"MECH 4250 Operational Readiness Review"

Spring 2013

Corp_6 – Hog Ring Application Improvement

April 29, 2013

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Sponsors

Johnson Controls

Summary

The purpose of this senior design project is to improve the process of marrying seat upholstery to the seat foam at the Johnson Controls manufacturing plant in West Point, Georgia. The current process utilizes hog rings and pneumatic hog ring guns to bond the seat fabric and foam. Problems presented with this process include poor ergonomics, presenting the risk of musculoskeletal conditions, as well as the amount of overall time consumed. Also, the guns are constantly being repaired and replaced, which causes the company to spend an unwanted amount of money each month.

With each result of testing, the design of the station has altered slightly to improve its quality and fix issues. Extensive testing has shown that several gun entry angles are possible, depending on the apparatus setup. Auburn Corp_6 has chosen to pursue vertical gun entry in the final design. The guns will enter at a common angle of -3.8 degrees from the vertical, but will need to vary in height levels due to the gradual incline of the cushion's depth. Guns will be mounted to horizontal steel arms extended outwards. The guns will be stationary, but easily removable for maintenance if required. The chair will rise up to the stationary guns via two actuators on the side of the stand. After the guns have fired, the chair will lower back to its starting position.

This report will briefly review the process of concept generation, and then detail the final design.

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Introduction

Johnson Controls manufacturing plant, located in West Point, Georgia, assembles seat systems and door panels for several local automobile manufacturing plants. The process of bonding the seat fabric to the foam is currently the slowest and most labor intensive process in the plant. Employers handle three-pound hog ring guns for hours at a time while twisting and rotating their wrists, resulting in ergonomically-based issues. Also, the guns are being repaired on a daily basis, because they are mishandled by employees. This is costing the company thousands of dollars per month.

In order to solve the problems, Johnson Controls would like to improve the gun, automate the process, or improve other aspects of the process. The main goal is to perform the operation in less time and with minimal damage to the gun and the operator's wrist; however, consistency, operator safety, and easy access, is required and must be considered.

The CDR provided feedback regarding the new proposed gun mount design. Johnson Controls was concerned with the size of the shafts, so we increased the diameter. We also decided to use the new design based on Johnson Control's feedback. They were also concerned with how we were going to control the cylinders for the seats. A limit switch and pressure regulators were used to address this concern.

Mission Objectives

The Mission objective is to improve the process of marrying the seat upholstery to the foam in a way that eliminates equipment abuse, eliminates ergonomic based issues, requires less time, and maintains operator safety. The final product's details are discussed in the MPCOD that follows.

Manager's Project Contract of Deliverables

Team: Corp 6- Johnson Controls

Manager: Brandon Hughey

Date: February 18, 2013

Task:

1. Manufacture the Gun Support subsystem
   a. Fabricate and assemble constitutive parts including:
      i. Steel Tubing (Cut & welded)
      ii. Tubing Brackets (Welded to tubing & bolted to Modu-tek)
      iii. Gun Brackets (Drilled, machined, & bolted to gun)

2. Manufacture the Fabric Restrainer subsystem
   a. Fabricate and assemble constitutive parts including:
      i. Aluminum & Steel Plates (Cut, drill, & bolt to hinges and table)
      ii. Hinges (Bolt to Plates)

3. Manufacture the Toggle Clamp Mount subsystem
   a. Fabricate and assemble constitutive parts including:
      i. Steel Plates (Cut, drill, weld, & bolt to toggle clamps and table)
      ii. Toggle Clamps (Bolt to Toggle Clamp Mount)

4. Mount the Pneumatic Cylinders (Move the table up/down)

5. Modify Hog Ring Guns

   a. Remove Trigger
   b. Attach Fitting and Cylinder

6. Mount and route the following electrical and pneumatic parts:
   a. Solenoid Valves
   b. Limit Switches
   c. PLC

Measure of Performance: Performance can be measured by the completeness of the above tasks and how well the subsystems interface and function relative to one another.

Interfacing Plan: The subsystems will interface with the system as stated in the Tasks section above.

Delivery Date: All tasks should be completed by the end of the semester (May 8, 2013).

