5-2019

Torch Mounted Wire Nipper

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MDF Group

Spring 2019 Report

Team Members:

Garrett Foust

Matt Montgomery

Steven Patrick

Ben Rouse

Erfan Zahraei

Client: Oak Ridge National Lab Manufacturing Demonstration Facility

ORNL Facilitators: Dr. Mark Noakes & Dr. Andrzej Nycz

Course Instructor: Dr. William R. Hamel

1. Introduction

Oak Ridge National Laboratories' (ORNL) Manufacturing Demonstration Facility (MDF) is a research institution that focuses on additive manufacturing. The metal Big Area Additive Manufacturing (mBAAM) team at the MDF has an industrial robotic arm that implements direct energy deposition (DED) in order to weld metal beads together. After hundreds of beads are welded together a 3D part that is near net shape is made.

The team's project was to help the mBAAM team reduce their printing time by reducing the amount of time spent on cutting wire. After every bead is done being welded, the robot arm needs to cut off the corroded metal in order to get a precise and clean start to the next bead. Before this project, the total time to do a bead cut took 10-15 seconds depending on the location of the robotic arm. The goal for the team was to reduce this time below 5 seconds. In addition to the time requirement, the MDF had weight and size requirements for the team that will be enumerated in later sections.

A 10 second reduction in time may not sound like much, but for parts like the excavator arm shown in Figure 1. 6 hours of the total print time could be spent on just cutting wire. With a 5 second cut time, this could be reduced to 2 hours shaving 4 hours off the total print time. Not only is this saving time, but also money from labor costs to oversee the machine and energy costs to keep the 3D printer on.

During the first meetings, the team found multiple hurdles that needed to be addressed, the biggest one being where to mount the assembly. The team could not put any holes into the torch, and circular objects are more difficult to mount on. The second biggest challenge the team saw ahead of them was keeping the assembly away from the heat while the torch was active. This meant the team needed to think of a moving assembly rather than a stationary one that was already present. The last major obstacle the team discovered was the weight requirement. The older system was at least 10 lbs and the requirements for the team were less than 2.5lbs. Therefore the team needed to optimize any design to remove any unnecessary material.

Figure 1. *Wolf robotic arm used for additive manufacturing. A MIG welding torch is mounted to the end of the actuator.*

2. Team Roles, Responsibilities, and Statements of Work

a. Garrett Foust

My contribution in the second semester was predominately all in the 3D modeling. I helped with the initial modeling and printing of the ball screw design which included four guide rods and two ball screws. The team decided to go with a two guide rod, two ball screw system which I helped optimize the top mounting plate for. I also helped assemble the test stand, and formulate ideas on where components should be placed, such as where to mount the spool of wire and adding a support to the other side of the wire feeder. I designed the mounting plate for the torch to be attached to in order to test the ball screw and pneumatic designs. I measured where the torch needed placed, measured where the holes needed to be for the u-bolts, and designed a "Power T" for aesthetic purposes. I helped with the designing the "Power T" for the cover plate to hide all the cables on the test stand, as well as, the plate to hold the electronic components in the back. After all assembly was done, I helped with alignment, testing, and data collection for both Designs A and B. My role at the showcase was to inform the public on what the overall project was about, what the benefits of both designs were, and some of the drawbacks of each as well.

b. Matt Montgomery

I began this semester by helping with idea generation after feedback from ORNL. We knew that we would need to have means of motion besides pneumatic for our up and down stroke, and therefore I began research for alternate methods. I found a ball screw that fit within our requirements. Once the designs were finalized, and 3D modeling was completed by my teammates, I was able to investigate parts for other areas as well. This included a nipper and blades. The next task that I worked on was the test stand. Using the design that Steven created, I coordinated the build for the torch mounting setup with other team members using aluminum extrusion and completed the the build. After the initial setup, I designed a mounting method for the wire feeder and, with help from other team members, finalized the test stand to display our prototypes. Once the test stand was completed, I was able to help Steven to program the electronic components and confirm the system functioned properly. With the programming complete, it was then time to begin testing the devices. I helped to troubleshoot errors as they arose as well as collect data for the final report and presentation. Finally, at the faculty judging and the showcase I was present to answer questions that others had as well as show how the device functioned.

c. Steven Patrick

For this semester, I have been designated the team leader. Therefore, my tasks from last semester will be augmented with the managerial tasks. This includes setting up meetings with ORNL, setting up meetings with Dr. Hamel, making sure everything gets turned in, and keeping our team motivated. In addition to being team leader, I will also contribute in writing portions of deliverable documents and presenting at meetings.

For the team's project, I will be implementing the coding and wiring of our project this semester. For this task I will be aided by Matt. For coding, I will need to integrate the sensors to make sure the nippers are level, send electrical signals for on and off, and finished signals to the main robot controller. For wiring, I will need to power all of the sensors, nipper, and Arduino, as well as have signal connections between all of those components.

In addition to those tasks that were previously mentioned last semester. I am also in charge of creating the testing stand. This stand will be used for both reliability testing and as a demonstration piece at the expo. For this task, I will model the test stand and specify all the pieces needed for its construction. Matt and I will work together to create a written document to define the goals of this testing stand and relay the results. We will also work together to put the test stand together.

d. Ben Rouse

My goals for this project were to contribute to the overall success of the group by utilizing my specific knowledge and skill sets. In particular, I enjoy the design and modeling process and I feel that I am skilled at making poster presentations and editing reports. These were the tasks that I intended to assist with.

At the beginning of the semester I helped edit and refine the model. Some of this help was in the form of suggestions while some were actual models that I designed. I designed the mounting plate which held the pneumatics as well as the back plate which hid our wiring from the public. I oversaw the design of our poster and provided heavy editing to our final report. Aside from these specific tasks I also tried to make myself available to the team to provide background assistance where needed, for instance during the building of the test stand and during testing of the final prototypes.

e. Erfan Zahraei

My duties this semester included: creating the finalized Design 'B', creating our main order list for both designs, maintaining the GANTT schedule, researching and updating existing pneumatic diagrams. Group based duties included: attending group and client meetings, participating in feedback, and ensuring I communicated with Steven to understand the action items.

The main update to was the mounting clamps and type of air cylinder utilized for the design. Using feedback from our clients, I created the new Solidworks assembly file to model and demonstrate the functionality of the pneumatic option we agreed on. This new design featured a custom non-rotating pneumatic cylinder with dual-rods as well a stronger mounting clamp to facilitate mounting the devices to the torch. The design eliminated the requirements for adding linear guide rods and bushings, and was able to still be self-aligned using the dual-rod cylinder.

We had to control our air components with pneumatic solenoid valves. I researched and learned about pneumatic symbology to create the required pneumatic PID diagrams on AutoCAD® LT. The main issue with regard to the pneumatic system for our test stand consisted of procuring the appropriate pneumatic solenoid valve for our air nipper. I realized a single acting pneumatic solenoid valve was required with a spring return mechanism built-in. After consulting Dr. Hamel and the group, we agreed to install all three of our solenoids on one solenoid manifold, but due to the vendor not offering the same style pneumatic solenoid that matched the interface of the solenoid manifold, we had to mount two of our pneumatic solenoids on the manifold base, and the one for the pneumatic nipper separately on a mounting plate. We managed to create an aesthetically appealing presentation using Ben's custom made mounting plate.

3. Work Breakdown Structure

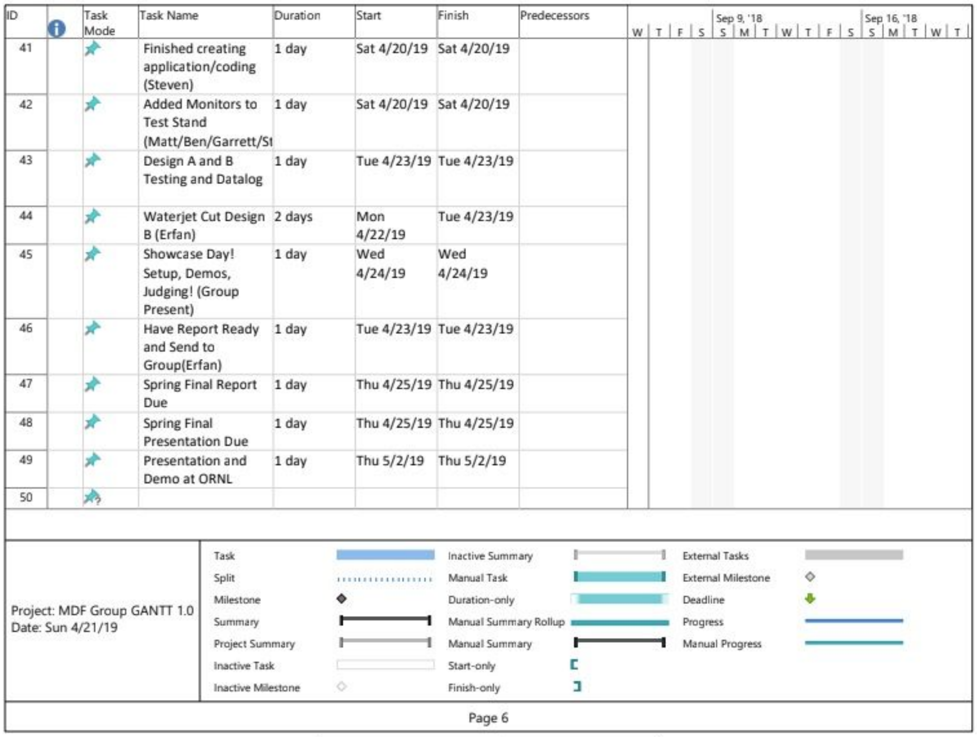
The first semester of the project was largely spent on organization and design. The initial project guidelines were discussed with the MDF contacts and team members documented the functions and requirements as well as their individual statements of work. Each member also developed a design pitch, with the full team performing a concept trade-off analysis to choose the best potential design.

In the second semester it was determined that the team would actually be constructing two prototypes, one actuated by a ball-screw motor and one actuated by a pneumatic cylinder. From here, the team began to split into groups to divide the work. Steven and Matt did research to choose ball-screw motors. Ben and Garrett worked developing a base model for the ball-screw design. Erfan began work on the pneumatic design, developing a model that was later optimized by Steven. Matt and Garrett began working on the design for the test stand, which was constructed by the team. The pneumatics were worked on by Erfan, who ordered the parts, and Ben, who developed a mounting plate to store the components neatly on the test stand.

With the rest of the team developing the mechanics of the project, Steven worked on the electrical wiring and developed the software that would control the prototypes during testing and demonstrations. The group then reunited to mount all components onto the test stand, rearrange wires and tubing to make the prototype more visually appealing, and run testing and data collection for each prototype. The team then presented their work at the University of Tennessee 2019 Senior Design Showcase.

4. GANTT Schedule

The GANTT schedule underwent 11 revisions since August 2018. It was updated each month to reflect changes. A sample of the GANTT schedule for the final portions of the project has been included in Figure 2.



ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
41			Finished creating application/coding (Steven)	1 day	Sat 4/20/19	Sat 4/20/19	
42			Added Monitors to Test Stand (Matt/Ben/Garrett/St	1 day	Sat 4/20/19	Sat 4/20/19	
43			Design A and B Testing and Datalog	1 day	Tue 4/23/19	Tue 4/23/19	
44			Waterjet Cut Design B (Erfan)	2 days	Mon 4/22/19	Tue 4/23/19	
45			Showcase Day! Setup, Demos, Judging! (Group Present)	1 day	Wed 4/24/19	Wed 4/24/19	
46			Have Report Ready and Send to Group(Erfan)	1 day	Tue 4/23/19	Tue 4/23/19	
47			Spring Final Report Due	1 day	Thu 4/25/19	Thu 4/25/19	
48			Spring Final Presentation Due	1 day	Thu 4/25/19	Thu 4/25/19	
49			Presentation and Demo at ORNL	1 day	Thu 5/2/19	Thu 5/2/19	
50							

Figure 2. *GANTT Schedule for Mid-April/May 2019*

5. Overall Design Process

During the first semester, the team brainstormed ideas independently. Everyone's initial concepts can be seen in Figure 3. Once everyone had 3D modeled an initial concept, the team quantified the pros and cons of each design into a cost analysis chart seen in Appendix G.

