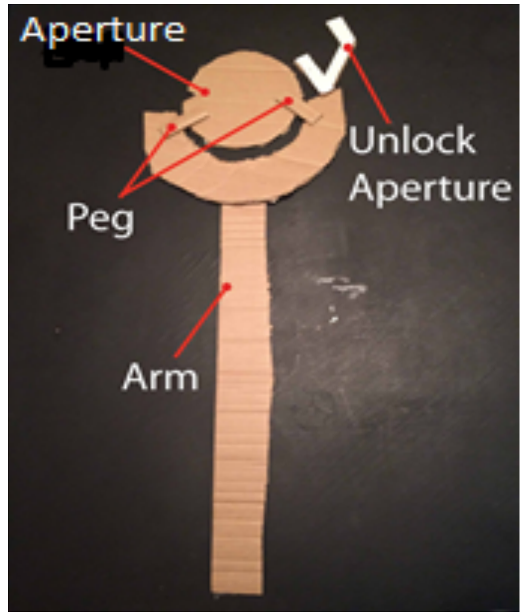


Figure 4. Design Concept 1

4.2 Design Concept 2

Design concept 2 was based off the same principle as concept 1. Pegs would be used to grab a hold of the aperture. However, instead of grabbing the aperture about the perimeter, two pegs would be inserted 10 mm into the perimeter of the aperture. This design proved to be unreliable because of numerous points of failure of the pegs. The 30 lb aperture would create too much torque on the small 10 mm pegs. The aperture would potentially slip off the pegs during movement or deform during the process.

4.3 Design Concept 3

Design concept 3 utilized a platform aperture supporting mechanism in order to address the problem of the aperture placing too much torque on the robotic arm, as seen in Figure 5. The platform would support the aperture at its base and load the apertures from the front of the nozzle. A lever mechanism would load the aperture into the nozzle of the proton therapy system. This design proved to be unreliable because the lever mechanism would potentially load the aperture, but the same system could not unload the aperture. Additionally, the lever mechanism could potentially jam the aperture in the nozzle and the correct alignment would not be achieved.

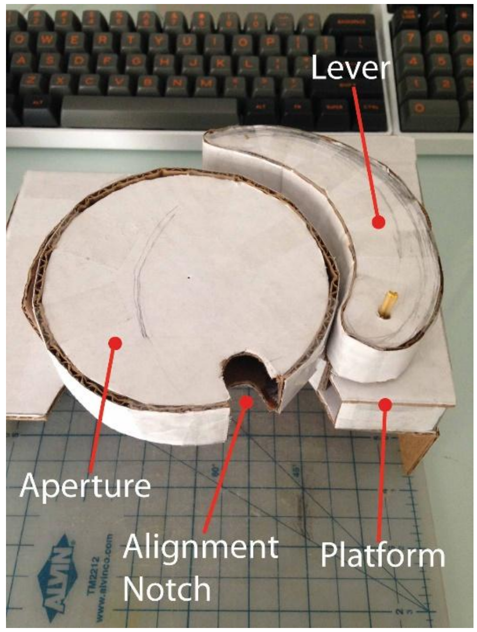


Figure 5. Design Concept 3

4.4 Design Concept 4

Design concept 4 utilized the same platform mechanism as design concept 3. However, instead of loading directly from the front, the aperture would be loaded from the left side of the nozzle, as seen in Figure 6. The apertures are 86.4 mm in diameter, Figure 7, and they will be mechanically moved using a stepper motor in to the nozzle, Figure 8.