_______________________ _______________________ _______________________

Sponsor's Signature **Manager's Signature** **Technical Advisor's Signature**

Architectural Design Development

In order to understand and clearly outline the problem, a list of requirements, engineering characteristics, and a functional decomposition were created. Using these tools, each member created a unique concept and presented it to the group.

Understanding the Problem

General System Requirements

- Main function – marry upholstery to seat foam using hog rings
- Should – last for 3-4 years
- Should- not take longer than current manual operation
- Must- be consistent and eliminate error
- Must- be durable for at least 18 shifts (low maintenance until off-day)
- Must- be safe for operator
- Must- be ergonomic
- Must- be adjustable
- Must- keep same workspace size

Safety

- Should – operator be clear of area when in use
- Must- guard pinch points
- Must- emergency stop button
- Must- be stable (not fall over)

Economics

- Must – be within budget

Geometric Limitation

- Must- be same width and length as current
- Must- be within height reach of worker

Maintenance

- Must- be easy for human to gain access to parts
- Must- be easy to remove parts
- Should- standard parts (no special orders)

Ease of Use

- Should – 2 or 3 step human procedure
- Must – easy hog ring reload

Human Factors

- Must- eliminate abuse
- Must- be able to handle abuse
- Must- be operable by single user

Manufacturing

- Company production least two systems

Standards

- Device must meet all standard safety regulations and codes (OSHA)

Engineering Characteristics

During the first trip to Johnson Controls, the process of marrying seat fabric to the seat foam was observed and recorded on a camera. Using the video as a reference, a time study was performed to determine the cycle time and reload time. To limit machine downtime, the gun must have maintenance intervals of at least 18 shifts. This interval allows the machine to remain in operation until servicing can be completed during scheduled maintenance periods. The dimensions of the workspace were extracted from the cad drawing of the floor layout at Johnson Control. The distribution of adult heights was considered when determining a vertical adjustment range for the work station. Finally, the team concluded that the machine must utilize multiple guns in order to reduce automated process times to below those achieved by the manual process.

Table 1: Engineering Characteristics

Customer Wants	Engineering Char	Units	Limits
Take less than manual	Cycle time	sec	≤ 45
Must be durable	Durability	shifts	≥18
Easy to reload	Reload Time	sec	≤ 3-5
Workspace Size	Size limit	ft	≤ 4x4
Machine height	Adjustable height	ft	≤ 6
Min staple amount per gun	Load capacity	rings	≥ 50
Min staple per punch	Punch number	Rings	≥ 2

Functional Decomposition

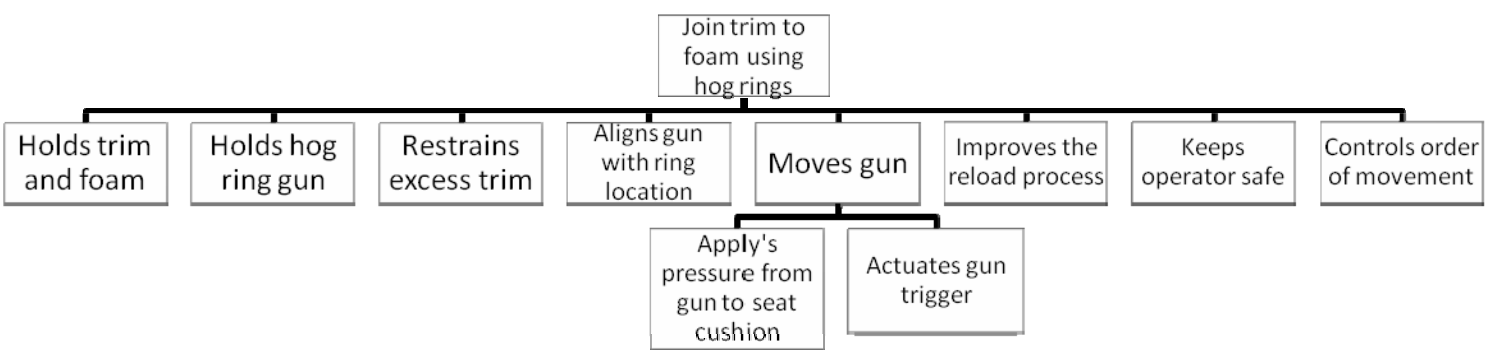

Figure 1: Functional Decomposition

Concept Generation

The guns were angled towards the seat in the first stages of the design. Testing showed that gun entry angles must differ slightly from each other in order to properly staple each site if the guns are to enter at an angle. The angles were found to be 68 and 69 degrees when moving guns towards the seat. If left at an angle, but moving the seat towards the guns instead of the guns towards the seat, the angles change to 86.2 and 87.5 degrees. The current and final design chosen by this team eliminates this variation of angles by using vertical gun entry with a common angle; however, different gun mount heights are now required.

