2018

Eaton Automated Tuft Cutter

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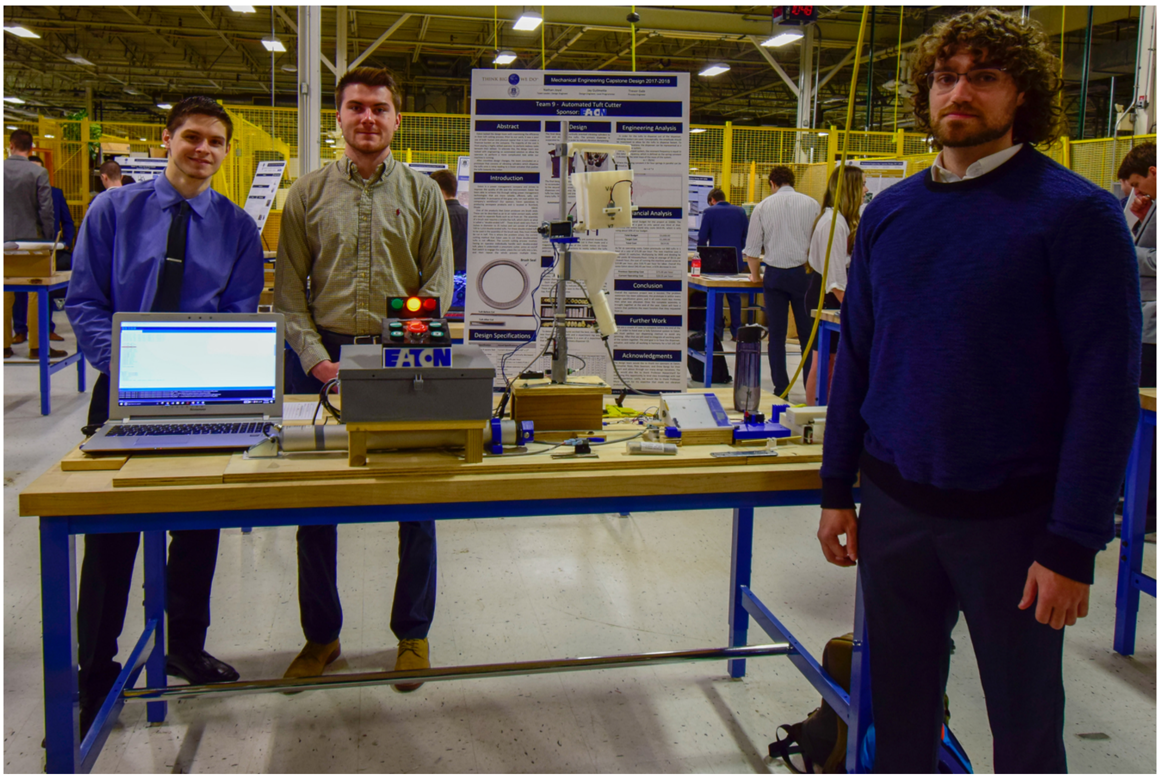
Team Eaton
Automated Tuft Cutter



Team Members:

Nathan Joyal : Team Leader, Design Engineer
Jay Guilmette : Design Engineer, Lead Programmer
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Abstract

The primary purpose of this project was to maximize the efficiency in Eaton's tuft cutting process, which is an essential part of their manufacturing business. The current process is a poor use of both human and physical capital that creates an unnecessary financial burden on the sponsor company, Eaton Corporation. The primary source of this lost money is from paying highly skilled operators to perform tedious tasks beneath their skill-set. The team was tasked with minimizing these burdens either through a new process or by reducing waste in the current process. The primary goal was to decrease the amount of money spent per hour ($75.00), with a secondary goal of increasing throughput (currently $900 hour). The team was given 1 academic year and a budget of $3,000 to design and create a working prototype for Eaton to implement on their factory floor.

The group designed and prototyped an automated system that removes a considerable amount of human labor from the job, and with it, creates a large source of revenue which the company can better spend elsewhere. The prototype uses a two dispenser system to minimize jamming and reliably place the tufts for cutting. An electric actuator then pushes the tuft via the end weld bead into the pneumatic cutter. Finally, the cutter splits the tuft in two. The prototype does not currently include a cutting mechanism. The new system decreases costs by 60% and increases total output by 33%.

Aside from meeting the primary goal of reducing operator time, the group also met all other design specifications: the prototype has an emergency stop button, was built under budget, requires no PPE, and takes up less than 7 square feet.

Eaton expressed their satisfaction with the finalized project and plans on incorporating the design into their seal manufacturing process.

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Nomenclature

k Spring constant

V Volts

w Natural Frequency

1 Introduction

Eaton is a power management company and strives to improve the quality of life and the environment. Eaton has been able to achieve this through selling power management technologies that are more reliable, efficient, safe, and sustainable [1]. In pursuance of this goal, why not start within the company's workforce? Our sponsor, Eaton specializes in producing aerospace products and is located in Rumford, Rhode Island.

One of the products that Eaton produces are brush seals. These can be described as air to air radial contact seals, which are used to separate fluids such as oil from air. The seals are able to achieve this because they are non-contacting and ride on a thin film of air, essentially eliminating any heat generation and prolonging the life of the seal [2]. The assembly of a brush seal requires a bristle-like tuft, which starts as what is called a "double-ended tuft." The *Merriam Webster Dictionary* states that a tuft can be described as "a cluster of elongated flexible outgrowths attached or close together at the base and free at the opposite ends" [3]. This double-ended tuft can be described as a bundle of wires with welds at each end, representing a combination of two tufts. Each bundle of wires contain between 140 to 200 wires which range in diameter from 2 to 6 thousandths of an inch. To maximize efficiency, the material of these thin wires consist of heat resistant nickel-cobalt alloy. For further illustration, a double-ended tuft can be seen in Figure 1 below with a nickel for reference.

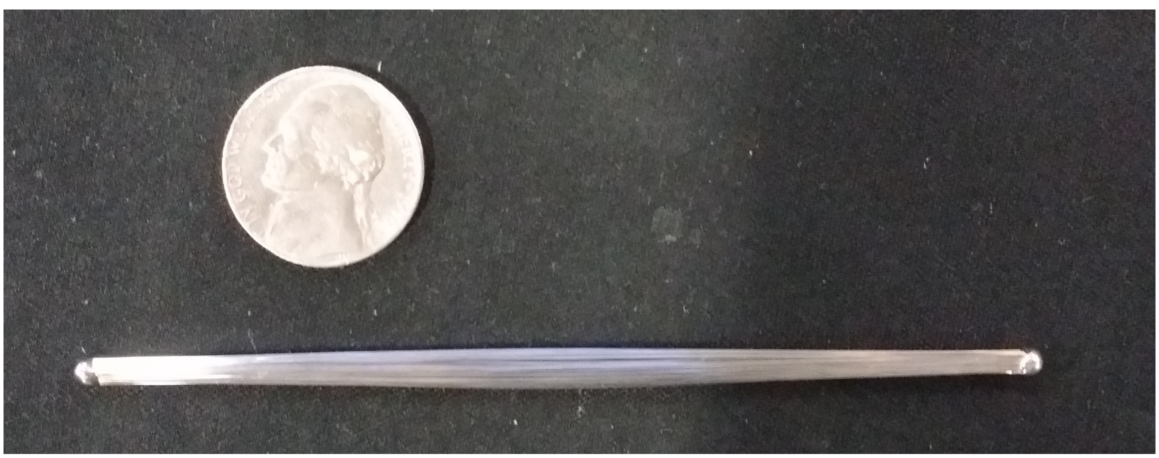


Figure 1: Double-ended tuft.

These brush seals vary from 3 inches in diameter to 25 inches and can consist of between 120 to 1,010 double-ended tufts. For these double-ended tufts to be used in the assembly of the brush seal, they must initially be cut in half. This is where the problem arises; the current cutting method that Eaton uses to cut these double-ended tufts is not efficient. The current cutting process involves having an operator individually handle each double-ended tuft, place it underneath a pneumatic cutter, press an on/off foot switch to engage the cutter, place the cut tufts into a bin, and then repeat the whole process multiple times. A cut tuft can be seen below in Figure 2, again, with a nickel for reference.

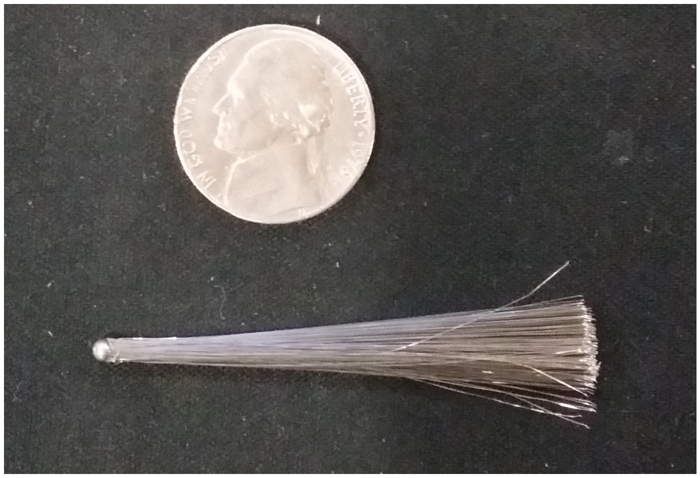


Figure 2: Cut tuft.

The primary expectation of the group is to reduce costs through reduction of operator time. The largest source of loss with the current process is paying an operator a high wage to perform a task that does not merit one. In order to do this, Eaton requires either a system or a product that minimizes human involvement. By reducing the time spent in front of the machine, Eaton will see a proportional reduction in costs of this specific part of the manufacturing process.

The second goal is to increase total throughput. If the team can produce more than the current system without increasing expenditures, then Eaton is likely to adopt the proposed system.

Finally, the replacement system must follow all OSHA regulations, fit within a 7 square foot footprint, and be practical for use in an manufacturing environment (durable, not requiring the use of PPE, fairly easy to maintain, etc.).

2 Project Planning

2.1 Early Concepts and Patent Search

The first step in the project was to meet with the sponsor company and gain a better understanding of what they wanted and the conditions that would play a vital role in the design. The first meeting at Eaton allowed the team to inspect the physical space requirements, handle tufts for the first time to get a sense for how the moved, and see the conditions that the design would operate in. This meeting was the first of many with the Eaton liaisons.

The task at hand deals heavily with automation, mechatronics, and robotics. The team assembled had the necessary skills to achieve the goals laid out and quickly established an efficient division of labor. Nathan Joyal, the most organized of the bunch, took the role of team leader and lead design engineer, as he had the most hands on experience in dealing with automation. Jay Guilmette took some design duties as well and was in charge of programming related tasks. Trevor Gale was the process engineer. To organize and track team progress, a Gantt chart was made with assigned tasks and estimated completion times. Completion times could be changed based on new developments. In addition to the Gantt chart, the team decided to meet weekly on Thursdays in the Fall and Mondays in the Spring, and discuss the progress or problems of each member. These meetings were then summarized in weekly progress reports to both Eaton and Professor Nassersharif. This chart can be found in Figure 4 on page 5.

The first step in design was to break the project down into smaller components. It goes without saying that several small problems are easier to solve than one massive problem. Specifically, the general system was broken down as follows: tuft package opening, tuft sorting, tuft cutting, and tuft rinsing. Each of these problems could then be broken down again into smaller problems (which they often were). Tuft cutting became a multi-part problem of tuft transportation and actual mechanism of tuft cutting. These smaller problem subsets were then ranked in terms of difficulty and importance. For example, package opening would be the most difficult part as well as the least important in terms of time saved, so it was therefore given a low priority. After all, opening a package of tufts takes 2 to three minutes at most, but cutting all 100 tufts in a package takes nearly 7 minutes at the constant pace of 1 tuft per four seconds. In this way, the work was better designated to accomplish as many of the tasks as possible instead of getting caught up on a few tasks that would present little overall improvement.

With a better idea of which tasks needed to be done and the urgency of those tasks, a patent search was done to try and determine if there were any relevant preexisting mechanisms that could be incorporated. This initial search was broad and shallow: all methods of cutting super-alloys were researched, as well as any way of sorting or dispensing anything remotely shaped like a tuft. Despite casting a wide net, this search yielded little results, but there were a few ideas that further designs were based off, especially early in the project time line. Most notably was a dispenser system that was modeled after a straw dispenser. The Gantt chart for the first semester can be observed in Figure 3 on page 4.

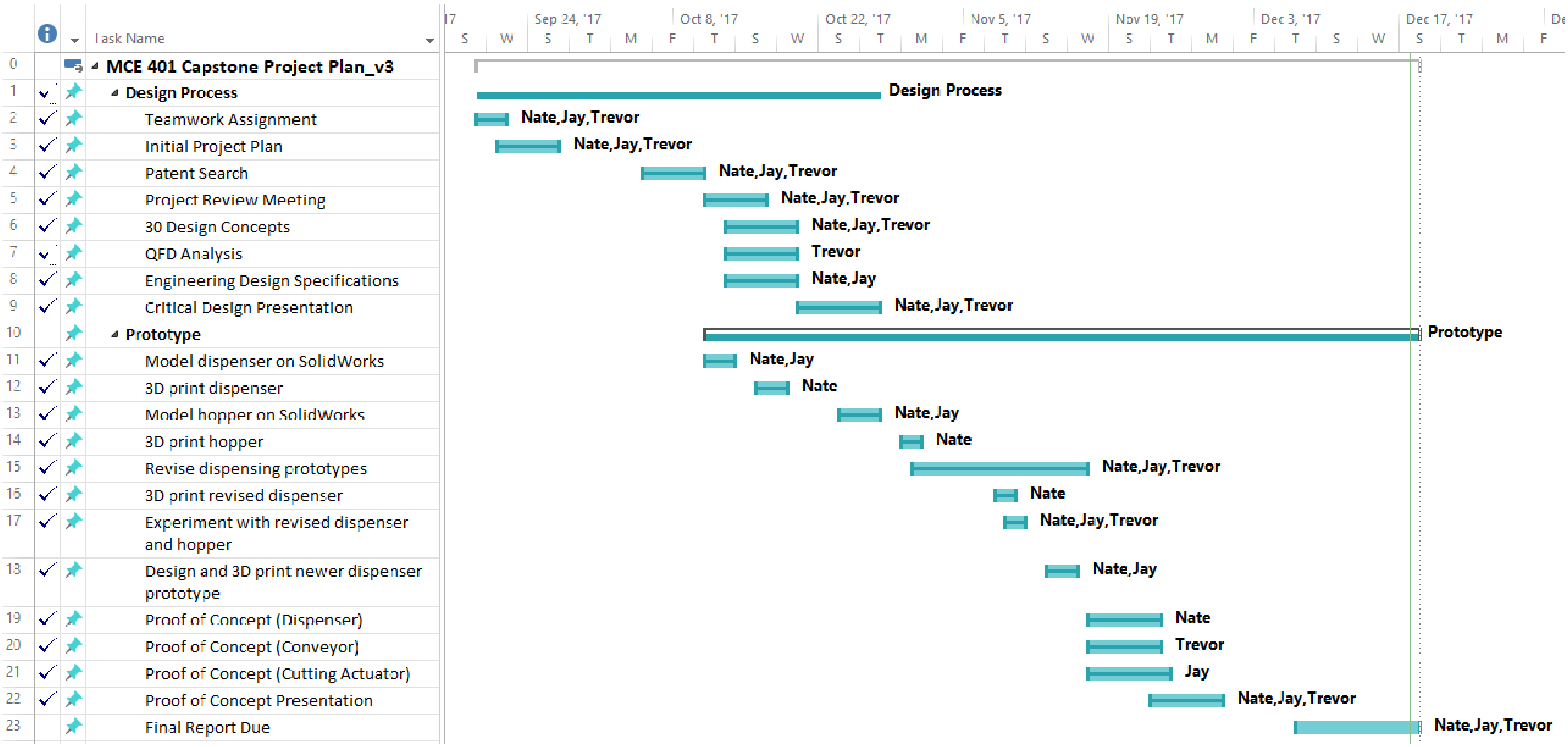


Figure 3: Gantt Chart (First Semester)

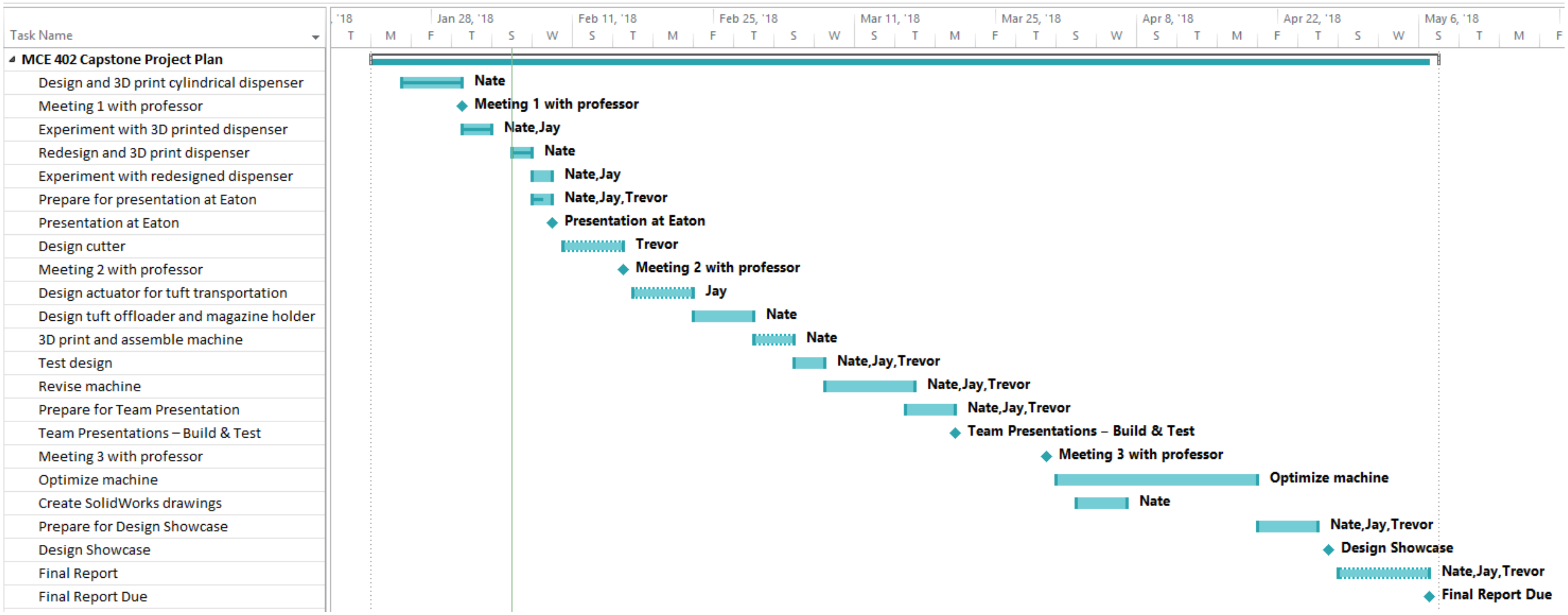


Figure 4: Gantt Chart (Second Semester)

In addition to a patent search, each team member was required to generate 30 unique concepts for how to solve the problem. These design concepts ranged from package opening to cutting to tuft sorting. At this time there were several different ideas on exactly how to cut: mechanical cutting (similar to the system Eaton currently uses), electrical discharge machining (EDM), and a water blade. All three of these ideas were present and expanded upon during this concept generation.

Concurrently, the team was tasked to determine design specifications as well as a QFD. The design specifications put the customers needs and desires on paper and gave them team concrete goal to work towards. The design specifications were derived from the Quality Function Deployment (QFD), which allowed the team to better conceptualize what it was they were supposed to be designing. By October 20th, these were completed in time for the group to present the progress that it had made so far to the class and Professor Nassersharif.

2.2 First Prototype

By the time the group presented the first design presentation, the group had developed a rudimentary plan and an early prototype for a drum style tuft dispenser, similar to the straw dispenser that they had found during the patent search. The progress of the group was met with skepticism from the rest of the class regrading feasibility. Problems with the EDM were becoming apparent, mainly in regard to drastically diminished throughput and an increase in cost per tuft. Problems with the water blade were primarily based on the need for a lot of water (a risky thing to add a machine shop floor), as well as the enormous energy needs to cut high-strength super allows. A return to the pneumatic cutter was becoming more popular. Another visit to Eaton was scheduled to confer with the sponsors. Here, it was established that the EDM would not be a viable solution due to the high cost of operation and the slow process time. The team could not justify producing fewer tufts at a higher cost per tuft. A mechanical blade would be the way to go moving forward.

With a rough design in mind, the team began to flesh out the smaller problems with more detail. A dispensing system was implemented and automated. A conveyor system for transporting the tufts needed to be designed. A system of sensors to monitor the tufts would have to be implemented. And of course, a micro-controller was still needed for all of these tasks.

An Ooyoo Mega (an off brand Arduino board) was used as a micro-controller. A Raspberry Pi was considered, but the Arduino was considered to be more appropriate due to more familiarity with the Arduino micro-controller as well as the scope of the project. A Raspberry Pi is essentially a compact computer with a LINUX operating system. That seemed excessive for what the team was tasked to do and carried little upside for the increased learning curve compared to the Arduino. The progress milestones for the Fall semester can be found in Table 1.

Table 1: Fall Semester Achievements

Task	Accomplished by	Date
30 Design concepts	Team 9	10/23/2017
QFD	Trevor Gale	10/23/2017
Design Specifications	Jay Guilmette, Nathan Joyal	10/23/2017
Dispenser prototype 1	Nathan Joyal	10/30/2017
Dispenser motorization	Jay Guilmette	11/13/2017
Photosensor integration into prototype	Jay Guilmette	11/20/2017
Linear actuators installed	Nathan Joyal	11/20/2017
Servo motors installed	Jay Guilmette	11/27/2017
Touchscreen integrated	Nathan Joyal	11/27/2017
Preliminary Design Report	Team 9	12/11/2017

The first prototype was completed in time for the end of the semester and to prove as a proof of concept. Though the early design worked in carefully controlled settings, it was apparent that it would be insufficient for the task of full time cutting for a number of reason. First, it jammed frequently. The water wheel design was not compatible with the smaller, flimsy tufts, that would become tangled on one another as they made their way down the chute. Second, the jamming was not only frequency but disastrous as the machine had a relatively closed design. Unjamming the water wheel design required nearly disassembling the entire thing. Third, the use of two actuators proved to be a burden to control as the internal potentiometers were not equal to one another. This led to variable speeds and variable positions. Though this was correctable, it was a headache that could have been avoided. Fourth, the use of phototransistors were unreliable. Different lighting conditions changed the voltage they allowed through, which meant the entire code needed to be tweaked every time the machine was brought somewhere with a different level of ambient light. Though the first prototype was not up to par, the challenges the group encountered allowed for a radical redesign that was both simpler and more effective in the Spring semester.

2.3 Second Prototype and Redesigns

The team reconvened in the early Spring with a much clearer idea as to how to approach the semester. Using the lessons learned from the Fall, a new design was already vaguely known. To help accomplish this redesign, a Gantt chart was used once again. This semester focused more on the testing and redesigning aspect rather than creating a new design from scratch. Having made a new dispenser before the end of the last semester, the focus was more on optimizing rather than creating. Additionally, the team got a break during an early meeting with Eaton: the pneumatic cutter than Eaton currently uses would not be modifiable due to union issues. Though this limited the design options somewhat, it also removed a large portion of the engineering analysis needed to be done. Instead of having to create a whole new case and optimize the force, the team would have no choice but to settle on using the current cutter with the current blade. The final design would then need to be spatially designed around the cutter. The team kept in touch with Eaton and Professor Nassersharif through weekly updates.

The new dispenser was a departure from the water wheel system. After many hours of frustrating testing performed in the final days of the Fall, the team learned that the tufts are too difficult to work with along their length. The shape of the wires will deform and bend under stress. If tufts are stacked on top of one another, they will get tangled between each other, and the middle will sag in while the weld bead holds it shape. It is through these observations that the new dispenser was designed. The tufts can only be reliably moved along their width axis: the firm weld bead is a fixed diameter that is relatively uniform for all the tufts of a given size.

The new dispenser loads the tuft upright and dispenses them straight down. This sidesteps the issue of the flexible middle entirely. The earliest redesign was nothing more than a cylinder that tufts would be loaded into upright and then slip through a bore with a diameter small enough to only allow one tuft at a time. This system uses vibrations from unbalanced DC motors as well as gravity to assist in the dispensing.

This particular design was more reliable and minimized the jamming issues that the previous dispenser created. The team then set to work to complete the rest of the project. Testing and redesign was initially estimated to only take a few weeks. It ended taking from late February, through March, and even into the beginning of April for a reliable system that could dispense an appropriate number of tufts. This testing phase included 2 trips to Eaton and 4 consultations with Professor Jouaneh from the University of Rhode Island. Everything else beyond this was assembled, programmed, and tested fairly quickly. Difficulties in this semester primarily included difficulty in meeting with Eaton to test new designs. Research also became a more important task as the vibration analysis on the dispenser system proved difficult to properly implement.

Given the physical nature of the tufts, jamming will always be an issue. A second, larger dispenser was added to the top the first one designed that acted as a sieve: a jam in one cylinder is not going to hinder the process if 4 other chambers can still reliably dispense. The team never found a way to conclusively end the jamming problem, but this redesign drastically minimized the effect of it. In addition, the cause of the jamming was different with the new orientation. Jamming now occurred from weld beads bumping into each other and both getting stuck in the bore at the same time. The weld beads are solid, however, and could be easily removed without damaging the tufts themselves. Instead of a full disassembly to unjam, they can simply be pulled out. To accomplish this, a large solenoid was affixed the dispenser that would violate shake it at intervals to shake any stuck tufts loose and aid in overall dispensing.

The phototransisotrs proved too difficult to work with, and the total number of sensors was reduced in general. In place of phototransistors, photoresistors were used. These were used by themselves instead of in series. This gave more accurate readings by reducing the sensitivity of the system. Overall sensor reduction was made possible by using a single actuator instead of two. The single actuator could be set to run on a consistent cycle, and would trigger limit switches (still sensors, but far more reliable than photovoltaic ones based on the simple HIGH/LOW designation instead of an analog signal). Using a single actuator also greatly simplified the programming.

This new design was a considerable upgrade over the first prototype, but it still required large amounts of testing and tweaking to work reliably enough. The top dispenser went through 17 different variations before it could dispense a full batch of tufts. This process alone took up the majority of the second semester. The achievements and milestones of the Spring semester can be found in table 2

Table 2: Spring Semester Achievements

Task	Accomplished by	Date
New dispenser design	Jay Guilmette, Nathan Joyal	1/29/2018
Second dispenser design	Nathan Joyal	2/12/2018
Dispenser ramp and slide	Nathan Joyal	2/12/2018
Dispenser funnel	Nathan Joyal	2/26/2018
Dispenser time test program	Jay Guilmette, Nathan Joyal	2/26/2018
Built, Test, Redesign Presentation	Team 9	4/4/2018
Test Report	Team 9	4/9/2018
Limit switches installed	Nathan Joyal	4/16/2018
Code written	Jay Guilmette, Nathan Joyal	4/16/2018
Brochure completed	Trevor Gale, Nathan Joyal	4/26/2018
Design showcase	Team 9	4/27/2018

3 Financial Analysis

3.1 Funding

The team was allotted $3,000 in order to complete the project. This cost was spread out over both semesters to fund the first prototype and the final product. To save money, the first proof of concept prototype was made using cheap, over the counter parts. The total cost for parts for the first semester can be found in Table 3 below.

Table 3: Prototype Costs

Part Name	QTY	Unit Cost	Total	Vendor
Motorized linear potentiometer	2	$22.87	$45.74	sparkfun
Motor and shaft coupling (2 pack)	1	$5.29	$5.29	Amazon
ATmega2560 & 3.2" LCD touch screen	1	$32.99	$32.99	Amazon
Solid hook-up wire kit	1	$15.34	$15.34	Amazon
Vibration motor (2 pack)	1	$6.99	$6.99	Amazon
Stepper motor and driver	1	$2.80	$2.80	Amazon
TCRT5000 optical sensor	4	$0.60	$2.40	Amazon
SG90 micro servo motor	2	$4.99	$9.98	Amazon
		Total:	$121.53	

The majority of the components were purchased at an earlier time for personal use and were reconfigured for use in the prototype. This allowed the group to maintain most of the entirety of the budget for future allocation. However, the total sum of the parts used in the prototype was $121.53.

The final prototype cost considerably more as it was made of more robust, industrial grade components. Additionally, the decision was made to use PLA filament for most of the construction to save money. The initial plan called for the dispensers and ramp to be made of aluminum. However, after performing an engineering analysis on the PLA filament, it was decided that the benefit of using aluminum was not worth the cost to buy the raw materials and then machine it into a suitable shape, let alone the extra weight having a direct impact on the dispenser system. This allowed for a considerable savings in cost. The engineering analysis can be found in the engineering analysis section. The total cost of the final product can be found in Table 4.

Table 4: Final Design Costs

Part Name	QTY	Unit Cost	Total	Vendor
Motorized linear potentiometer	2	$ 22.87	$ 45.74	Sparkfun
White PLA 3D Printer Filament	1	$ 23.99	$ 23.99	Amazon
Vibration motor (2 pack)	1	$ 6.99	$ 6.99	Amazon
ATmega2560	1	$ 32.99	$ 32.99	Amazon
Slippery Tube	1	$ 8.20	$ 13.99	Amazon
Aluminum rod	1	$ 17.12	$ 17.12	McMaster
Spring Stud Anchor	4	$ 3.22	$ 12.88	McMaster
Springs (0.875" long)	1	$ 7.15	$ 7.15	McMaster
Steel Rod	2	$ 3.28	$ 6.56	McMaster
Aluminum Tube	1	$ 1.01	$ 1.01	McMaster
Actuator (12" travel, 9"/sec)	1	$ 157.00	$ 157.00	Progressive Automations
Actuator mounting brackets	1	$ 17.00	$ 17.00	Progressive Automations
Electrical enclosure box	1	$ 49.99	$ 49.99	Amazon
Terminal block shield for arduino mega	1	$ 24.99	$ 24.99	Amazon
12V 30A power supply	1	$ 18.85	$ 18.85	Amazon
24V 2A power supply	1	$ 12.79	$ 12.79	Amazon
Emergency stop button	1	$ 7.25	$ 7.25	Amazon
LED indicator lights	1	$ 8.70	$ 8.70	Amazon
8 channel relay	1	$ 9.59	$ 9.59	Amazon
Push buttons	1	$ 11.87	$ 11.87	Amazon
Motor controller (for linear actuator)	1	$ 21.98	$ 21.98	Amazon
Motor controllers (vibrating motors)	1	$ 19.98	$ 19.98	Amazon
Vibrating motor	3	$ 9.83	$ 29.49	Amazon
Solenoid	1	$ 20.26	$ 20.26	Amazon
Plywood (2' x 2')	1	$ 10.34	$ 10.34	Home Depot
Plywood (2' x 4')	1	$ 22.49	$ 22.49	Home Depot
Metal strap bracket	2	$ 1.97	$ 3.94	Home Depot
Wood screws	1	$ 1.18	$ 1.18	Home Depot
Solid-core copper wire	1	$ 11.69	$ 11.69	Home Depot
		Total:	$ 627.80	

The team finished the final design under budget. The most expensive single item was the linear actuator. The actuator used was the cheapest high speed actuator available, and as such it lacks a linear potentiometer inside. Should this design be implemented by Eaton, upgrading the actuator would be necessary, as it minimizes the complexity of the system and increases reliability, as well as making repairs easier by reducing the total number of possible failure points. Furthermore, the team highly recommends upgrading the micro-controller to a more reliable brand. The current micro-controller is already beginning to show signs of failure in some of the pins after a full years worth of implementation.

3.2 Labor Costs

The team spent a combined 283.15 hours on the project during the course of the first semester, as well as 463 additional hours during the second semester bringing the total hours worked to 746.15. Nathan Joyal spent a total of 373.5 hours on the project. Jay Guilmette spent 192.5 total hours on the project, and Trevor Gale spent 180.25 hours. In addition to the team labor, Professor Jouaneh of the University of Rhode Island Department of Mechanical, Industrial, and Systems Engineering was consulted for 1 hour during the first semester and 4 more hours during the second hour. The sum of total labor costs can be found in Table 5.

Table 5: Labor Costs

Consultant	Total Hours	Hourly Cost	Total Cost
Team 9 Members	746.15	$30.00	$22,384.50
Professor Jouaneh	5	$75.00	$375.00
		Total:	$22,759.50

The total cost of the labor on the prototype is valued at $22,759.50. This is a comparatively low number considering class content, especially in the Fall semester, overlapped with the project immensely. For example, familiarity with Arduino and circuits came from a course in mechatronics, which greatly decreased the amount of time billed directly to the project. Total work hours can be found in the Appendix.

3.3 Operating Costs

With the goal of the project to reduce costs as much as possible to Eaton, the actual cost to run the final design is of utmost importance. The reduction in manpower is reduced only to loading the tufts in batches of 300. The team estimates this time requirement to be 5 minutes per batch of 300 tufts. With an average cutting time of roughly 3 seconds per tuft, that brings the total number of tufts cut in 1 hour to 1,200. This means that the operator will be required to load the machine 4 times in 1 hour, requiring (4 * 5) 20 total minutes of labor from the operator. Using the base line of $75.00 per hour of labor, it is estimated that the 20 minutes will cost Eaton $25.00 to pay the operator. Additionally, the final design uses quite a bit of power. Measured using a multimeter, the total power consumption of the design is 90 kilowatts per hour on average. Rhode Island charges an average of $0.12 per kWh, bringing the cost of operating the machine for 1 hour to $10.80 of energy costs. Combining this with the estimated labor costs brings the total cost of operation to $35.80.

3.4 Return on Investment

The current method employed by Eaton cuts 900 tufts in 1 hour at a cost of $75.00 per hour, which breaks down into slightly over $0.08 per tuft. The new design only costs %35.80

per hour, which is a decrease in costs of over 52%. This number does not take into account the increased production per hour. However, output increased from 900 tufts per hour to 1,200 tufts per hour, which is an increase in 33%. To get a better idea of total improvement, it is better to look at cost per tuft. The cost per tuft has decreased from $0.08 to $0.03, which is a 62% decrease in cost per tuft. Implementing the new design saves Eaton slightly over $0.05 per tuft.

The total cost of production then is the labor hours combined with the material costs. It cost a total of $23,379.45 to finish the project. Saving %0.05 per tuft cut, it would require Eaton to use the design to cut 467,589 tufts to earn back the money spent on the design. At a cutting rate of 1,200 per hour, it would take 390 hours of cutting for Eaton to break even.