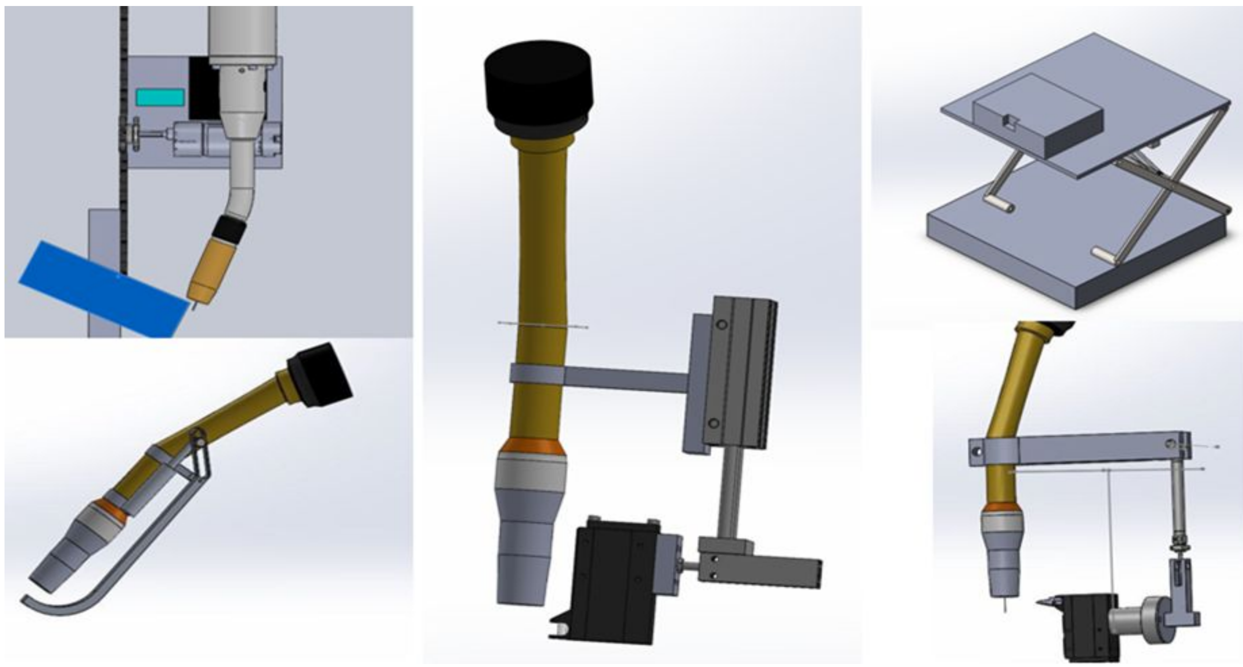


Figure 3. *These are the first initial design concepts. (Top Left) Rack and pinion with servo (Bottom Left) 1 DOF linkage system (Center) 2 stage pneumatic (Top Right) Non-torch mounted elevated platform (Bottom Right) 2 stage pneumatic.*

Once the top design from the cost breakdown chart was chosen, then the team made more edits to the assembly and presented it to the MDF. This iteration can be seen in Figure 4. The MDF brought up many concerns with the design. They said it would not stay mounted because the two top halves were touching, the assembly was likely to bind from asymmetry, and the cutters used would result in a bent wire.

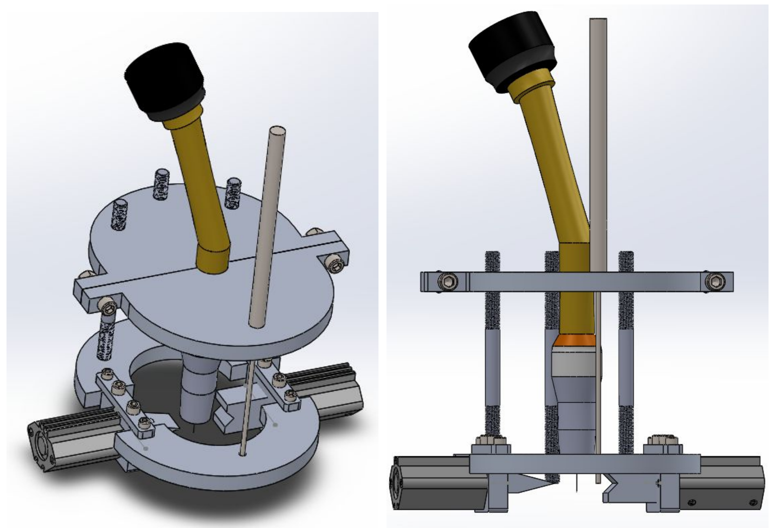


Figure 4. *First concept proposed to the MDF*

With all of those critiques in mind, the team went back to the drawing board and came up with a new iteration. This iteration can be seen in Figure 5. The team changed from a pneumatic for the downward motion to synchronous ball screws accomplishing the task. Furthermore, the sleeves were added to the guide rods to prevent misalignment. With those design changes, the major improvements on this design came from its symmetry and better nipper action. An added bonus with the new design was that the ball screws would allow for a variable wire length, unlike the pneumatics previously used.

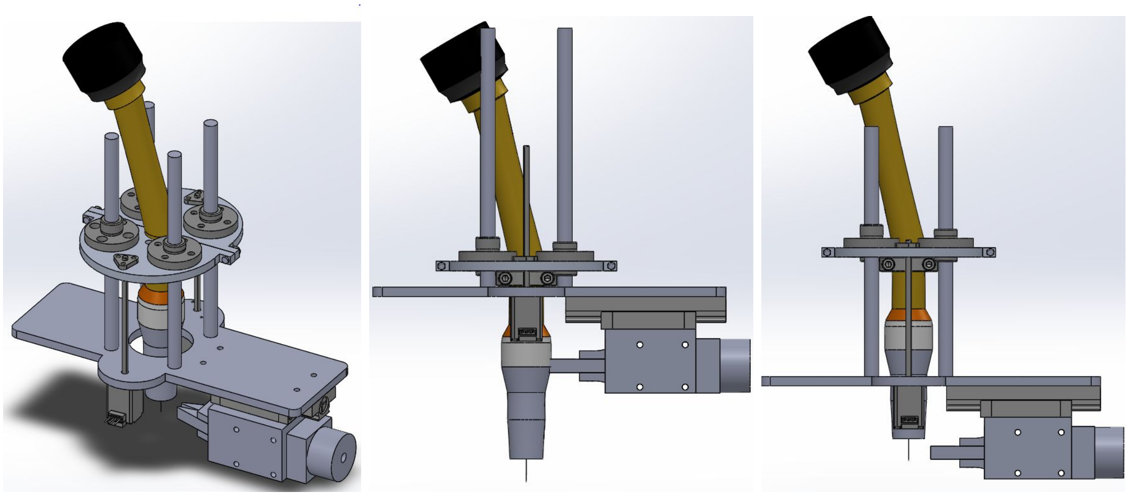


Figure 5. *Second concept proposed to the MDF*

Even though the MDF was happy overall with the design, they still wanted the team to improve upon it by optimizing it for weight as well as have a fall back plan in case getting the ball screws to move synchronously proved to be impossible. The team took these challenges and implemented them in the next iteration of designs.

The improvements to the ball screw design focused on reducing weight. The team took out unnecessary material out of the top and bottom plates. One team member even found a way of removing two of the guide rods to further reduce the weight. For the second design that was requested by the MDF, a pneumatic approach was introduced. This design would be far lighter and was less likely to bind. Both of these designs can be seen in Figure 6.

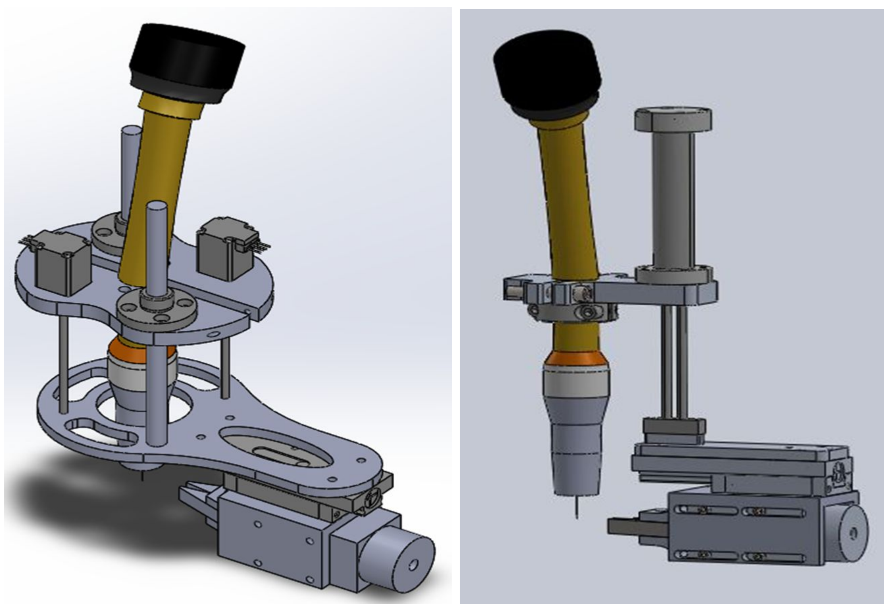


Figure 6. *Third iteration shown to the MDF. (Left) Optimized ball screw design. (Right) New pneumatic design*

6. Mechanical Design Features

6.a Ball Screw Design

Two linear motors were installed on 3D printed brackets on a torch mount design to actuate a pneumatic nipper upwards and downwards. A linear pneumatic slide was then used to actuate the nipper towards the electrode wire. Finally, the nipper was activated to nip the electrode wire from the torch at a predetermined length of 12mm (+/- 0.5mm). This design used off-the-shelf parts consisting of: a Nile-Merry® MS-10 Air Nipper, Thompson® MLA series motorized ball-screw motors, and a Misumi® pneumatic slide. The pneumatic solenoid valves were obtained from McMaster-Carr. A 5/2 pneumatic solenoid valve which was normally closed was installed and plumbed to the Misumi® pneumatic slide. A 3/2 pneumatic solenoid valve which was normally closed was installed and plumbed to the air nipper.

Relays were utilized to power the pneumatic solenoids and controlled by an Arduino® microcontroller. A 24VDC power supply powered the relays, motors, and motor controllers. The Arduino® was controlled by a graphical user interface (GUI), which allowed the user to control device positioning and command the device to run through a given number of cycles. For each cycle the design would lower, actuate forward, nip the wire, and reset to home position above the torch nozzle.

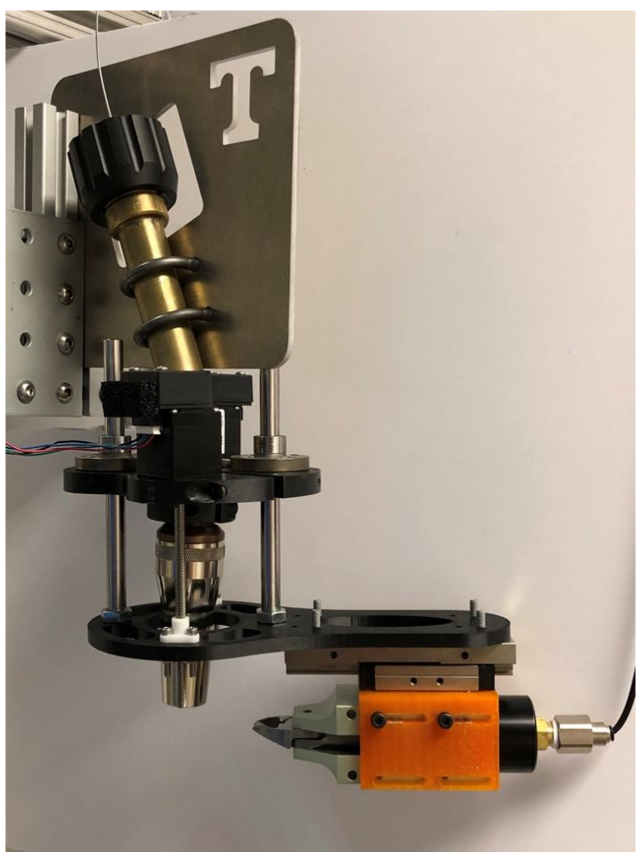


Figure 7. *Ball screw design*

6.b. Pneumatic Design

In this torch-mounted final design, three pneumatic components were installed for functionality. The three pneumatic components used in this design were: a round-body non-rotating dual-rod Bimba® pneumatic round body cylinder, a Misumi® double acting linear pneumatic slide, and a Nile-Merry® MS-10 spring-return single acting pneumatic machine-mountable square body nipper. The brackets designed to mount to the welding torch were 3-D printed and cut on the waterjet machine.