This progression from the original design to the final one has greatly reduced the power required to operate the system, unnecessary movement that must be controlled and maintained, and has provided a little more forgiveness in the movements in order to reach success.

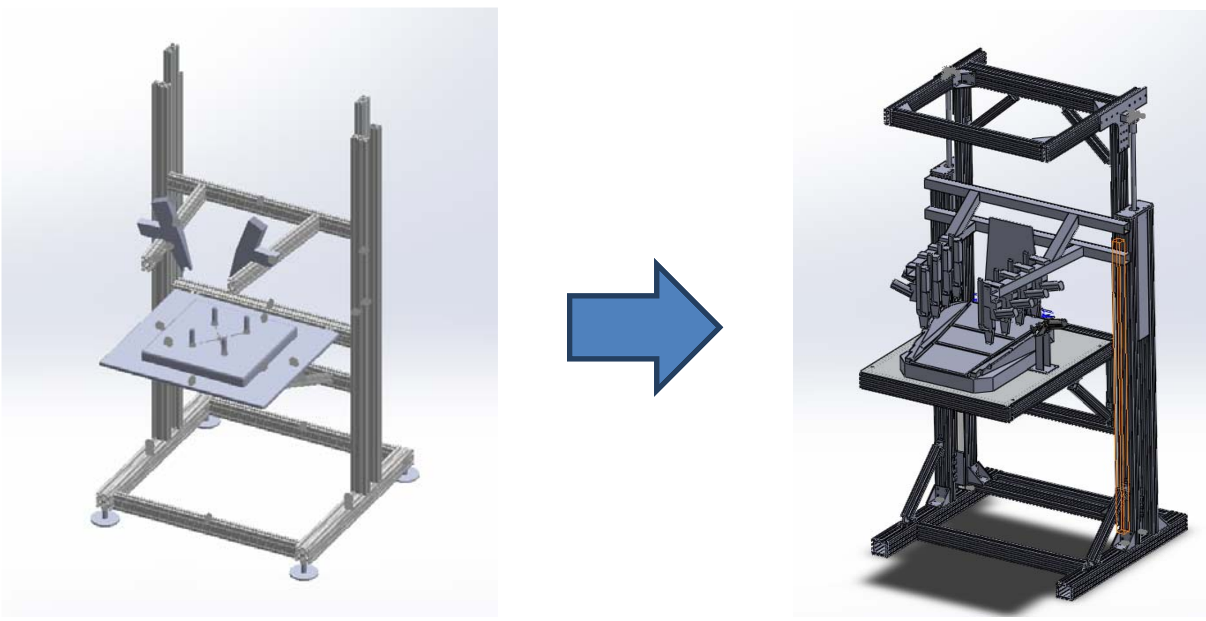

Figure 2: Concept Progression

Final Concept:

Our final concept involves stationary guns and a mobile nest.

Gun Arrangement Subsystem

Functional Requirements:

1. Align with wire and fabric
2. Shoot hog ring
3. Support guns

Two 24 in. side arms that run along the length of the crevice on the foam are welded to two aluminum bars along the back of the stand. Attached to these arms will be eight guns (four on each side) that are mounted using the four holes already present at the back of their bodies. No new holes will need to be drilled into the gun as the location of the mounts take advantage of pre-existing ones. The location of these holes can be seen in Figure 3 below.