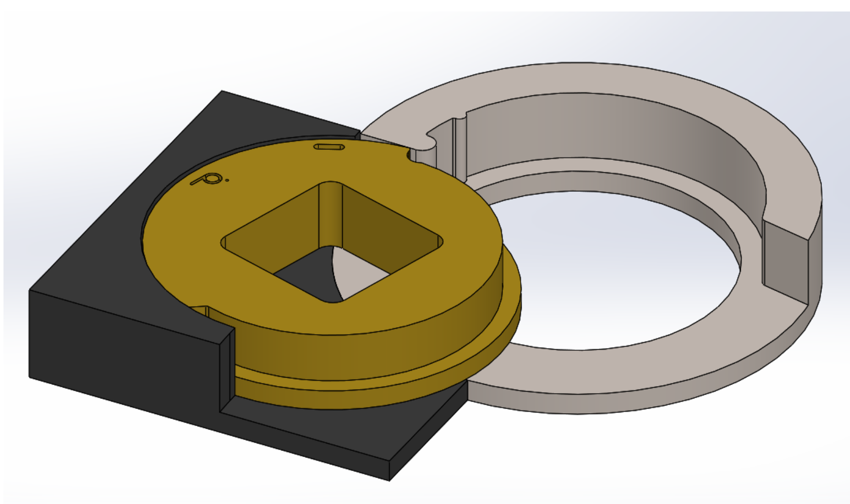


Figure 6. Trimetric View of Design Concept 4

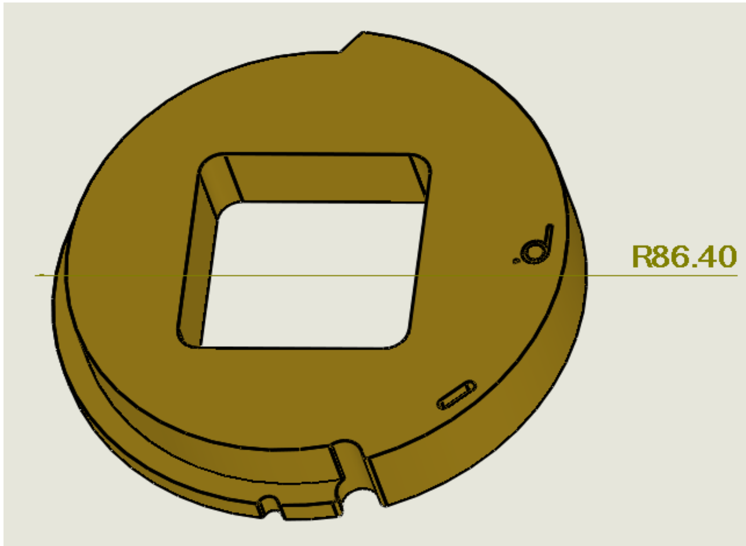


Figure 7. Trimetric View of Brass Aperture

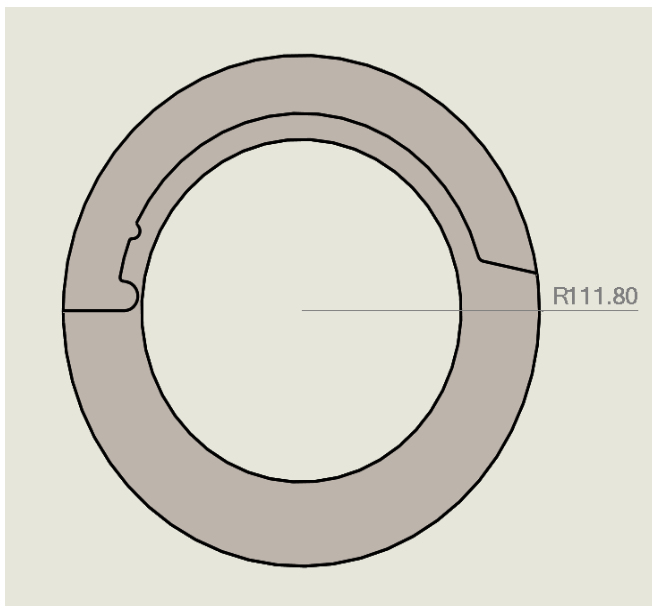


Figure 8. Top View of Mevion S250 Nozzle

The platform, Figure 9, would support the base of the aperture. It be attached to a robotic arm that would allow for movement of the aperture. The platform incorporates a cradle that will allow for visual alignment of the aperture. The cradle will help the technician identify potential problems during loading procedures.

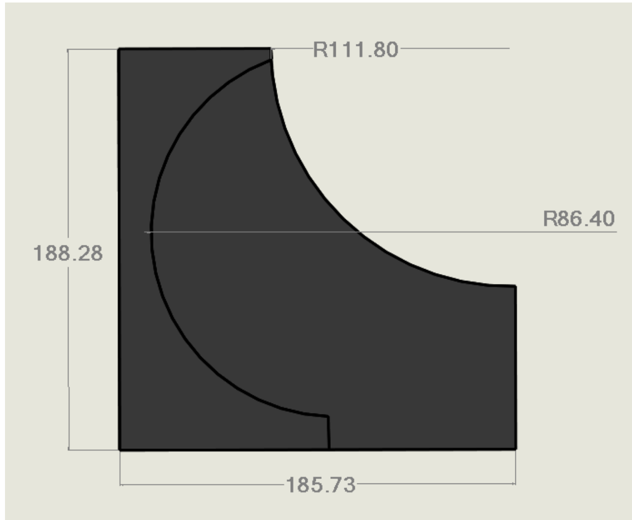


Figure 9. Top View of the Platform

Figure 10 depicts how the aperture will be positioned on the platform.