3.5 Other Considerations

This design is fairly cheap to manufacture considering the extensive use of PLA filament over aluminum. This allows the unique components to be made on site by any company with a 3-D printer. Given the number of companies that manufacture brush seals, especially for Aerospace applications, demand for an efficient tuft cutting system seems highly plausible. However, manufacturing of such seals are generally company secrets, as are the seals themselves. The team was required to sign an NDA to work on the project, and the tufts themselves are considered company intellectual property. Should Eaton wish to sell the design to other companies, it would depend largely on the cost of taking it to a specialist in dealing with PLCs to make it easier to use and adapt to other companies. Depending on the volume of the competitors, it should be feasible to manufacture the tuft cutter design to other brush seal manufacturers.

However, there exists other applications within Eaton itself. If other locations make brush seals, then this design should be able to seamlessly be implemented in other locations, with a building cost of less $1,000.00 (again, depending on the quality of the PLC). Another potential use for this product is not in cutting tufts but in the manufacturing of the tufts themselves. Eaton buys the tufts from itself, and has a factory in Batam, Indonesia, where the tufts are mass-produced. Depending on how the tufts are packaged, this design could easily reduce costs through automation of additional tedious jobs. For example, if Eaton currently pays someone to count out 100 tufts per pack, this design could easily be modified to accomplish such a goal (all one need to do it is remove the cutter and instead implement a counter).

4 Literature and Patent Searches

The first step in the project was to better understand the purpose and function of brush seals. Eaton has several competitors in the brush seal market, particularly with regards to aerospace applications. For example, Cross Manufacturing, Eagle Industry Co, Ltd, and even GE all manufacture brush seals for aerospace use. Research into the processes these companies used was a good starting point, but was filled with roadblocks. First, these processes are company property, Eaton can't simply copy them and they are typically kept secret. Second, what information could be gleaned was not necessarily helpful. The team was tasked with improving on the process of cutting the tufts used in seals, not redesigning the entire manufacturing process. It would seem that some companies don't use double ended tufts at all, much less cut them in half before welding the seal in place. For instance Cross Manufacturing uses packs of "10 to 20 wires," though what exactly a pack is is never stated [4].

However, one thing that did seem consistent was the type of alloy used in the manufacturing process. Technetics Group, Waukesha Bearings, and MTU all use a super-alloy called Haynes 25 [5], [6], [7]. According the Haynes 25 manufacturers website, it is a nickel-cobalt based heat-resistance super-alloy [8]. This is the same kind of alloy that Eaton uses in their brush seals. However, this tells nothing about how the alloy is machined and implemented, only that it is used.

To better understand the manufacturing process, research into machining super-alloys was essential. A goal of the project at the outset was to extend the life-cycle of the blade to minimize the frequent and lengthy resharpening occurrences. The physical properties to heat-resistant super-alloys makes them ideal for operating in temperature extremes and under extremely high forces, but it makes machining them difficult. This is especially true at Eaton where the pneumatic cutter currently being used was never designed to machine super-alloys. The blade currently used is a carbide blade that is more suited to cut sheet metal. According to the American Machinist [9], the force applied to cutting tools should be nearly double that than those used for traditional steel (4,000 N/sq-m as opposed to 2,500 N/sq-m). Additionally, the cutting speed must be kept below traditional metals.

However, upgrading the blade permanently seems like the best solution, as Sandvik Coromant [10], world leaders the field of manufacturing tools, recommend using a ceramic graded tip, as these have very high heat and wear resistance at higher cutting speeds than do traditional cutting materials. However, much of the available research and literature seems to be focused more on milling and turning than it does not simple shear cuts.

The team conducted a preliminary patent search early in the semester. This initial search yielded few results. A second patent search was conducted as the design became more developed and refined. The usable and relevant patents are listed on the following pages.

United States Patent 4308974 - Tampon Dispenser

Date: February 29, 1980

Rights owned by: Jones, Linda M.

Abstract: This invention is a device for the discreet storage and dispensing of tampons. The device is characterized by including a storage container having a dispensing apparatus which will dispense one tampon at a time without display except when actually dispensed and wherein it is dispensed by means of an elongated member having a suitable pocket therein for said purpose. It is further characterized by being suitable to accommodate different sizes of commonly used tampons.
The tampon dispenser uses a wheeled drum system similar to what the tampon dispenser, even down to the four grooves in the wheel as can be seen in Figure 5. The primary difference is that this dispenser is a hand cranked system, whereas the one in the prototype is motorized. The final iteration of the product, if the wheel dispenser system is kept, will move further away from this particular patent because 4 grooves have shown to be a poor number for the dispenser to have (3 would be ideal).

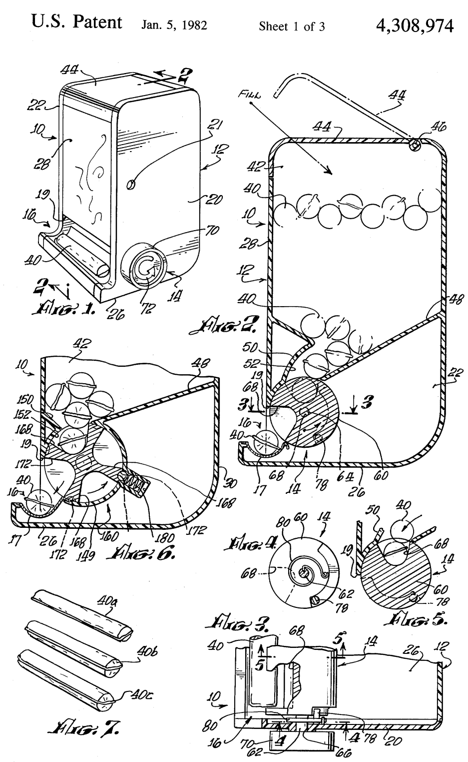


Figure 5: Design Schematic

United States Patent US20120298683 A1 - Soda Straw Dispenser

Date: May 25, 2012

Rights owned by: Domit, Antonio

Abstract: A straw dispenser that hold two individual straws, sequentially selected from an inventory of straws. The upper straw is staged in a position to fall, and the lower straw is in a position made available to a person. The person grasps the available straw and pulls the same, which moves a lower movable part of the dispenser. The forward movement of the lower movable part allows the upper staged straw to fall downwardly to a transitory position, and during backward movement of the lower movable part the straw moves from the transitory position and is made available. At the same time a successive straw is selected from the inventory and held in the staged position. The person need not touch any other part of the dispenser or touch other straws to be dispensed. A subsequent straw cannot be dispensed until the available straw has been removed from the dispenser.
Fairly similar to the tampon dispenser, this particular patent also focuses on the dispensing method. It relies in a manual lever to be pressed in order to dispense the straw. This patent was not used in the prototype, but a similar design was proposed earlier in the project. It was revealed later that that the actual cutter would not be changed, nor would the team be allowed to interact with it due to union issues at Eaton. This removed a great deal of responsibility for the team, as all of the design work could be focused into dispensing and moving the tufts rather than how to cut them. This also made a large part of the previous literature and patent searches unnecessary, as cutter improvements would not be made anywhere.

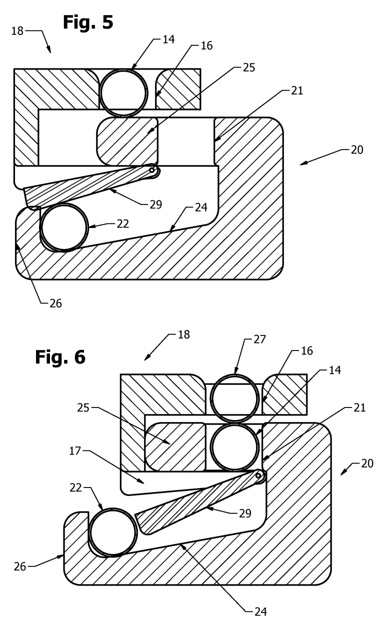


Figure 6: Soda Straw Dispenser

United States Patent 6308957 - Brush Seal

Date: October 8, 1998, 1980

Rights owned by: Rolls Royce Plc.

Abstract: A brush seal designed for use between regions of high pressure differential and in an environment in which there is disturbed flow has a bristle pack sub-divided into a plurality of bristle pack regions with a leaky diaphragm between each region. The brush seal may comprise an assembly of individual seals with diaphragms between them or a single bristle pack which is sub-divided by at least one internal diaphragm. The diaphragms are preferably compliant and designed to allow a predetermined leakage flow between bristle regions. The leakage flow has several functions: it causes the pressure differential across the whole seal assembly to be more evenly distributed, and by providing an amount of flow in each pack this acts to calm the bristles thus helping to ensure each bristle region effectively contributes to the seal performance.
The brush seal patent is relevant only insofar as it gives a better idea of how the overall seal is made. Though the team was not tasked with redesigning the actual brush seal, whatever process improvement the team accomplishes needs to be compatible with the next step in the process. This will allow for future improvements to the entire system instead of this one individual aspect of it. It also gives a better idea as how compact the brushes need to be when inserted into the weld filament.

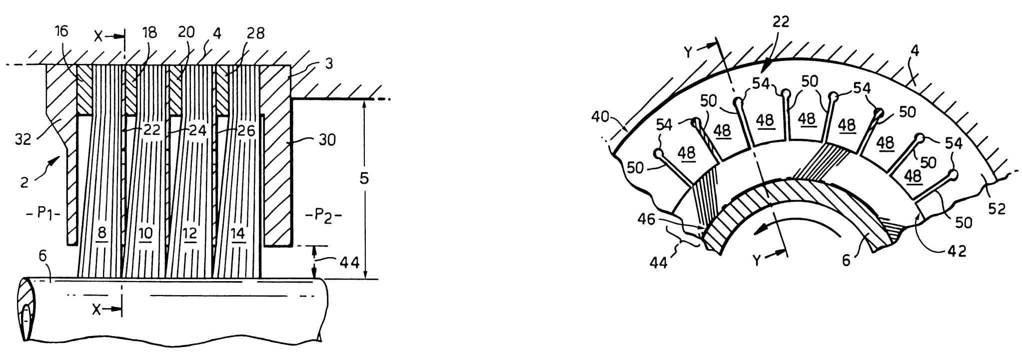


Figure 7: Brush Seal Patent

United States Patent US5090710A - Brush Seal

Date: May 29, 1987

Rights owned by: Cross Manufacturing Co Ltd.

Abstract: A brush seal assembly for use in a gas turbine, jet engine or the like where a shaft which rotates at very high rates is to be sealed to a housing. The seal assembly has a plurality of brush seal elements each of which comprises a generally accurate carrier and a plurality of bristles projecting therefrom. All of the brush seal elements are supported in the engine housing in a substantially continuous end-to-end manner with the bristles of the seal elements arranged to form a substantially continuous brush seal wiping against the shaft.
The above patent is the one held by a direct competitor to Eaton, Cross Manufacturing. Cross Manufacturing has a unique patent on how the seals are actually manufactured. This patent gives the team a better understanding about the approach of the competition.

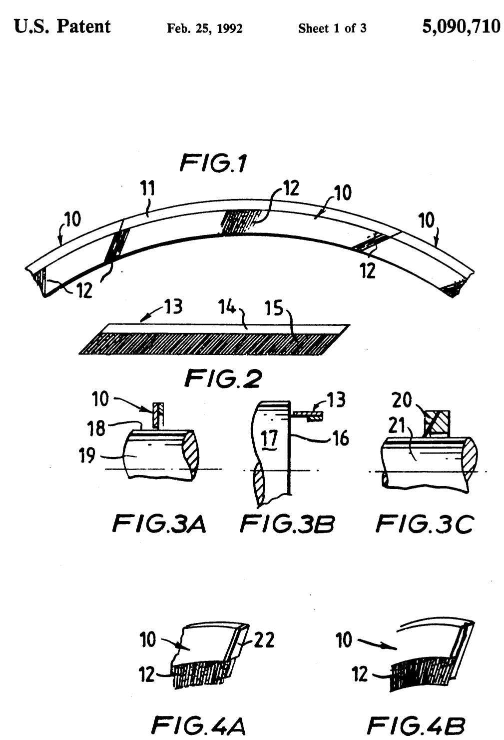


Figure 8: Cross Manufacturing Brush Seal

United States Patent US8110075B2 - Coated Cutting Tool for General Turning in Heat Resistant Super Alloys (HRSA)

Date: August 24, 2007

Rights owned by: Sundstrom, Erik, et al.

Abstract: Coated cemented carbide inserts are particularly useful in general turning of superalloys. The inserts are formed from a cemented carbide of WC about 5.0-7.0 wt-% Co, and about 0.22-0.43 wt-% Cr, where the substrate has a coercivity (Hc) of about 19-28 kA/m. The coating contains a single layer of (TixAl1-x)N-layer, where x is 0.25-0.50, with a crystal structure of NaCl type, a total thickness of about 3.0-5.0 m, (200)-texture, and a compressive residual strain of about 2.5103-5.0103, optionally containing an outermost TiN-layer.

This patent is related to a cemented carbide tool that is useful for machining super-alloys. Should the team decide to upgrade the cutting blade, a new tool like this would be especially helpful. The new blade would most likely have to come from Sandvik-Coromant (Eaton's vendor), but this provides a decent starting point for a new idea on what to look for.

5 Competitive Analysis

There exists already a substantial brush seal market, especially with regards to aerospace. In addition to Eaton, Technetics, Cross Manufacturing, Eagle Industries, Herber Aircraft, MTU, Sealeze, and Waukesha Bearings all compete for market share. The exact nature of their brush seal manufacturing are company secrets that the group does not have access to. This makes any kind of competitive analysis difficult. With the entire process closed to the team, and exact costs unknown, it is impossible to say if the team is even in direct competition with any of these companies. What information could be gained from public releases did not seem relevant to the project. For example, in a video released by MTU about their brush seals, it gives the impression that the brushes do not come from cut tufts, but rather a single long wire that is wound hundreds of times before being welded, as seen in Figure 9.

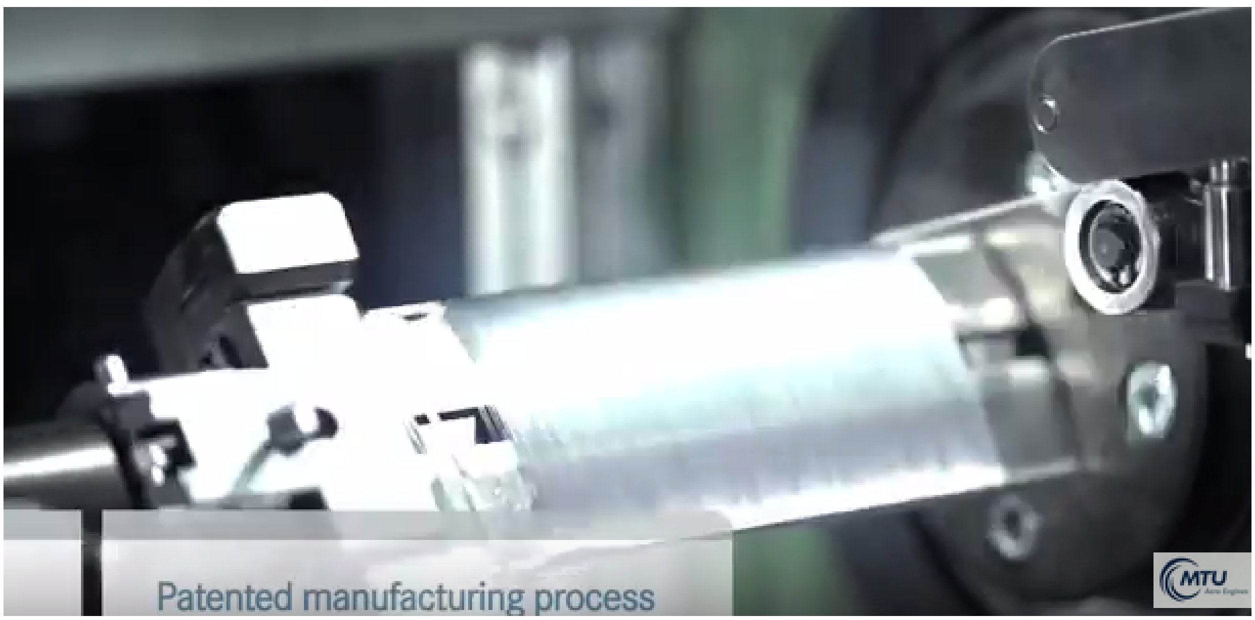


Figure 9: MTU Promotion Video

If a competitor is not using tufts at all, but rather just the wire, then Eaton is adding two additional, superfluous steps: one by welding the tufts together in the first place, and the second by cutting them. It may be in Eaton's best interests to change the way the tufts or wires arrive and not bother with the cutting process at all. This is, however, beyond the scope of the project. Not only does the team lack the resources to analyze which if these methods would be better for Eaton, but, and more importantly, it is not the task the team was given by Eaton. The customer requirement was to make X more efficient, not tell them why they should do Y instead. It is therefore in the best interest of the team to make the cutting process as efficient as possible, and do so in a way that will help streamline the next step of the process as Eaton currently performs it.

6 Specifications Definition

Table 6: Design Specifications.

Category	Required Specification	Actual Specification
Size	No more than 7 square feet	6.4 square feet
Throughput	Under 4 seconds per tuft	3 seconds per tuft
Cost to operate	Under $0.08 per tuft	Under $0.03 per tuft
Robust	Support 100 tufts	Supports 300 tufts
Safety	Operating volume of less than 90 dB	68 dB maximum
Safety	Emergency stop button	One emergency stop button
Ease of Maintenance	Must be repairable on site	0 non-electronic components that can't be 3-D printed, 0 non-standard electronic components
Ease of Use	Less than 30 minutes to learn how to use machine	5 minute learning time for machine
Ease of Installation	Requires 0 special equipment to install	Requires 0 special equipment to install that is not already available (pneumatic pressure hoses)
Ease of Disposal	0 components that require special disposal	0 components that require HAZMAT disposal, 5 components that are considered "E Waste."
Building Cost	Under $3000	Current prototype projected to cost $619.95

The design specifications are fairly straightforward and were drawn from Eaton's direct requirements to the team as well as the QFD. First and foremost is the physical footprint of the new design. While Eaton was willing to allocate additional space to the product if it was necessary, the team was instructed to try and fit it into the physical space already available. The current set-up has a table that is 7 square feet that holds three cutters. It is here that the current process occurs and also where the new design would go. The team met the requirement of fitting the new design, including the cutter, into an acceptable physical space.

The next 2 specifications refer to the performance of the design. Eaton assigned the team with increasing throughput as well as reducing costs. The current process cuts 1 tuft every 4 seconds at a cost of $75.00. As previously stated in the financial analysis, both of these goals have been surpassed.

The design is required to be robust enough to be of practical use. After all, a design that can only hold a few tufts is not worth implementing, as the first prototype showed. Due to the tufts coming in packs of 100, the team designed the machine around holding tufts in factors of 100 for ease of use: an operator need not waste time counting out how many tufts to load. It would be preferable if he could simply open a package and dump the whole package in. With the current design, he can do that with 3 packages at a time. This current design uses a fairly low factor of safety for a number of reasons, primarily the lack of risk in case of failure at the dispenser loading point. The entire machine will be encased in carbon fiber, the tufts are separated from the cutter, and the operator loads the machine from the top and nothing is ever beneath it. Due to these factors, a high factor of safety seemed unnecessary. Should Eaton want increased durability, the easiest way of accomplishing it is to simply use thicker, tougher springs at the corners of the primary dispenser.

Safety is of the utmost importance to Eaton, and it would be unethical to release a product that the team felt was unsafe. To make sure that the final product is safe, it needs to be encased in carbon fiber to keep the operator away from either the blade or the actuator. This is one aspect that the team did not have the time to get to, but adding it would be simple and straightforward. Additionally, the machine has an emergency stop button that terminates all power to the machine. This is not the best solution, as the capacitors inside the machine continue to discharge for a few milliseconds after the button is pressed. On the last prototype, the emergency stop was much more effective and immediately stopped everything. The Ooyoo interrupt pins, however, were not functioning correctly. However, upgrading the micro-controller is enough to correct this issue. Additionally, the prototype is not loud enough to merit any protective ear covering and there is no threat from chemicals or chipping caused by the machine.

The final few rows of the design specifications refer to how easy the product is to use, install, maintain, and dispose of. For these aspects, the design team paid special attention to the materials used as well as how easy it is to get those materials. The use of filament instead of aluminum for dispensers and ramp allows for ease of manufacturing. Using electrical components that are industrial grade but not unique allows for simple replacement of damaged or depreciated components. This allows for on-site repairs with parts that are cheap and plentiful. Additionally, the installation is very easy as the whole machine uses a single, three-pronged plug, instead of a series of voltage converters that the first prototype required. The training time to use the machine is incredibly low, one need only load the machine and hit "START" for the process to begin. Finally, disposing of the machine if very straightforward. There are no components that pose unique environmental hazards (in fact, the PLA is biodegradable). The only part that can't be disposed of in a typical trashcan are the motors and the actuator, which would constitute electronic waste.

7 QFD

The first part of the Quality Function Deployment process is to obtain from the customer a list of qualities that the product should have and the weight or importance of each quality. In this case the customer was Eaton and their demanded qualities are shown below in Figure 10.

Demanded Quality (a.k.a. "Customer Requirements" or "Whats")
Cuts tuft at x/2
Maximize the amount of automation to avoid human interaction
Cost of running being less or equal to current method
Time per tuft cut less or equal to current method
Safety is a must
Clean cut
Rinse in de-ionized water
Easy to use
Able to cut different length tufts
Avoiding stored chemicals/equipment
Would be nice to integrate with next step of process
Needs emergency stop
Cannot not be a hassle to maintain
Ergonomically friendly
Aesthetically pleasing

Figure 10: Demanded Qualities

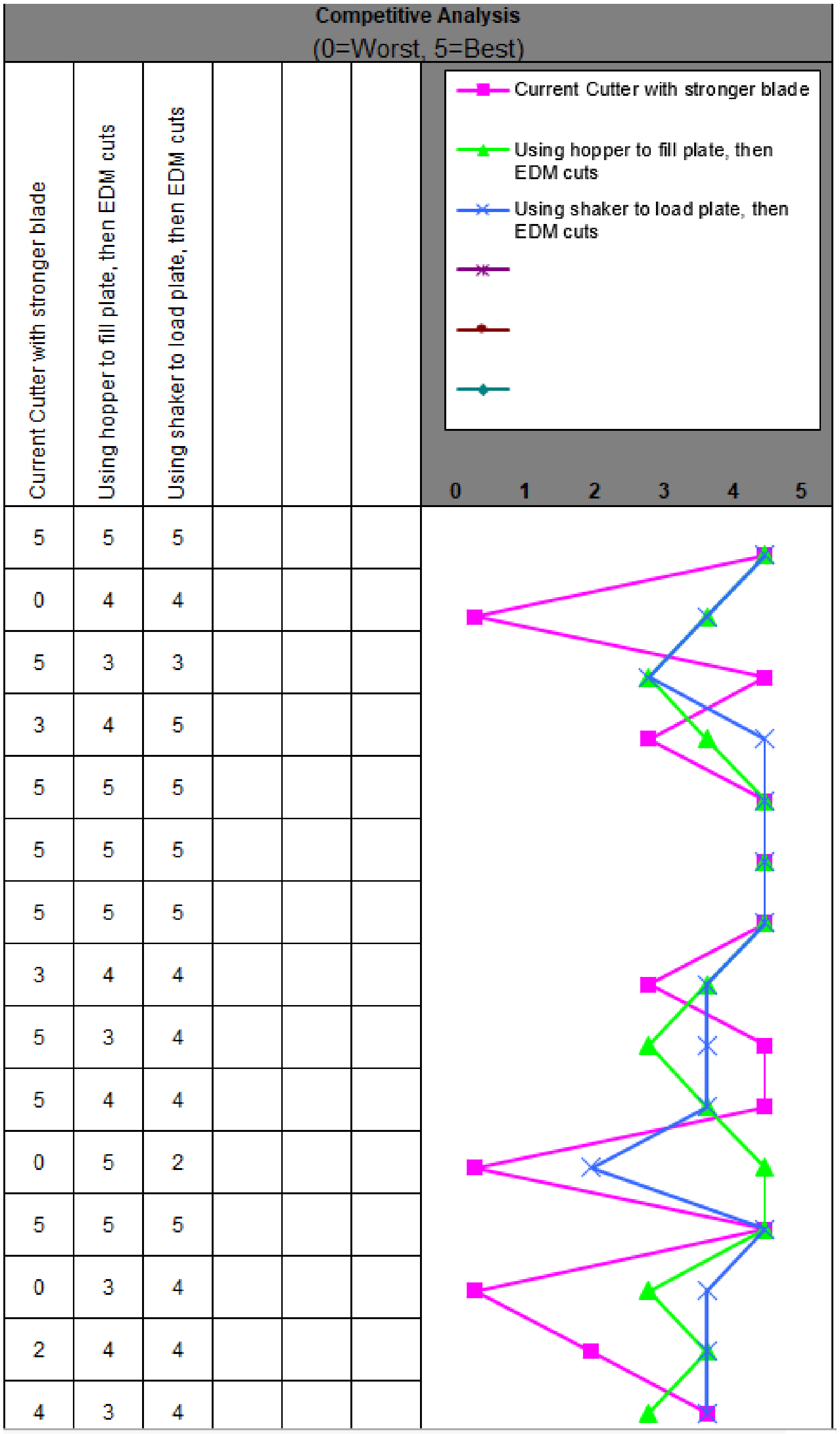
Once the list of customer requirements is obtained the overall product must be broken down into characteristics which describe the final design. These characteristics must be able to be represented in some quantitative manner such as time in hours or volume in cubic feet. The characteristics that cutting methods were broken down into is shown below in Figure 11.

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Time per tuft cut	Cutting method	Loading Style	Sorting Style	Ability to open package	Weight	User Interface	Source of energy	Actuator Design	Conveyor System/Transportation	Cost of running EDM	Physical Durability	Electrical Dependability	Ability to integrate with next step	Cost of system production	Adaptability to different tuft lengths	Physical footprint	Ergonomics

Figure 11: Product Characteristics

The final step of the QFD process is to make two comparisons, the first of which being the relationship between the demanded qualities and the product characteristics. These relationships are denoted as strong, moderate, or weak and are used to show how a change in a characteristic for the better or worse will impact certain end qualities.

The grades that each potential solution is given can be presented in the form of a line chart. This allows the design team to easily view which solution fulfills the customers needs the best. If one solution has a strong drawback, it can be seen as poorly graded compared to the other concepts. An example in this case is the human interaction involved in the original cutting method used by Eaton. It received a poor score due to full human interaction and it is easily seen in the plot. This method of scoring can be seen on the next page in Figure 12.



Current Cutter with stronger blade	Using hopper to fill plate, then EDM cuts	Using shaker to load plate, then EDM cuts			
5	5	5			
0	4	4			
5	3	3			
3	4	5			
5	5	5			
5	5	5			
5	5	5			
3	4	4			
5	3	4			
5	4	4			
0	5	2			
5	5	5			
0	3	4			
2	4	4			
4	3	4			

Figure 12: Competitive Analysis

8 Design for X

8.1 Design for Manufacture

Originally, the design was primarily made of aluminum. However, PLA filament ended up being the better choice for a number of reasons. Given the geometry of the dispenser, it is more practical to use PLA filament for the final version as well, which Eaton would easily be able to replicate on site within a few hours. Furthermore, the weight of aluminum would make it more difficult to work, as it would require much more robust springs. The physical properties of the PLA are sufficient for the design, and any upgrades to improve durability would be unnecessary. The use of PLA allows Eaton to manufacture as many units as they need to in-house. Not only in terms of cost, but in terms of man power is the PLA the superior choice: 3-D printing is passive and can even be done overnight so as not to waste manpower. Additionally, all the non-PLA components (electrical components primarily) are fairly standard and require no change or modification: new motors can simply be attached to the dispenser, the sensors are easy to replace, and even the actuator can be replaced due to the external sensors being independent of any kind of linear potentiometer a replacement actuator may have.

8.2 Design for Cost

The design uses PLA over aluminum not just for ease of manufacturing, but also for cost. The filament costs only $20 for 2.2 lbs. All printed components weigh a combined total of 2.65 pounds. The total cost of producing the prototype using filament then comes to 24 dollars and 9 cents. In comparison, a 125 inch^3 block of aluminum (not even enough for the primary dispenser) would cost in excess of 80 dollars. This is just the raw cost of the material and does not include the labor costs to machine it into the required dimensions. Cost reduction can also be found in the types of components used. The linear actuator that the team chose is one of the cheapest, high speed linear actuators. The low cost comes from the lack of an internal potentiometer, which makes controlling the position difficult. The three limit switches help to overcome this, and the cost of three limit switches is insignificant compared to a more expensive actuator.

8.3 Design for Testing

Testing played a massive role in the project, and the group initially underestimated how long the testing phase would take by a considerable amount. The project not only underwent a complete redesign for the Spring semester, but the new dispensers went through no less than 17 additional redesigns. The primary purpose of the design is to increase throughput, so testing the main aspect to be tested was the speed of the design. The Arduino has built in timers that were used to make sure the throughput was in fact greater. The chute that the tufts come down was affixed with a sensor, and that sensor was programmed to count how long a tuft took to fully leave the secondary dispenser, but also how much time passed between tufts. Another aspect that was important to determine was the speed of the actuator, which was the only part that the group could not alter without pumping more current into it. A timer began when the actuator began a full stroke and ended when it returned to its starting position. This time was just under 3 seconds, and it confirmed that the group did indeed beat the output target.

8.4 Design for Use

The dispenser is to minimize the tedious labor of skilled technicians. It is therefore necessary for the system to be as simple as possible to minimize the time sunk into training and troubleshooting. The whole system will ideally require almost no training beyond a few very basic guidelines. Pre-programmed choices for tuft size will remove most of the human decision making. Except for occasional monitoring of possible jams, the operator should not need to be present while it is operating. In addition to simple use, it must be simple to learn how to use. Currently, the set up consists of a panel of buttons that consist of "START," "STOP," "RESTART," and "EMERGENCY STOP." The nature and purpose of these buttons should be universal. The team recommends to Eaton, however, that the finished product be taken somewhere else for a programmable logic controller that will allow an operator more interface with the machine, as well as incorporate a sturdier micro-controller. Such a PLC may also allow Eaton to see who used the machine last, how many tufts were cut, etc.

8.5 Design for Safety

The design is quite safe. The whole design is enclosed on all four sides. This keeps the actuator and the cutter out of the way to avoid accidents. The part of the machine that poses the greatest danger, the pneumatic cutter, is not an original design, but rather an incorporation from the previous process. This means that the safety specs on the cutter from the original manufacturer are still valid, and the use has not been altered in any way for the final product. Additionally, it comes with an emergency stop that will stop the machine where it is. The tufts themselves can only be loaded in a maximum of fifteen at a time, so the ergonomic stress is minimal. Additionally, the design is OSHA compliant [11]. This will be addressed in detail more under the "Testing" section.

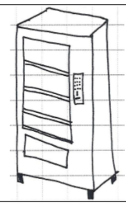
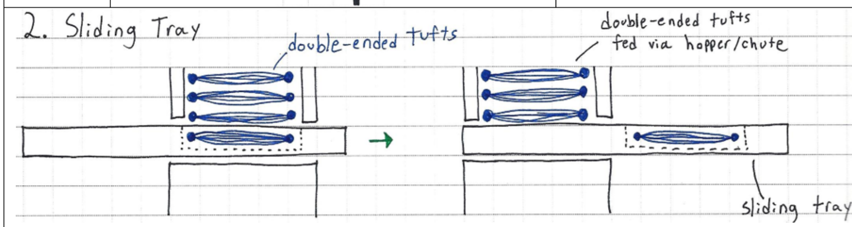
8.6 Design for Maintenance

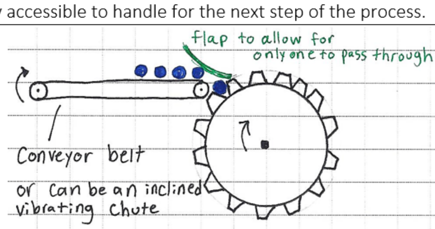
The machine is fairly easy to keep maintained. Most of it is 3D printed, so replacing damaged or worn out parts is as straightforward as reprinting. The motors are relatively cheap and not particularly unique (as long as they have a maximum frequency of 3200 RPM). The actuator is the most complicated component: it lacks an internal potentiometer, which makes finding the exact location of it somewhat difficult. Adjustable limit switches are used to keep track of the position (which changes depending on the length of the tuft). However, as long as the limit switches are in the correct position, it should work for all other actuators.

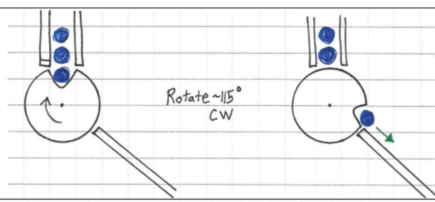
9 Conceptual Design

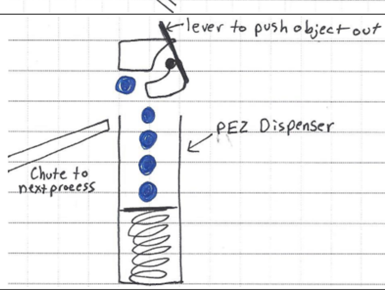
The first activity assigned to each team member was to come up with thirty unique concepts for fulfilling the project requirements. These ideas could focus on things as broad as the cutting method or could be as specific as the material of the blade. The list of concepts generated by each team member are shown below.