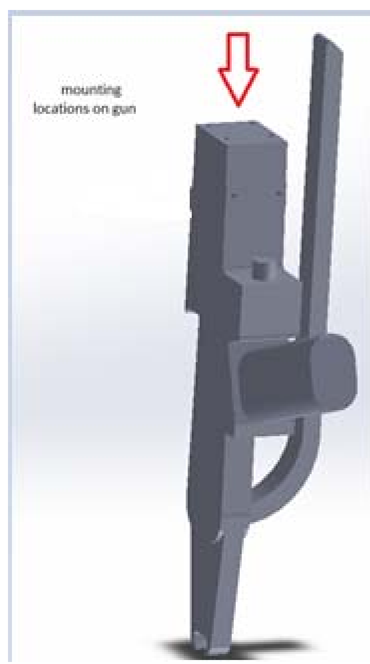

Figure 3: Gun Mount Location

Due to the gradual incline of the seat cushion a spring and shaft mount has been designed to allow for difference in each location's height. The shaft will be able to slide up and down as needed, and the spring will compress as needed. Figure 4 shows this design.

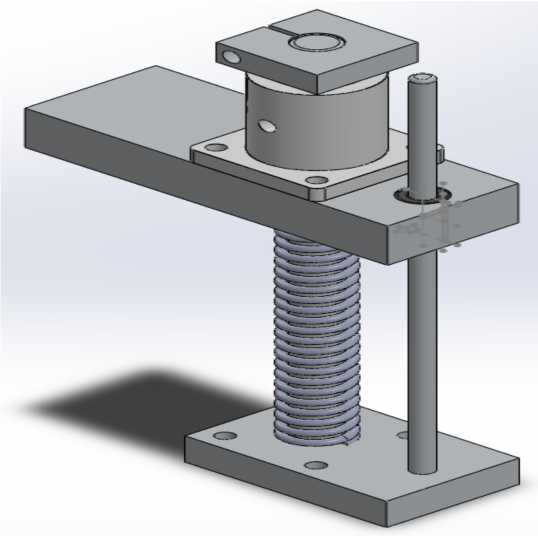

Figure 4: Gun Mount Bracket

The guns will be easily removable by loosening the top square plate on the mount. However when the guns are removed they will remain bolted to the bottom plate, which has the two shafts press-fitted into it.

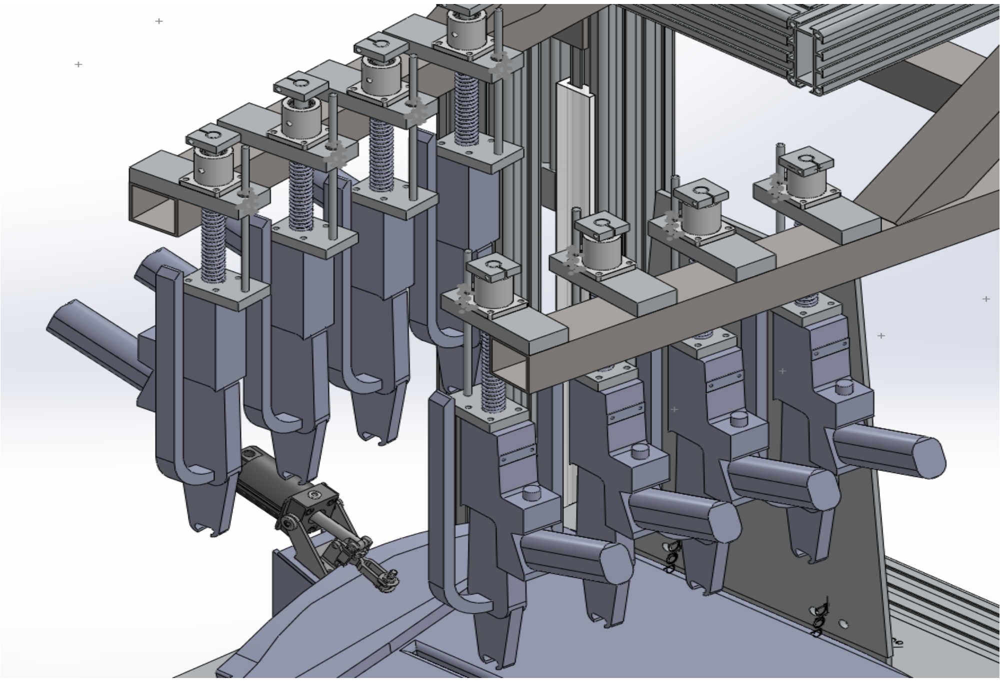

Figure 5: Gun Mount Setup

Gun mounting locations vary for different cushions. Each location needs to be assessed separately and be based off of the foam wire openings.