The Bimba® air cylinder extends downwards lowering the slide and nipper. The slide actuates the nipper forward to meet the electrode wire. The air nipper then cuts the electrode wire. Pneumatic solenoid valves (24VDC NC) obtained from McMaster-Carr were used to facilitate air to the components upon a signal. A 5/2 valve was connected to the Bimba® cylinder, and another 5/2 valve was connected to the Misumi® pneumatic slide. The air nipper was connected to a 3/2 valve. The external power supply of 24VDC supplied the pneumatic solenoids and relays the power required to operate. An Arduino® microcontroller activated each component per instruction from code. A GUI was utilized to operate the design from a laptop. The extension and retraction speed of the Bimba® pneumatic cylinder could be controlled using adjustable meter in/out valves placed on the in/out ports of the Bimba® air cylinder.

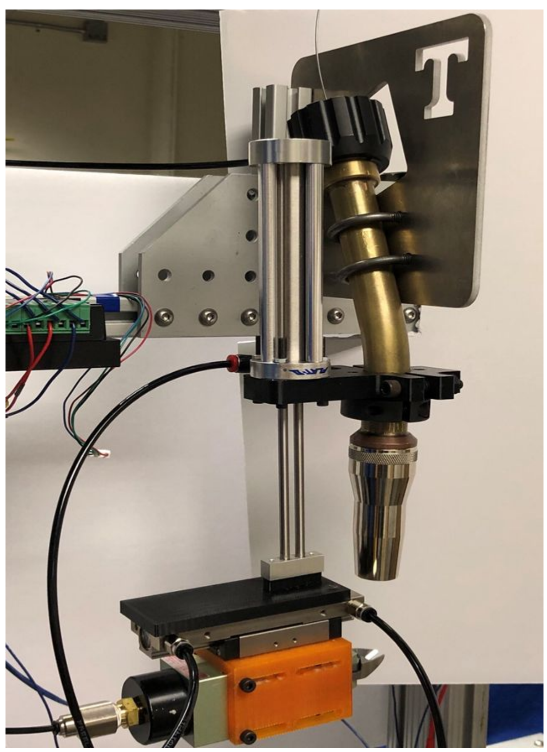


Figure 8. *Pneumatic Design*

7. Electrical and Electronic Features

7.a. Control System

The electronics architecture, on a high level, consists of a laptop sending commands to an Arduino. The Arduino then executed the commands by either activating relays, spinning the motors, or measuring the sensors. There were three modes of operation for this project: Manual, Automatic, and Individual Functions. These windows are further discussed in the next section.

On a lower level, the relays worked by creating a open circuit between the power and the pneumatics. Whenever the Arduino sent an ON signal to the relay, the open circuit would close thereby supplying 24V to the pneumatic connected to the relay. An OFF signal would open the circuit back up. A diode was used to prevent voltage spikes. The ball screws worked by activating the coils in a clockwise or counter-clockwise order depending on the desired motion. This involved having an Enable, Pulse, and Direction pin connected to the Arduino. The sensor was read by connecting the output terminals to a resistor connected to ground. The Arduino pin for the sensor was analog, so it could read the output voltage. A high level schematic of the signal paths can be seen in Figure 9.

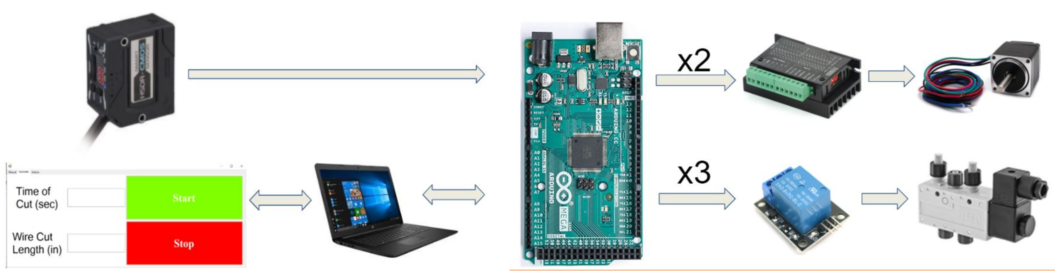


Figure 9. *High level diagram of signal paths.*

The code for this program was a large switch statement with every function having its own unique character to identify which function to run. For the ball screw design, first the motors would activate simultaneously to the human eye. In reality, they would alternate taking a step until the desired amount of rotations was made. Then the pneumatic slide would activate placing the nipper in cutting range of the wire where it would activate the nipper pneumatic to cut the wire. To return, the nipper blade pneumatic deactivated. Soon after the slide pneumatic would deactivate making the nipper clear the torch. Finally, the ball screws would move opposite to the downward motion and return to the home position.

7.b. User Operator Interface

There are three main windows of the User Interface (UI). They are titled manual, automatic, and arduino. The manual mode is meant for activating each stage of the cutting process a single action at a time. The user first activates the assembly going down, then moving the nipper inwards, cutting, moving the nipper outwards, and finally moving the assembly back to the home position. All of these actions have a button associated with them. In addition to that, the user can see both motor positions and the wire cut length. The window for manual can be seen in Figure 10.

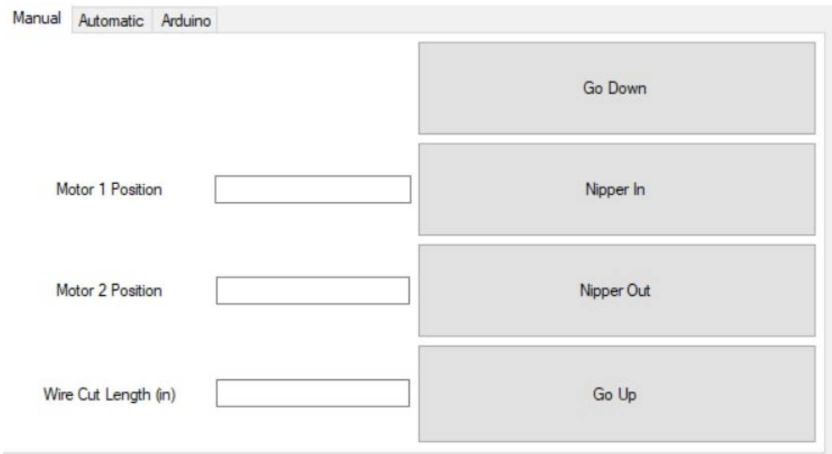


Figure 10. *Manual window of UI*

The second window, "automatic", just has a start and stop button. Start makes the assembly do multiple cuts in a row and will stop cutting whenever the stop button is pressed. The user will see the amount of time each cut took as well as the wire length that was cut. The window for this can be seen in Figure 11.

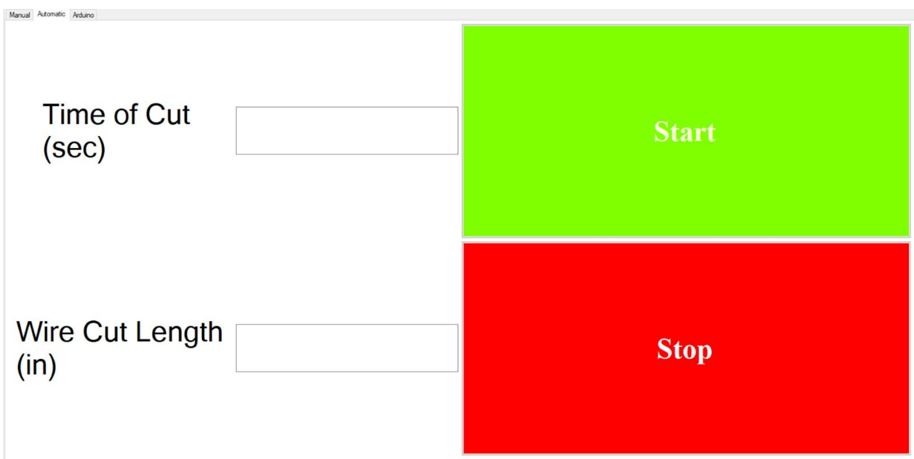


Figure 11. *Automatic Window*

The final window for the UI was to test all of the functional aspects of the assemblies. So every function that was in the Arduino code had a corresponding button to press. These included unspooling and respooling the wire, turning on/off all of the relays, moving the motors individually, and moving the motors synchronously in both upward and downward directions. This window can be seen in Figure 12.

Figure 12. *Arduino functions window*

8. Engineering Analyses

8.a. Safety

Most of the safety hazards associated with the current prototypes involve the pneumatic nipper which is mounted to them. It is essential that personnel keep their hands clear of the wire when the nipper is functioning to avoid being cut. It is also important to be aware that due to the power exerted by the nipper when in use, the cut ends of the wire can become airborne, causing a potential eye risk. It is recommended that safety glasses be worn when testing the device. Even when inactive, the sharpness of the blades presents a potential safety concern and users would be advised to handle the devices with care to avoid piercing or cuts.

For safe device operation, insulation of wires is necessary. Heat wrap and tape are possible solutions which the clients will have to implement upon installation of the device. Heat-rated pneumatic tubing will also have to be substituted upon final installation at ORNL. Welding temperature data from FLIR camera recordings provided visual data of heat zones around two key areas a) torch nozzle and b) torch body. The aluminum construction of brackets for the device will be able to withstand the average temperature of 60℃ along the torch body. The nipper will be able to tolerate the higher average temperature of 275℃ along the torch nozzle.

8.b. Materials

The base plates and mounting brackets used in the prototypes were 3D printed. This was done for cost, as well as for ease and speed of creation. For a "proof-of-concept" model, these parts were acceptable. For actual application, however, a new material would have to be chosen which would be capable of withstanding the heat experienced when welding. The team recommends using 6061-T6 aircraft grade aluminum due to its strength and lightweight nature. In a high-heat environment, aluminum of this grade will have enough capability to withstand the temperatures surrounding the welding torch and provide a rigid platform on which to mount the device.

For the pneumatic design, a finite element analysis (FEA) provided displacement data to ensure the loads on the bracket would not bend it more than 2mm. The FEA was run through Solidworks and showed that the expected deformation was within range, as shown in Figure 13. Analysis of the effects of loading on the pneumatic cylinder head was not performed, but would have provided finer details on the effects of loading.