9.1 Nathan Joyal Concept List

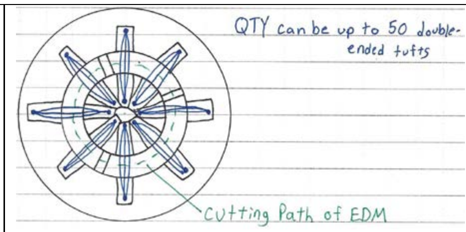
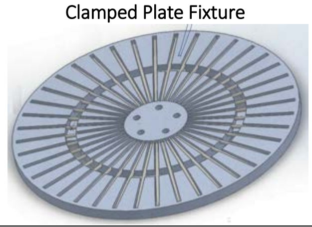
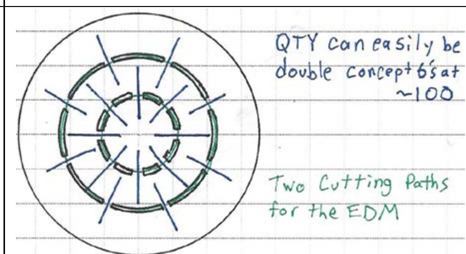
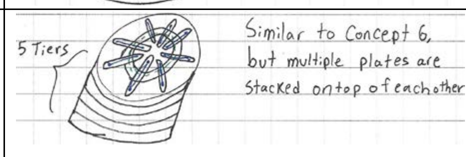
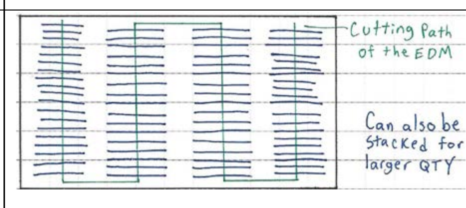
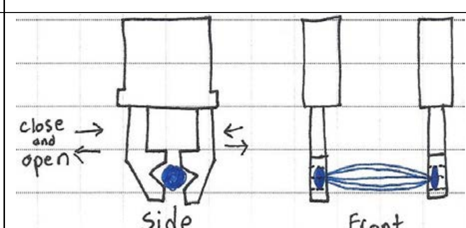
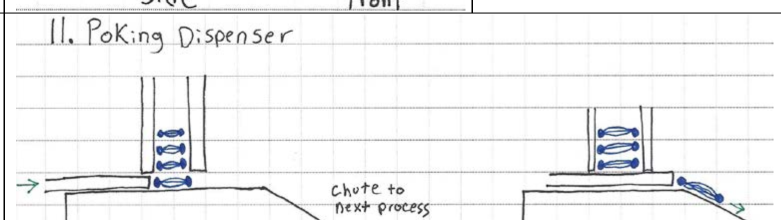
<table>
<tr><th>Concept #</th><th>Sketch</th><th>Description</th><th>Ranking
0 to 10
(10 being most relevant)</th><th>Purpose
(What will this do with the double-ended tufts?)</th></tr>
<tr><td>1</td><td></td><td>Vending Machine
Could use a dispensing method similar to a vending machine</td><td>3 / 10</td><td>To individually sort</td></tr>
<tr><td colspan="3">

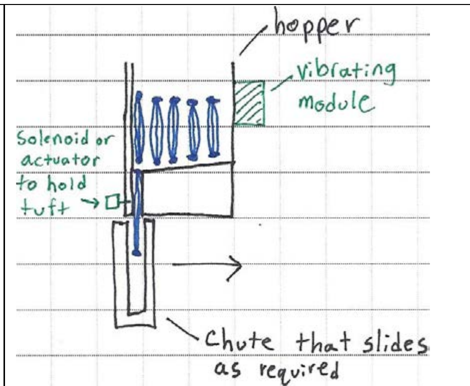
Double-ended tufts are loaded into a hopper/chute and are fed into a column where they rest on top of each other. As the tray is pushed out with an actuator, the tray dispenses only 1 double-ended tuft and can be easily accessible to handle for the next step of the process.</td><td>7 / 10</td><td>To individually sort</td></tr>
<tr><td>3</td><td>
</td><td>Water wheel with flap

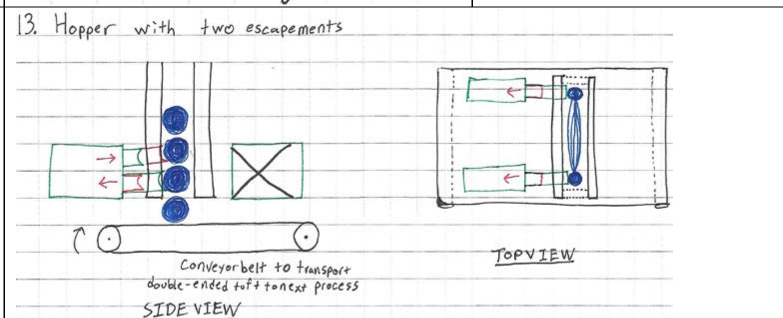
Double-ended tufts are transported from a conveyor belt and loaded into a wheel, similar to a water wheel. After this, it can proceed to the next process. Only possible downside is that it may be difficult to transition from the conveyor belt to the wheel and also reliably load only 1 at a time.</td><td>6 / 10</td><td>To individually sort</td></tr>
<tr><td>4</td><td>
</td><td>Rotating dispenser

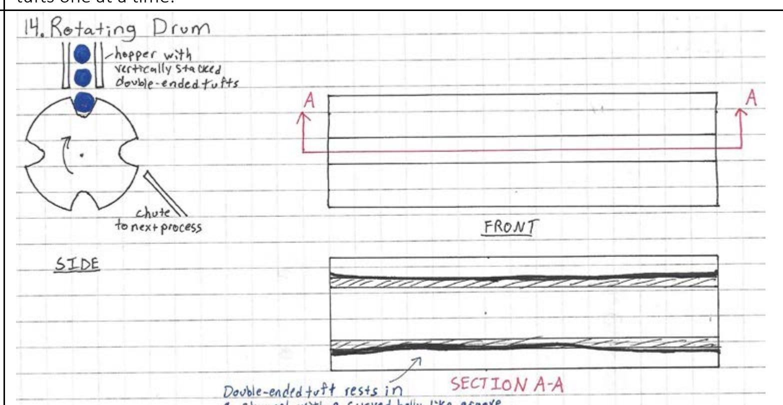
The drum rotates and can either be operated by a servo or a step motor. We have 3D printed a prototype and the idea appears to be promising.</td><td>8 / 10</td><td>To individually sort</td></tr>
<tr><td>5</td><td>
</td><td>PEZ Dispenser

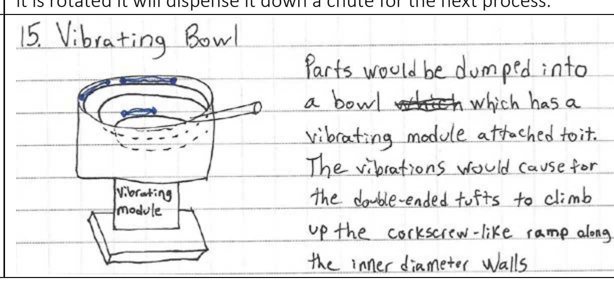
The mechanism inside a PEZ dispenser is a similar application to our project. The double-ended tufts will most likely be gravity fed into a hopper, however, it will be good to keep this concept in mind.</td><td>3 / 10</td><td>To individually sort</td></tr>
</table>

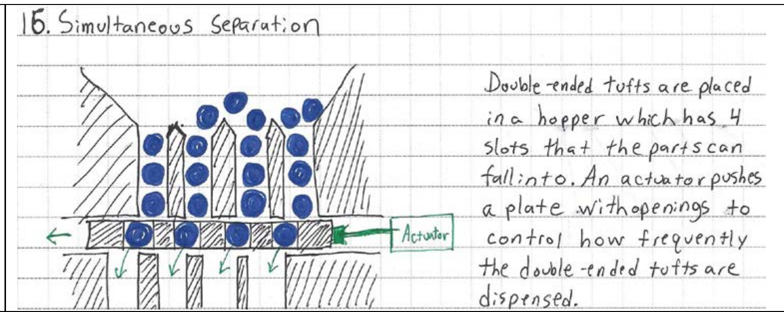
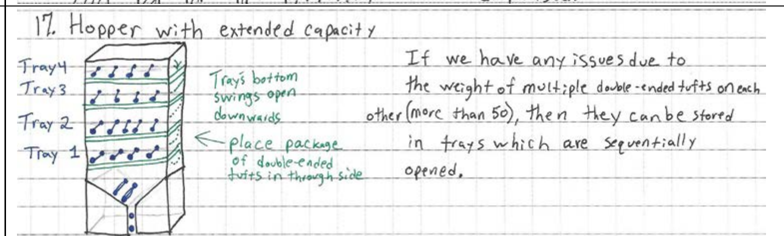
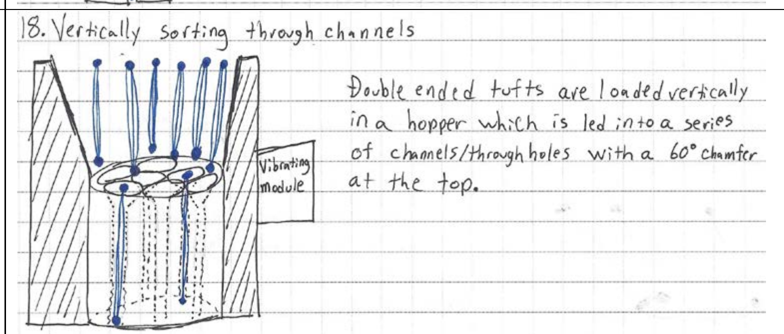
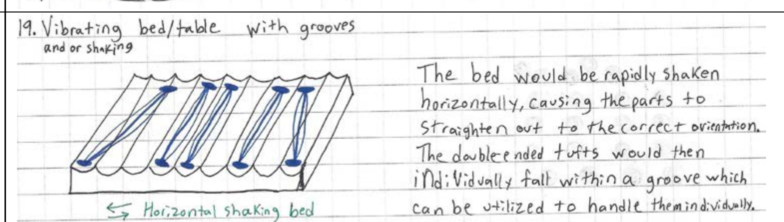
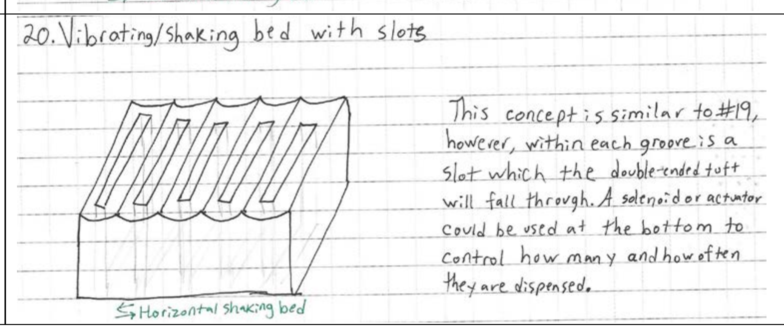
6		**Clamped Plate Fixture** 	9 / 10	To cut
	This is the bottom of a plate fixture, which the double-ended tufts will sit in. There will also be a top plate fixture and bolts will clamp the two plates together, creating a reliable ground. The assembled plate fixture will then be placed in the EDM and a circular pattern will be used to cut them in half.			
7		**Extended Circular Plate Fixture** This is similar to concept #6 and allows for double the amount of double-ended tufts to be cut, but features a more complex plate fixture.	6 / 10	To cut
8		**Multi-Tiered Clamped Plate Fixture** Cycle time will increase with each additional tier, but if they are being cut overnight then this may not be as much of a concern.	8 / 10	To cut
9		**Rectangular Clamped Plate Fixture** This fixture consists of an upper and lower plate which have slots for the double-ended tufts to rest in. By using a rectangular approach, it allows for everything to be more compact and more efficient.	8 / 10	To cut
10		**Gripper with fingers** Grabbing the double-ended tufts at the corners is the best location. If they need to be transported somewhere specific, they can be attached to actuators and provide reliable transportation.	5 / 10	To transport
11	 This concept is straightforward and has potential to be part of our final process. Especially based off testing we have done with dispensing double-ended tufts through a narrow column, no more than the width of a single tuft.		8 / 10	To individually sort

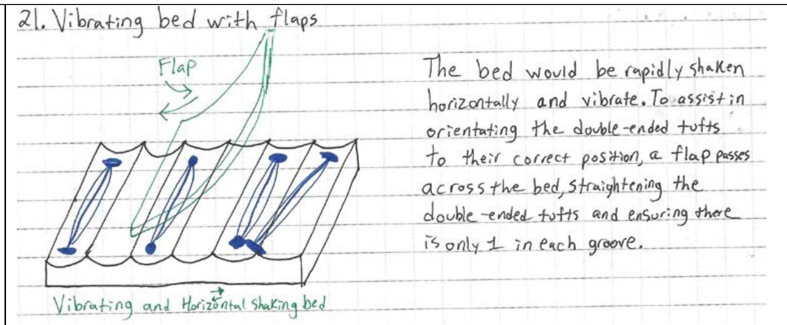
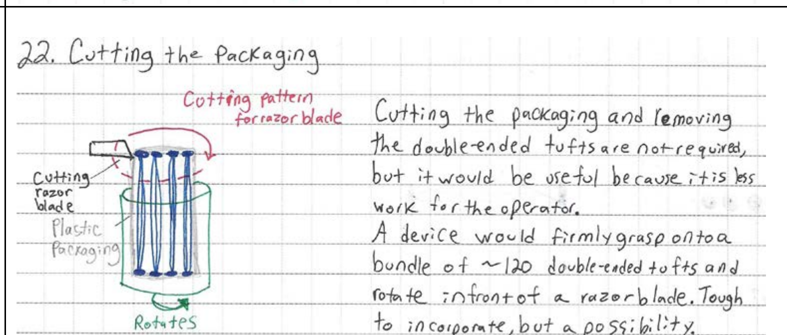
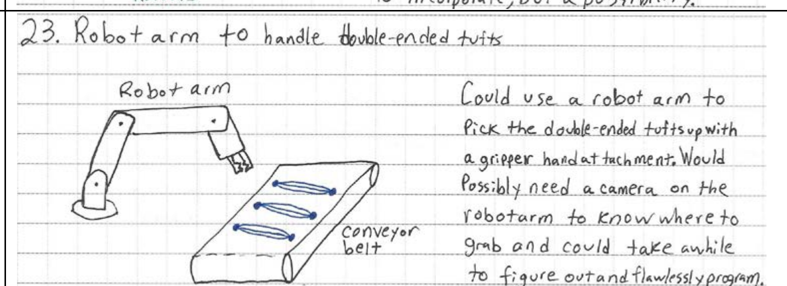
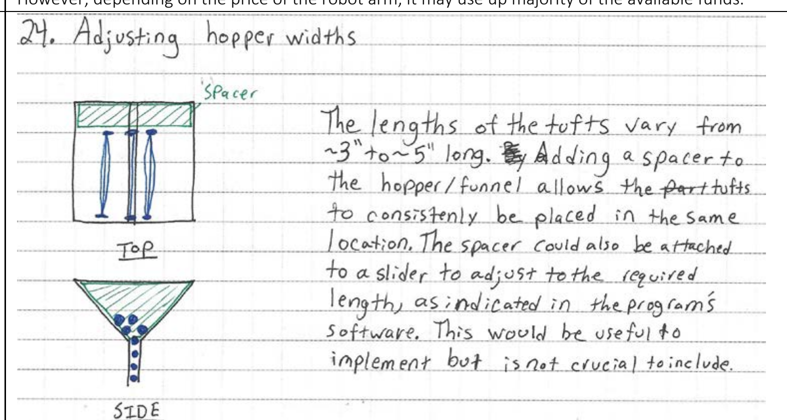
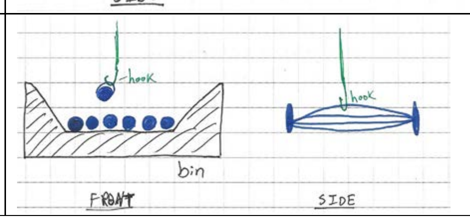
<table>
<tr><td>12</td><td>
</td><td>Vertical Dispenser

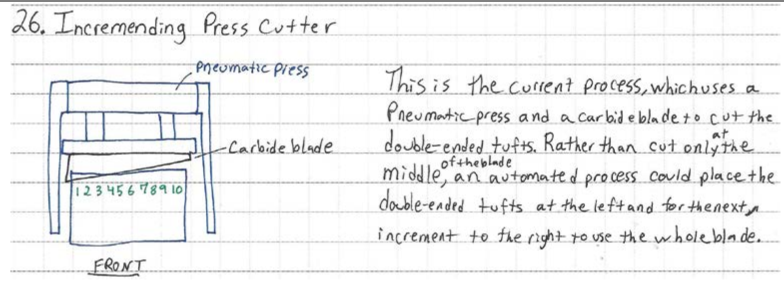
Double-ended tufts are vertically loaded into a hopper which has a vibrating module and helps the tufts load through an opening and into a chute, from which transports the tuft to the next step of the process.</td><td>6 / 10</td><td>To individually sort</td></tr>
<tr><td>13</td><td colspan="2">

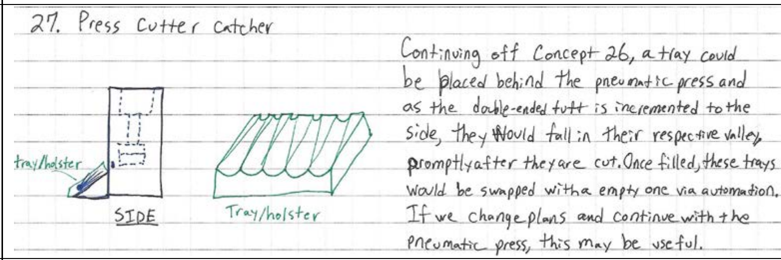
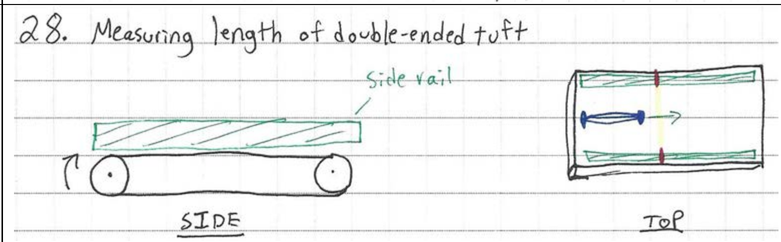
The escapement has two fingers, so either both fingers can be extended or only one can be extended and the other retracted. During operation when the escapement is actuated, one finger extends and the other retracts. This means 1 double-ended tuft can be released and it will apply pressure to the one above it. This method is particularly good for dispensing the tufts one at a time.</td><td>7 / 10</td><td>To individually sort</td></tr>
<tr><td>14</td><td colspan="2">

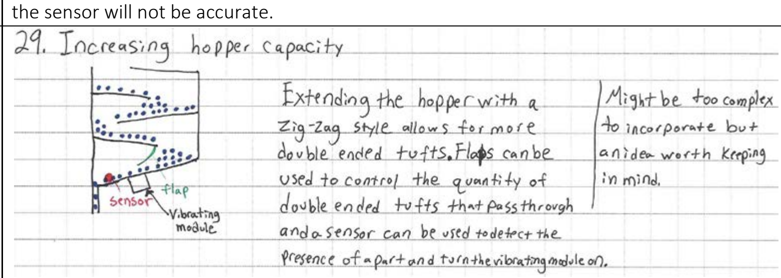
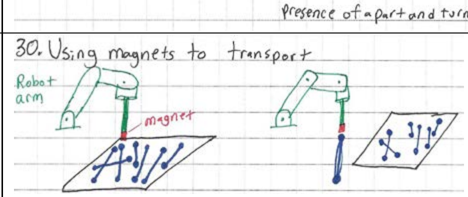
The drum will be rotated by either a servo or a step motor. As the double-ended tufts are fed through the hopper by gravity, one of them will fall into the channel of the drum and as it is rotated it will dispense it down a chute for the next process.</td><td>10 / 10</td><td>To individually sort</td></tr>
<tr><td>15</td><td colspan="2">
</td><td>5 / 10</td><td>To individually sort</td></tr>
</table>

16		6 / 10	To individually sort
17		5 / 10	To individually sort
18		5 / 10	To individually sort
19		5 / 10	To individually sort
20		6 / 10	To individually sort

21		6 / 10	To individually sort
22		4 / 10	Cut the packaging
23	 However, depending on the price of the robot arm, it may use up majority of the available funds.	4 / 10	To transport
24		6 / 10	To adjust lengths
25	 **Hook Transportation** As illustrated in the diagram, a hook could be used to pick up the double-ended tufts. However, it is not practical because it risks bending the wires.	1 / 10	To individually sort

<table>
<tr><td>26</td><td>

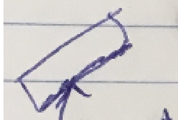
This would drastically increase the lifetime of the blade and it won't have to be sharpened as often.</td><td>6 / 10</td><td>To cut</td></tr>
<tr><td>27</td><td>
</td><td>6 / 10</td><td>To individually sort</td></tr>
<tr><td>28</td><td>

If the velocity of the conveyor belt is known, a fiber-optic light sensor could be used across the conveyor belt to know if a tuft passes through. Using the velocity and duration of how long the signal was received, the length of the tuft can be calculated. Prior to running the automated machine, a specific part number was entered which knows the length of the part. This feature could be used as a fail-safe to verify that the correct tufts are being run. However, this concept has a major flaw. If the tuft is rotated 10 degrees, the reading from the sensor will not be accurate.</td><td>3 / 10</td><td>To transport</td></tr>
<tr><td>29</td><td>
</td><td>5 / 10</td><td>To individually sort</td></tr>
<tr><td>30</td><td>

Although this would appear to work well, it won't because the alloy used does not contain enough ferromagnetic materials for a magnet to attract to. Also, it would require purchasing a robot arm which could be expensive.</td><td>1 / 10</td><td>To transport</td></tr>
</table>

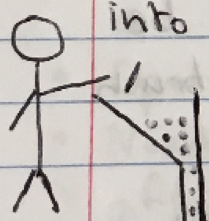
9.2 Trevor Gale Concept List

- Possible Concept #1: Water Jet cutting.
Currently they use a flat blade to shear the brushes. We could use pressurized water to cut it instead. This would eliminate the problem of blades dulling. Score: 6/10



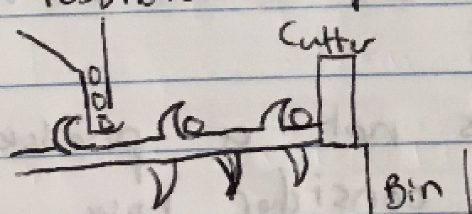
- Possible Concept #2: Diamond Tipped Blade.
The current blade dulls after 1 week. If we used a diamond tipped blade, it could be kept in service longer.
(Cost of diamond blade) ∠ (cost of old blades + labor of changing)
Score: 7/10

- Possible Concept #3: Using a hopper to feed brushes into automated line.



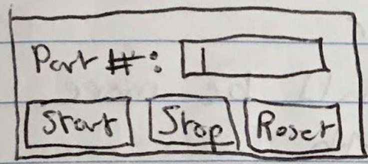
However our automated line is set up, one way to begin it is to use a hopper that the employee will load.
Score: 8/10

- Possible Concept #4: Hook shaped line conveyor.



An assembly line shaped like this could pick the brushes up out of the hopper and hold them while a cut is made.
Score: 9/10

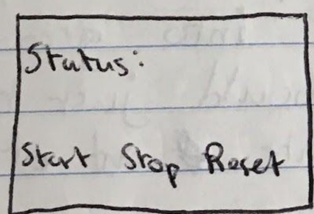
- Possible Concept #5: Assigning Part #'s for different Length's.



Use an interface with Visual Basics to know length based on part number.

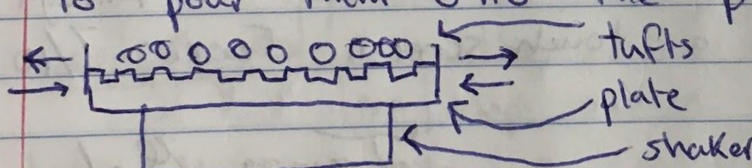
Score: 7/10

- Possible Concept #6: Touch screen as ~~the~~ UI.



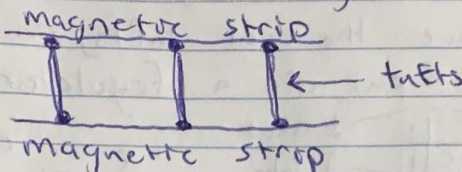
If our line is programmed, it would be great to be able to ~~automate~~ operate it through a touch screen. Score: 7/10

- Possible Concept #7: Use a shaker plate to sort the 145 double ended brushes into grooves in a plate. The operator would just have to pour them onto the plate out of package



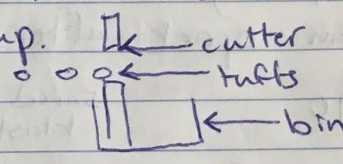
Score: 5/10

- Possible Concept #8: Using magnets to carry the tufts through an automated line.



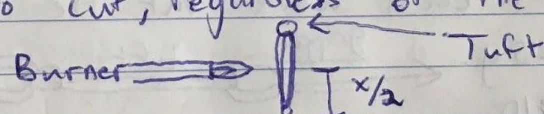
Score: 5/10

- Possible Concept #9: Keep a bin under the cutter to collect the already cut tufts. We would have to keep it close to the cutter to make sure they dont tangle up.



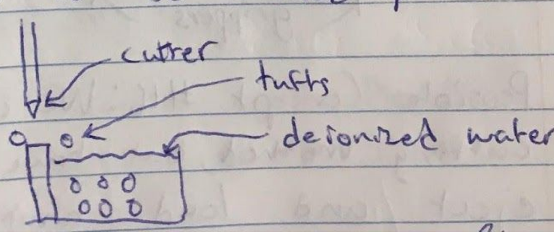
Score: 8/10

- Possible Concept #10: Heat up the middle of the tuft in order to make it easier to cut, regardless of the cutting method



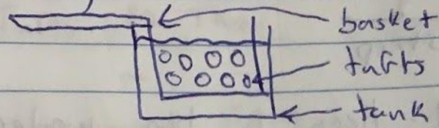
Score: 2/10

- Possible Concept #11: Keep de-ionized water in the collection bin in order to save time. Once the tufts are in there, they will not need to be soaked prior to the cut.



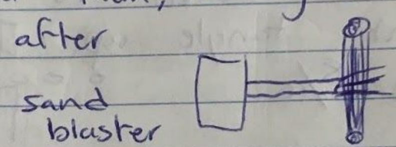
Score: 7/10

- Possible Concept #12: Keep a basket in the tank of de-ionized water in order to easily remove the cut tufts, similar to pulling fries out of a fryolator.



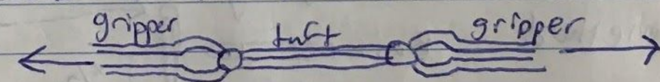
Score: 9/10

- Possible Concept #13: Sand blast the tufts at x/2 to cut them in half. It may not completely cut them, but you could pull them apart after



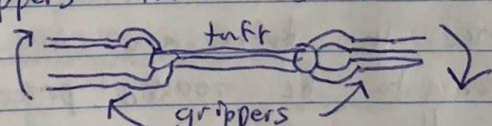
2/10

- Possible Concept #14: Use two grippers to pinch the tuft at x/2 to pull them apart. It could work but the cut could be messy.



Score: 3/10

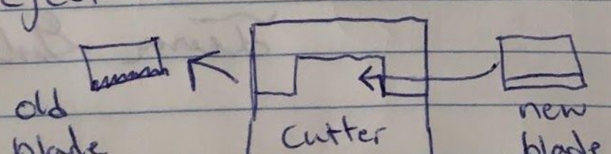
- Possible Concept #15: Same as #14, but the grippers twist instead of pull



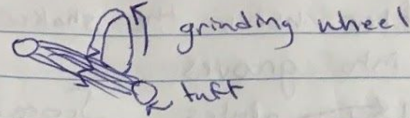
Score: 4/10

- Possible Concept #16: We could use the current cutting method, but have the blade automatically eject and load another one.

Score: 5/10

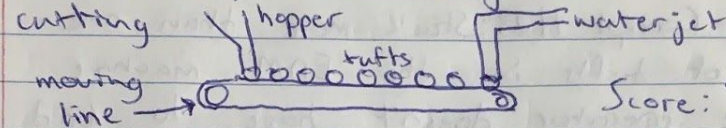


- Possible Concept #17: Use a grinding wheel to grind the tufts in half.



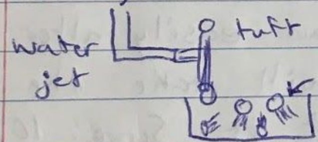
Score: 5/10

- Possible Concept #18: Attach an automated moving line to a hopper feeds the line through a waterjet that is continuously cutting



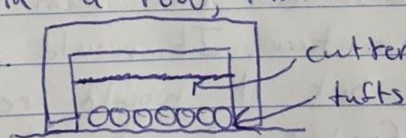
Score: 9/10

- Possible Concept #19: Horizontally orient the water jet and cut the tufts while held on both sides. After the cut is made, the tufts will fall into a basket



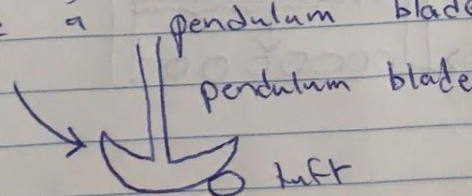
Score: 5/10

- Possible Concept #20: If a stronger blade is used, we could line up multiple tufts in a row, then cut them all at once.



Score: 9/10

- Possible Concept #21: Instead of the blade cutting straight down, it could swing like a pendulum blade.

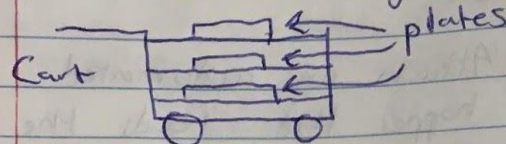


Score: 5/10

(10)

- Possible Concept #22: Use a cart to transport the sorted tufts to the EDM machine after using the shaker plate to put them into grooves

Score: 9/10

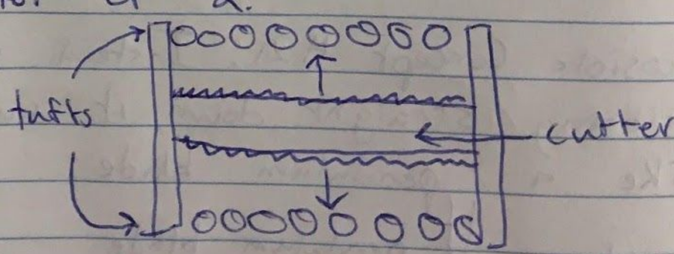


- Possible Concept #23: Stack more than one plate of tufts in the EDM machine so the operator doesn't have to load it multiple times

Score: 8/10

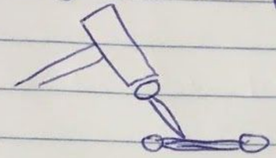
- Possible Concept #24: Be able to test and time the job so they can easily alter the estimated time it will take the operator and keep track of it. Score: 10/10

- Possible Concept #25: Make a double-sided blade so it can cut them on the up-turn and down-turn. It would need double actuation, but it would reduce time by a factor of 2.



Score: 5/10

- Possible Concept #26: Have the operator use a hammer and chisel type of system to cut them in half at his station. Accuracy is completely up to the operator.



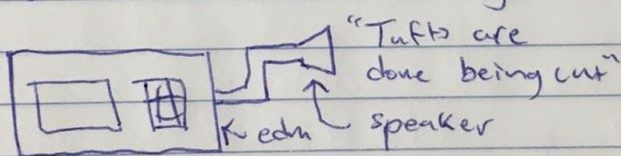
Score: 2/10

- Possible Concept #27: Attach a light to the EDM machine that will alert the operator when it is done cutting

Score: 8/10

- Possible Concept #28: Attach an audible speaker to alert the operator when the EDM is done cutting

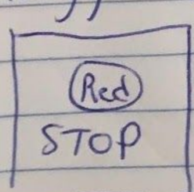
Score: 8/10



- Possible Concept #29: Enclose the waterjet cutting idea so that it can only be fed by a hopper for safety purposes

Score: 10/10

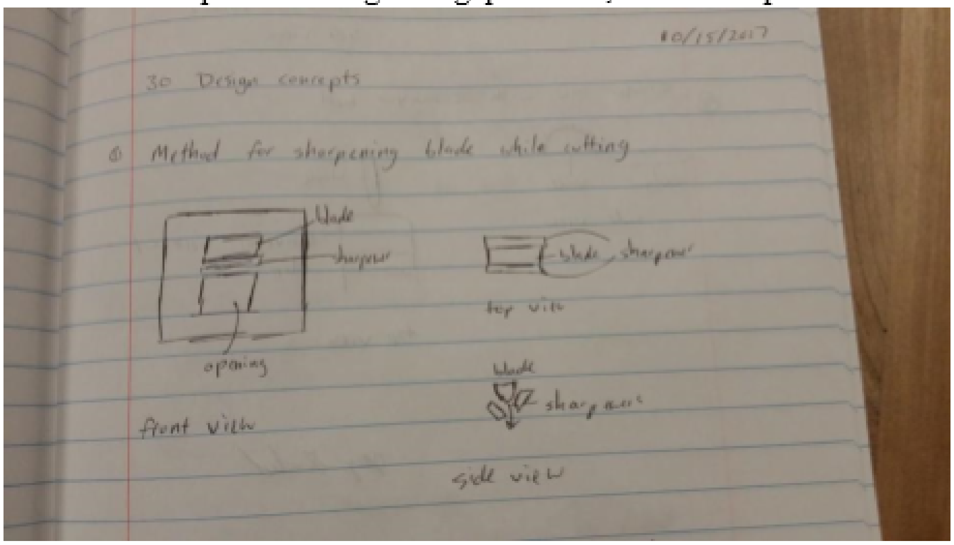
- Possible Concept #30: Install an E-stop for the entire process to cut all energy incase of an emergency



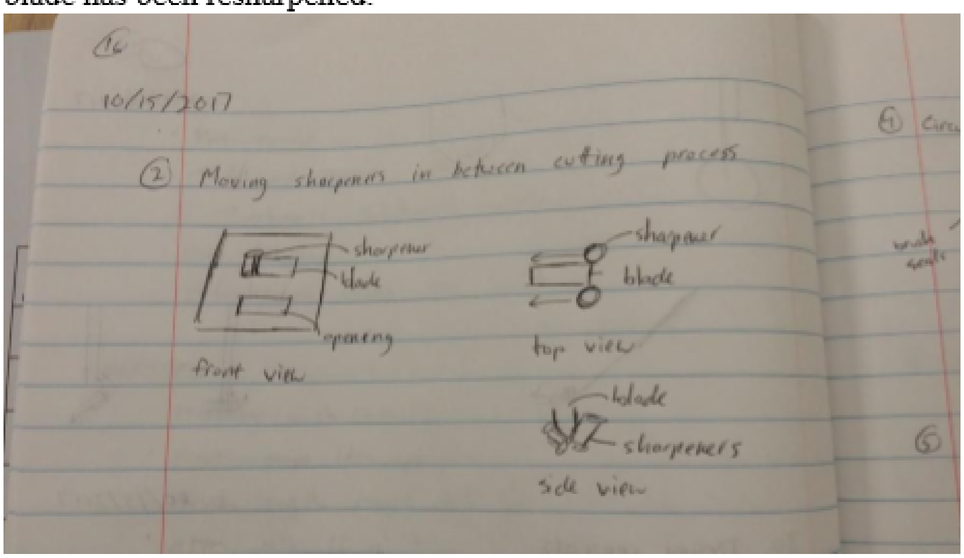
Score: 10/10

9.3 Jay Guilmette Concept List

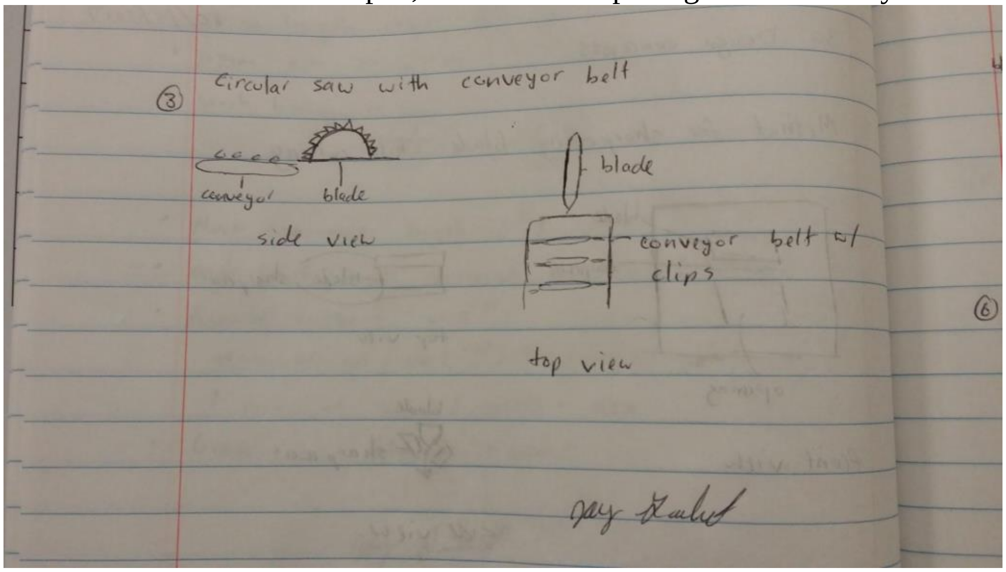
1. Method for sharpening while cutting - 7- As the carbide blade descends down to cut the wire seals, it passes through two stationary grinding stones tightly angled together. Every time the blade cuts and passes through the gap created, it will sharpen itself.