In order to support the weight of the guns, 2 inch square aluminum tubing was chosen for the material of the horizontal bars. Minor deformations were observed on the testing apparatus made from Modutek with the use of only two guns on a single bar. With added weight, and a long life expectancy of the machine, 2 inch tubing was the appropriate choice to help prevent future damage. The arms were welded approximately at angles of 82 degrees. Steel was initially chosen as the gun arms in order to improve strength, however, the overall weight of the subassembly became an issue.

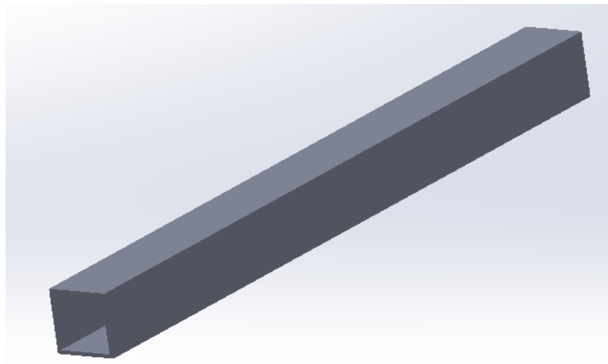

Figure 6: Aluminum Gun Bar

Figure 7: Aluminum Welded Piece

In order to use a pre-existing cylinder to trigger the gun, the jaws of the guns were rotated around, so that certain extensions were out of the way of the trigger site. The cylinders used are ¾-16 inch thread size, 1 inch in diameter, and have a ¼ inch stroke length in order to match the gun's size. The one chosen is shown in Figure 9.

Figure 8: Bimba Trigger Cylinder

The trigger will be removed, and the screws of this cylinder will fit into the existing hole. Air will be supplied to this cylinder in order to activate the gun. The gun requires specific placement of the front valve seat in order to operate; therefore, the cylinder is not threaded into the gun, but is pushing an existing square stem within the gun. An external mounting bracket was made to support the cylinder. Figure 8 provide a view the trigger.

Nest/Cushion System

Functional Requirements:

1. Hold foam at certain height
2. Move foam up and down
3. Keep foam stable

The nest will be bolted to an aluminum plate that is attached to the foundation of the stand. The stand will have two linear actuators (one on each side) that will move a portion of the stand, including the aluminum plate and the nest, up and down. The current electric actuators are being replaced for pneumatic ones in order to speed up the lifting process. The current aluminum plate is also being exchanged for one that extends further out towards the operator, (because of the added length that the new arms create) and increased in width (to allow room for the toggle clamps). New pieces of Modutek had to be cut and bolted to the stand in order to accommodate the larger size of the plate. Figure 10 provides a side view of the cylinder and new length of the guns.

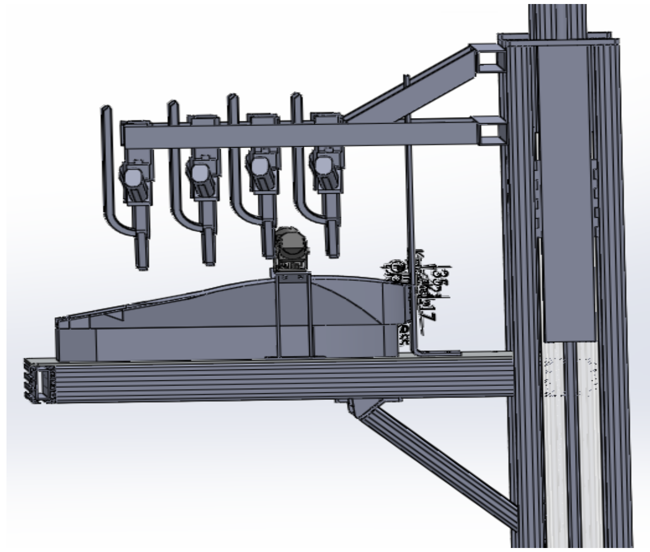

Figure 9: Nest and Cylinder

Fabric Restraining System

Pneumatic toggle clamps will be used to compress the sides of the foam in order to access the wire sites, as shown in Figure 11. The clamps will be mounted on a stand that rests upon the aluminum plate underneath the nest. The stand is welded steel, with the two vertical bars placed as wide as the width of the toggle clamps. Small plates will be bolted to the ends in order to gain a wider area that is compressed.