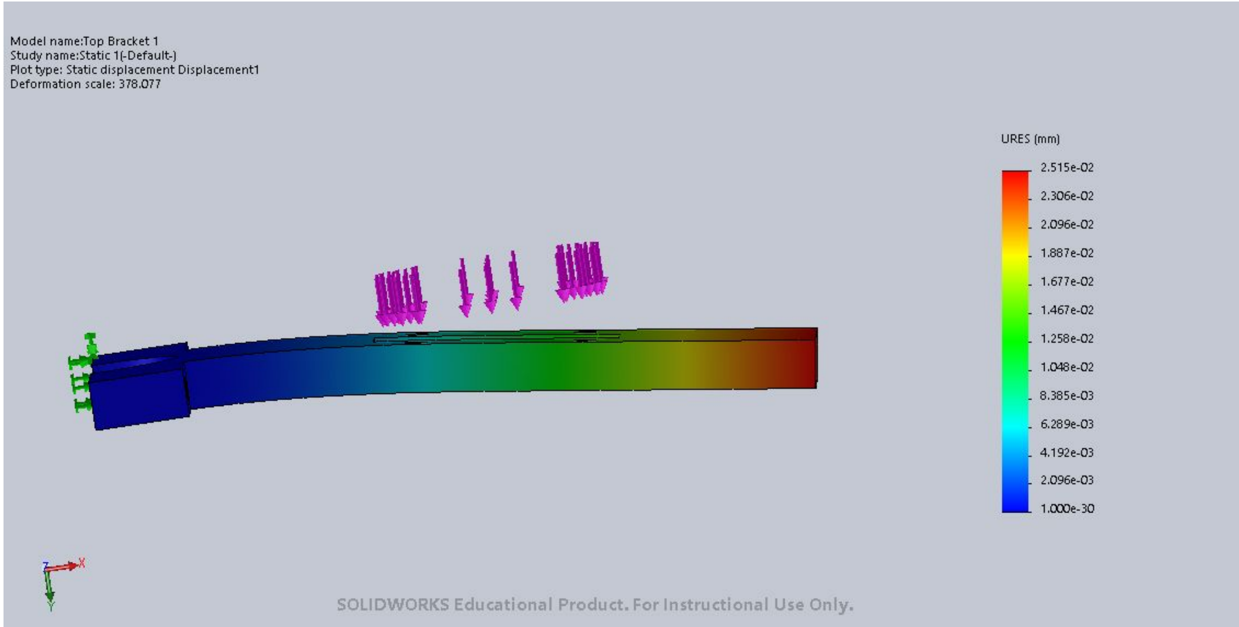


Figure 13. *Finite Element Analysis Displacement Results from Static Study for the pneumatic design bracket*

8.c. Fabrication and Assembly Notes

The ball screw design features holes which must be drilled on the mounting face, after it is printed or cut on the waterjet machine. The pneumatic design also follows this modification process. Both design brackets are first cut on the waterjet machine using ⅜" (ball screw) and ½" (pneumatic) 6061 aluminum plates. Mounting holes for the devices are pre-cut on the waterjet to the size the tap drill requires, so hand-tapping can be performed after waterjet cutting is performed. The hardware utilized to attach brackets together are black-oxide steel. The components such as the pneumatic slide, nipper, and round-body cylinder can be assembled using stainless steel or black-oxide coated fasteners. For longevity, black oxide fasteners on all parts in contact with aluminum are recommended to prevent galvanic corrosion.

The small spacer bracket of the pneumatic design must be cut on the waterjet using 0.16in 6061 aluminum sheet. Correct fastener lengths must be used for the adapter plate of this design which connects the Misumi® pneumatic slide to it such that the bolts bottom out at the top of the adapter plate and do not interfere with the torch bracket right above it when in a retracted state.

9. Testing

9.a. Test Stand

The test stand was constructed from aluminum extrusion tubing. The base was designed to facilitate a mounting plate for: an Omron® displacement sensor, a plate for mounting pneumatic solenoid valves, and leveling legs. The mid-section was built to clamp the torch provided by ORNL for testing. A custom waterjet cut plate was added to the mid-section to extrude outwards and serve as a mounting plate for the torch. Also included on the mid-section were motor controllers mounted to the extrusion tubing. Above the torch mounting plate, an upright was added with extrusion tubing beams to facilitate mounting a wire-feeder motor. The wire-spool of electrode was mounted above the wire-feeder motor and inserted into the wire-feeder motor. From the wire-feeder motor, wire was inserted into the top hole of the torch. This test stand was finalized with the addition of LCD monitors on the left and right sides for showcase display. The final design can be seen in Figure 14.

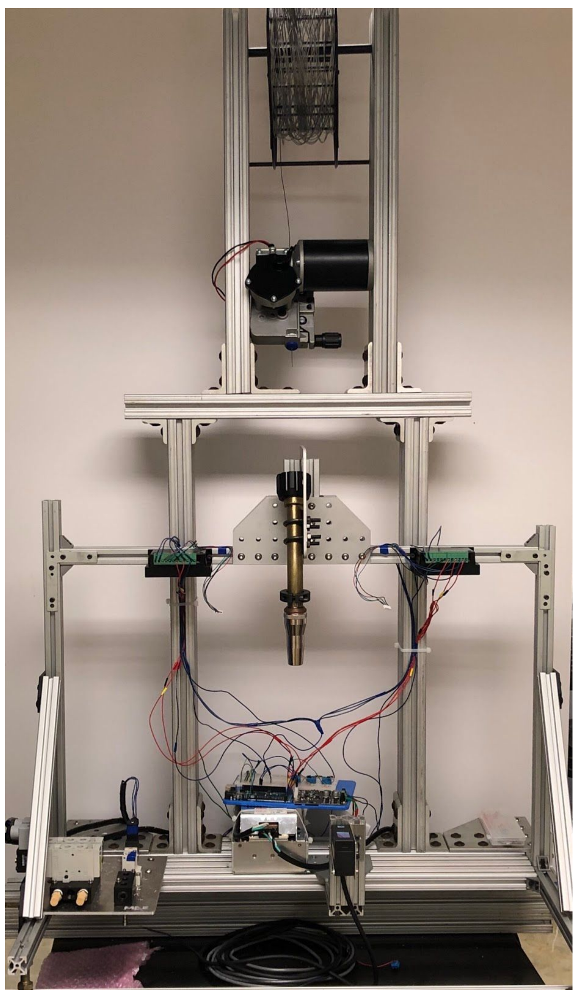


Figure 14. *Completed Test Stand Testing Procedure*

9.b. Testing Procedure

For testing, both designs were tested by mounting them onto the torch attached to the test stand. 50 test runs were done for each design. These were done in increments of 10 by pressing the Start button on the app and letting it run 10 times. The team read the displayed measurements and recorded them in addition to whether or not the cut was successful.

9.c. Testing Results

The results for the ball screw and pneumatic design can be seen in Figure 15 and 16 respectively. The ball screw design had a 100% successful cut rate. However, it did have a slight variability in the length of the wire cut. The pneumatic design was nearly the complete opposite. It consistently failed to cut the wire, but it had a much tighter range of wire cut lengths.

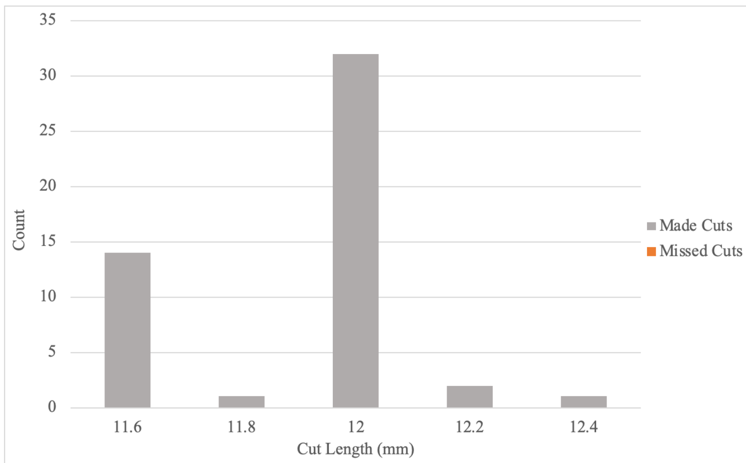


Figure 15. *Ball screw design testing showing successful and failed cuts for 50 device cycles*

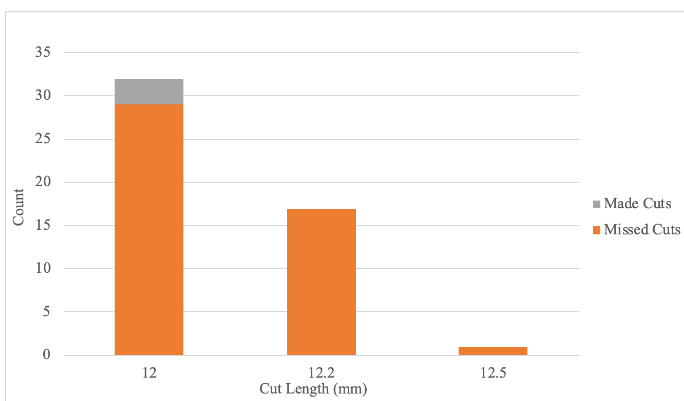


Figure 16. *Pneumatic design testing showing successful and failed cuts for 50 device cycles*

10. Conclusion

Overall, both designs accomplished the project goal of consistently cutting the welding wire to the desired length. Both designs met the time and size requirements the MDF gave. However, neither of them met the weight requirement. After talking with the customer, they said this was the least stringent requirement. The two designs did have a few differences. The ball screw design had a 100% cut rate while the pneumatic design missed more than it cut. Additionally, the pneumatic design had a more consistent wire cut length, but the ball screws' had a slightly larger variation.

In regards to senior design as a whole, all team members have become better engineers with this experience. Learning how to design a working assembly from scratch is an amazing experience to have as an undergraduate student. The learning is even more valuable because of the experiential knowledge the mentors and advisor supplied the team. Not only were technical skills heightened, but the team also bettered their soft skills like communication, aesthetics, and most importantly team work.

Appendix A Functions & Requirements

Client: Oak Ridge National Laboratory- Manufacturing Demonstration Lab (MDF)

Project: Signal-Activated Torch-Mounted Pneumatic Welding Wire Nipper
Project Completion Date: Spring 2019 (January-May)

1. Project/System Objectives:

Design and build an automated wire cutting device which shall be mounted on the M.I.G. welding torch attached to the robotic arm at ORNL MDF.
Design a device that meets the requirements of ORNL MDF for application on the robotic welding arm.
Manufacture the prototype(s). Off-the-shelf parts are subject to use.
Assemble the prototype(s). Make enhancements to achieve quality final build.
Test the device utilizing a quantitative testing procedure.
Submit a final proof of concept to client and demonstrate operation by May 2019.

2. System Structure/ Configurations:

The software configuration will be performed using C++ programming language.
The hardware configuration will be performed using an Arduino MEGA microcontroller, pneumatic components, and digital sensors.
The metallic device will be affixed to the welding torch body and operate in stages.
Activation of the device shall be performed outside of the room that the device is in.

3. Functional Requirements:

Device must mount to the torch body and sit above the torch nozzle when at rest.
Device must be simple to install and remove.
Device maximum cycle time is 5 seconds, and within this period the device will have to be back in resting position.
Device must repetitively nip the welding wire with a high degree of reliability.
Device must remain aligned always.
Device must be programmed to not activate its cutting function during misalignment.

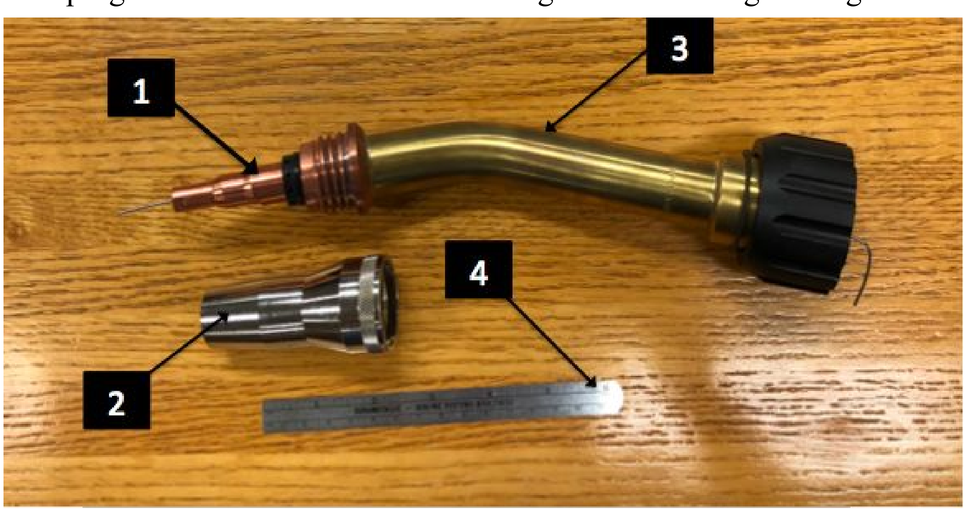


Fig. 1 Torch Provided for Prototype and Iterative Testing (Property of Oak Ridge National Labs)
1) Collet Body 2) Torch Nozzle 3) Torch body 4) Scale for visual reference

4. Physical Requirements:

Device must be less than or equal to 2.5lb.