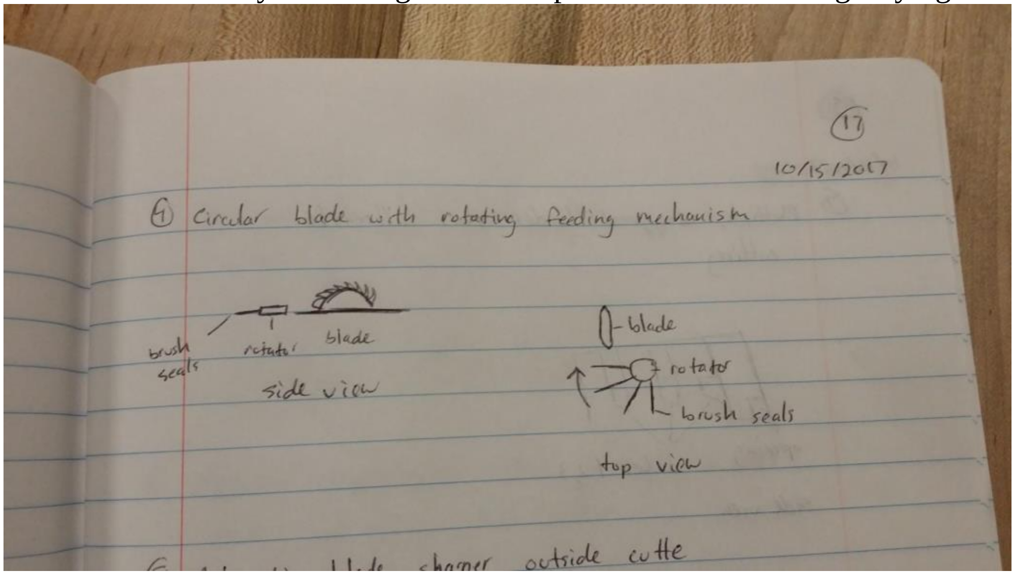
2. Method for sharpening while not cutting - 7 - In between cuts (or after some predetermined number of cuts), two grinding cylinders situated tightly next to the blade will begin to spin. Then, the two stones will simultaneously travel the length of the blade, back and forth, until the blade has been resharpened.



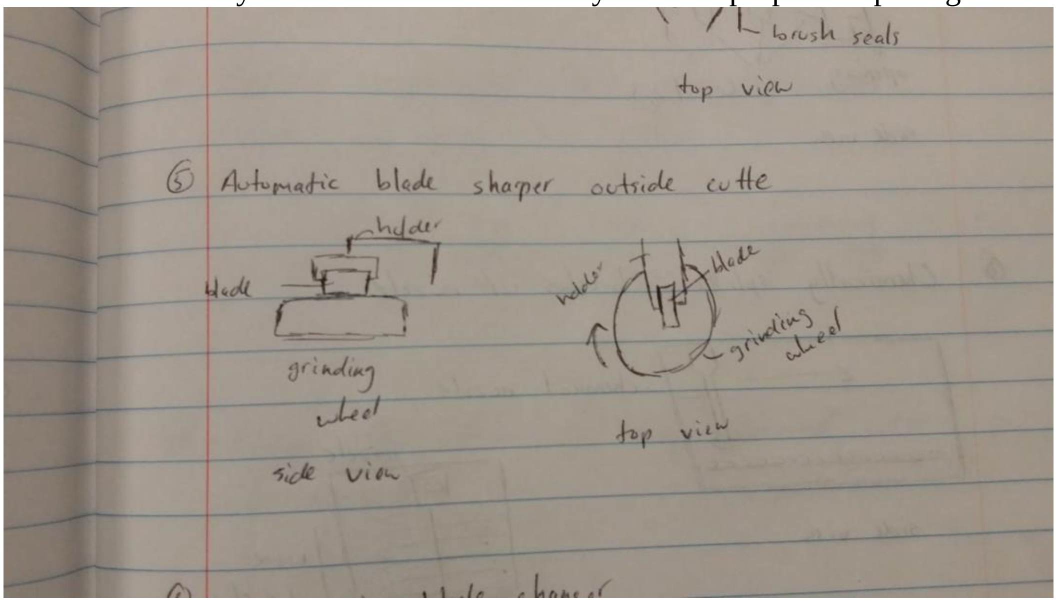
3 - Circular blade with conveyor belt feed - 5 - A circular blade that spins continuously will be able to cut more brushes than one that is pneumatically powered. A conveyor belt system (with the middle missing) that secures the brushes with clips could continuously feed the brushes into the blade, allowing for more to be cut in a given time. The primary drawback is that a circular blade is much harder to sharpen, and blade sharpening time is already a considerable drawback.



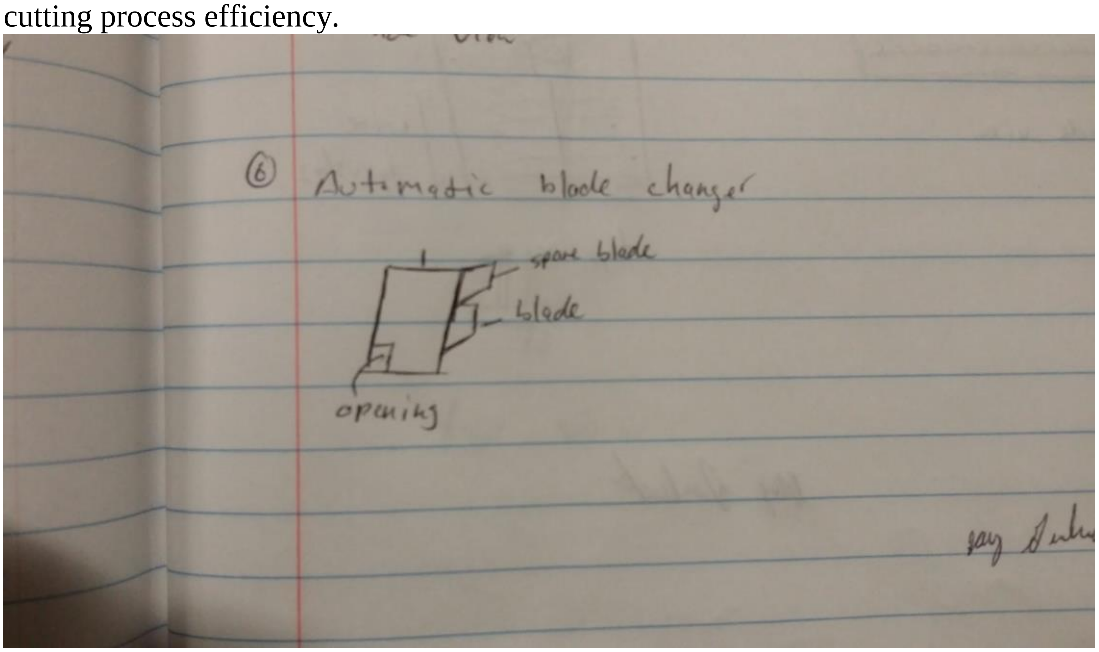
4 - Circular blade with rotary feeding system - 4 - Similar to concept 4, except that a rotary feeding system could conceivably feed the brushes even faster. The brushes would be connected to the rotating feeding system, which would then feed the brushes into the teeth of the blade. In addition to the sharpening drawback, attaching the brushes would be difficult, and there would need to be some way of making sure the separated halves do not go flying.



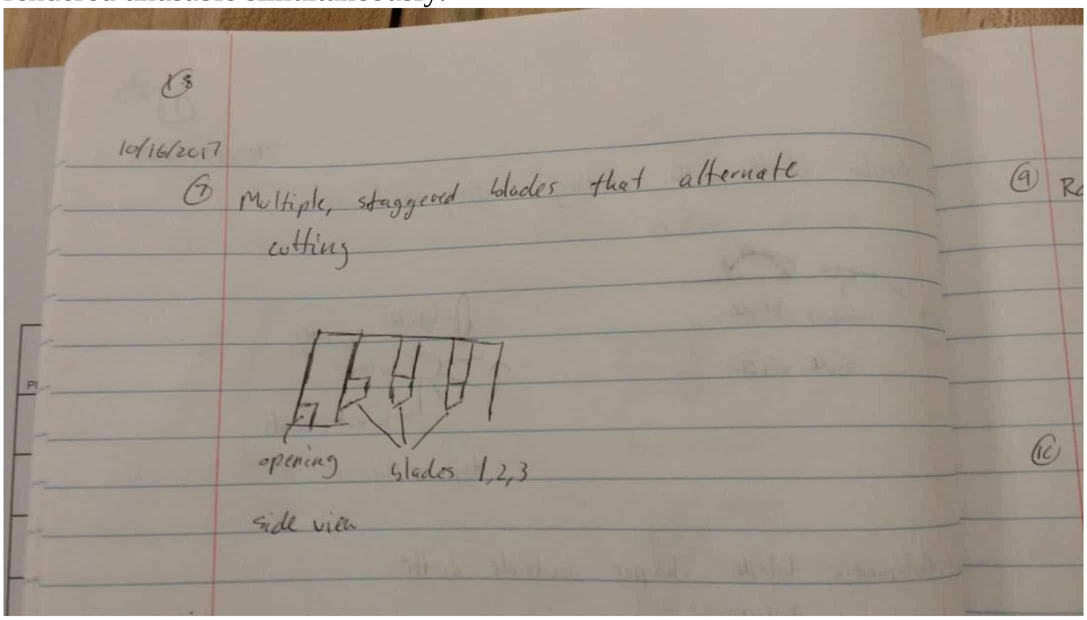
5 - Automatic blade sharpener outside cutter - 3 - A grinding wheel affixed next to the cutter. When a blade needs to be sharpened, it would simply be removed and attached to a holder while the grinding wheel spins against it. The holding mechanism could turn the blade to sharpen it on both sides. Primary drawbacks would be safety and it improper sharpening can ruin the blade.



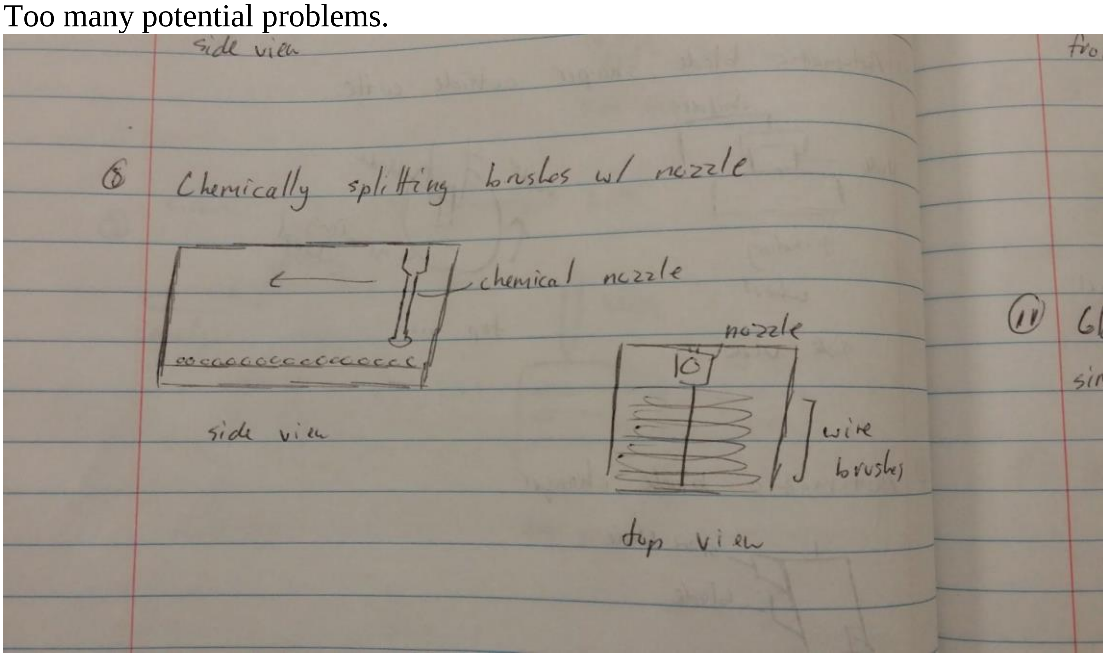
6 - Automatic blade changer - 7 - A mechanism that would attach to the cutter. It would hold additional blades, and after a preset number of cuts, would automatically change the blades. It would allow each cutting machine to double its use before needing to be sharpened. Drawbacks include not addressing the actual issue of the sharpening, which is the primary obstacle in the cutting process efficiency.



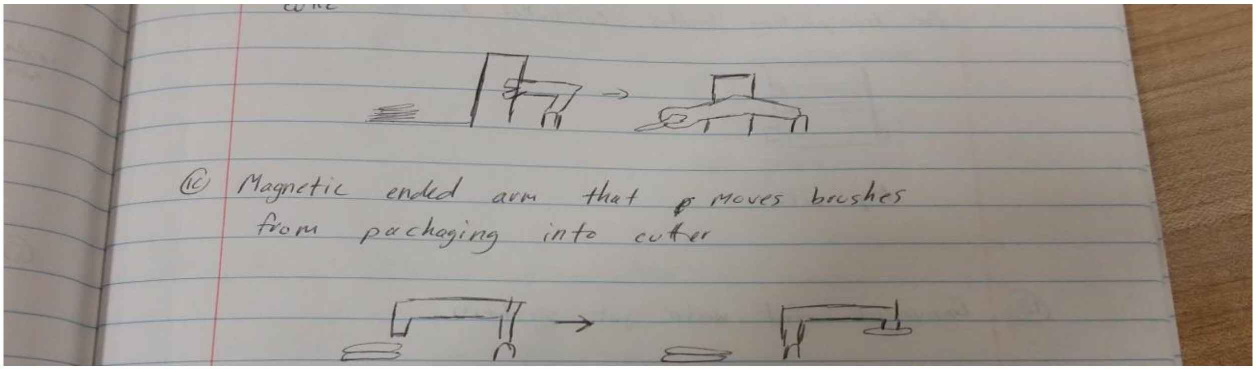
7 - Multiple staggered blades - 6 - Multiple blades that alternate in between cuts. The feeding system would need to be adjusted to the different distances, but it would allow one machine to cut many more times before needing to be sharpened. Again, main drawback is that the whole machine would need to be sharpened, potentially causing backups as multiple blades are rendered unusable simultaneously.



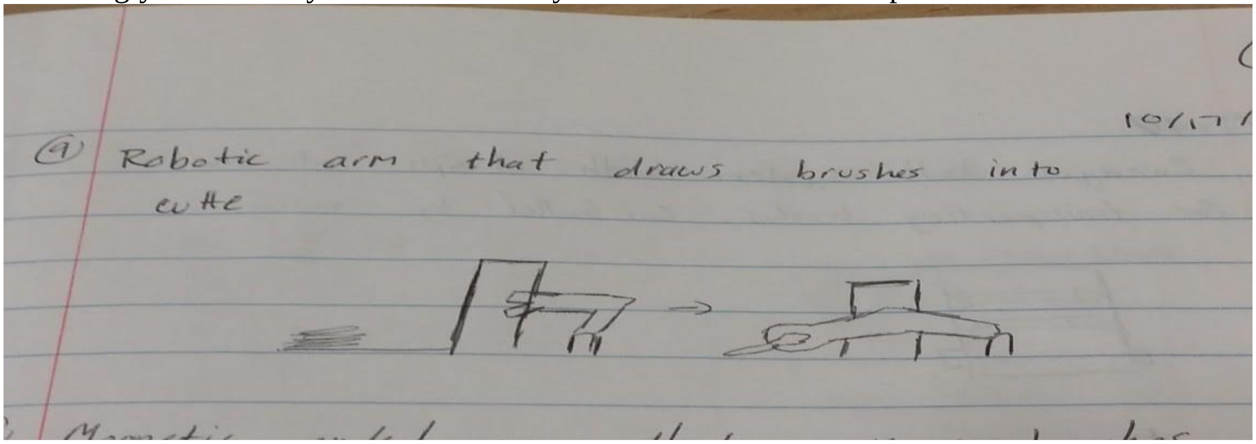
8 - Chemically cutting brushes - 3 - Sharpening of a carbide blade is difficult and improper sharpening could do harm than good. Chemically cutting the brushes would resolve that. However, the time to cut would be somewhat unpredictable, chemical exposure is an unnecessary hazard, and stopping the process at the desired point on the brush could be difficult. Too many potential problems.



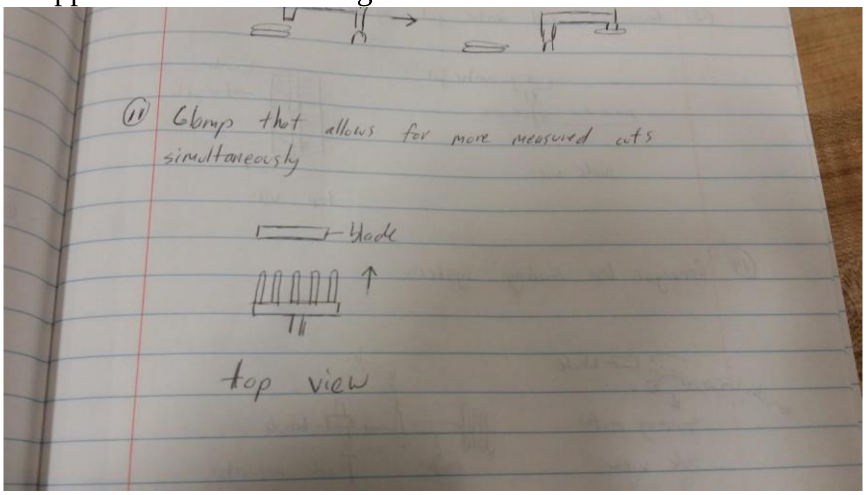
9 - Magnetic ended arm - 8 - A feeding system for sorting the brushes from their packaging. Any automated process to the brushes should be preceded by a system that either counts the number of brushes or control the amount to be cut. A



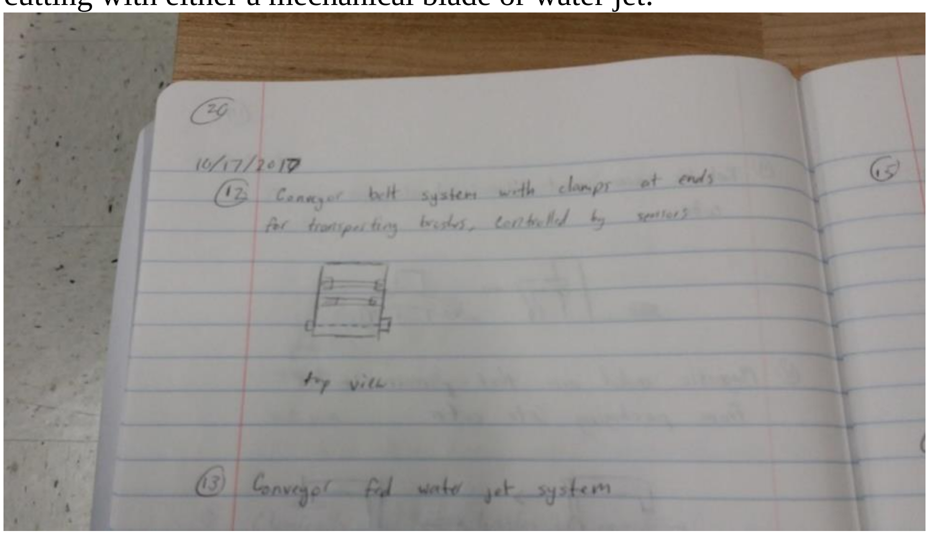
10 - Robotic Arm - 6 - A robotic arm that simply grabs the brushes one at a time and draws them into the cutter. The arm would be programmed to know the length of the cut and position it accordingly. Technically difficult and likely less effective than concept 9.



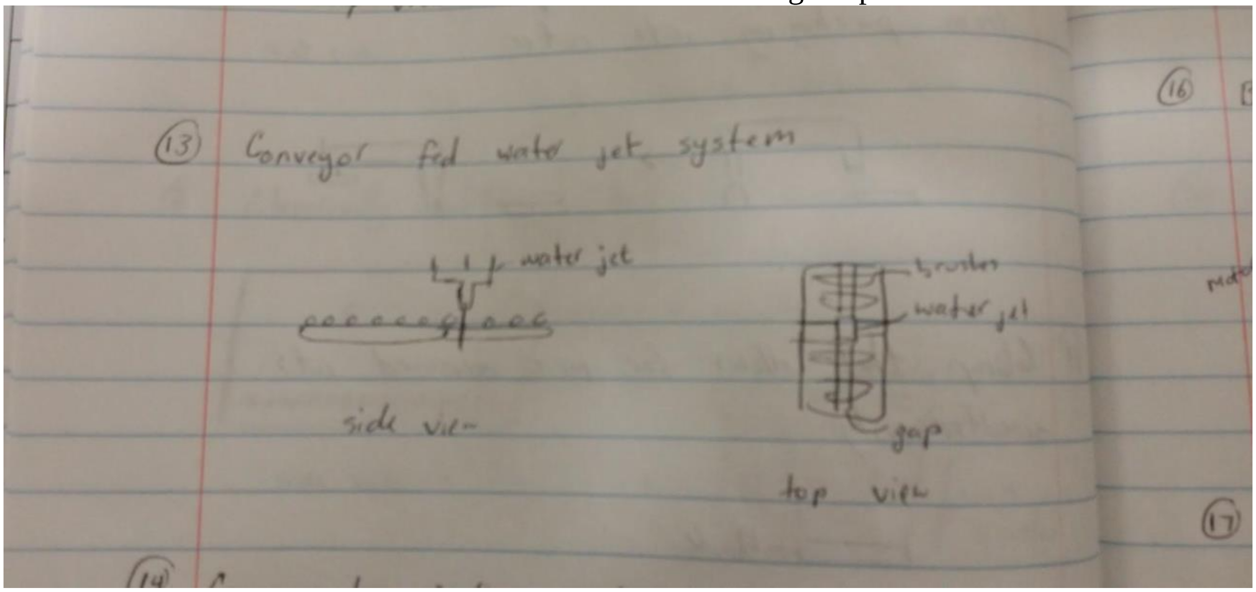
11 - Clamp System for Multiple Cutting - 7 - A clamp system that would feed several brushes at once into the cutter to be cut simultaneously. The idea is to use the entire edge of the blade to increase time between sharpening. By using the entire blade equally, more brushes could be cut, as opposed to a human using the same section over and over.



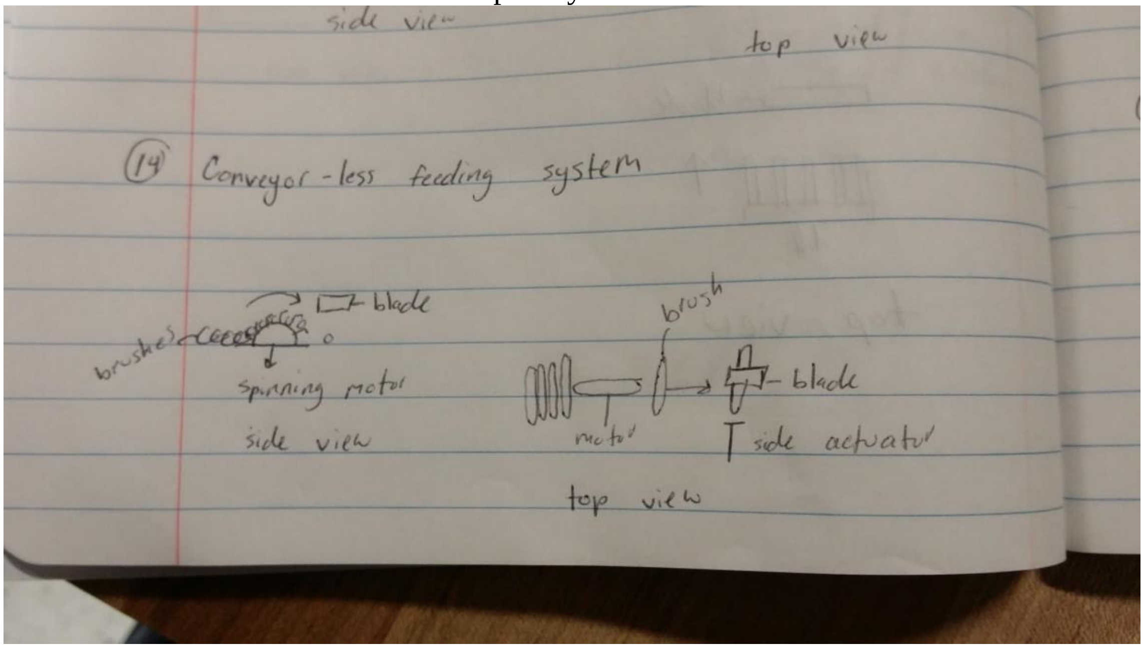
12 - Sensor Activated Conveyor System - 6 - A conveyor system that holds the brushes in place using clamps. The clamps would be activated by a light sensor: when a brush is placed between two sensors, a photodiode would activate, engaging small clips to hold the brush in place for cutting with either a mechanical blade or water jet.



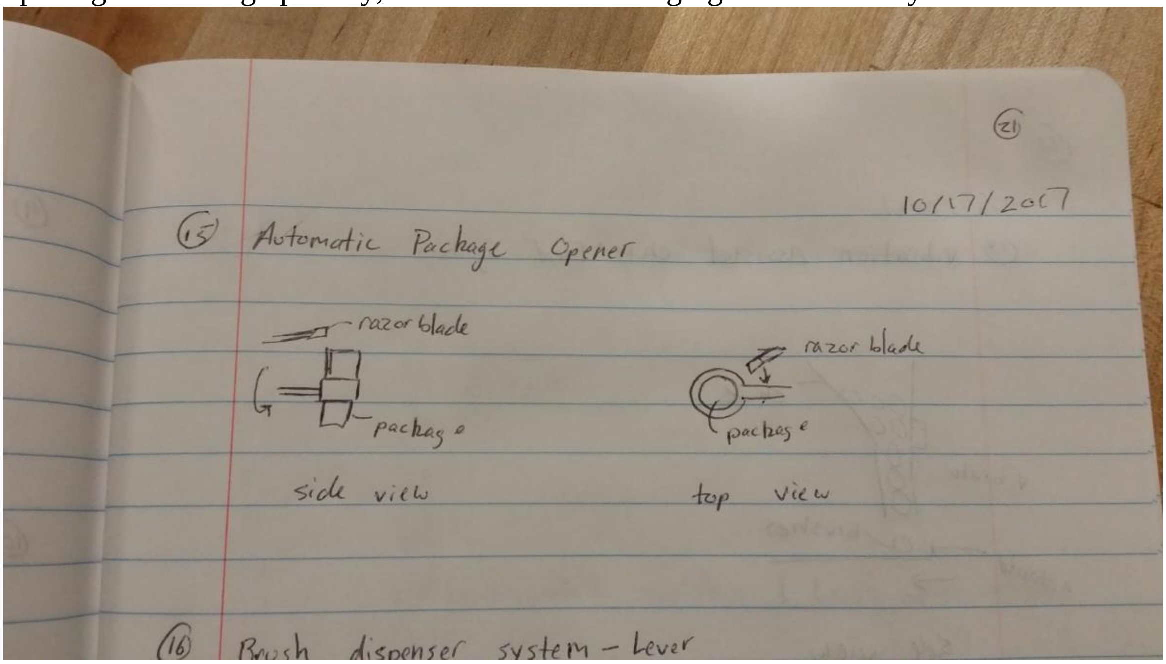
13 - Conveyor fed water jet - 8 - A workaround to the time intensive sharpening process. The brushes would be fed on a conveyor belt (with a gap in the middle) into a water jet. The water jet would then cut the brushes without the use of a blade. As an untested system, it would need be tested first to make sure the brushes were not deformed during the process.



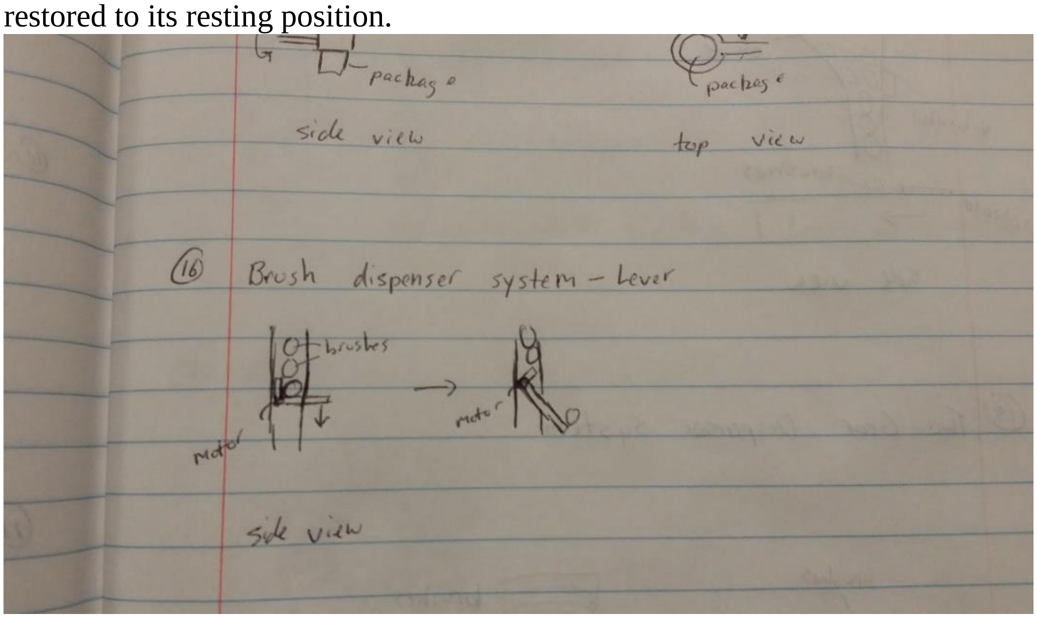
14 - Conveyor-less Feeding system - 7 - A feeding system that does not use a conveyor. The brushes would simply be placed in a pile next the cutter. A motorized wheel normal to the stack would rapidly push them against a stop gap under the blade. A sensor would detect the presence of a brush and cut. Finally, an actuator normal to the blade would then push the two cut halves aside before another one is fed. Conceptually the faster idea.



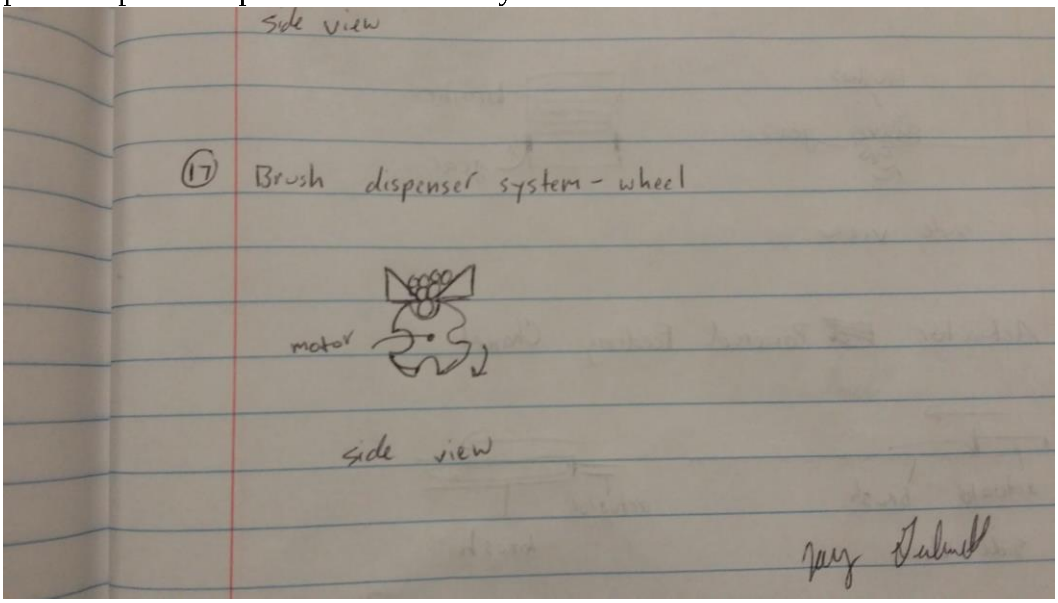
15 - Automated Package Opener - 5 - A mechanism to open the packages of brushes. The packages would be placed snugly into a cylinder. A small razor blade would penetrate the very top of the package and rotate 90 degrees, allowing the package to be easily dumped out. Package opening is not a high priority, and the risks of damaging the blades may make it not worth it.