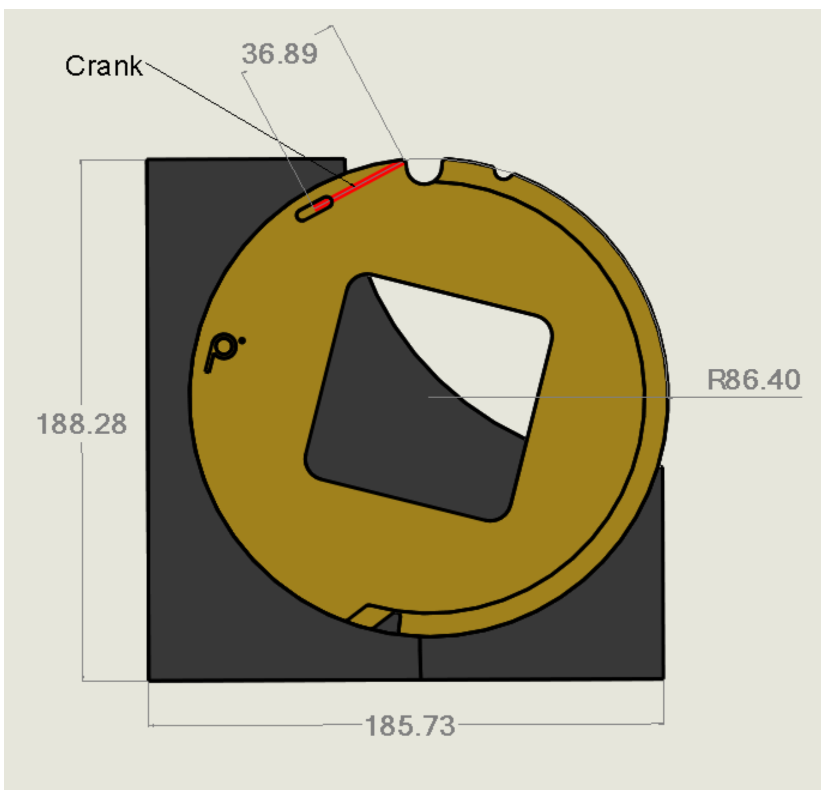


Figure 10. Top View depicting how the platform will support the aperture

The platform will move to the left side of the nozzle and position itself flush to the base of the aperture's slot, as seen in Figure 6. A tool (again, yet to be designed) will fit inside a straight slot notch that will be machined onto the top of the brass aperture. The tool will rotate the aperture about an instantaneous center of zero velocity near the alignment notch. Figure 11 depicts the initial position of the unloaded aperture. After the tool rotates through 87 degrees, about the instantaneous center, the aperture will be loaded into the nozzle of the Mevion S250, as seen in Figure 12. The unloading procedure will utilize the same mechanism.

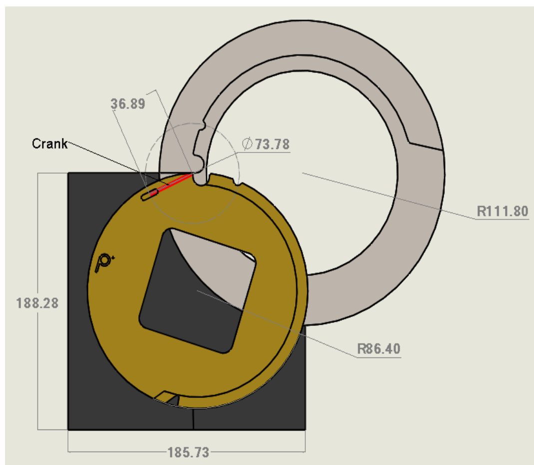


Figure 11. Top View of aperture in the unloaded position

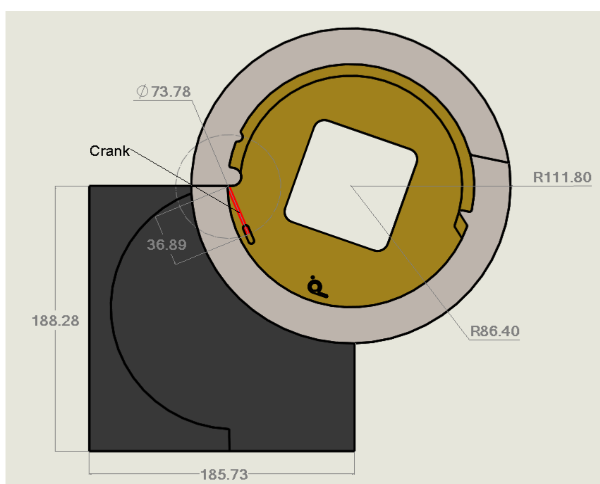


Figure 12. Top View of Aperture in the loaded position

Concept 4 had the highest design ranking. The repeatability, loading and unloading time, and simplicity of the design make it the best design concept. It should be noted that material cost was given the same rating for each concept because the price of the final mechanism has yet to be determined.

5 Conclusion

The team is off to a good start and we are excited about the coming weeks in our project. The team has accomplished many of the goals set forth in the schedule, and have maintained a positive and productive group dynamic. We had several ideas and are moving forward with concept 4. We are on track according to the schedule we established in the first few weeks, and we plan to have our first prototype built by the end of the semester. Our biggest challenges are going to be designing and analyzing the mechanisms required to load and unload the aperture, due to the designed notches in the nozzle. These mechanisms must also be easily manipulated by a controller, which will lead to programming the operation of the system. There will be troubleshooting along the way, but this will be a good platform to start the spring semester with. We will be restricting our focus to the loading/unloading of the aperture. If time permits, we will explore designs for the storage and indexing of the apertures within the treatment room. We have been in contact with our sponsor, Kevin Erhart, and will be maintaining contact throughout the coming months. We have also been maintaining regular meetings with our advisor, Dr. Clark.

References

[1] Astes4 Explained. SMD Machinery Inc. Web. 22 Sept 2015. <http://smdmachinery.com/astes4/Astes4-Explained>

[2] Zen Robotics. Web. 22 Sept 2015. <http://zenrobotics.com/zenrobotics-recycler/zenrobotics-recycler>

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