Device must not exceed 6in of length in all directions.

Mounting location of device shall be along torch body.

Device must be mounted with adequate clamping to prevent motion along the vertical axis.

Device may use different style clamps or a clamshell style mounting feature to mount onto the torch body.

Device must remain in a non-interfering position when not in use.

5. Performance Requirements:

The final cut length of welding wire shall be 12mm +/- 0.5mm.

Device shall have guide rods to prevent misalignment.

Device must pass quality control and iterative testing before submittal to client.

6. Safety Requirements:

Device must be insulated against temperatures common in its environment.

Research will be performed and data logged from FLIR recordings of the welding arm in operation to assist in material selection and component selection.

Heat rated pneumatic hose shall be used for all pneumatic accessories integrated into the device.

Digital sensors with level sensing capabilities may be used to align the device shears to prevent misalignment and damage to surroundings.

The iterative testing procedure that will be written by the team shall be reviewed by all facilitators before being subject to utilization in assembly testing.

7. Materials and Fabrication Requirements:

Materials shall be ordered from ORNL following review from the facilitators.

Device must be manufactured from material that will withstand very high-temperatures for prolonged periods of time.

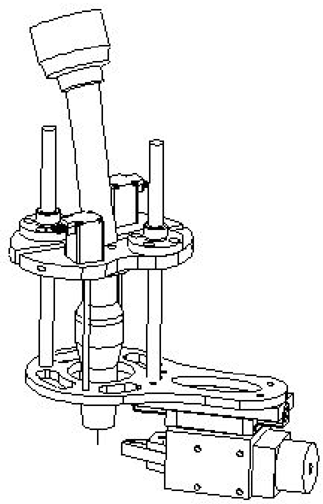
All fabrication shall be performed at the University of Tennessee MABE department manufacturing lab.

Electrical accessories and components shall be mounted in a location away from the device with appropriate wiring insulated from heat along the welding arm.

Heat-rated insulation shall be used and procured for proof of concept.

Appendix B Bill of Materials for Ball Screw Design

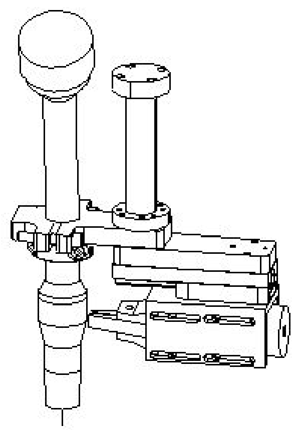
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MLS08A05-180050P04000N-A000-RS1	Thompson Motors with Ball Screw	2
2	MS10 Square Machine Type Air Nippers	Merry MS-10 Air Nipper	1
3	9246K21 McMaster-Carr	6061 Aluminum Plate .375in 8"x8"	2
4	U-LHIFR0.38	Misumi Bushings Stainless Steel	2
5	MPPT12-25-N	Misumi Pneumatic Slide	1
6	U-SSFAN0.38-L5-F0.75-B0.75-T0.38	Misumi Linear Guide Rods	2



DesignA BOM

A3

Appendix C Bill of Materials Pneumatic Design



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	McMaster-Carr 9246K31	6061 Aluminum Plate 1/2"	1
2	McMaster-Carr 89015K94	6061 Aluminum Sheet .16"	1
3	FTM-0485-3SV	Bimba Metric Flat-II Non-Rotating Metric Cylinder 19mm Bore 85mm Stroke	1
4	Misumi (MS-10)	Merry MS-10 Nipper	1
5	MPPT12-25-N	Misumi Pneumatic Slide	1

DesignB BOM

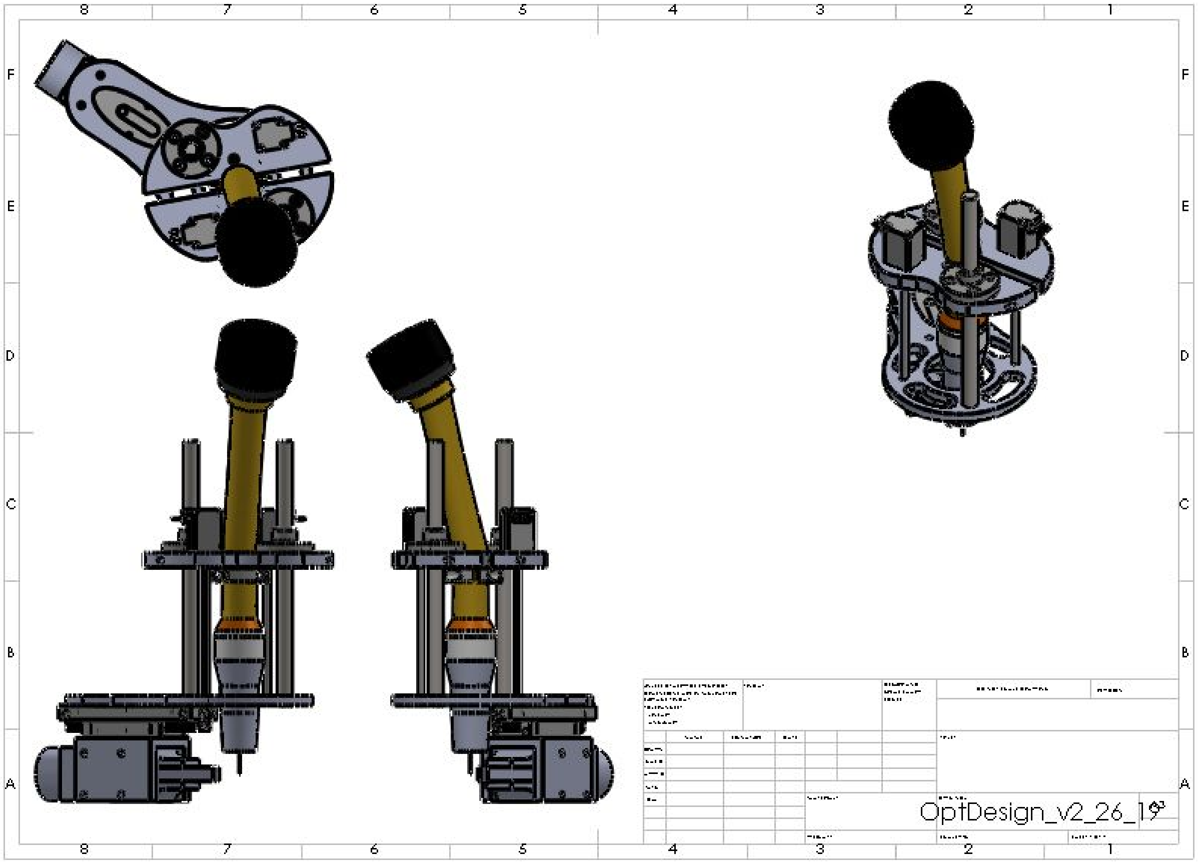
A3

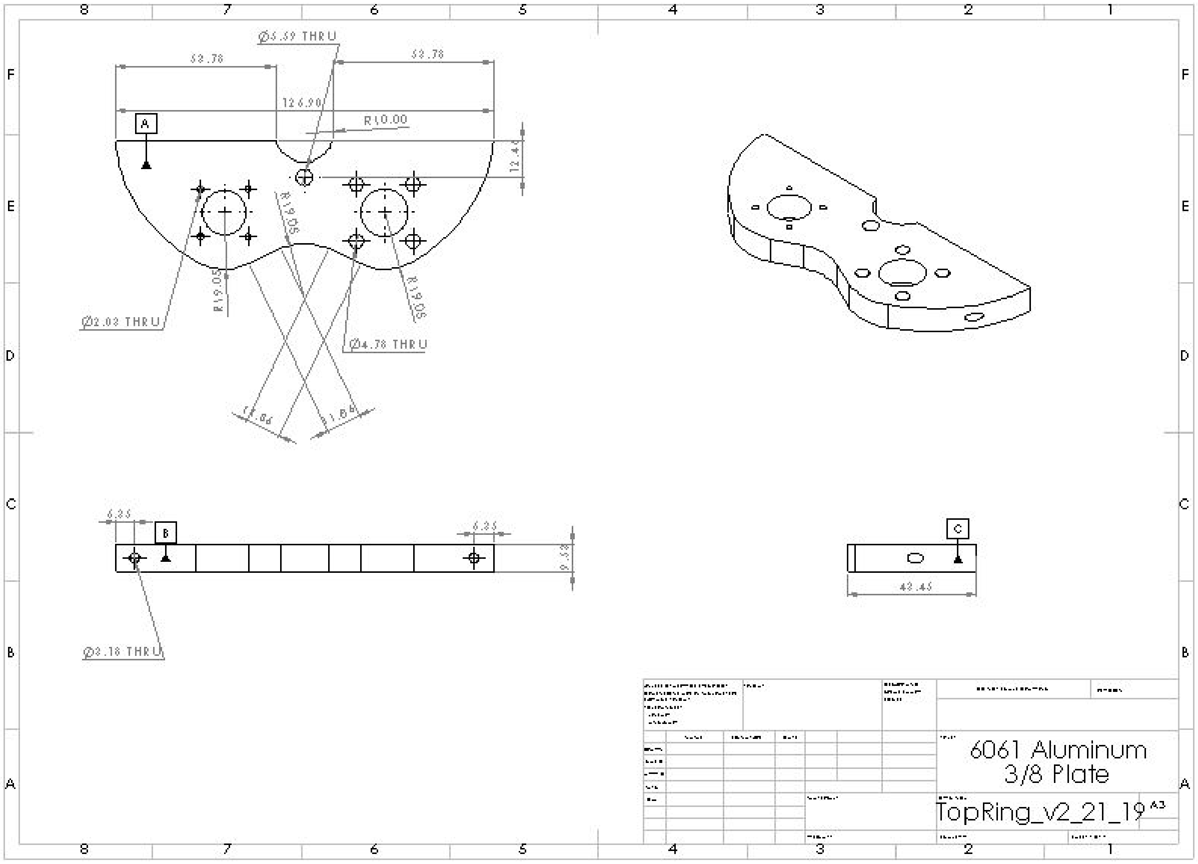
Appendix D Bill of Materials for Pneumatic Components