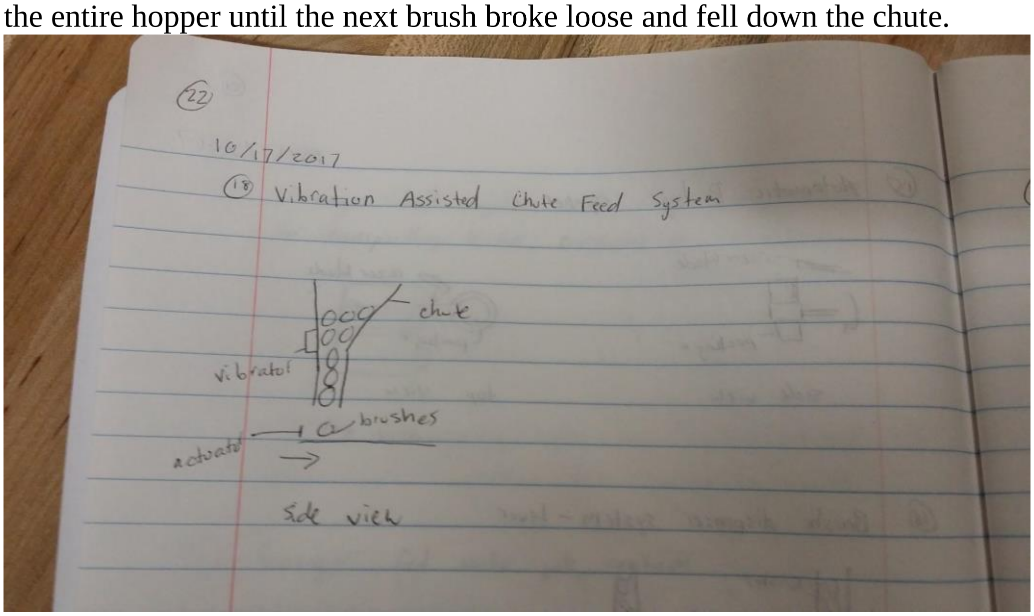
16 - Brush Dispenser System (Lever) - 10 - A system of dispensing the brushes one at a time is a high priority, as it is not only proving to be technically challenging, but also critical in design plans. This system was inspired by a chopstick dispenser. The brushes are loaded into a chute. The chute tapers near the bottom to be the diameter of one brush. The lever interior is only deep and wide enough to fit a single brush. As the lever rotates, the brush sitting in the cradle is dispensed, and the shape of the lever blocks other brushes from falling behind it until the lever is restored to its resting position.



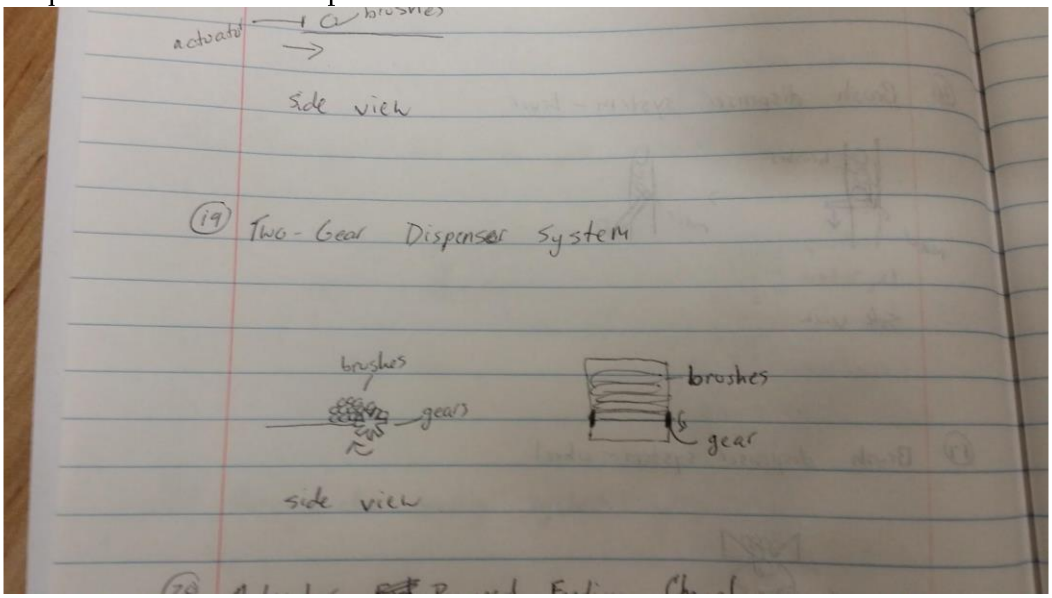
17 - Brush Dispenser System (Wheel) - 10 - Another brush dispensing system. This concept uses a rotating wheel with grooves deep enough to only hold one brush. As the wheel spins, the brush in the groove will be dropped one a time, while any brushes on top will hopefully be harmlessly pushed up the ramps and out of the way.



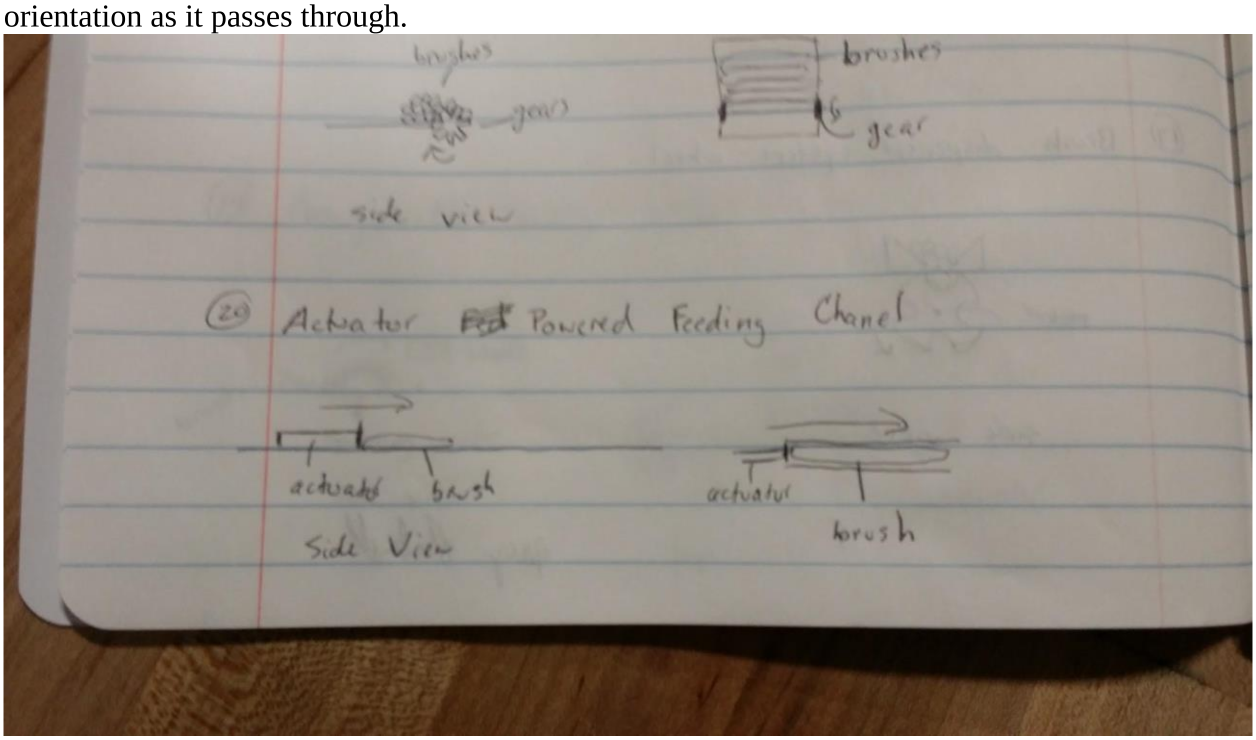
18 - Vibration Assisted Brush Dispenser - 9 - A chute that is mechanically simple but less reliable. The hopper would taper down into a chute just wide enough for one brush at a time. In the event that the hopper has brushes in it but they are bottlenecked, a vibrating unit would shake the entire hopper until the next brush broke loose and fell down the chute.



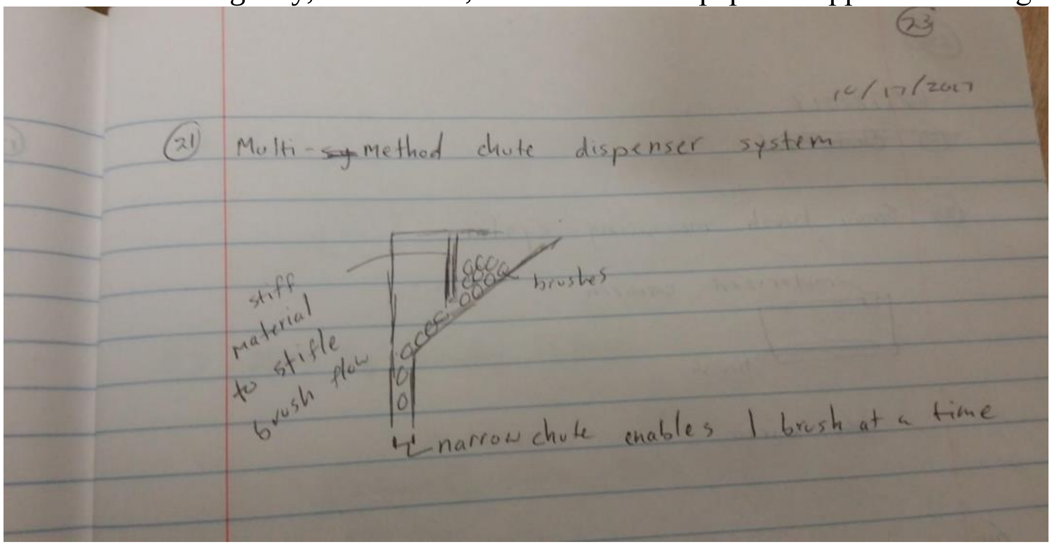
19 - Two Gear Dispenser System - 9 - Two gears with enough space between the teeth to accommodate one brush end at a time would spin, pushing the brushes one at a time out of a pile. Requires two motors to operate and difficult to transfer between different brush diameters.



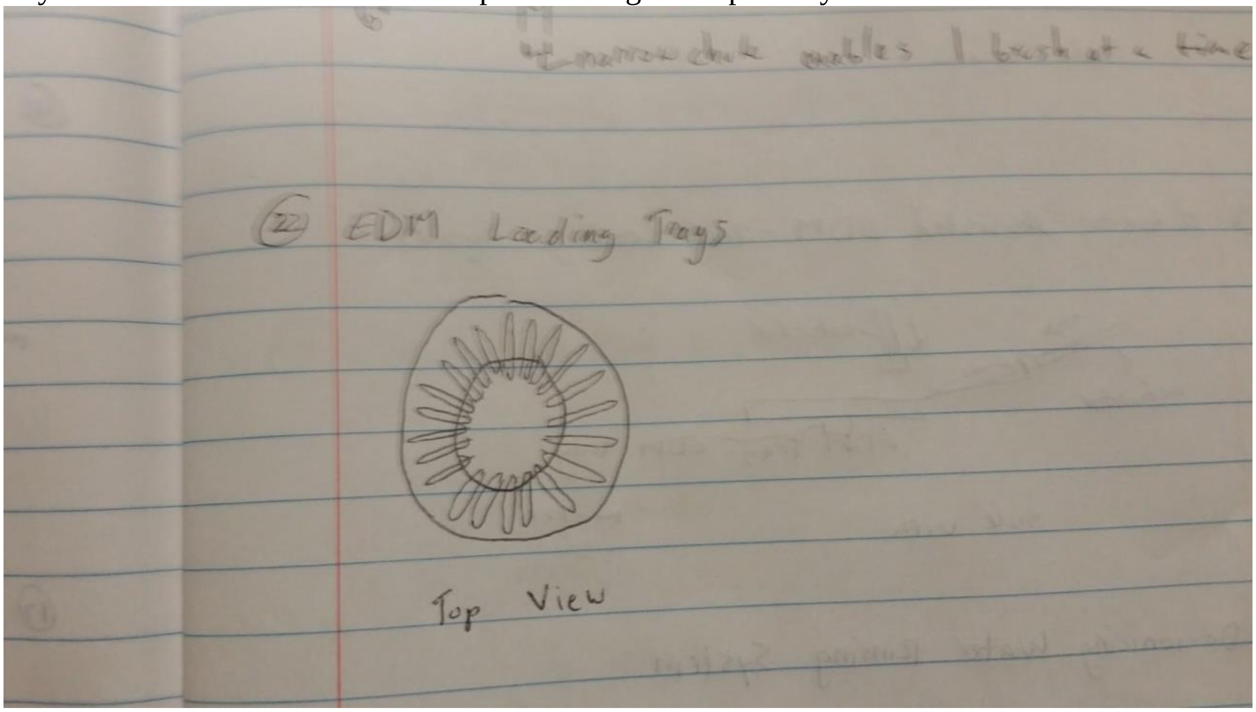
20 - Actuator Powered Feeding Channel - 8 - A method of moving the brushes after they have been dispensed to the next step of the process. Easier than a conveyor system (less moving parts and easier to regulate). The channel would be narrow, so the brush will not turn into the wrong orientation as it passes through.



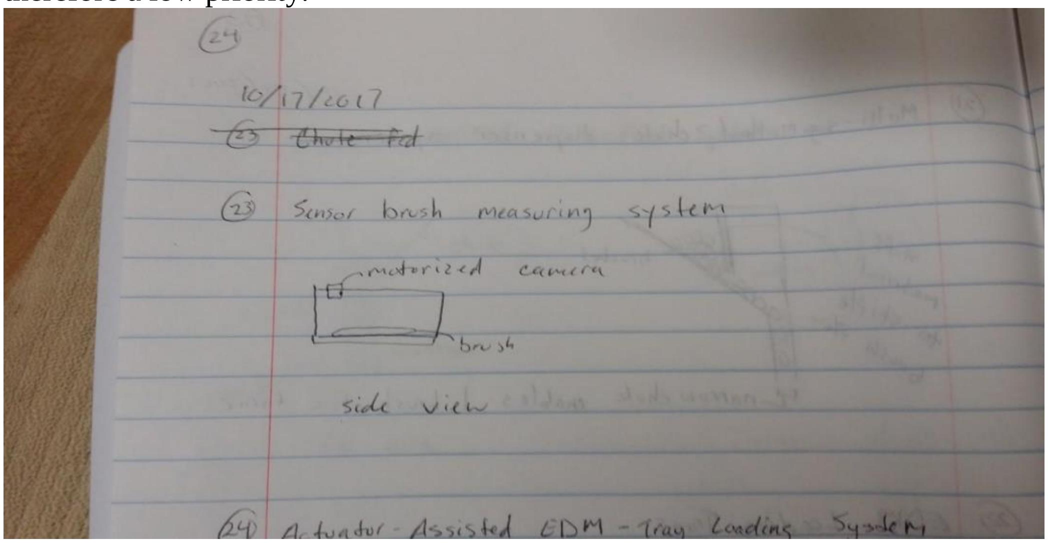
21 - Multimethod Chute Dispenser System - 8 - Another system for dispensing the brushes. This one would use several simple controls to make sure that the brushes a) are dispensed one at a time and b) are dispensed in the proper orientations. A flap of stiff material would be placed on the hopper incline to make sure that the brushes do not pile up and cascade down the chute. Additionally, the placement and dimensions of the chute/hopper junction ensure that brushes oriented the wrong way, in this case, oriented into the paper as opposed to along the "x-axis."



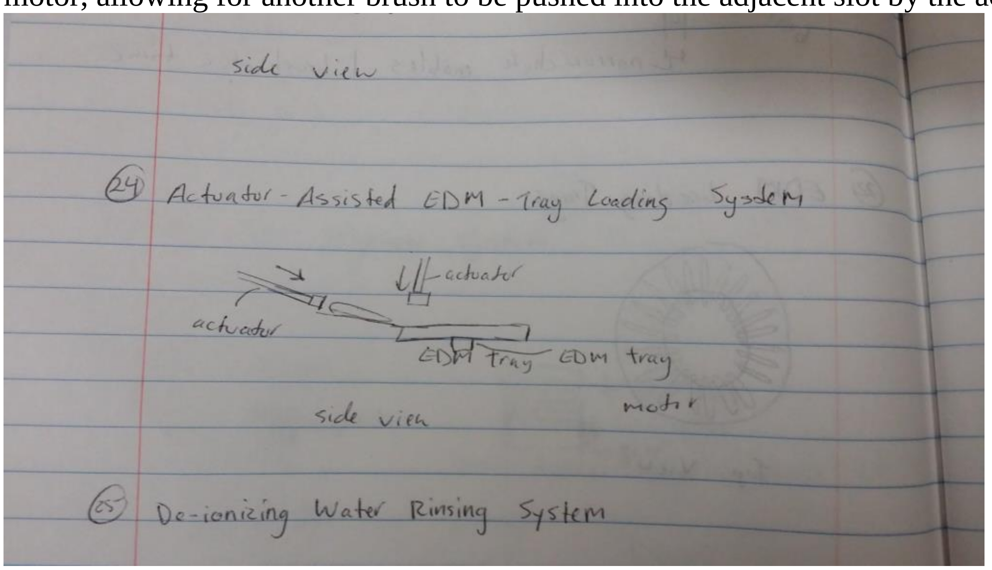
22 - EDM Loading Tray - 9 - A system that uses an EDM instead of a mechanical cutter to split the brushes. This bypasses the lengthy sharpening time completely, but the EDM cuts slower per brush. The brushes would be loaded onto the tray which would then be placed into the EDM. the trays would need to be custom made per unit length and possibly even diameter.



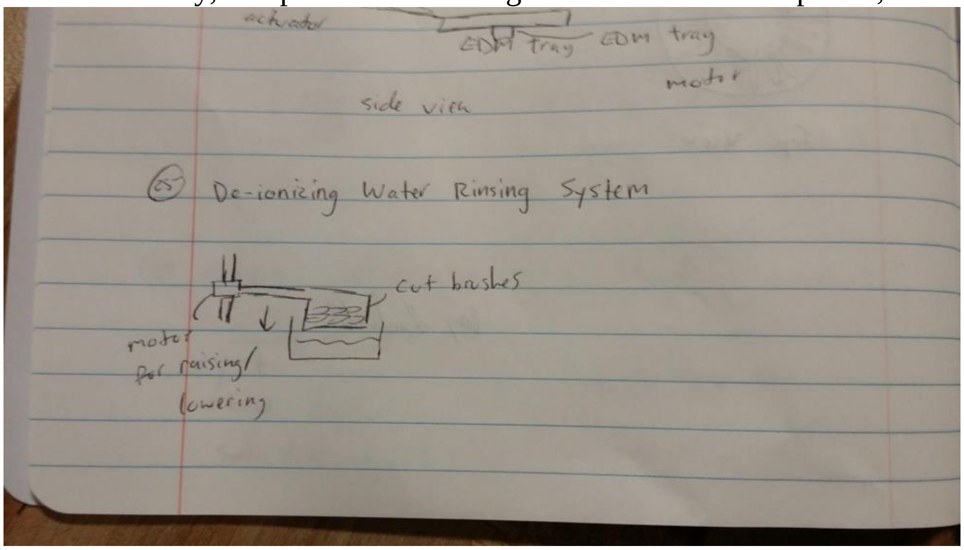
23 - Sensor Brush Measuring System - 4 - A method of automatically measuring the brush lengths to be cut. A camera would be affixed to a bar above where the brush is placed, and it would simply move along the bar until the brush was no longer in sight. Though fairly simple to make, measuring the brushes is currently not a significant drain of manpower or resources, and is therefore a low priority.



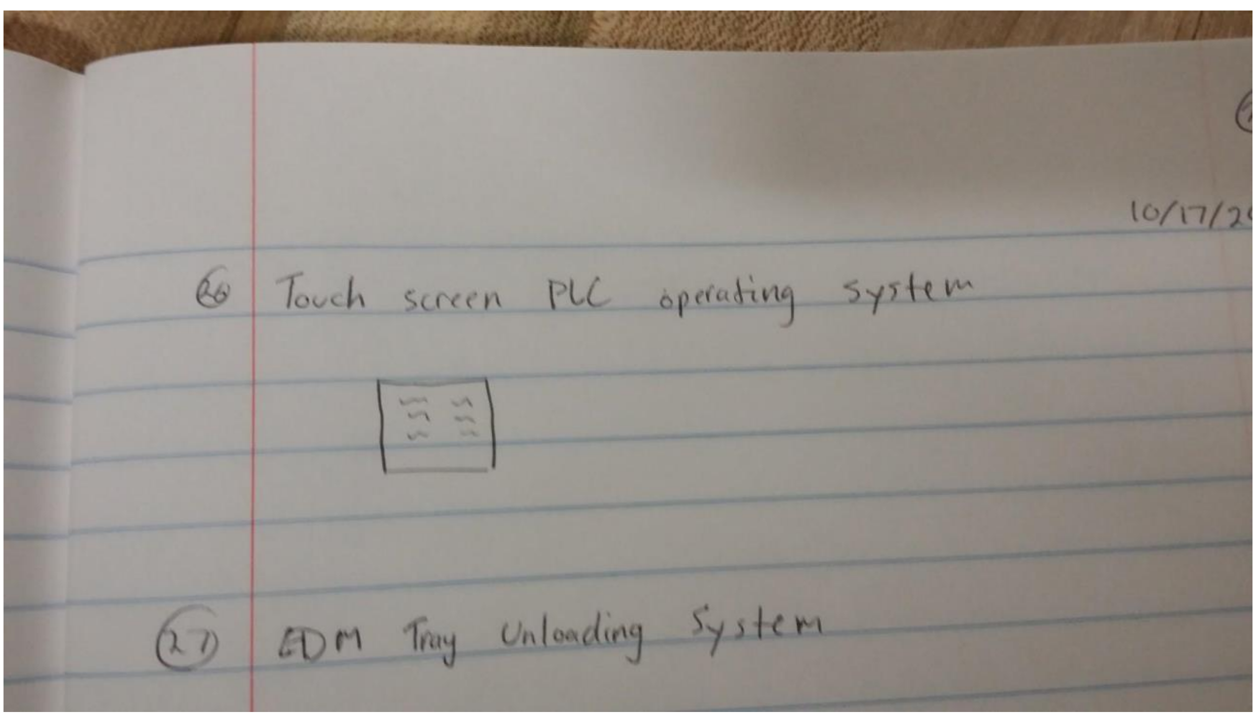
24 - Actuator Assisted EDM Tray Loading System - 9 - A system for loading the EDM trays that does not require human interaction. The brushes would be pushed down a channel by an actuator into a slot on the EDM tray. The EDM tray would then rotate by means of a stepper or servo motor, allowing for another brush to be pushed into the adjacent slot by the actuator.



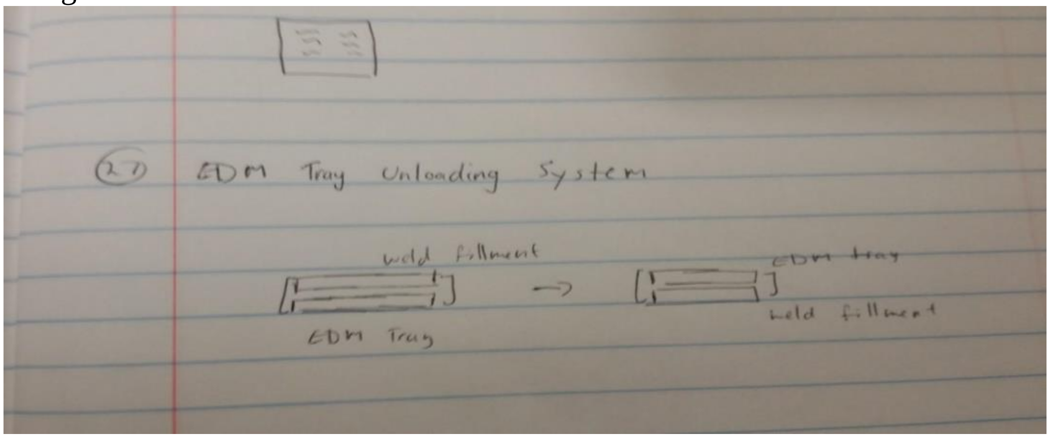
25 - Deionizing Water Rinsing System - 2 - A system for quickly rinsing the cut brushes. Inspired by a French Fry cooker, the tray, with slots to allow for water to enter and exit, would be submerged into the water and vibrated. Upon removal, the water would drain through the holes. Currently, this process is not a significant drain on manpower, and is not a priority.



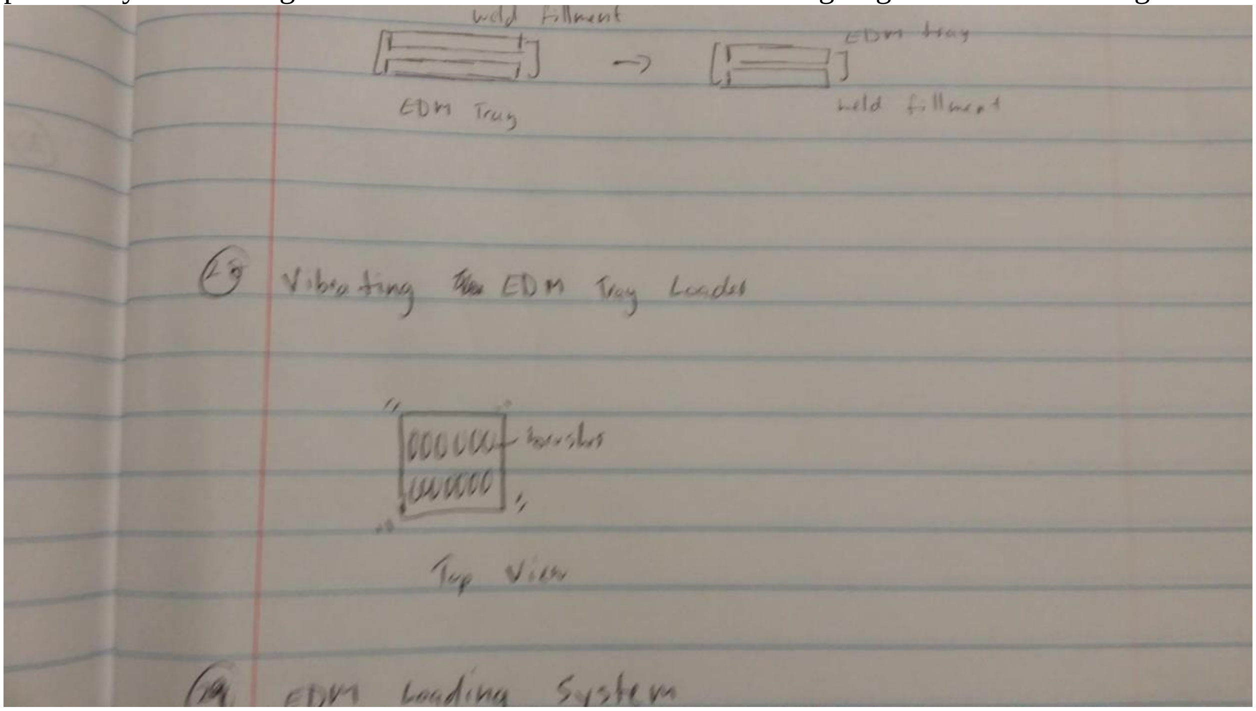
26 - Touch Screen PLC Operating System - 8 - Difficult to draw, but essentially the method that the automated process would be brought together. The operator would need only to select an item number from the screen, which would then tell him what size tray to use for the EDM and perhaps how many brushes are required for that size of seal. Designed to be user-friendly and updateable for new products. PLC systems are rather affordable and not particularly difficult to program. Probably the last step of any system used in the project.



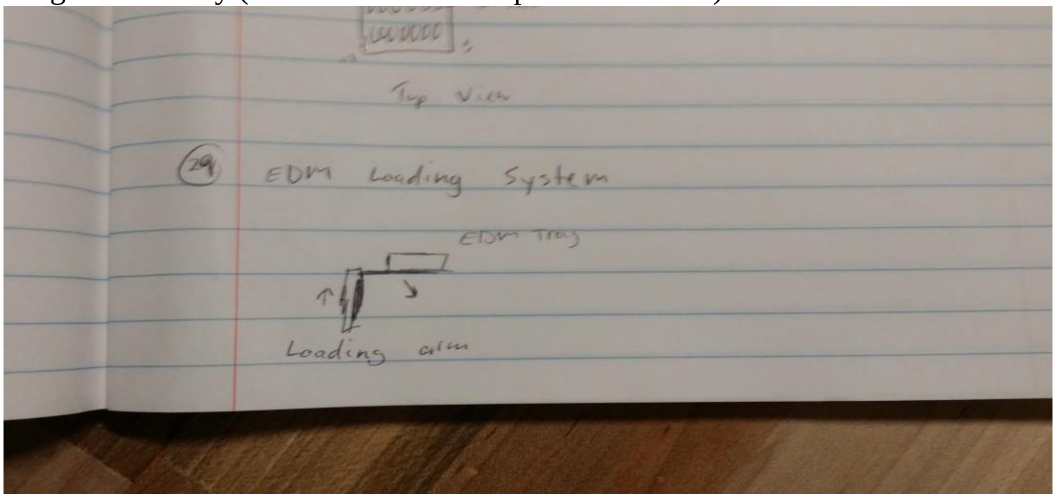
27 - EDM Tray Unloading System - 2 - A system to unload the cut brushes from the EDM Tray without having to tediously reload them back into the weld fillment. Designed to automate the next step in the process that is fairly time consuming, but this is probably not the best way of doing it.



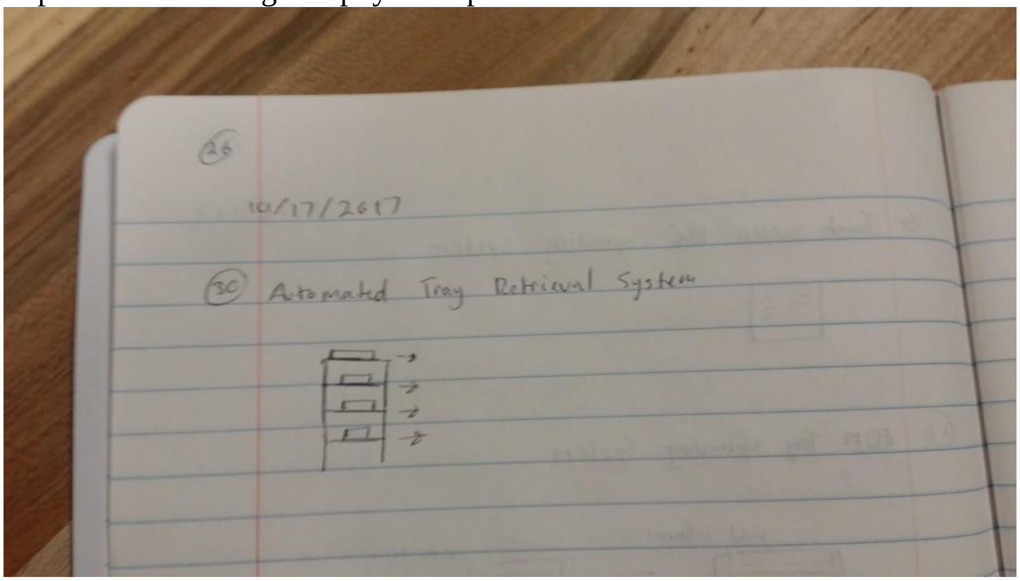
28 - Vibrating EDM Tray Loader - 5 - Mechanically simple method of loading the EDM trays, yet also the most unreliable and the least automated. The brushes would simply be placed on the tray, and the entire unit would vibrate until all the brushes have fallen into a slot. Non-zero possibility of vibrating forever with the last few brushes refusing to go into the remaining slots.



29 - EDM Loading Mechanism - 3 - A method of loading the trays into the EDM. Primarily designed around ergonomics, it may be totally unnecessary depending on the final size and weight of the tray (material selection dependent as well).



30 - Automated Tray Retrieval System - 2 - Going along with the PLC, the tray dispenser would automatically retrieve the correct size tray for a given brush length. Depending on the size and weight of the tray, it may not be necessary. Also most likely very difficult to make and implement with the given physical space constraints.



10 Project Specific Details & Analysis

The State-Transition Diagram for the process can be seen in figure 13. This outlines the steps that the product will perform without human intervention. The whole operation begins in the "START" state. This is when the machine is turned on, but not doing yet. This state can be identified by the yellow light on the control panel. When the operator presses the "START" button, the motors turn on. Currently, the primary motor is on a time based cycle, and thus is not part of the state diagram (it is state-independent). The secondary motor, however, is dependent on the state.

As the motors vibrate, tufts fall down the slide and line up in the chute. As the tufts accumulate in the chute, the sensor near the bottom of the ramp is activated. If the sensor remains activated for more than 200 milliseconds, the actuator extends. The actuator will extend until it reaches the middle sensor. This is the halfway point where the cut will be made. The actuator stops and waits for the cut to occur. Due to the lack of a physical cutter, the Lego ax works as a stand in for the cutter. The cutting simulation requires 350 milliseconds.

The actuator then finished the extension to remove the cut tuft form the machine. During this extension, the micro-controller checks the bottom sensor to detect if it is covered. If it is not covered, then the chute is nearly empty, and the motor turns off. If the sensor is till activated, no change occurs. This continues until the actuator hits the maximum limit switch.

At this point, the actuator retracts until the minimum limit switch is triggered. Once this switch is activated, it begins the process again. The entire Arduino code can be found in Appendix 21.4.