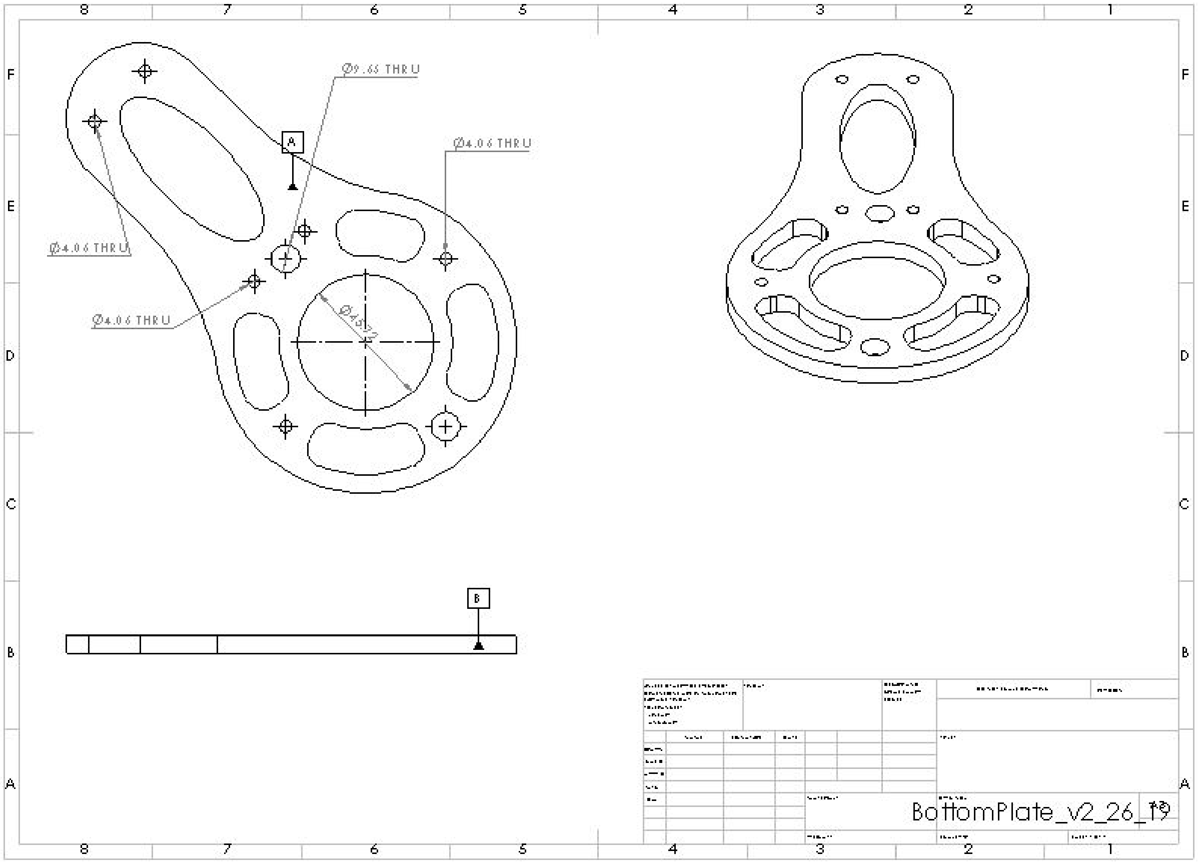
Part Number	Description	Quantity	Source
6124K272	3-Way Spring Return Solenoid, 3 Port, 1/8 NPT, 24V DC	1	McMaster -Carr®
6425K113	High-Flow, Single Solenoid, 1/8 NPTF, 24V DC, 56 scfm	2	McMaster -Carr®
4934A13	Pipe Thread Sealant Tape	1	McMaster -Carr®
1023N12	Straight-Flow Rectangular Manifold	1	McMaster -Carr®
5779K135	Straight Adapter, for 3/8" Tube OD x 1/4 NPT Female	1	McMaster -Carr®
5388K14	Steel Screw, 5/16" Wide Band, 7/32" to 5/8" Clamp ID	1	McMaster -Carr®
5361K32	1/4" Hose ID, 1/4 NPT Male End	1	McMaster -Carr®
6534K66	Size 1/4, Zinc-Plated Steel Plug, 1/4" Hose ID	1	McMaster -Carr®
5108K52	Tubing for Compressor 1/4" ID, 1/2" OD 10 FT LENGTH	1	McMaster -Carr®
6425k31	2 Station Manifold for Style A Pneumatic Solenoids	1	McMaster -Carr®
4450K2	1/4" NPT Muffler	4	McMaster -Carr®
8288A51	Tubing Cutter	1	McMaster -Carr®

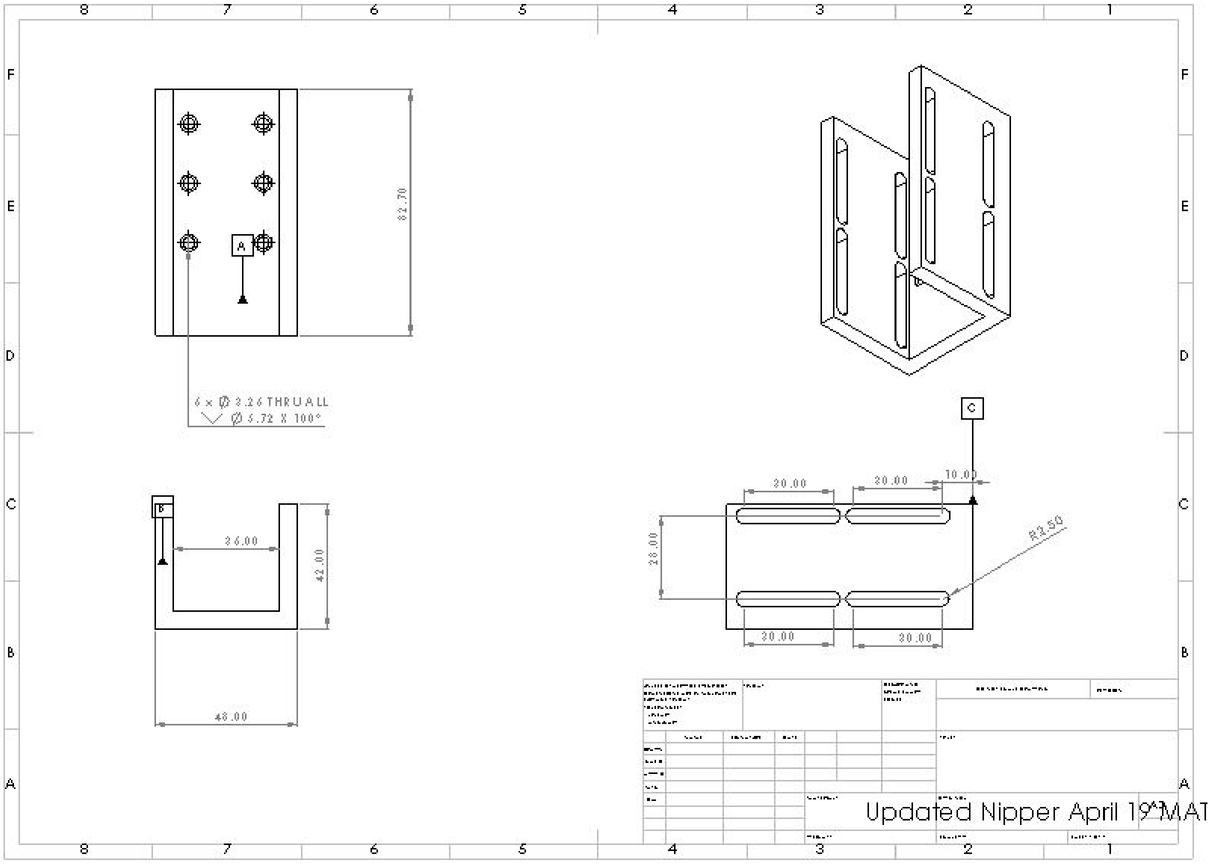
5779K116	Straight Adapter, for 3/8" Tube OD x 1/4 NPT Male	2	McMaster -Carr®
62005K512	Elbow, PBT Plastic, M5 Metric Male x 6 mm Tube OD	2	McMaster -Carr®
5779K115	Straight Adapter, for 3/8" Tube OD x 1/8 NPT Male	6	McMaster -Carr®
5225K506	Straight Adapter, 6 mm Tube OD, M5 X0.8 mm Male Pipe	4	McMaster -Carr®
5225K712	Push-to-Connect Tube Fitting for Air, Straight Adapter, 6 mm Tube OD x 1/8 NPT Male	4	McMaster -Carr®
5648K71	10FT Polyurethane Tubing for Air and Water, 1/4" ID, 3/8" OD, Clear Colors	1	McMaster -Carr®
50315K69	25ft Polyurethane Tubing for Air and Water, 4 mm ID, 6 mm OD, Clear Colors	1	McMaster -Carr®
PC1010	1-Horsepower Peak, 1/2 hp running 1-Gallon Compressor	1	Amazon

Appendix E: Ball Screw Assembly Drawings



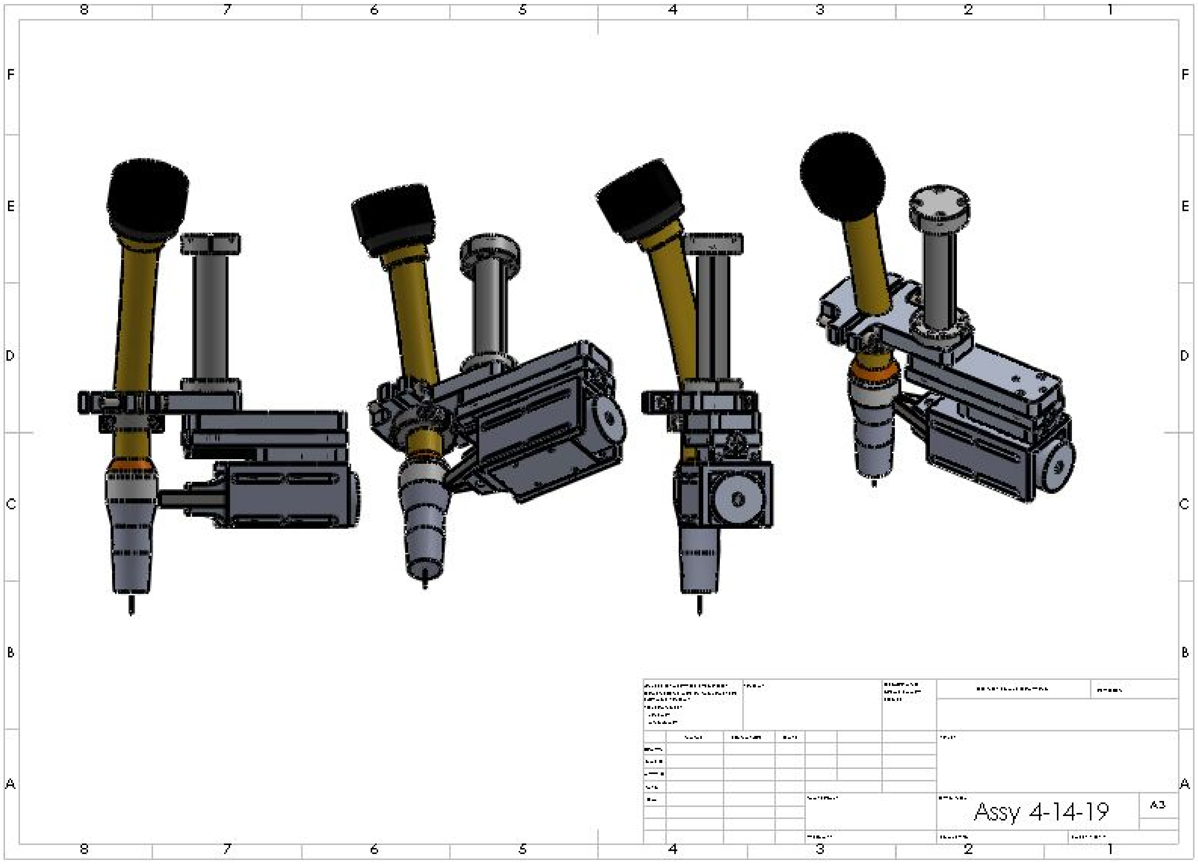

Ø5.59 THRU
53.78
53.78
126.90
R10.00
12.40
Ø2.02 THRU
R19.05
R19.05
R19.05
Ø4.78 THRU
6.35
6.35
9.53
Ø3.18 THRU
43.45
6061 Aluminum
3/8 Plate
TopRing_v2_21_19
A3

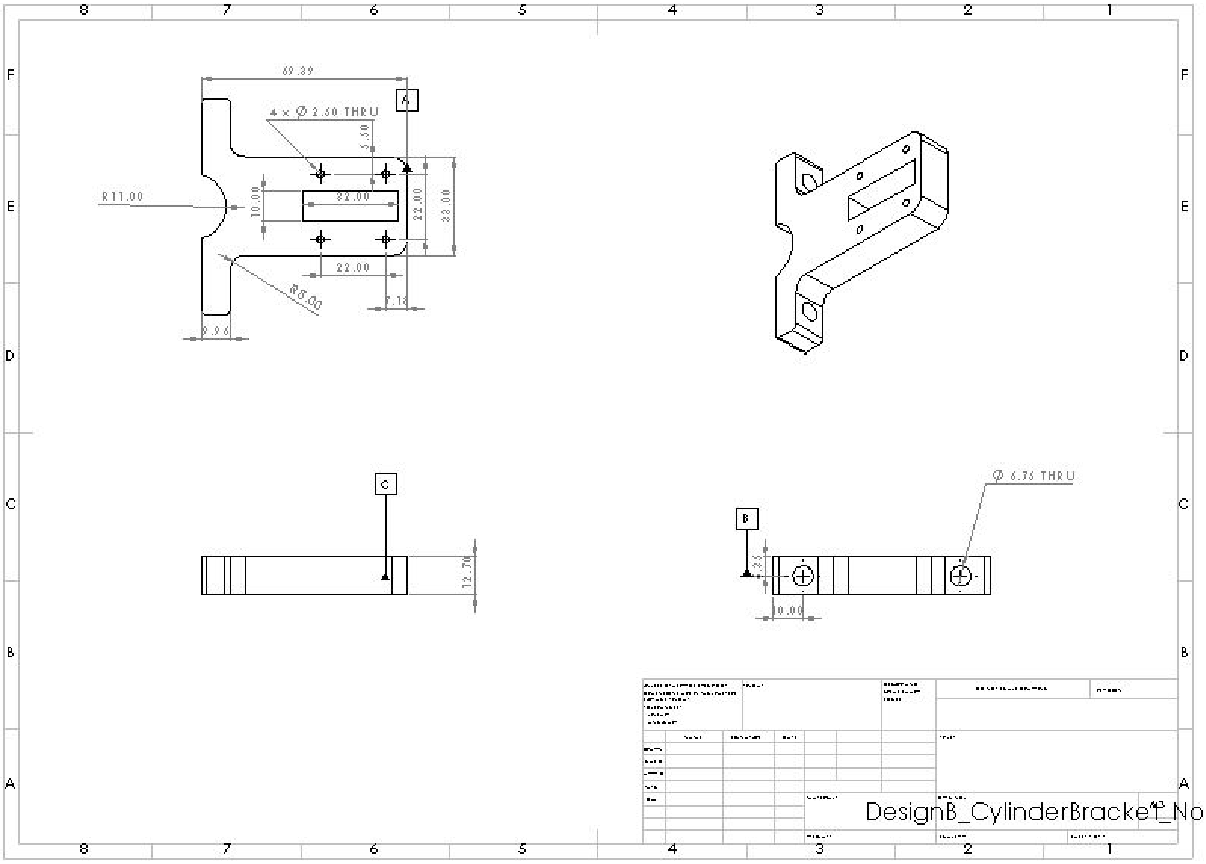

Ø9.65 THRU
Ø4.06 THRU
Ø4.06 THRU
Ø4.06 THRU
A
B
BottomPlate_v2_26_19

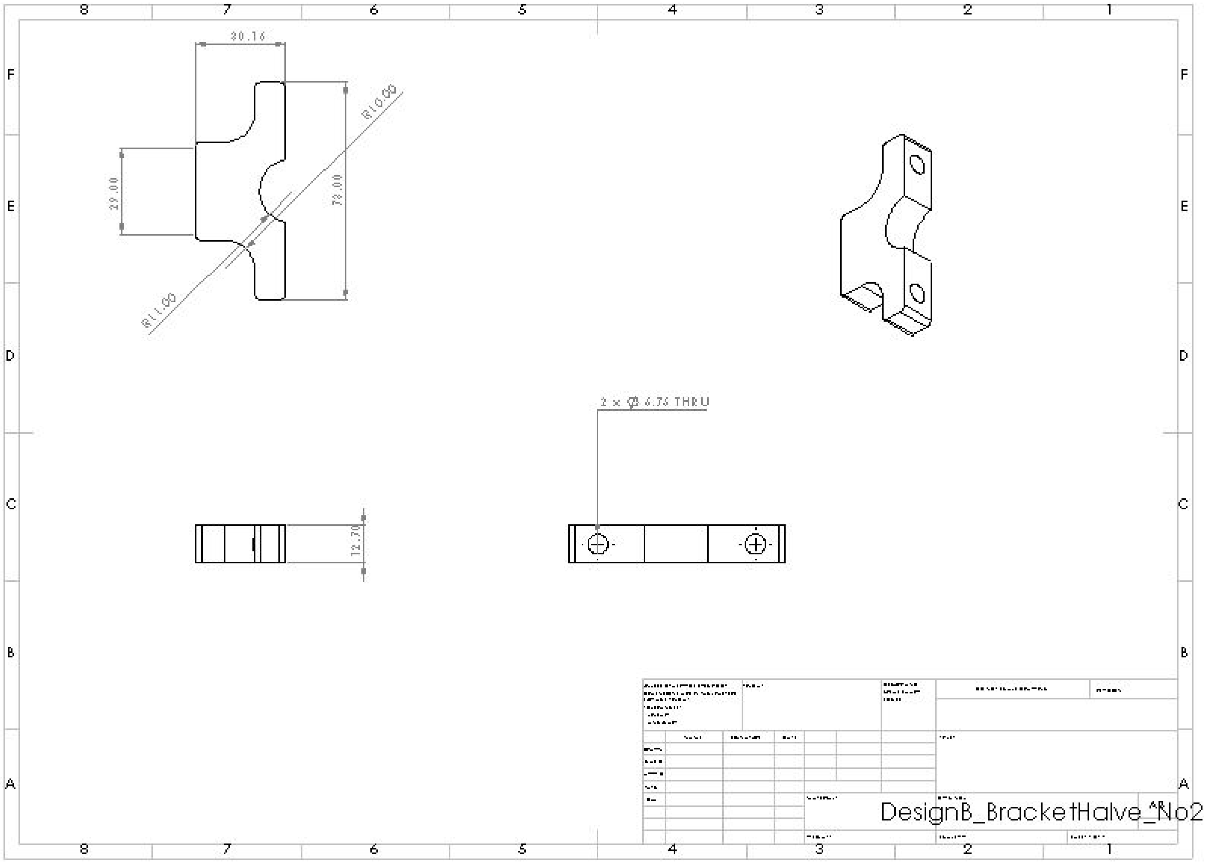


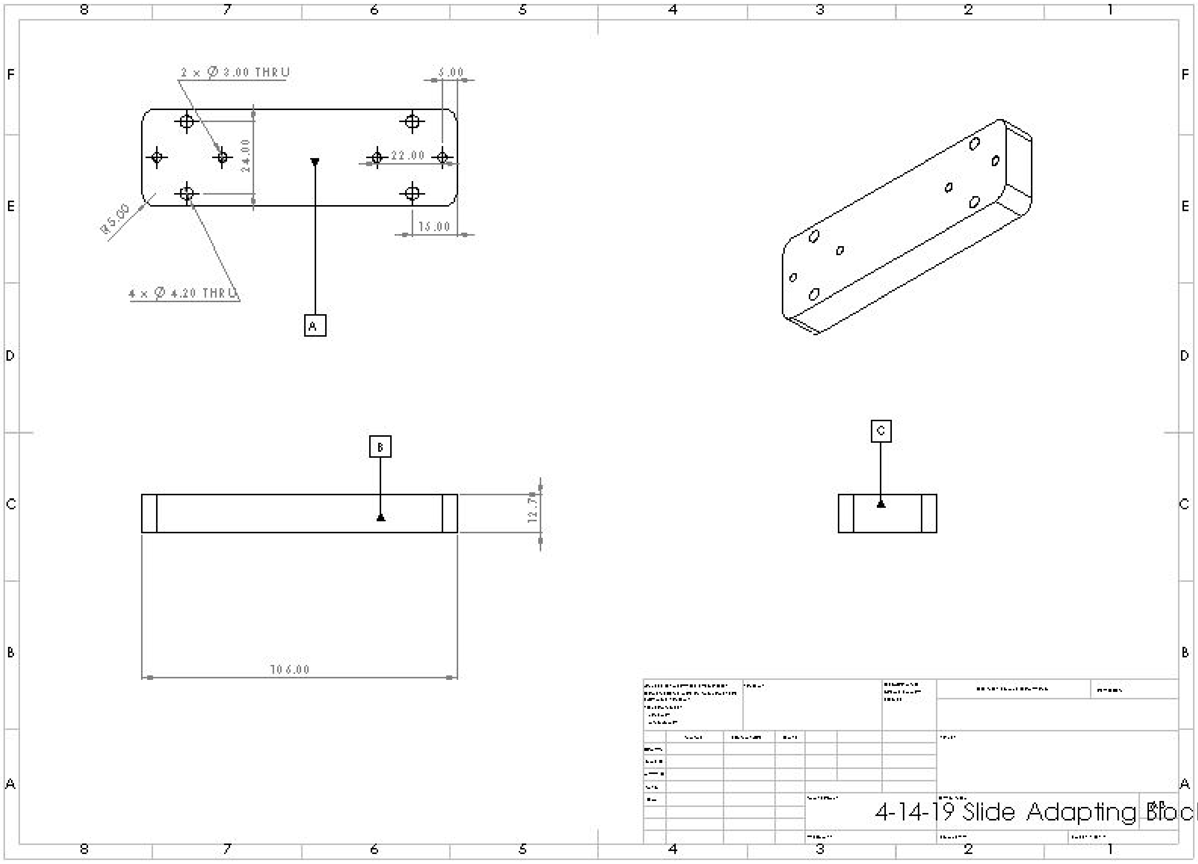
82.70
6 x Ø 3.26 THRU ALL
Ø 5.72 X 100°
A
B
C
36.00
42.00
48.00
20.00
20.00
10.00
28.00
R2.50
20.00
20.00
Updated Nipper April 19