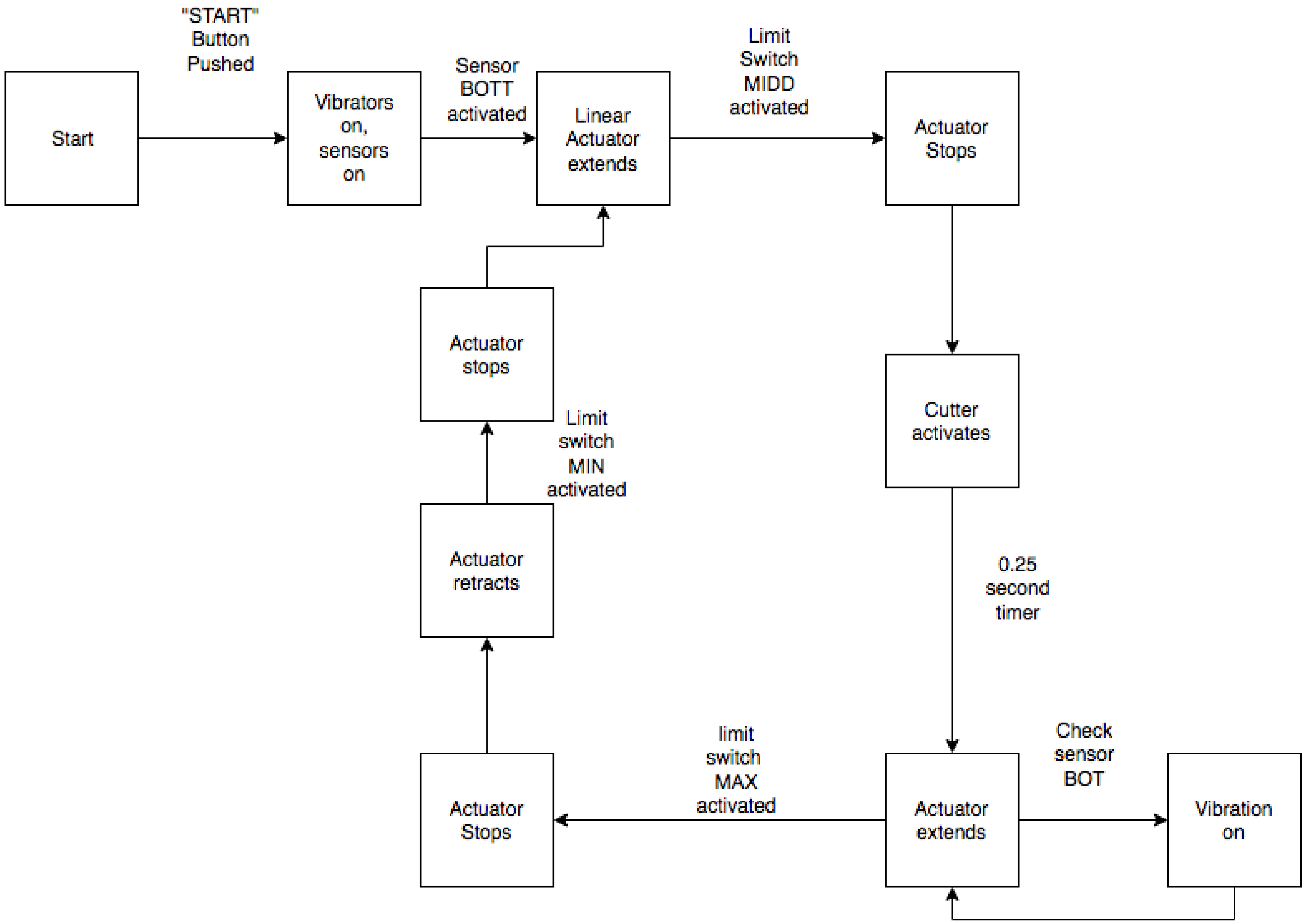


Figure 13: State Transition Diagram

11 Detailed Product Design

The final design can be seen in 14. It consists of 2 dispensers, a slide, a ramp, an actuator, and a cutting mechanism.

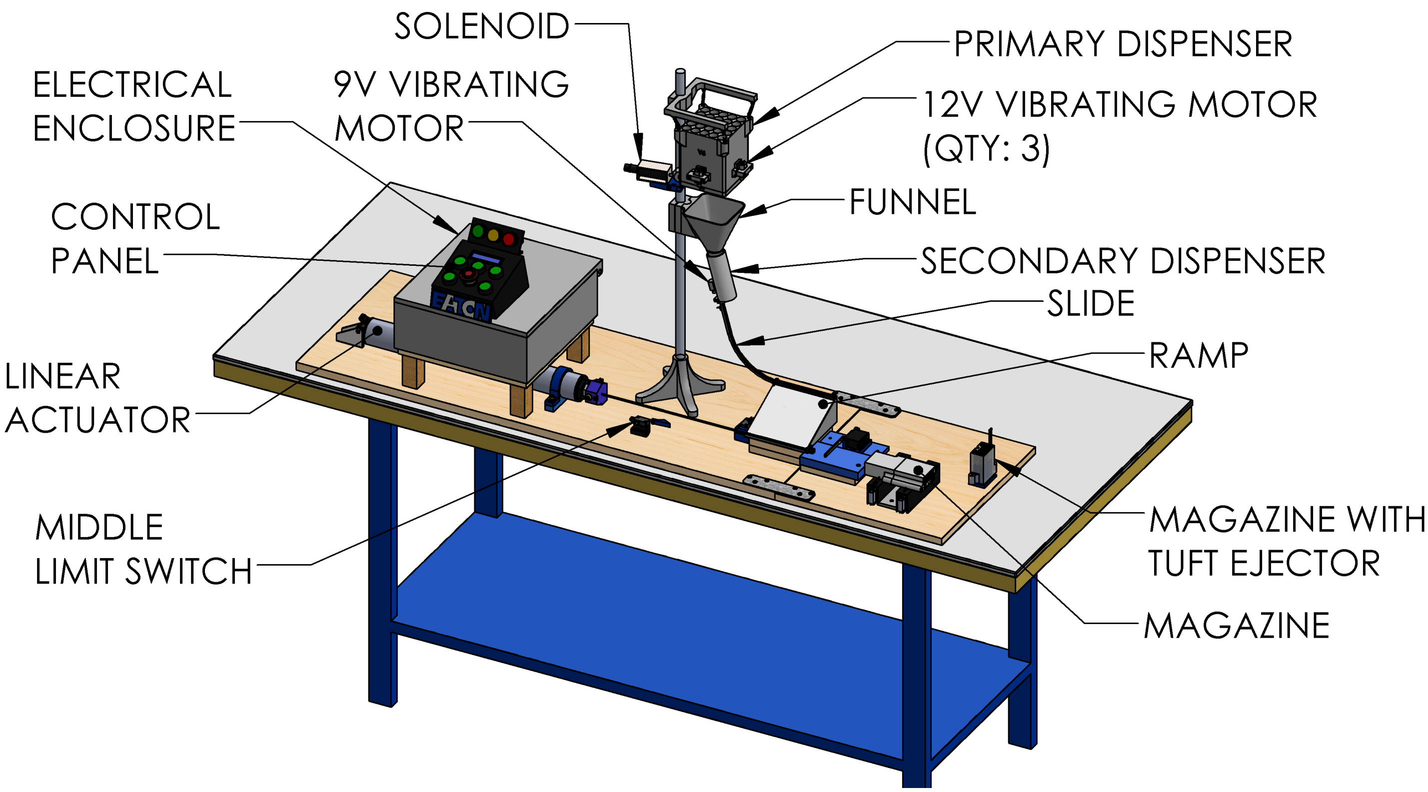


Figure 14: Prototype 2

11.1 Dispensers

The dispensing system, shown in figure 15, uses 2 dispensers, a primary dispenser and a secondary dispenser. The primary dispenser sits directly above the secondary dispenser. The primary dispenser is suspended by 4 springs, one on each corner. Inside is divided into 25 smaller cylinders that act as chambers for the tufts. Each chamber has a diameter of 0.75 inches. Attached to the bottom corner of the primary dispenser is a 24 V solenoid. The primary dispenser is loaded with tufts, and when the entire contraption is turned on, three unbalanced DC motors cause vibration, assisted by the solenoid. This displaces the tufts within the chambers and they fall down into the second dispenser. This dispenser is suspended to allow for maximum vibration.

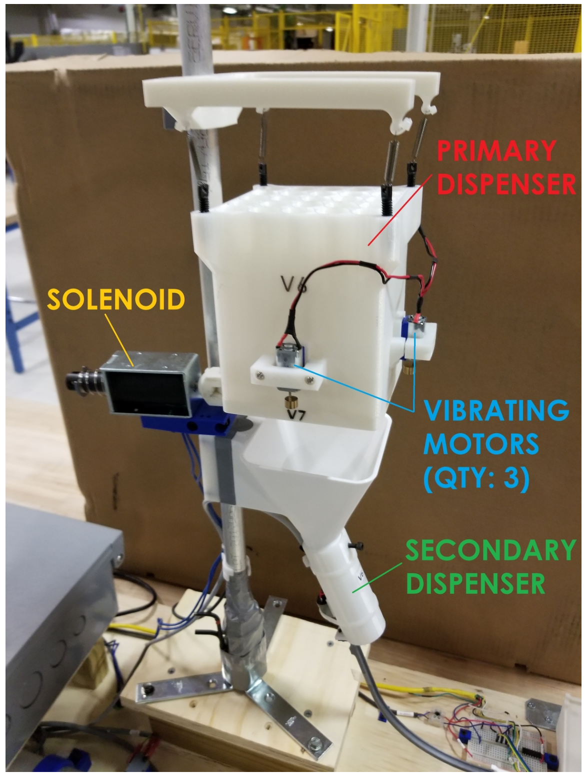


Figure 15: Dispensers

When it is full, there is a significant amount of weight inside, and it needs to be shaken quite violently to dislodge the tufts. It also acts as a sieve: some tufts get jammed on the way out, but with 25 possible chambers, a jam in one cylinder does not stop production.

The secondary dispenser is smaller and is designed to hold roughly 20 tufts at a time. The funnel helps make sure the tufts are dispensed properly. This dispenser can hold fewer tufts because it is fixed in place, and as such has a much smaller amplitude of vibration. It is necessary to fix this dispenser in place because the tufts that are dispensed must be oriented correctly and go to the same location. If it were free to sit suspended like the primary dispenser, tuft placement would be random, and tuft orientation unpredictable. The tufts travel through this dispenser and down the slide. The primary dispenser is suspended by the overhead bracket. The drawing for the overhead bracket can be found in Appendix /refAppendix:Hanging dispenser bracket. The cross-sectional views of the dispensers can be found in Appendix 21.1.3, 21.1.4, and 21.1.5. The funnel can also be found in Appendix 21.1.6.

11.2 Slide and Chute

The slide is the small gray component fixed to the secondary dispenser. It's main purpose is to make sure that the tufts that are dispensed travel into the ramp. These two components can be seen more clearly in Figure 16.

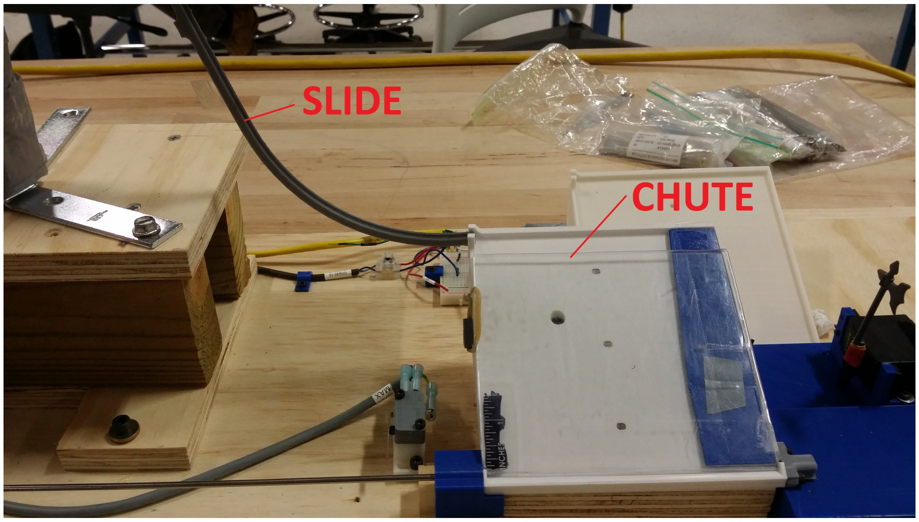


Figure 16: Slide and Chute

The ramp is the inclined component that is fixed to the ground. The top is covered with clear plastic, and the space in between the ramp and the plastic shielding is the chute. The chute is only wide enough to accommodate 1 tuft at a time, and as such the tufts stack similar to cord-wood. From here, the actuator will push the bottom tuft out by the weld-bead through the hole in the side of the ramp, located at the bottom right hand side. From here, the tufts are passed to the cutter. The cross sectional drawings for the slide and ramp can be found in Appendix 21.1.7 and 21.1.8.

11.3 Actuator and Cutter

The actuator is a standard, high speed electric actuator with a 12 inch long, 0.12 inch diameter rod attached to the end. It begins the cycle fully retracted, and once the sensors activate, it extends until it reached the middle limit switch. The middle limit switch can be adjusted to accommodate for different tuft lengths. Upon striking the middle limit switch, the actuator turns off. This is the point where the cutting action is imitated. After the cutting motion has completed, the actuator extends the rest of the distance, pushing the (cut) tuft halves through the machine and onto the next step of the process. When the actuator fully extends, it makes contact with the maximum limit switch. This turns the actuator off and immediately retracts all the way. This retraction pulls the rod completely clear of the bottom of the chute and allows for the next tuft to slide down. When the actuator is fully retracted, it makes contact the minimum limit switch and begins the cycle again.

The team could not actually work with the cutter due to union issues at Eaton. However, the team incorporated the cutter being used currently as the assumed cutter moving forward. The design, therefore, is designed to fit around the cutter, and the cutter can be seen, modeled to dimensions, in figure 14. For the sake of the project, however, the team used a servo motor with a Lego ax attached to it to mimic the cutter as well as simulate the time the cutter may take. There is an additional component that was modeled, but not incorporated into the current prototype, and that is a metal tube that will hold the tufts in place while they are cut, as well as guide them through the machine after the cut and on to the next step of the process. The stand in cutter can be seen in all it's glory in Figure 17

Figure 17: Ax

11.4 Circuits and Wiring

The circuit diagram for the machine can be seen in Figure 18. Mega pins 34, 35, and 36 control the three LEDs that tell the operator what state the machine is in. Green is in operation, Yellow is waiting for user input, and Red is stopped. These LEDs are connected to the Mega through the relays (the eight blue squares in the top half of the figure). The relays also control the linear actuator through pins 7 and 8. The actuator can be controlled moved by setting pins 7 and 9 to different settings and stopped by assigning them to the same setting.

The vibrating motors are controlled through the 2 motor controllers (the red squares in the left hand side of the figure). The motor controllers operate the same way as the relays and are controlled by pins 42 through 45.

The input sensors on the chute and slide are set to analog input pins 0 through 3. The digital limit switches are set to pins 1, 4, and 5. Input pin 17 detects the "START" button.

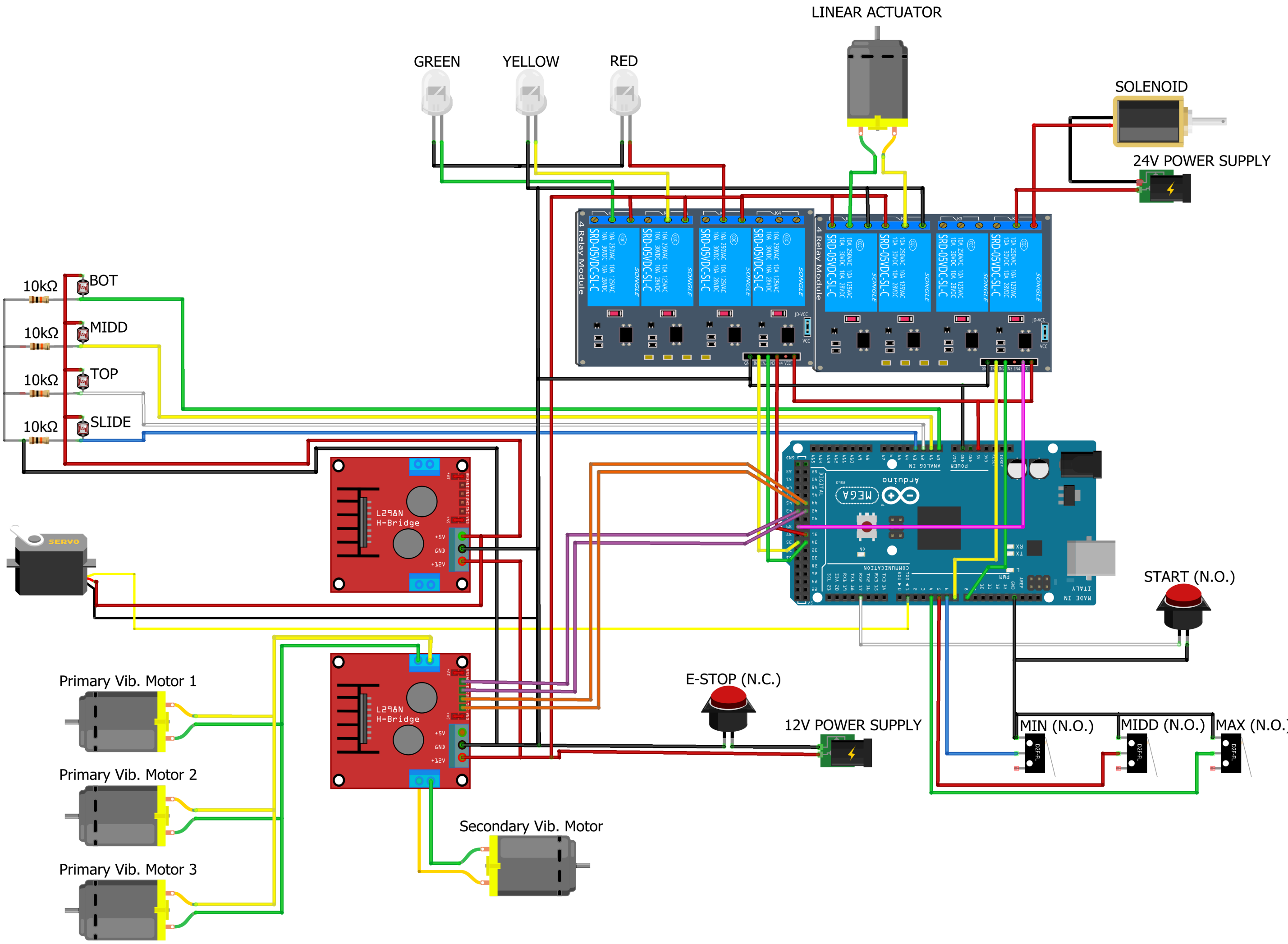


Figure 18: Circuit Diagram

12 Engineering Analysis

12.1 Stress Analysis

The primary dispenser has 4 springs in parallel, and with a spring rate of 0.62 lbf/in. The equivalent spring rate is defined as:

$$Ke = 4 * k = 4 * 0.62lbf/in = 2.48lbf/in \tag{1}$$

The extended length of the spring is also given by the data sheet accompanying the spring. With a maximum extended length of 1.907 inches and the spring rate of 0.62 lbf/in, the maximum weight each spring can support can be found using Hooke's Law:

$$F = k * x = (0.62)\frac{lbf}{in} * 1.907in = 1.18lbf \tag{2}$$

The maximum amount of weight that the four springs can hold is then 4.72 lbs. The dispenser itself has a total volume (as given by the SolidWorks drawing) of 36.22 inches cubed. The material of the dispenser, PLA filament, has a density of 1.25 grams per centimeter cubed [14]. In Imperial units, this is equivalent to 0.045 lbs per cubic inch. The total weight of the dispenser is then simply:

$$\begin{aligned} weight &= density * volume \\ &= 0.045\,\frac{lbm}{in^3} * 36.22\,in^3 \\ &= 1.63\,lbm \end{aligned}$$

The total weight minus the weight of the dispenser itself equals 3.08 lbs. The vibration is driven by three 5 volt motors, weighing a total of 0.147 lbs. The heaviest tuft weighs roughly 4 grams, which is equivalent to 0.0088 lbs per tuft. To determine the total number of the heaviest tufts, (which will be the maximum applied to all other sizes for simplicity), one must simply divide the remaining total weight by the weight per tuft:

$$max\ number\ of\ tufts = \frac{2.93}{0.0088} = 332 \tag{3}$$

Due to the tufts coming in packages of 100, the total number of packages to be loaded at any time is not to exceed 3 full packages. The dispenser is broken up into a series of smaller chambers.

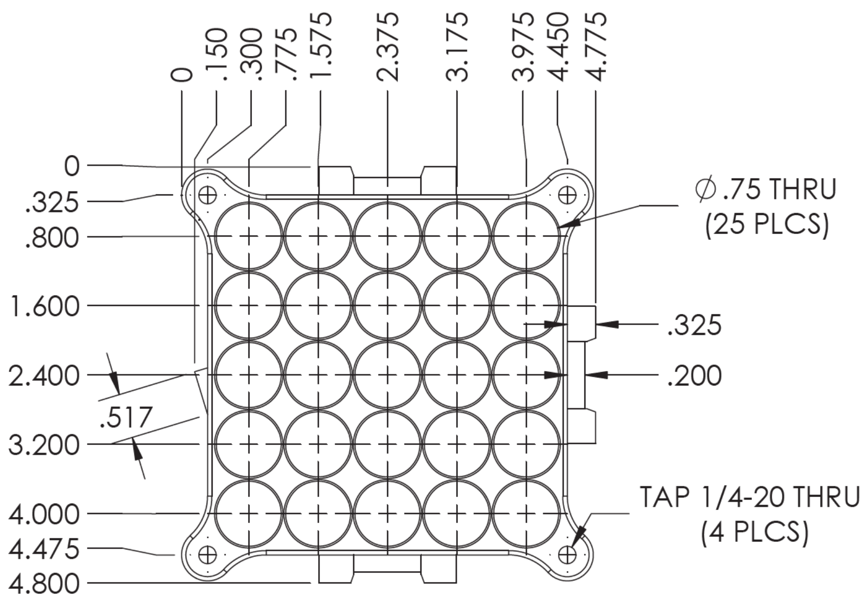


Figure 19: Top view of Primary Dispenser.

As shown in Figure 19 the chambers have a diameter of 0.75 inches, which leads to a total surface area of 0.44 inches^2. The largest tuft has a diameter of 0.189 inches. This gives an area of 0.028 inches^2 per tuft. This means that each chamber can hold a maximum of 15 tufts, which would be a total weight of 0.132 lbs. The bottom of the chamber can be treated as a simple cylinder subjected to an axial, compressive force.

$$\sigma = \frac{F}{A} = \frac{0.132lbf}{0.044in^2} \tag{4}$$

The stress in the bottom of each chamber comes to a maximum of 0.3 psi. The standard compressive strength of PLA is 2600 psi, therefore, the dispenser is structurally sound [14].

12.2 Vibration Analysis

The primary dispenser is modeled as a spring-mass-damper system. Though there is no actual dampener attached, there is inherent damping in the system. As long as a system is under-damped, then there exists a resonance frequency that will cause any input amplitude to multiply itself several times over [15]. This can be useful in forcing the tufts to dispense. The results of the initial test to determine whether or not the system was under-damped can be found in Figure 20.

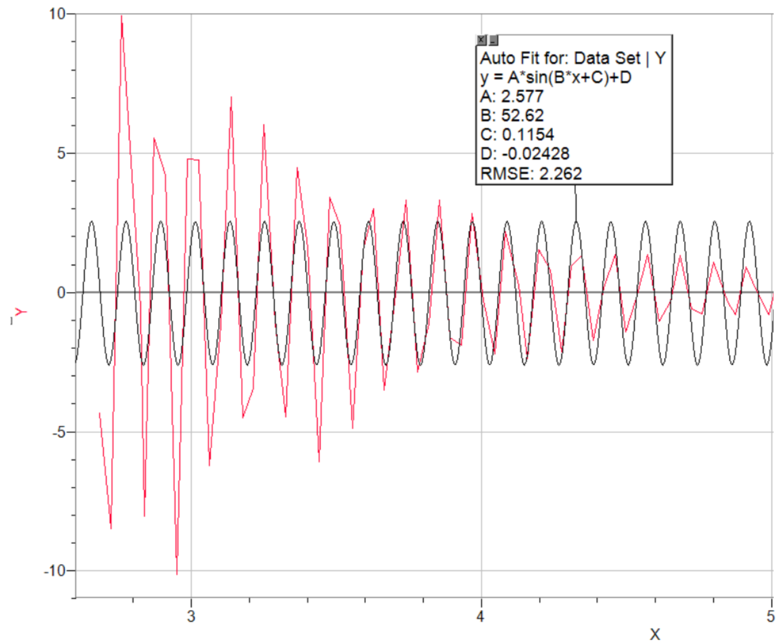


Figure 20: Damped graph.

The resonance frequency for an under-damped system can be found by using the following equation:

$$\omega_d = \omega_n \sqrt{1 - \zeta^2} \tag{5}$$

Where the ω_d is the damped frequency, ω_n is the natural frequency, and ζ is the damping ratio. The natural frequency can be found as

$$\omega_n = \sqrt{\frac{k}{m}} \tag{6}$$

Two problems emerge at this point in the analysis: first, the mass is changing with every tuft that is dispensed, which means that for 300 tufts, there will be 300 different natural frequencies. Additionally the damped frequency is not cannot be found through calculation, but must be found through experimentation. Again, due the changing mass, there are 300 different damped frequencies, and therefore 300 different resonant frequencies per tuft size, or 2,100 total resonant frequencies. At this point, the theoretical analysis act more as guidelines. A frequency close to resonance can be found through observation of adjusting the input voltage to the rotating motor, but it will not be precise [16]. In order for the tufts to dispense out of the dispenser, vibrating motors are used. Conceptually, the amplitude should be maximized to allow for the tufts to dispense fastest. To analyze the vibrations, the dispenser can be represented as a spring and mass system.

In order to ensure that the vibration produced by the motors wouldn't break our dispenser, a finite element analysis program was used to simulate the effects. SolidWorks was designed to draft the part itself. Then the team imported the part's file into Abaqus to run the vibration analysis. The program subjects the part to a variety of Hertz levels ranging from low to high. A maximum displacement of 1.18 millimeters was found at 42.118 Hz during the analysis.

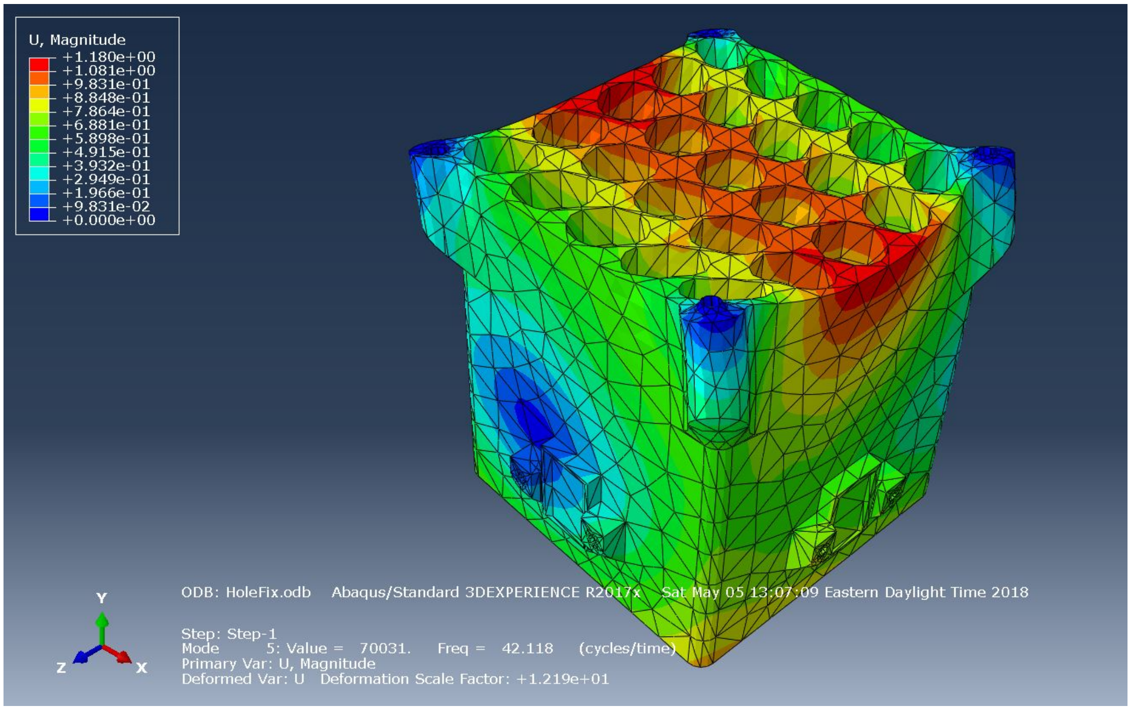


Figure 21: Vibration Analysis of Primary Dispenser in Abaqus.

13 Build/Manufacture

Production of the final design was fairly straight forward and cost relatively little. To build the second prototype, the following tools were required: hand drill, dremmel, 3D printer, soldering iron, allen wrenches, bandsaw, wrenches, chop saw, threaded taps, slotted screwdriver, phillips screwdriver, and assorted socket head cap screws. A piece of plywood was used for the base of the automated tuft cutter and holes were drilled then tapped into the plywood to provide mounting locations for the components of the machine. These mounting locations may not provide strong connections, however, for a prototype it will suffice. In addition to the plywood being tapped with threads, various 3D-printed components were tapped as well.

The primary dispenser is composed of two parts, the upper portion which contains the tufts and a thin, lower bottom plate. This bottom plate can be replaced with one with different diameter holes for the tufts to pass through. To secure the bottom plate of the dispenser to the top portion, two screws are used. This bottom plate will experience a maximum of 5 lbs and these screws should have a reliable connection. To ensure this, rather than tap threads into the upper portion of the dispenser, threaded inserts were inserted. These inserts require using heat to melt the plastic which it is being inserted into and has grooves, which the melted plastic flows between. This provides a much stronger and reliable connection point.

Each component was either 3D-printed or purchased from an online vendor. If this automated tuft cutter were to be mass produced, the realistic quantity would be approximately 5. The primary manufacturing processes that would be used involves machining and additive manufacturing. Some of the components, such as the slide, funnel, and a portion of the ramp could be manufactured with sheet metal. The primary dispenser and the tuft magazine could be machined out of a material such as delrin and the other components can be created with additive manufacturing.

14 Testing

Testing took far longer than the team initially estimated, and much of it was dedicated to the primary dispenser. The first test, which took place early n the semester, did not work at all. The total number of tests can be found in the Appendix 21.2, as it is quite long. Three main things were tested: the dispensers, the ramp, the actuator speed, and the overall noise of the machine.

14.1 Dispenser Testing

The dispenser testing took far longer than anticipated. The team encountered two main problems: the vibration was not enough to induce dispensing, and the tufts would jam on the way out. To solve the first problem, the team attempted to maximize the amplitude. This was attempted vibrating the dispenser as close to resonance frequency as possible.

Before any progress could be made on finding resonant frequency, the system must first be shown to be under-damped. This first test was quite easy. Nathan Joyal used the app, Kinetic Sensor Pro, to determine the frequency of the system. The app was opened and then his phone was secured to the suspended dispenser. The dispenser was then displaced, and the resulting motion captured on the app. The app showed that the system returned to it's original location, overshot, and then displaced the other way. The actual value of this frequency was not important, as it would reflect the true damped frequency, but it did show that there does exist a resonant frequency that is possible to reach.

After proving such a frequency, the team then struggled to find the frequency. Professor Jouaneh from the University of Rhode Island helped in this endeavor. He provided needed guidance for the team to realize the signs of resonance. However, even after finding the resonance frequency, the tufts would still not dispense. Resonance frequency is when the amplitude is at its highest, but it still may not be enough to displace the tufts when the dispenser is full and the tufts are tightly packed in place. Additionally, the tufts dispensed best when the frequency was highest, regardless of resonance.

The problem of tuft dispensing took more than a month, and eventually, through sheer trial an error, took the advice from Professor Jouaneh, and "shook the shit" out it. By adding additional motors an smaller chamber, the team was able to induce dispensing. With three motors attached, it successfully dispensed nearly 200 tufts within a matter of 15 seconds. Furthermore, once the primary dispenser motors were turned off, dispensing stopped immediately, which made it possible to control the flow of tufts reasonably well.

The secondary dispenser worked fairly well from the start, and the team found that a simple modification in the bore at the bottom was more than enough to make it work. The caveat with this dispenser was that it could not hold more than 20 tufts without slowing down considerably. The primary dispenser was then set on a timer to make sure the secondary dispenser did not get too full.

14.2 Ramp/Chute

The ramp and chute system worked reasonably well from the beginning and only ran into problems on the extremes. Large tufts would bounce out of the smaller ramps, and small tufts would shift orientation in the longer ramps. The solution to this problem was to print a small plastic insert that could be used to make a larger ramp smaller. Another problem that was unanticipated was the hole for the tufts to dispense out of being slightly too large. The actuator would sometimes push 2 tufts out at the same time. This issue, occurring every 20 or so tufts, would not damage the tufts themselves and seemed to correct itself within 2 or three tufts at most. The team printed a 5th and final version of this ramp with a smaller hole to prevent this happening again, but did not have time to adequately test it.

14.3 Actuator Speed

The actuator speed is the linchpin in beating the output goal. The tufts can dispense as quickly as they need to by simply increasing the vibration, but the tufts can only be cut as fast as the actuator can move them into position. The actuator has a top speed of 11 inches per second. The team first tested the cycle time using motor controllers. This test led to disappointing results, with a cycle time of 4 seconds, which would not increase throughput at all.

After measuring the current being drawn by the actuator, the team realized that more current was needed, and there was a voltage drop across the motor controller. Voltage drops across these motor controllers is to be expected. To compensate, the team attempted to force more voltage into the motor controller. This did nothing to increase the speed and risked damaging the electrical components.

To workaround this, the team replaced the motor controller with mechanical relays, which did not throttle the current passed through them. After this addition, the speed of the actuator increased so that one cycle took less than 3 seconds (2.98). This gave the team the output required to accomplish one of their primary targets.

14.4 Noise

One consideration that the team had was noise. The machine, with two vibrators and an actuator, can be somewhat loud. This was a very easy test and took only a few minutes. The machine was turned and an app, Sound Meter, was used to get a decibel reading of the noise generated while standing right to next it. The maximum noise was 68 decibels. In order to be compliant with the Depart of Labor OSHA Standard 1910.05, appendix A [11], the maximum volume an employee can withstand during an 8 hour shift is not to exceed 90 dB. The machine runs at less than 70 dB. The team can therefore say that the machine is in compliance with the OSHA noise limitation. The precise results of this test can be seen in Figure 22.

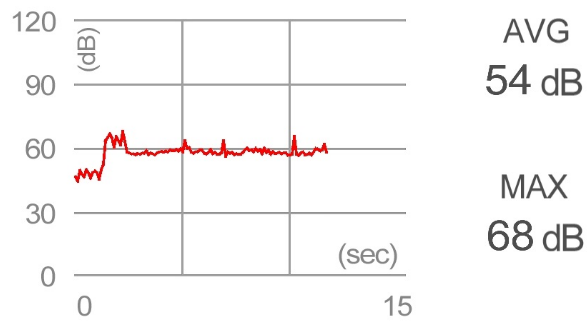


Figure 22: Audio levels of automated tuft cutter

15 Redesign

The design from the Fall semester can be seen in Figure 23.