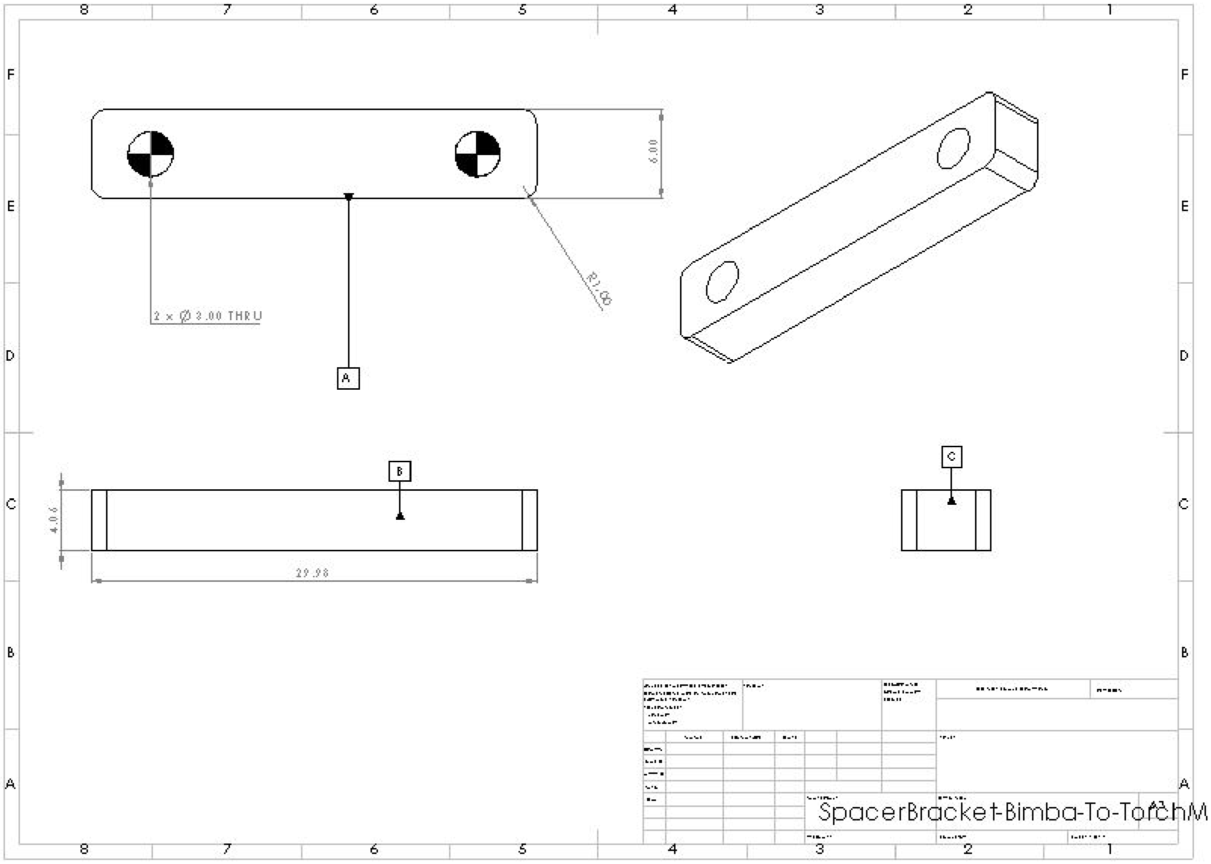
Appendix F Pneumatic Design Drawings

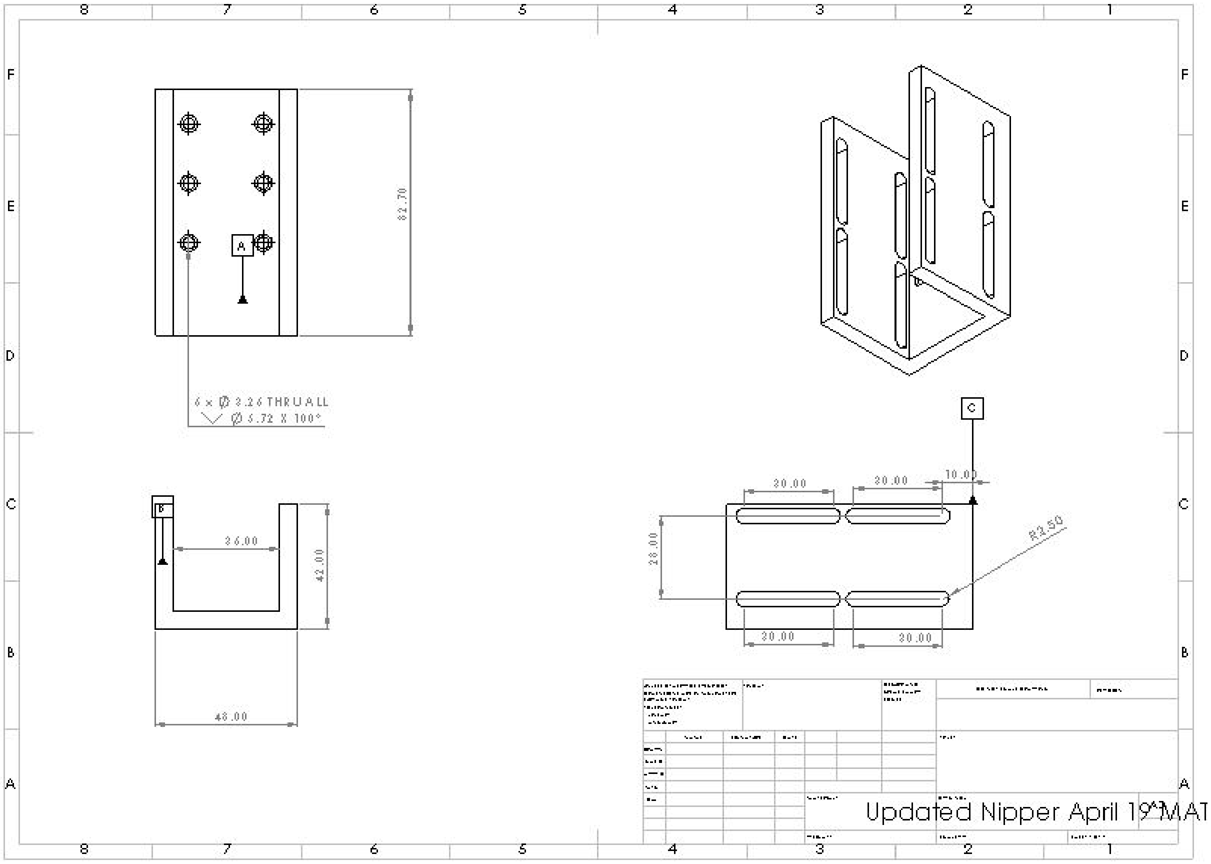



69.39
4 × Ø 2.50 THRU
A
R11.00
22.00
R5.00
Ø 6.75 THRU
B
C
12.70
10.00
DesignB_CylinderBracket_No

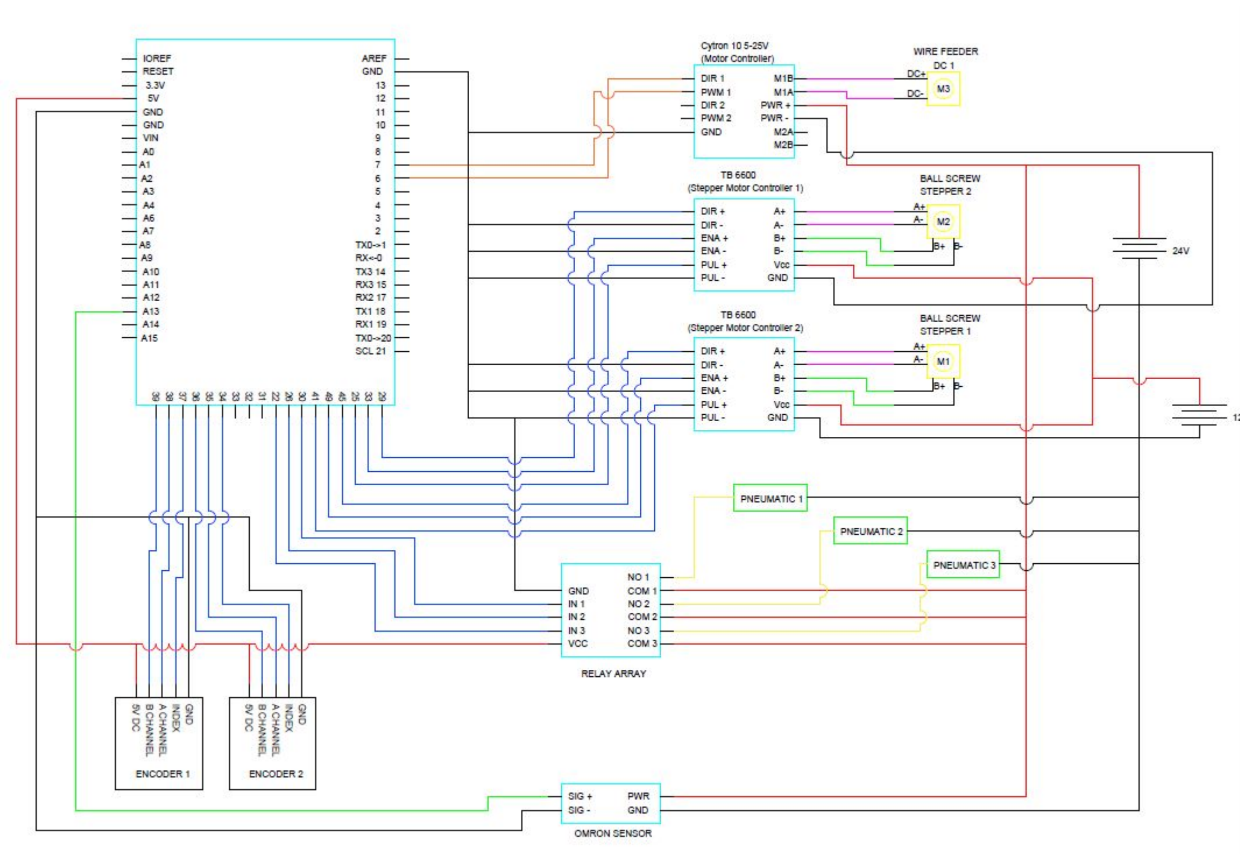

20.16
29.00
72.00
R10.00
R11.00
12.70
2 × Ø 6.75 THRU
DesignB_BracketHalve_No2


2 × Ø 3.00 THRU
5.00
24.00
22.00
15.00
R5.00
4 × Ø 4.20 THRU
A
B
C
12.7
106.00
4-14-19 Slide Adapting Block

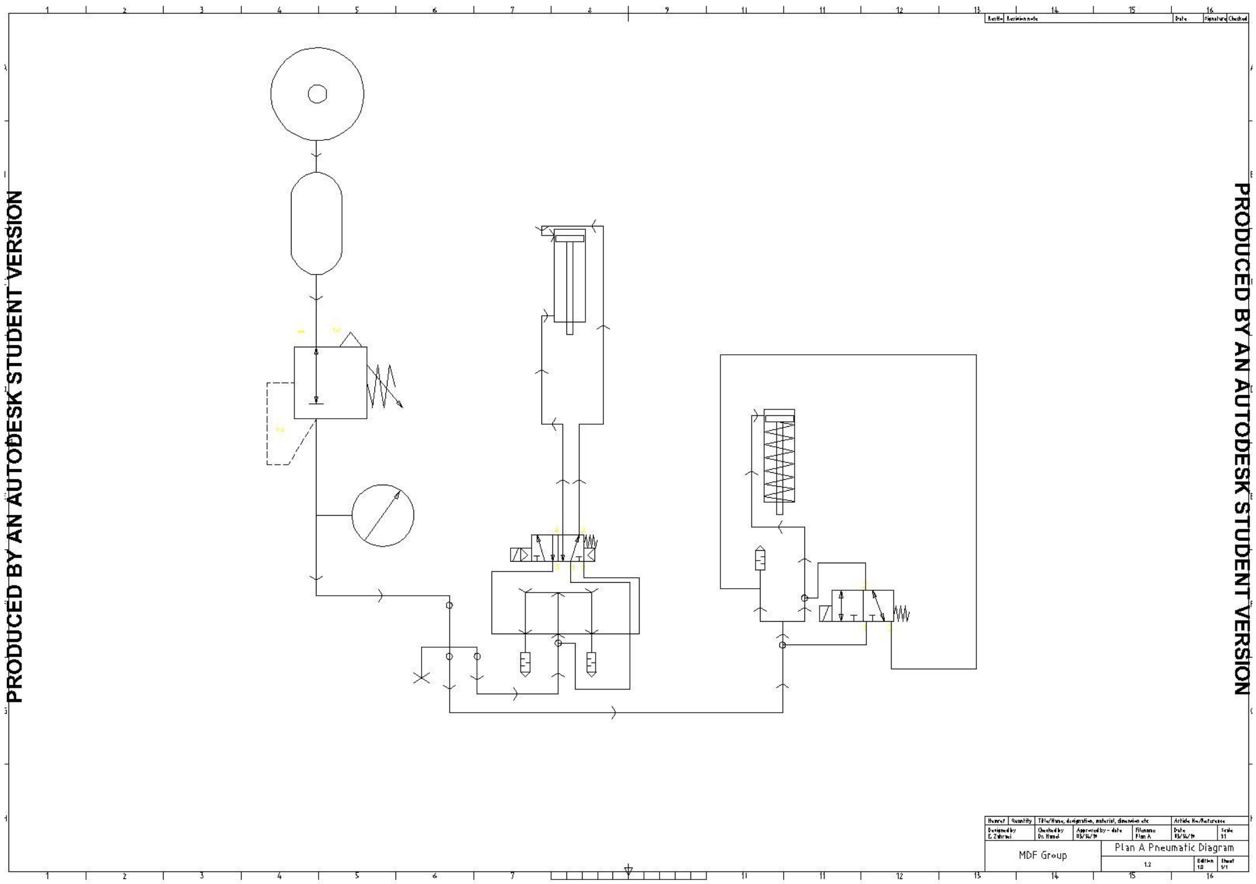

6.00
2 x Ø 3.00 THRU
R1.00
A
B
C
4.06
29.98
SpacerBracket-Bimba-To-TorchM
A3


6 x Ø 3.26 THRU ALL
Ø 5.72 X 100°
82.70
36.00
42.00
48.00
20.00
10.00
28.00
R2.50
Updated Nipper April 19^MAT

Appendix G Electrical Schematics



Appendix H: Ball Screw Design Pneumatic Diagram



Appendix I Pneumatic Design Pneumatic Diagram