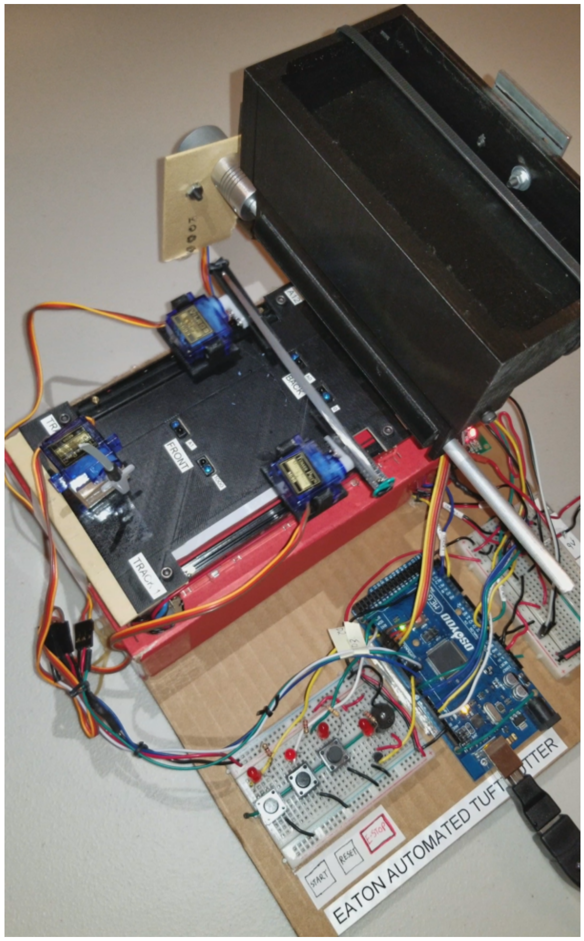


Figure 23: Prototype 1

Obviously, the final design is extremely different. The team focused heavily on redesigning during the Spring semester. Not only did the entire project get a complete redesign (with zero components in the Proof of Concept present in the final design), but the project changed drastically over the course of the semester. The dispenser system underwent no less than 17 redesigns. The evolution of the redesigns can be seen in figure 24.

Figure 24: Dispenser Iterations

In addition to the dispensers themselves, the suspended design was originally fixed horizontally to the support pole. It was later moved to the suspended orientation to help model it as an undamped system. Despite this alteration, the primary dispenser would still not dispense when it was fully loaded. To compensate for this, more motors were progressively added until the induced amplitude was enough to displace the tufts inside. The original design used one motor, while the final design uses three motors, all of which are heavier than the original one.

The first primary dispenser had fewer chambers as well. The original idea consisted of only 5 chambers. Increasing the amount decreased the required vibration by reducing the normal force pushing against each tuft. Before reaching the 25 chamber design, fewer chambers were attempted, as well as some that had multiple bores but only one large chamber. None of these succeeding in dispensing with the consistency that was required. As an additional measure, a solenoid was affixed to the bottom corner that would violently shake the dispenser at regular intervals. This was added to primarily help with tufts that got jammed on the way out.

Beyond the primary dispenser, the slide underwent three design changes. Most of these involved tweaking the length. If it was too steep, the tufts would slide down too fast, strike the inside of the chute, then bounce back up the ramp, causing a jam. If the slide was too flat, the longer tufts would bend and flex on thew way down, which would possibly damage the tufts.

The ramp itself went through 4 iterations before the fifth one was chosen as the best. The ramp had a few problem: if it was too narrow, the longer tufts would bounce out. If it was too long, the shorter tufts would orient themselves wrong and cause jamming. Additionally, the hole through which the tufts would be pushed needed to be precise or the actuator would attempt to push through 2 tufts t the same time, causing not just a jam, but destroying the tufts in the process.

The electrical wiring inside the control box was originally situated on the outside, upper left hand corner. it began as a breadboard with four motor controllers. As more and more parts were incorporated, the wiring grew unsightly and difficult to manage. The other primary problem was excessive current coupled with current throttling.

The motor controllers that were used were rated as having a maximum current of 2 amps. The actuator was pulling up to 4 amps at times. This pushed the motor controllers to the limit and caused overheating. The overheating happened rapidly, and caused the actuator to stall. The first solution to this problem was to use 2, 12 V cooling fans that were scavenged from an X-Box 360. These fans were installed at the top corner of the base due to a lack of room. These fans were effective in cooling the motor controllers, but made the design even more unwieldy. With the addition of these cooling fans, the entire design required 4 different power outlets to run, which was not only troublesome, it would be unacceptable in a professional environment.

The solution to this was to replace the motor controllers with higher rated relays. The relays could handle more current and not overheat. Additionally, all the power to the design went through one outlet, that turned the 124 V into 2 separate voltages: 12 V and 24 V. This transformer also had a built in fan and did not need the cumbersome external cooling sources. To make the set-up more professional and robust, a control box was added that contained all the wiring. Directly on top of this the control panel was added that allowed the user to operate the machine without constantly manually resetting the Ooyoo Mega.

16 Operation

The operation of the machine is designed as straightforward and simple as possible. It only has three steps: first, the operator must load the tufts. The machine is designed to hold up to 300 of the largest size tufts. Total tuft loading should not exceed 300. Second, the operator must push the start button. Finally, the operator should return within 20 minutes and gather the tufts have been cut.

Due to time constraints, a manual for operating the machine was not written. A manual dealing especially with the electronic components would most certainly be helpful, and if the demand for the machine were there, the design team could quickly write one up. However, at the present time, a manual was not written.

17 Maintenance

The machine was designed to be easy to maintain and require very little maintenance. According to the data sheet for the relays, they have a life expectancy of 10^5 operations at rated coil voltage. The rated cold voltage for 5 V and in the current design are operating at 5 V. With one actuator cycle consisting of 3 stops or changes of direction, 1 actuator cycle is equivalent to 3 relay cycles. This means that the relays will only last for 33,333 tufts until they will fail. The relays are the components that will die first. The current layout has the relays easily accessible with all the wiring clearly labeled. The team estimated that replacing the relays will take no more than 10 minutes. Also, the relay system cost $14.00. This tacks on an additional $0.0004 per tuft expense. Including this, the cost per tuft is still less than $0.003.

The PLA filament will eventually wear down as the harder alloys slides across it. This wear rate is exceptionally difficult to estimate given the uneven orientation and the different number of tuft mass and sizes. Each size of tuft will have different travel patterns on the filament. Additionally, the actuator rod sliding along the ramp will cause some level of wear. However, given the cheap nature of the filament, replacing worn parts is simple ad cheap. Given that most of the assembly can be done with an allens wrench, the team does not consider this to be a limiting factor in maintaining the design.

18 Additional Considerations

Economic Impact

The economic implications of this design is directly relate to a lower cost of production of Eaton manufactured brush seals. This may lead to an overall lower cost of buying parts to airline manufacturers. This is unlikely to have any far reaching effects (plane tickets will most likely not become more affordable due to the revolutionary tuft cutting design), but combined with process improvements across different areas, it may play a small part.

Environmental Impact

The environmental impact of a design must always be kept in mind. It would be unethical to use any design that damaged the environment without first considering other alternatives. Contrary to popular belief, PLA is not biodegradable. PLA can be disposed of safely in two ways: industrial composting and recycling. Eaton should pursue one of these alternatives in order to safely dispose of the filament after it has worn out in a way that does not involve dumping it into a landfill. Additionally, the electric components will constitute E-waste once they have ceased to operate. This puts an additional burden on Eaton to make sure these used up components are disposed of properly as well.

Societal Impact

The act of automating a humans job and potentially putting their job at danger will always generate a societal impact. Although the operators of Eaton certainly have plenty of other jobs to do around the facility, this could not always be the case. As the trend continues of more and more jobs to be automated, the demand for human labor shrinks. Next year's capstone project may involve automating the process of putting the cut tufts into weld filaments. This could be the first step in a series of future projects that costs people their jobs. On the other hand, with automation comes the freedom from doing tedious jobs. It is important to make sure that average working class people do not find themselves the victim of rampant bottom-line chasing.

Political Impact

There is no relevant political impact that comes from our product. It is a process pertaining to a private company and requires no change in legislature to be put into place.

Ethical Considerations

This design poses no ethical considerations not addressed in the societal impact section. The design is safe, and the team is confident that no engineering ethics are at stake. According to the ethics guidelines laid out by the National Society of Professional Engineers [12], the team follows all the guidelines. First, the team placed safety first, and feels 100% confident that the machine poses no risk to any operator. Second, the team performed all engineering work within a domain of competence. Third, everything the team reported has been truthful. Fourth, the team has not violated the NDA signed, nor have they betrayed the trust placed in them by Eaton. Fifth, nothing deceptive has been done or said, and none of their work has been misrepresented. Finally, the team has striven to enhance the reputation and usefulness of the engineering profession.

Health, Ergonomics, and Safety Considerations

The machine designed is compliant with OSHA prescribed guidelines regarding noise exposure. The design, however, does require the operator to lift above the shoulders. This is mitigated however, by following CDC guidelines regarding ergonomic movements. In the CDC published "Manual for Material Handling" [13], an administrative control for above the shoulder movements include varying jobs to avoid overworking the same muscle groups and providing adequate recovery time. The final design only calls for one lift of less than 3 pounds every 20 minutes, and this falls within an administrative control to avoid overworking in a vulnerable position.

19 Conclusion

The new design assembled is capable of decreasing the cost of operation from $75.00 per hour to $35.80 per hour, which is a decrease of 62%. This is an incredible decrease in costs, which satisfies the cost portion of the design specifications. The primary goal of decreasing costs has been met with this design.

It also increases the overall throughput of cut tufts. The speed at which our machine cuts each tuft is about 2.9 seconds. Before, the operator took approximately 4 seconds to cut a tuft. This is a 33% increase in output, satisfying our design specification to increase throughput.

Beyond the two primary performance criteria, the prototype has an emergency shutdown button integrated, requires no PPE to use, and is compact enough to fit into the allotted area. Perhaps most importantly to the future of the production cycle is that the estimated cost of the finalized version falls well within the budgetary guidelines. We are only using about 20% of our overall budget. To restate the design specifications:

Table 7: Design Specifications.

Category	**Required Specification**	**Actual Specification**
Size	No more than 7 square feet	6.4 square feet
Throughput	Under 4 seconds per tuft	3 seconds per tuft
Cost to operate	Under $0.08 per tuft	Under $0.03 per tuft
Robust	Support 100 tufts	Supports 300 tufts
Safety	Operating volume of less than 90 dB	68 dB maximum
Safety	Emergency stop button	One emergency stop button
Ease of Maintenance	Must be repairable on site	0 non-electronic components that can't be 3-D printed, 0 non-standard electronic components
Ease of Use	Less than 30 minutes to learn how to use machine	5 minute learning time for machine
Ease of Installation	Requires 0 special equipment to install	Requires 0 special equipment to install that is not already available (pneumatic pressure hoses)
Ease of Disposal	0 components that require special disposal	0 components that require HAZMAT disposal, 5 components that are considered "E Waste."
Building Cost	Under $3000	Current prototype projected to cost $619.95

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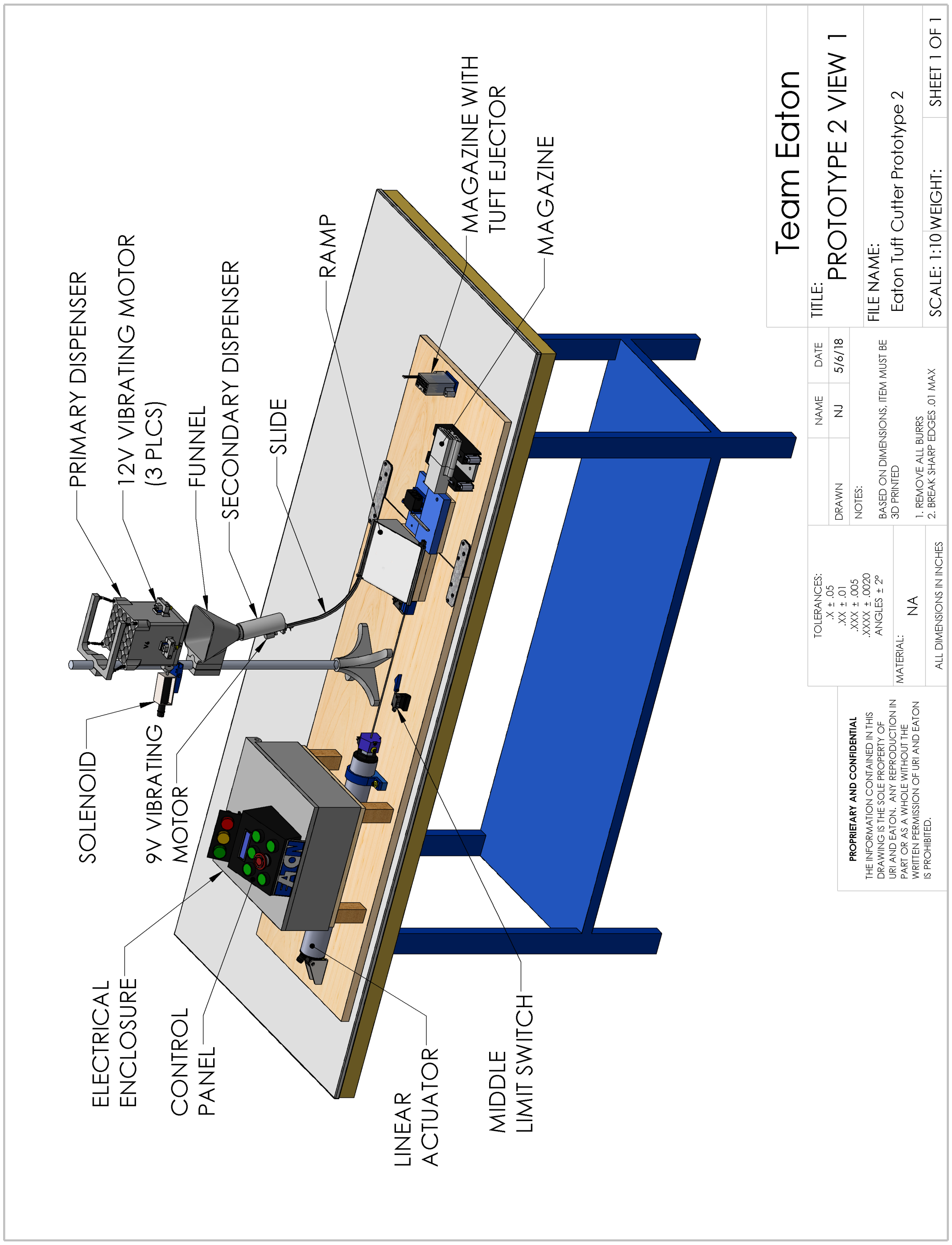
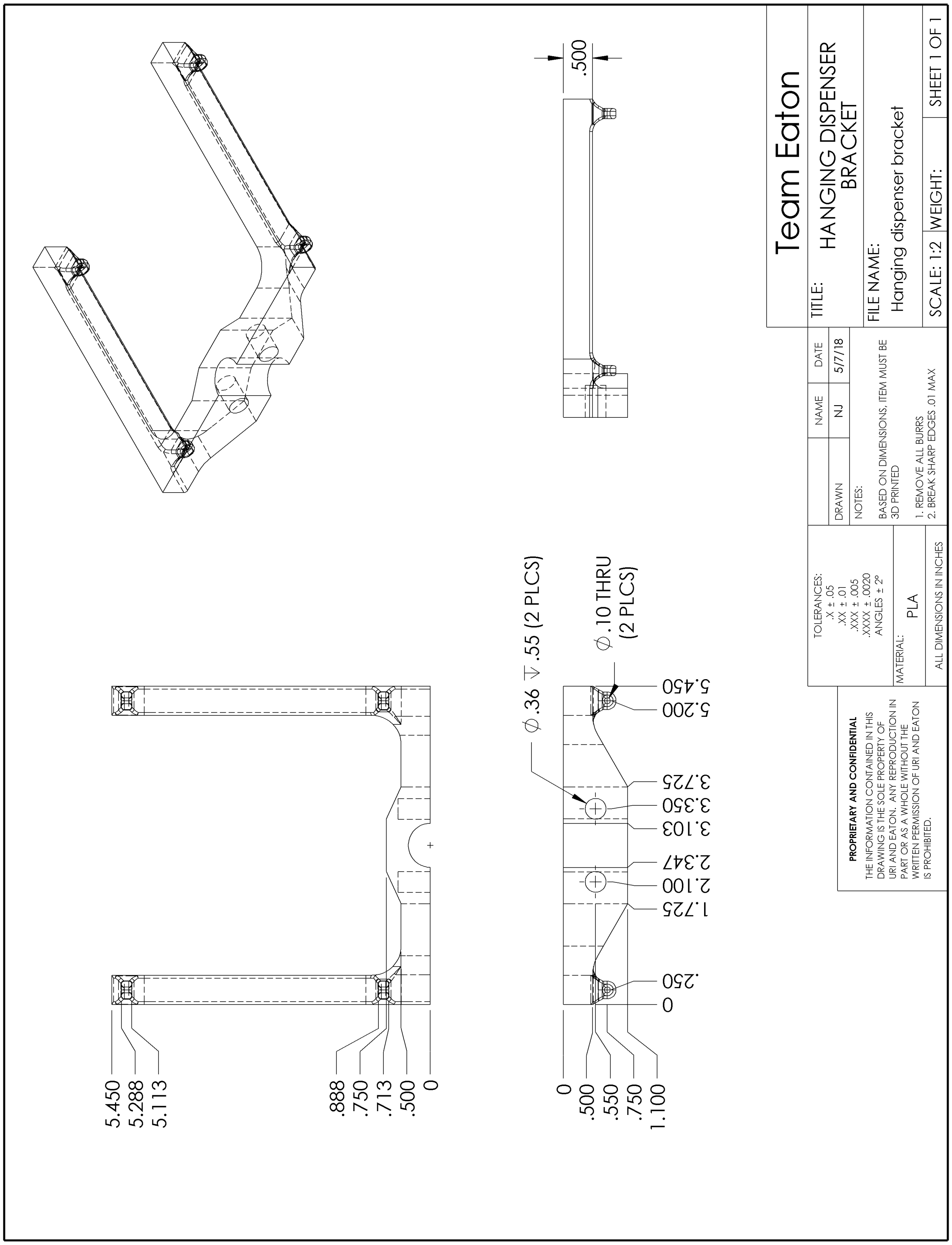
21 Appendices

21.1 Drawings

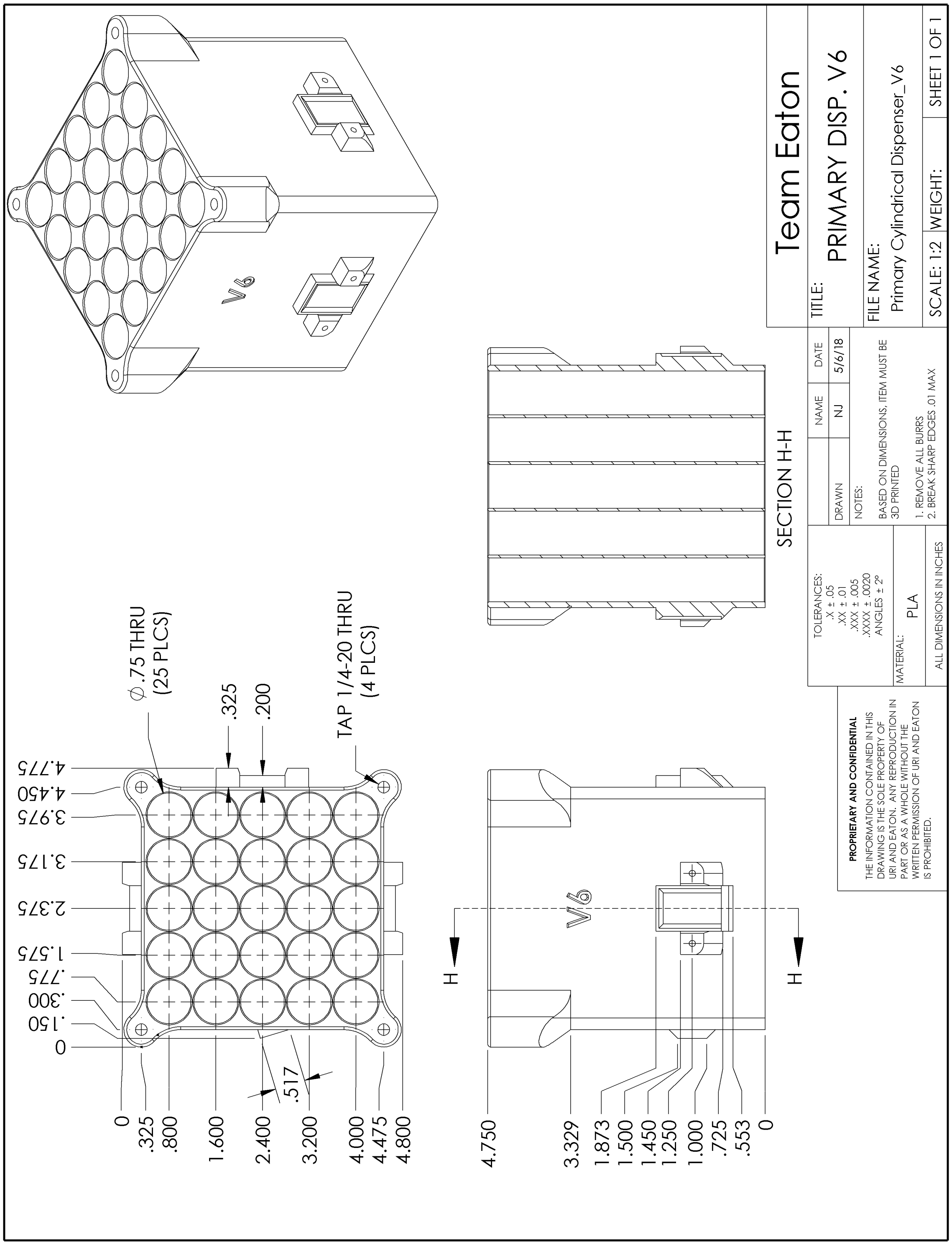
21.1.1 Prototype 2



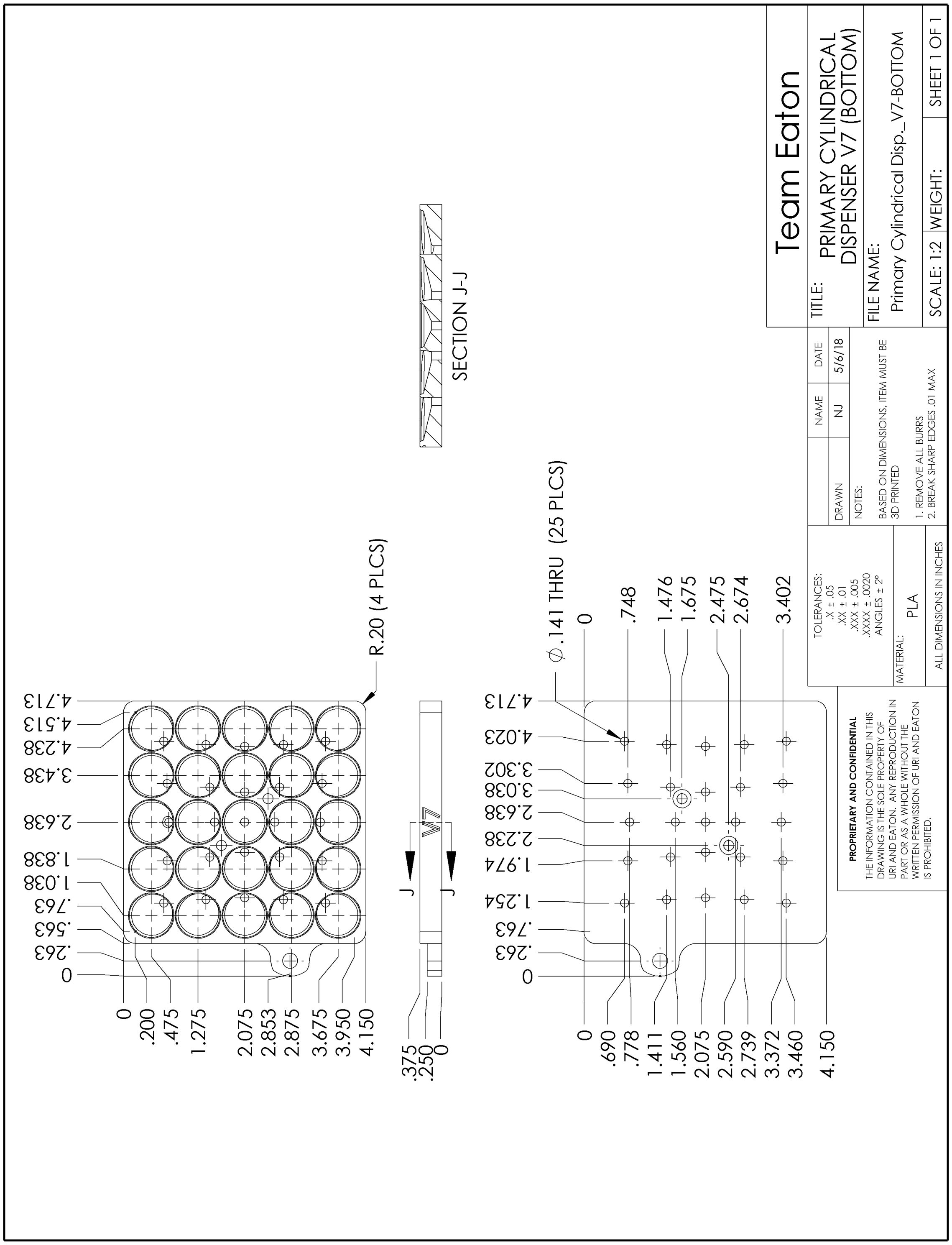
21.1.2 Hanging dispenser bracket



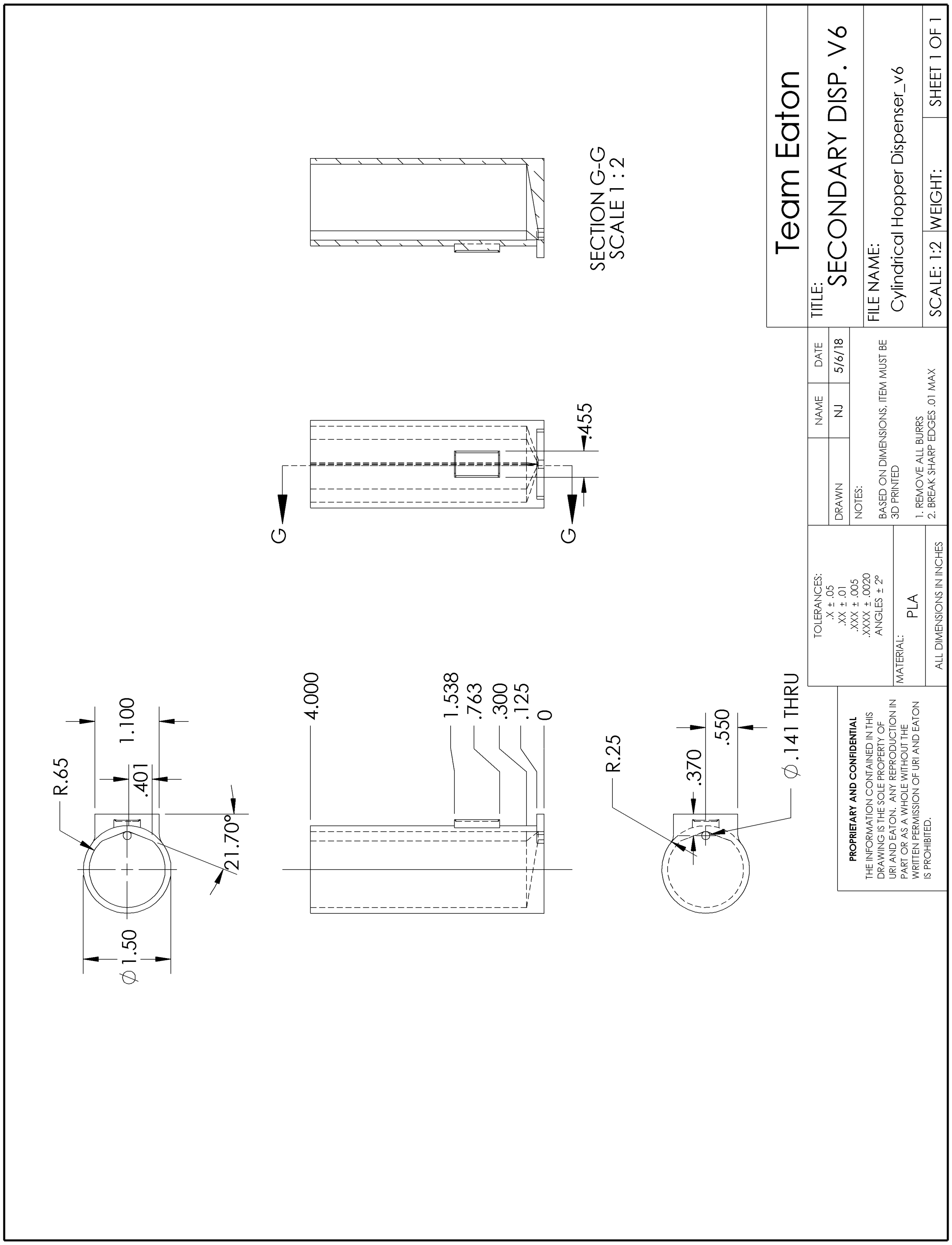
21.1.3 Primary Dispenser



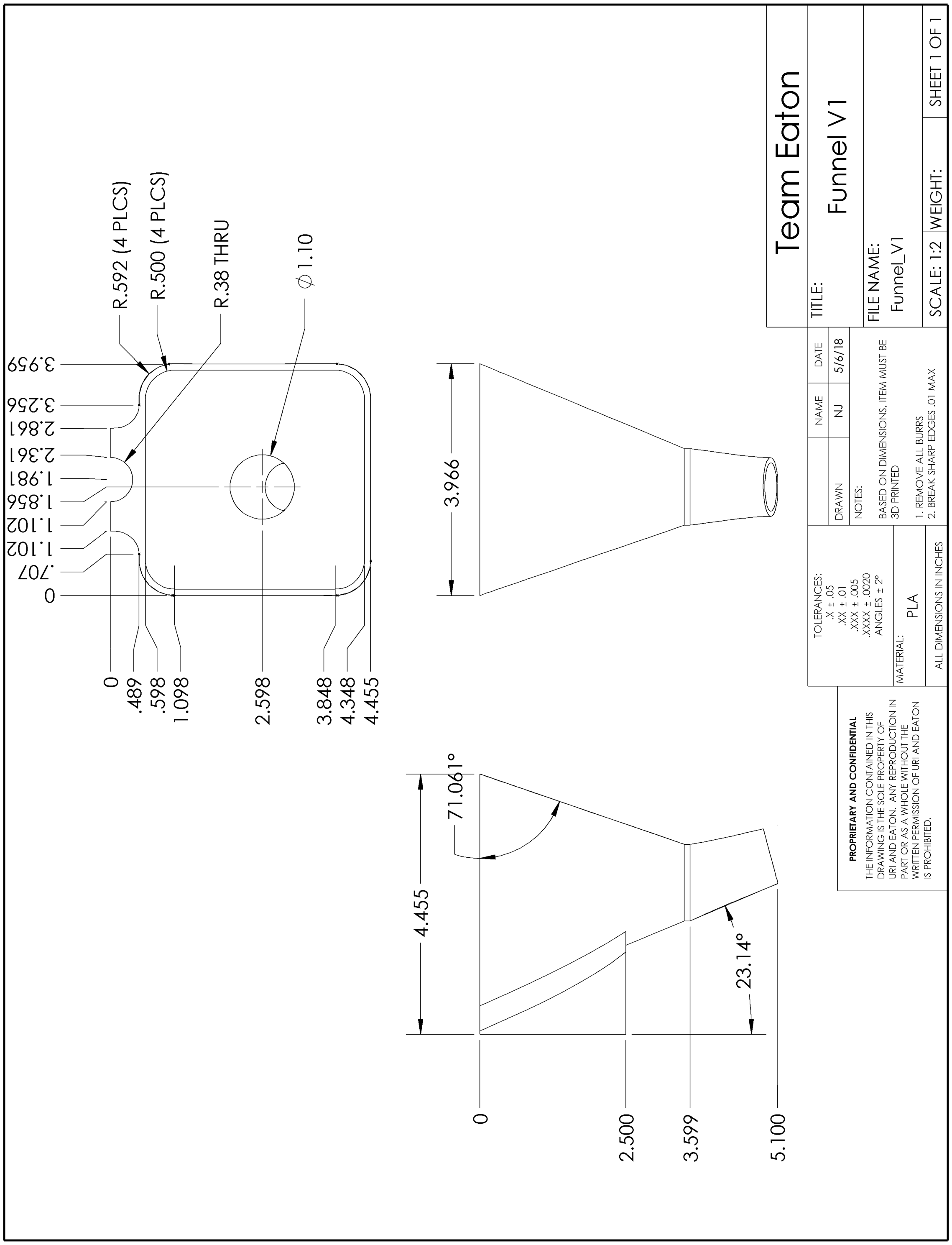
21.1.4 Primary Dispenser (Bottom)



21.1.5 Secondary Dispenser



21.1.6 Funnel



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Team Eaton
TITLE:
Funnel V1
FILE NAME:
Funnel_V1
SCALE: 1:2
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NOTES:
BASED ON DIMENSIONS, ITEM MUST BE 3D PRINTED
1. REMOVE ALL BURRS
2. BREAK SHARP EDGES .01 MAX
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.X ± .05
.XX ± .01
.XXX ± .005
.XXXX ± .0020
ANGLES ± 2°
MATERIAL:
PLA
ALL DIMENSIONS IN INCHES
PROPRIETARY AND CONFIDENTIAL
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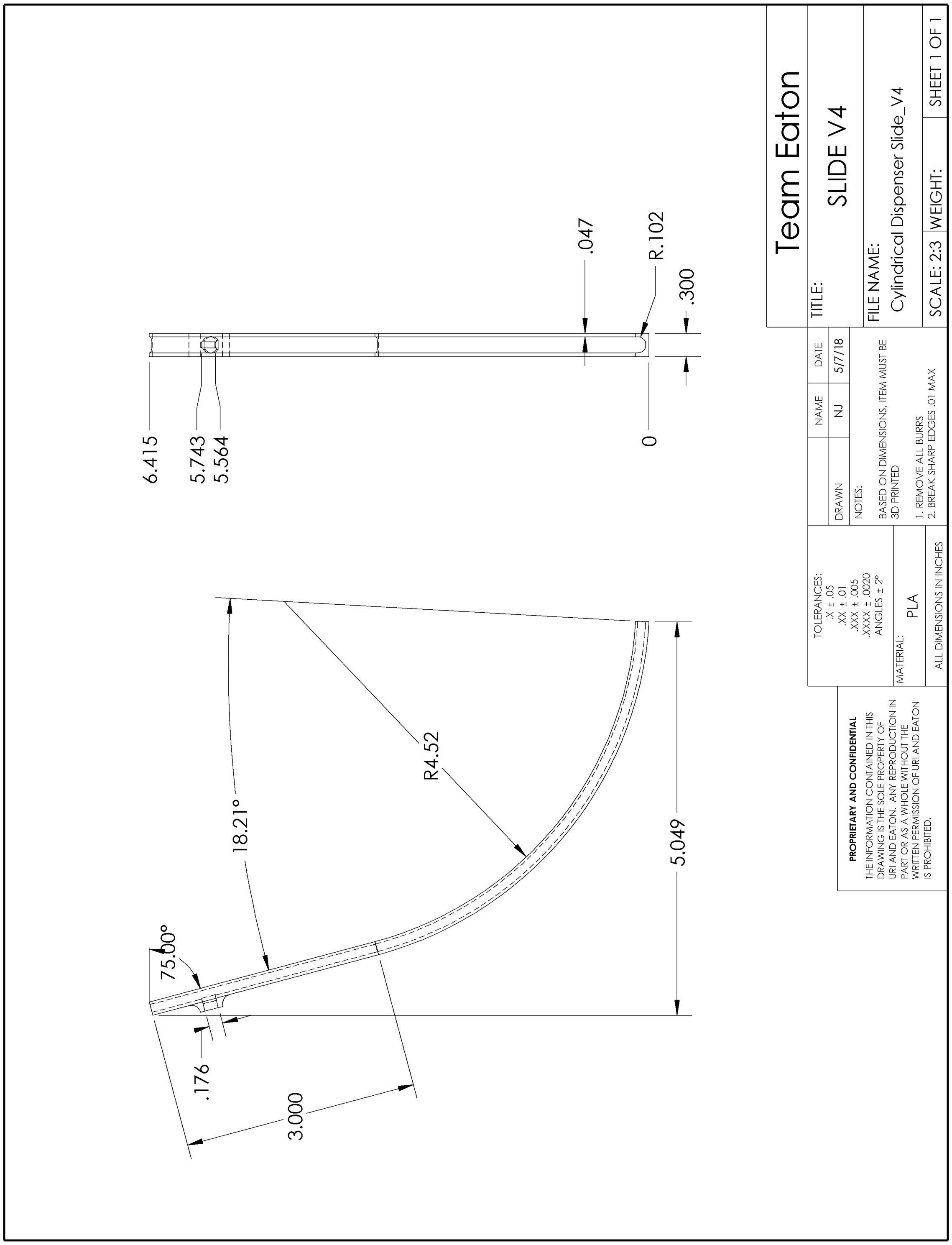
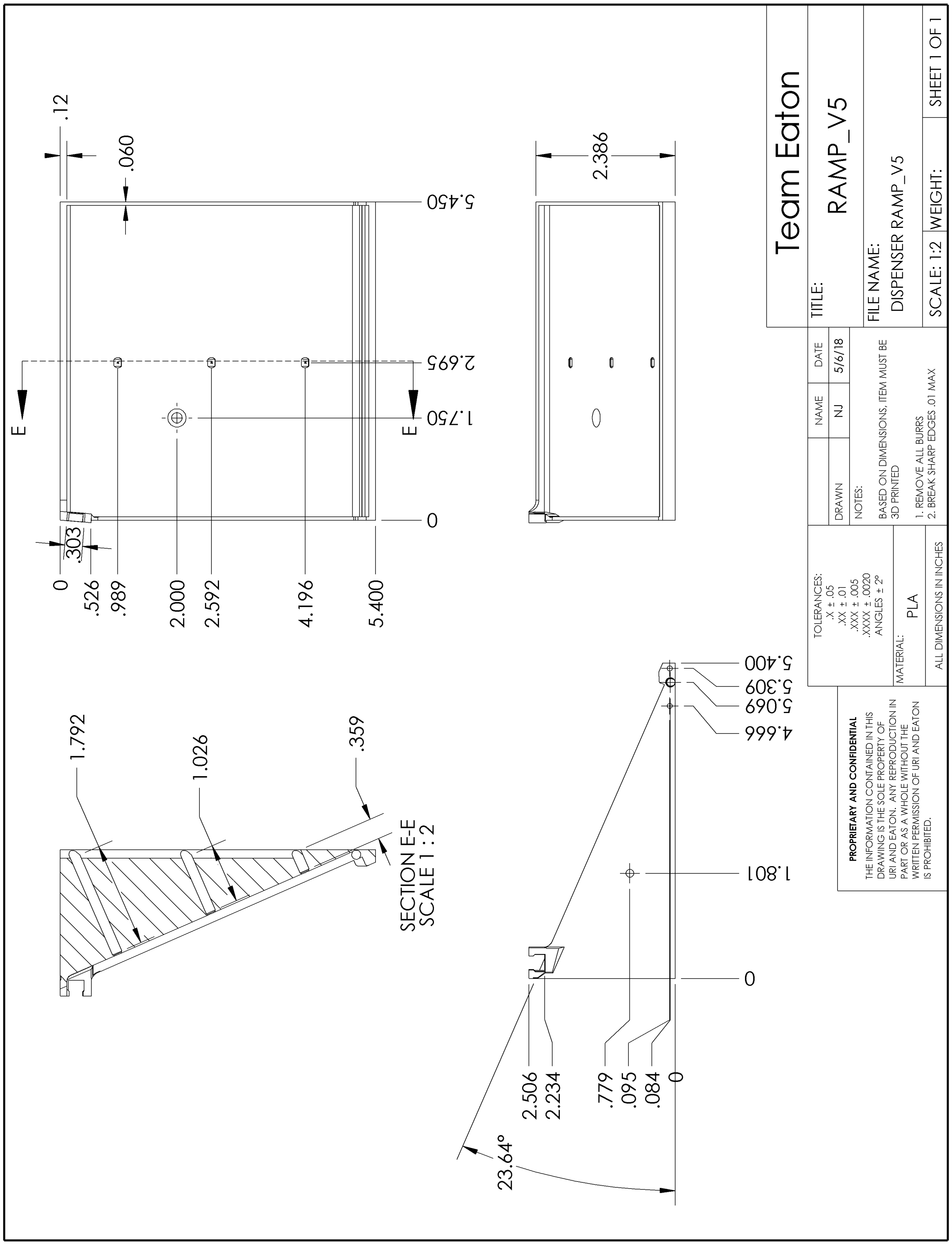
21.1.7 Slide V4



21.1.8 Ramp


Team Eaton
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FILE NAME:
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SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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NOTES:
BASED ON DIMENSIONS, ITEM MUST BE 3D PRINTED
1. REMOVE ALL BURRS
2. BREAK SHARP EDGES .01 MAX
TOLERANCES:
.X ± .05
.XX ± .01
.XXX ± .005
.XXXX ± .0020
ANGLES ± 2°
MATERIAL:
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ALL DIMENSIONS IN INCHES
PROPRIETARY AND CONFIDENTIAL
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SECTION E-E
SCALE 1 : 2
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1.792
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5.400
5.309
5.069
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1.801
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2.506
2.234
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.095
.084
0
23.64°

21.2 Test Matrix

Team 9 Test Results

Test	Results	Comments
Dispenser 1	12 tufts without jamming	Improvement from wheel design
Dispenser 1-fixed	3 tufts, stopped dispensing	Needs to be at angle to dispense
Dispenser 1 - fixed	2 tufts, stopped dispensing	
Dispenser 2	All 12 tufts	Bigger bore worked better
Dispenser 2 -1	All 12 tufts	
“Revolver” dispenser	27 tufts, some jamming	With multiple holes, 1 jam does not stop dispensing
Big dispenser at Eaton	Failed - 0 out of 100 dispensed	Too full, not enough vibration to displace tufts
Big dispenser at Eaton	Failed - 0 out of 50 tufts	Too full
Big dispenser at Eaton	Success - all 20 tufts	Each chamber can’t have more than 20 tufts
V 6 - fixed angle	Success	Dispenser V-6 is chosen to be secondary dispenser
Damping test	Success	Test to determine if the system is underdamped
Damping test - suspended	Success	Test to determine if the system is underdamped with new suspended orientation
Sawzall test	Failure	42 tufts in 3 seconds, multiple tufts damaged
V - 7	Failure	No dispensing
V 7 suspended	Failure	No dispensing
V 7 suspended - low frequency	Failure	No dispensing
V 8	Failure	No dispensing
V 8 low frequency	Failure	No dispensing

21.3 Team Minutes

21.3.1 Nathan Joyal Minutes

Table 8: Nathan Joyal Total Hours

Date	Description	Begin Time	End Time	Total Hours
9/21/2017	Brainstorm different cutting methods	2:00 PM	3:00 PM	1
9/21/2017	Brainstorm different cutting methods	2:00 PM	3:00 PM	1
9/27/2017	Organize questions and binder layout	12:00 PM	2:00 PM	2
10/5/2017	Brainstorm design, patent search keywords	2:00 PM	4:00 PM	2
10/8/2017	Design prototype fixture on SolidWorks	8:00 PM	10:00 PM	2
10/10/2017	Brainstorm methods to cut tufts	3:00 PM	4:30pm	1.5
10/12/2017	Chute design	2:00 PM	4:30 PM	2.5
10/16/2017	10 Design Concepts	8:00 PM	9:30 PM	1.5
10/17/2017	Engineering Design Specifications	4:00 PM	5:30 PM	1.5
10/19/2017	20 Design concepts research loading methods	11:00 PM	4:30 AM	5.5
10/23/2017	Continue adding to Critical Design Presentation	3:30 PM	4:30 PM	1
10/24/2017	Project Plan	12:00 PM	1:00 PM	1
10/31/2017	Model prototype hopper	7:30 PM	9:00 PM	1.5
11/1/2017	Design alternative drum dispenser designs on SolidWorks	12:00 PM	1:30 PM	1.5
11/3/2017	Completed hopper prototype on SolidWorks and 3D printed	2:30 PM	6:30 PM	4
11/9/2017	Researched different methods of dispensing of various products	8:00 PM	10:00 PM	2
11/13/2017	Started to program touchscreen LCD	8:00 PM	9:30 PM	1.5
11/14/2017	Model newer dispenser on SolidWorks	1:30 PM	4:30 PM	3
11/15/2017	Build track/shuttle for prototype	6:00 PM	10:00 PM	4
11/16/2017	Start proof of concept presentation	2:00 PM	4:30 PM	2.5
11/17/2017	Create platform for track and 3D print	6:00 PM	9:00 PM	3
11/27/2017	Assemble proof of concept prototype finish presentation	4:00 PM	3:30 AM	11.5
12/2/2017	Research linear actuators	6:00 PM	9:00 PM	3
12/4/2017	Design and 3D print offload mechanism	6:00 PM	11:00 PM	5
12/8/2017	Edit code for automation to run off of sensors	5:00 PM	10:30 PM	5.5

12/13/2017	Edit code for automation to run off of sensors	11:00 AM	7:30 PM	8.5
12/14/2017	Edit code for automation to run off of sensors	3:00 PM	12:00 AM	9
12/15/2017	Edit code for automation to run off of sensors	10:00 AM	1:00 PM	3
12/15/2017	Create SolidWorks drawings for 3D printed components	4:00 PM	9:30 PM	5.5
12/16/2016	Create SolidWorks drawings for 3D printed components	3:00 PM	9:00 PM	6
1/25/2018	Revise cylindrical dispenser and 3D print	6:00 PM	7:00 PM	1.00
1/26/2018	Experiment with cylindrical dispenser	12:00 PM	2:30 PM	2.50
1/29/2018	Meet with Eaton	10:00 AM	11:00 AM	1.00
1/30/2018	Design and 3D print primary cylindrical dispenser	8:00 PM	10:00 PM	2.00
2/6/2018	Designed and 3D printed ramp for dispenser	6:00 PM	9:00 PM	3.00
2/7/2018	Experimented with new, revised dispenser	12:00 PM	1:30 PM	1.50
2/7/2018	Finished powerpoint for presentation at Eaton	1:30 PM	3:00 PM	1.50
2/7/2018	Redesign loading ramp and 3D print	5:00 PM	7:00 PM	2.00
2/8/2018	Design and 3D print dispenser adapter and slide	5:00 PM	2:00 AM	9.00
2/9/2018	Presentation at Eaton	1:30 PM	3:15 PM	1.75
2/16/2018	Meeting 7 at Eaton	1:00 PM	2:30 PM	1.50
2/17/2018	Organize documentation and update notes from weekly meeting	1:00 PM	2:30 PM	1.50
2/17/2018	Redesign and expand primary dispenser	2:30 PM	5:00 PM	2.50
2/17/2018	Redesign and expand primary dispenser	9:00 PM	11:00 PM	2.00
2/21/2018	Redesign primary dispenser	7:00 PM	2:00 AM	6.00
2/21/2018	Redesign slide and transition piece	4:00 PM	7:00 PM	3.00
2/22/2018	Program arduino uno to analyze dispensing rate	3:30 PM	6:30 PM	3.00
2/23/2018	Meeting 8 at Eaton and experimented with dispenser	1:30 PM	3:30 PM	2.00
2/28/2018	Design and 3D print dispenser with 4 quarters	3:00 PM	5:00 PM	2.00
3/2/2018	Brainstormed why tufts are jamming and designed dispenser V10	12:00 PM	3:00 PM	3.00
3/6/2018	Redesigned and 3D printed ramp V3	11:00 PM	4:00 AM	5.00

3/7/2018	Meeting 9 at Eaton and experimented with dispenser	1:30 PM	2:30 PM	1.00
3/9/2018	Redesigned and 3D printed ramp V4	3:00 AM	5:30 AM	2.50
3/9/2018	Updated binder and calculated vibration values	10:00 AM	3:00 PM	5.00
3/14/2018	Designed overhang for suspended dispenser	3:00 PM	7:00 PM	4.00
3/15/2018	Designed magazine to hold cut tufts	3:00 PM	5:00 PM	2.00
3/15/2018	Modeled pneumatic cutter on SolidWorks	5:00 PM	9:00 PM	4.00
3/15/2018	Researched linear actuators	9:30 PM	12:00 AM	2.50
3/16/2018	Redesigned primary dispenser	11:00 AM	1:00 PM	2.00
3/16/2018	Researched and selected springs to purchase	1:00 PM	2:00 PM	1.00
3/16/2018	Designed housing for dispenser to sit inside of	2:00 PM	4:00 PM	2.00
3/16/2018	Designed spacer to offset funnel from post	4:30 PM	5:00 PM	0.50
3/17/2018	Organized data from vibration experiments on 3/9	2:00 PM	3:30 PM	1.50
3/17/2018	Designed adapters to accommodate different sized dispensers w/ suspended set up	9:00 PM	12:30 AM	3.50
3/20/2018	Test Report	4:15 PM	5:00 PM	0.75
3/21/2018	Designed cylinder dispenser V14	2:30 PM	3:30 PM	1.00
3/23/2018	Researched linear actuators	8:00 PM	9:00 PM	2.50
3/25/2018	Completed design for magazines to hold cut tufts	11:00 AM	1:00 PM	2.00
3/25/2018	Designed and 3D printed track for magazine to sit on	1:00 PM	5:00 PM	4.00
3/25/2018	Designed potential enclosure for covering entire machine	5:00 PM	6:30 PM	1.50
3/28/2018	Meeting 10 at Eaton and experimented with dispenser	1:00 PM	2:30 PM	1.50
4/3/2018	Research linear sensors which can be used with actuator	8:00 PM	9:00 PM	1.00
4/4/2018	Add content to Build and Test Presentation	3:45 PM	6:00 PM	2.25
4/4/2018	Experiment with dispensers and record videos for presentation	6:30 PM	10:00 PM	3.50
4/4/2018	Adjust slide and ramp to operate smoothly - and record video	12:30 PM	2:00 AM	1.50
4/5/2018	Edit and 3D print rod attachment to actuator	10:30 PM	11:00 PM	1.00
4/5/2018	Experiment w/ actuator - pushing multiple tufts through ramp	11:00 PM	12:00 PM	1.00

4/6/2018	Designed and 3D printed Primary Dispenser V5	12:30 AM	5:30 AM	5.00
4/6/2018	Experimented with Primary Dispenser V5	11:00 AM	12:00 PM	1.00
4/6/2018	Designed and 3D printed Primary Dispenser V6	4:00 PM	9:00 PM	5.00
4/9/2018	Reformatted Build Test Pres. for sakai (google presentat. drive to PowerPoint)	2:30 PM	3:00 PM	0.50
4/9/2018	Tested Pri. Dispenser V6	3:00 PM	5:00 PM	2.00
4/10/2018	Experiment with dispensers	4:00 PM	12:00 AM	8.00
4/11/2018	Meeting 11 at Eaton and experimented with dispenser	1:15 PM	2:30 PM	1.25
4/12/18	Attach wire connectors and write code for arduino uno to control actuator through motor controller and limit switches	6:00 PM	12:30 AM	6.50
4/12/18	Assemble and align dispenser, ramp, actuator, limit switches	12:30 AM	2:30 AM	2
4/13/18	Paper draft	3:45 PM	8:00 PM	4.25
4/13/18	Solder and insert wires into ramp, and program ardunio uno	10:00 PM	2:00 AM	4.00
4/13/18	Program Arduino Uno to control actuator, vibrating motors, and ramp's photoresistors	11:00 AM	3:30 PM	4.50
4/13/18	Program Arduino Uno to control actuator, vibrating motors, and ramp's photoresistors	1:30 PM	7:00 PM	5.50
4/13/18	Clean up wires, add switches to override control for actuator from arduino uno's program	8:00 PM	1:00 AM	5
4/14/2018	Improved alignment of actuator: Relocated ramp, dispenser, and limit switches	7:00 PM	11:00 PM	4.00
4/14/18	Soldered and secured custom wire to connect all photoresistors to arduino Mega	12:00 AM	1:00 AM	1
4/15/2018	Designed and 3D printed platform with mounting for servo for tufts to be pushed onto after the ramp			
4/16/18	Repositioned limit switches, added interrupts to arduino code for e-stop & manual override	12:00 AM	2:00 PM	2.00
4/17/2018	Replaced Arduino Uno with Mega, troubleshooted overheating issues, revised code	4:00 PM	7:30 PM	3.50

4/18/2018	Searched online for enclosure to put electronics inside of, as well as push-buttons	12:00 AM	1:30 AM	1.50
4/18/2018	Attached/wired a third limit switch, helped troubleshoot code	12:00 PM	4:00 PM	4.00
4/18/2018	Researched and purchased enclosure, push buttons, power supply, motor controller, relays	6:00 PM	8:30 PM	2.50
4/19/2018	Soldered and ran wiring for new 12V vibrating motors	1:00 AM	2:00 AM	1.00
4/20/2018	Meeting 12 at Eaton and experimented with dispenser	2:30 PM	4:00 PM	1.50
4/21/2018	Fabricate stand to mount electrical enclosure ontop of	4:00 PM	1:00 AM	15.00
4/22/2018	Design, 3D print, and assemble control panel to mount buttons, LCD, and LED indicators	9:00 AM	8:00 PM	11.00
4/23/2018	Rewire/relocate electronics into electrical enclosure	9:30 AM	7:00 PM	9.50
4/24/2018	Rewire/relocate electronics into electrical enclosure	5:00 PM	3:00 AM	10.00
4/25/2018	Finish re-wiring	11:30 AM	4:00 PM	4.50
4/25/2018	Write code for LED indicators and push buttons	5:00 PM	1:00 AM	8.00
4/26/2018	Troubleshoot/write code for buttons and vibrating motors to turn on/off	4:00 PM	1:00 AM	9.00
4/27/2018	Edit poster and brochure	4:00 AM	4:30 AM	0.50
4/27/2018	Edit poster and brochure	8:30 AM	9:30 AM	1.00
4/27/2018	Design Showcase	11:00 AM	3:30 PM	4.50
5/3/2018	Update 3D model of automated tuft cutter	9:30 AM	12:00 PM	2.50
5/3/2018	Updated total costs, updated 3D model	3:15 PM	7:45 PM	4.50

21.3.2 Jay Guilmette Minutes

Table 9: Jay Guilmette Total Hours

Date	Description	Begin Time	End Time	Total Hours
9/21/2017	Brainstorm different cutting methods	2:00 PM	3:00 PM	1
9/27/2017	Visit Eaton	8:00 AM	10:00 AM	2
10/5/2017	Brainstorm design, patent search keywords	2:00 PM	8:00 PM	6
10/7/2017	Developed concept for dispensing method based on straw dispenser	6:00 PM	7:00 PM	1
10/10/2017	Visit Eaton	1:00 PM	2:15 PM	1.25
10/10/2017	Brainstorm methods to cut tufts	3:00 PM	4:30pm	1.5
10/12/2017	Chute design	2:30 PM	4:30 PM	2
10/16/2017	30 Design concepts	4:00 PM	12:00 AM	8
10/17/2017	Model prototype dispenser for 3D printing	1:00 PM	3:00 PM	2
10/17/2017	Work on QFD	3:00 PM	5:00 PM	2
10/19/2017	Start Critical Design Presentation	2:00 PM	5:00 PM	3
10/21/2017	Critical Design Presentation - final draft	9:00 PM	12:00 AM	4
10/23/2017	Continue adding to Critical Design Presentation	3:30 PM	4:30 PM	1
10/25/2017	Actuator research/ methods	8:30 PM	9:30 PM	1
10/30/2017	HRSA cutting methods research	7:00 PM	8:00 PM	1

11/2/2017	Brainstormed and decided on new design approach - mechanical cutting	1:30 PM	4:30 PM	3
11/3/2017	Met with Eaton to discuss further design concepts, decided to move away EDM and back to mechanical cutting	1:00 PM	2:30PM	2.5
11/5/2017	Began servo design for feeder system into blade	7:00PM	9:00PM	2
11/11/2017	Stepper Motor programmed	8:00PM	9:30PM	1.5
11/14/2017	Dispenser redesign	1:00PM	4:30PM	3.5
11/16/2017	Start proof of concept presentation	2:00PM	4:30PM	2.5
11/27/2017	Assemble proof of concept prototype & finish presentation	4:00PM	3:30AM	11.5
12/2/2017	Stepper Motor Code	6:00PM	8:00PM	2
12/8/2017	Edit code for automation to run off of sensors	5:00PM	10:30PM	5.5
12/13/2017	Edit code for automation to run off of sensors	11:00 AM	7:00 PM	8
12/14/2017	Edit code for automation to run off of sensors	4:00 PM	12:00 AM	8

12/15/2017	Edit code for automation to run off of sensors	11:00 AM	1:00 PM	2
12/16/2017	Final Report - Financial Analysis, Design specifications, and circuit diagrams	3:30 PM	9:00 PM	5.5
1/26/2018	experiment with cylindrical dispenser	12:00 PM	2:30 PM	2.5
1/26/2018	Experiment with cylindrical dispenser	12:00 PM	2:30 PM	2.5
1/29/2018	Meet with Eaton	10:00 AM	11:00 AM	1
2/7/2018	Experimented with dispenser	12:00 PM	1:30 PM	1.5
2/7/2018	Power point for Eaton presentation	13:30	3:00 PM	1.5
2/9/2018	Presentation at Eaton	1:30 PM	3:15 PM	1.75
2/14/2018	Research sensors and design placement	12:00	2:30 PM	2.5
2/16/2018	Meeting 7 at Eaton	1:00 PM	2:30 PM	1.50
2/17/2018	User interface development	7:00 PM	9:30 PM	2.5
2/20/2018	Touch screen programming	7:00 PM	12:00 AM	5
2/22/2018	Dispenser testing program design	3:30 PM	6:30 PM	3
2/22/2018	Program arduino uno to analyze dispensing rate	3:30 PM	6:30 PM	3.00
2/23/2018	Meeting 8 at Eaton and experimented with dispenser	1:30 PM	3:30 PM	2.00
3/3/2018	Vibrations research	4:00 PM	8:30 PM	4.50

3/7/2018	Meeing 9 at Eaton and experimented with dispenser	1:30 PM	2:30 PM	1.00
3/8/2018	"Professor Jouaneh consult "	10:00 AM	11:00 AM	1.00
3/9/2018	Updated binder and calculated vibration values	9:00 AM	3:00 PM	6.00
3/18/2018	Test Report	8:00 AM	1:00 AM	5.00
3/20/2018	Vibrations research	5:00 PM	7:00 PM	2.00
3/20/2018	Test Report	4:15 PM	5:00 PM	0.75
3/22/2018	Vibrations research	2:00 PM	3:00 PM	1.00
3/22/2018	Jouaneh consulataion	10:00 AM	11:00 AM	1.00
3/28/2018	Meeing 10 at Eaton and experimented with dispenser	1:00 PM	2:30 PM	1.50
3/29/2018	Jouenah consultation	10:00 AM	11:00 AM	1.00
4/5/2018	Jouaneh consultation	10:00 AM	11:00 AM	1.00
4/11/2018	Meeing 11 at Eaton and experimented with dispenser	1:15 PM	2:30 PM	1.25
4/13/18	paper draft	4:00 OM	8:00 PM	4
4/13/18	Program Arduino Uno to control actuator, vibrating motors, and ramp's photoresistors	11:00 AM	3:30 PM	4.50

4/13/18	Program Arduino Uno to control actuator, vibrating motors, and ramp's photoresistors	3:30 PM	7:00 PM	3.50
4/17/2018	Replaced Arduino Uno with Mega, troubleshooted overheating issues, revised code	4:00 PM	7:30 PM	3.50
4/18/2018	revised code	12:00 PM	4:00 PM	4
4/20/2018	Meeting 12 at Eaton and experimented with dispenser	2:30 PM	4:00 PM	1.50
4/25/2018	"programmed "	5:00 PM	1:00 AM	8
4/26	last minute troubleshooting	4:00 PM	1:00 AM	9
4/27/2018	Design Showcase	12:00 PM	3:30 PM	3.50
5/2/2018	FDR	7:00 PM	12:00 AM	5
		Total:	192.50	

21.3.3 Trevor Gale Minutes

Table 10: Trevor Gale Total Hours

Date	Description	Begin Time	End Time	Total Hours
1/25/2018	Way of alerting operator	4:00 PM	7:00 PM	3
1/26/2018	Experiment with cylindrical dispenser	12:00 PM	2:30 PM	2.5
1/31/2018	Layout of electric/pneumatic energy needs	12:00 PM	3:00 PM	3
2/2/2018	Ramp concept	12:00 PM	3:00 PM	3
2/7/2018	Compiled list of criteria for product testing	12:00 PM	3:00 PM	3
2/8/2018	Change of plans with shielding/aesthetics for new cylindrical dispenser	2:15 PM	16:00	1.75
2/8/2018	Presentation for Eaton	4:00 PM	6:00 PM	2
2/9/2018	Presentation at Eaton	1:30 PM	3:15 PM	1.75
2/16/2018	Meeting #7 at Eaton	1:00 PM	2:30 PM	1.50
2/16/2018	Throughput per cutter we can integrate	4:00 PM	6:00 PM	3
2/21/2018	Tuft collection design considerations	12:00 PM	3:00 PM	3
2/22/2018	Surface finish research	6:00 PM	9:00 PM	3
2/23/2018	Meeting at Eaton and experimented with dispenser	1:30 PM	3:30 PM	2.00
2/25/2018	Product test criteria	2:00 PM	5:00 PM	3.00

2/28/2018	Research linear actuators	12:00 PM	2:00 PM	3.00
2/28/2018	Gear/Tooth/Motor Combination	2:00 PM	5:00 PM	3.00
3/2/2018	Brainstormed why tufts are jamming and designed dispenser V10	12:00 PM	3:00 PM	3.00
3/7/2018	Gear/Tooth/Motor Combo	6:00 PM	9:00 PM	3.00
3/8/2018	Spiral/Screw design that vibrates	3:00 PM	5:00 PM	2.00
3/20/2018	Test Report	4:15 PM	5:00 PM	0.75
3/25/2018	Research solutions to jamming	12:00 PM	5:00 PM	5.00
3/27/2018	Spiral/Screw Design	1:00 PM	4:00 PM	3.00
3/30/2018	Poster	12:00 PM	4:00 PM	4.00
3/30/2018	Build/Test Presentation	4:00 PM	6:00 PM	2.00
4/2/2018	Design magazine to be loaded as backup	12:00 PM	3:00 PM	3.00
4/4/2018	Finish Poster	4:00 PM	8:00 PM	4.00
4/5/2018	SolidWorks magazine	6:00 PM	9:00 PM	3.00
4/11/2018	Meeing #11 at Eaton and experimented with dispenser	1:15 PM	2:30 PM	1.25
4/13/18	Paper draft	3:00 PM	7:00 PM	4.00
4/25/2018	Brochure	11:00 AM	4:00 PM	5
4/26/2018	Troubleshooting before design showcase	5:00 PM	12:00 PM	7
4/27/2018	Design Showcase	12:00 PM	3:30 PM	3.50
5/1/2018	Update minutes/work on final paper	11:30 AM	3:30 PM	4
5/5/2018	Vibration analysis of primary dispenser	10:00 AM	2:00 PM	4.00

21.4 Arduino Code

```
#include <Servo.h>
Servo myservo;
int servo = 1;  //Servo signal
int pos = 45;
int MAX = 4;  //MAX limit switch
int MED = 5;  //MIDDLE limit switch
int MIN = 6;  //MIN limit switch

int MAXstate = 0;
int MEDstate = 0;
int MINstate = 0;
int dir1PinA = 8; //Relay 1 for actuator
int dir2PinA = 7; //Relay 2 for actuator
int PDM1 = 42;  //Signal 1 for motor controller (Primary vibrating motors)
int PDM2 = 43;  //Signal 2 for motor controller (Primary vibrating motors)
int SDM1 = 44;  //Signal 1 for motor controller (Secondary vibrating motor)
int SDM2 = 45;  //Signal 2 for motor controller (Secondary vibrating motor)

long timer = 0;
long timecheck = 0;
long timecheck2 = 0;
long timecheck3 = 0;
long timecheck4 = 0;
long timecheck5 = 0;
long timecheck6 = 0;

int motorstate = LOW;
int motor1state = HIGH;
int x;

void motorcontrol();
void EXTEND();
void RETRACT();
void RESET();
void OFF();
void motorOn();
void motorOff();
void motor2On();
```

```
void setup() {
  myservo.attach(servo);
  digitalWrite(21, HIGH); //enable pullup on digital pin 2, interrupt pin 0
  digitalWrite(2, HIGH); //enable pullup on digital pin 2, interrupt pin 0
  digitalWrite(3, HIGH); //enable pullup on digital pin 2, interrupt pin 0
  digitalWrite(18, HIGH); //enable pullup on digital pin 2, interrupt pin 0
  digitalWrite(20, HIGH); //enable pullup on digital pin 2, interrupt pin 0
  digitalWrite(19, HIGH); //enable pullup on digital pin 2, interrupt pin 0

  pinMode(MAX, INPUT);
  digitalWrite(MAX, HIGH);
  pinMode(MED, INPUT);
  digitalWrite(MED, HIGH);
  pinMode(MIN, INPUT);
  digitalWrite(MIN, HIGH);
  pinMode(dir1PinA, OUTPUT);
  pinMode(dir2PinA, OUTPUT);
  pinMode(SDM1, OUTPUT);
  pinMode(SDM2, OUTPUT);
  pinMode(PDM1, OUTPUT);
  pinMode(PDM2, OUTPUT);
  pinMode(36, OUTPUT);
  pinMode(35, OUTPUT);
  pinMode(34, OUTPUT);
  pinMode(17, INPUT_PULLUP);
  pinMode(21, INPUT);
  pinMode(39, OUTPUT);
  x = 1;
  //Serial.begin(9600);

}

void loop() {
  MAXstate = digitalRead(MAX);
  MEDstate = digitalRead(MED);
  MINstate = digitalRead(MIN);
  digitalWrite(39, HIGH);
  //motorcontrol();
  //motorOff();
 // motor2On();
  //digitalWrite(20, HIGH); //enable pullup on digital pin 2, interrupt pin 0
```

```
 //-------------------------------------------------------
switch (x) {
   case 1: //actuator returns to start position
   digitalWrite(36, HIGH); //RED LIGHT
     motorOff();
     RETRACT();
     if (MINstate == LOW) {
       OFF();
     }
     digitalWrite(35, LOW);  //GREEN LIGHT
     digitalWrite(34, LOW);  //YELLOW LIGHT
     if (digitalRead(17) == LOW) {
       digitalWrite(35, HIGH); //GREEN LIGHT
       x = 2;
     }
     break;

   case 2: //vibration that turns on actuator but doesnt stop vibration
     digitalWrite(36, LOW);  //RED LIGHT - OFF?
     motorOn();
     motor2On();
     motor1state = HIGH;
     OFF();
     timecheck = millis(); //checks for tufts in bottom
     while (analogRead(0) < 200) {
       timecheck2 = millis();
       if (timecheck2 - timecheck > 1000) {
         x = 3;
         break;
       }
     }
     break;
   case 3:
     EXTEND();
     if (MEDstate == LOW) {
       OFF();
       x = 4;
     }
     break;
```

```
    case 4: //servo
      myservo.write(22);
      delay(175);
      myservo.write(45);
      delay(175);
      x = 5;
      break;
    case 5:
      EXTEND();
      if (MAXstate == LOW) {
        OFF();
        x = 6;
      }
      break;
    case 6: //actuator returns to start position
      RETRACT();
      if (MINstate == LOW) {
        OFF();
        x = 3;
      }
      break;
  }
}

void RETRACT() {
  digitalWrite(dir1PinA, HIGH);//RETRACT
  digitalWrite(dir2PinA, LOW);//RETRACT
}
void EXTEND() {
  digitalWrite(dir1PinA, LOW);//EXTEND
  digitalWrite(dir2PinA, HIGH);//EXTEND
}
void OFF() {
  digitalWrite(dir1PinA, LOW);//STOP
  digitalWrite(dir2PinA, LOW);//STOP
}
```

```
void motorcontrol(){
while (analogRead(1) > 50){
  motorOn();
}
while (analogRead(1) < 10){
  motorOff();
}
}
void motorOn() {
  digitalWrite(SDM1, LOW);
  digitalWrite(SDM2, HIGH);
}
void motorOff() {
  digitalWrite(SDM1, HIGH);
  digitalWrite(SDM2, HIGH);
}
void motor2On() {
  if ((millis() - timer) > 1000){
  if (motorstate == HIGH){
    digitalWrite(PDM1, HIGH);
    digitalWrite(PDM2, HIGH);
    motorstate = LOW;
   digitalWrite(39, HIGH);
    timer = millis();
  }
}
if ((millis() - timer) > 3000){
  if (motorstate == LOW){
    digitalWrite(PDM1, LOW);
    digitalWrite(PDM2, HIGH);
    motorstate = HIGH;
   digitalWrite(39, LOW);
    timer = millis();
  }
}
}
```