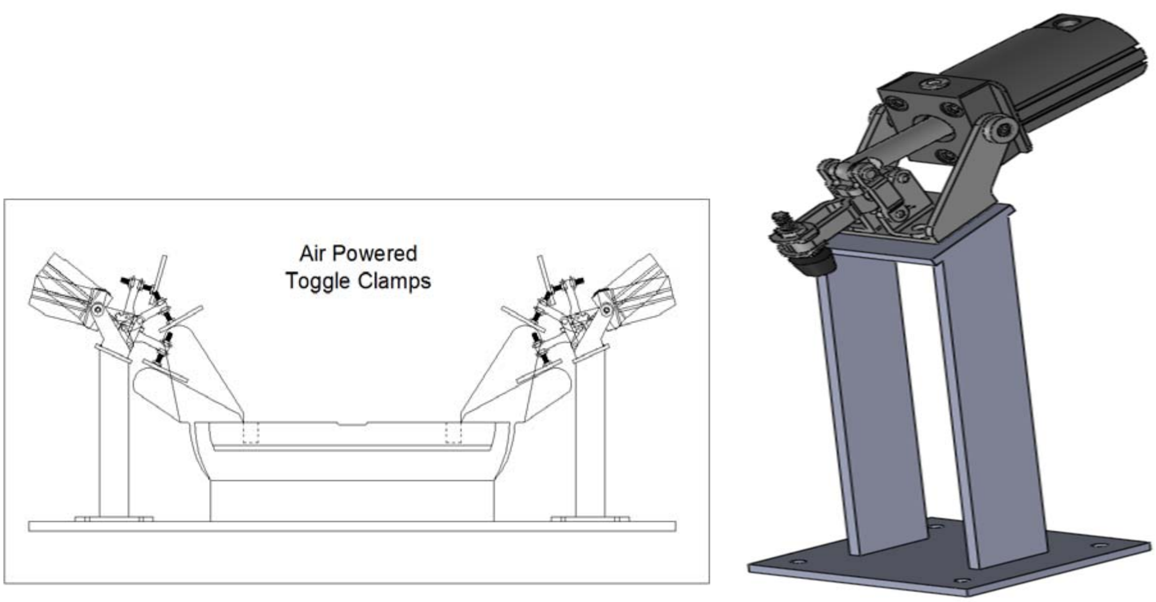

Figure 10: Toggle Clamps

In order to hold the fabric away from the crevices, a plate will be manually placed on top of the cushion, with the fabric flaps lying underneath it. Figure 12 provides a back view of the plate in the upright position.

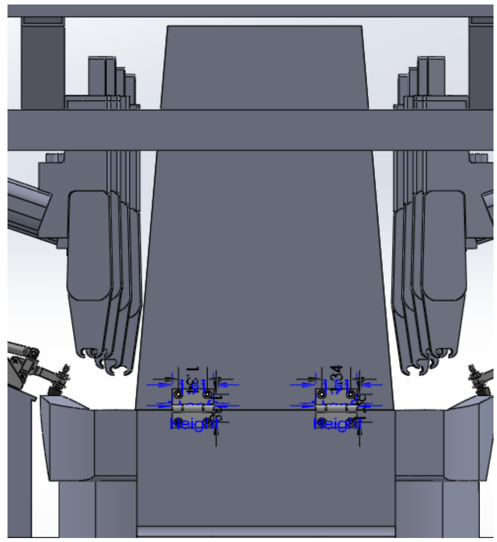

Figure 11: Back View of Fabric Plate

Electrical Subsystem:

Functional Requirements:

1. Send electrical signal to valves
2. Sequence the order of events

The electrical system includes eight cylinders to trigger the guns, three valves, two pressure regulators, two cylinders to move the stand, safety precautions (emergency stop button, etc…), and finger swipes that allow the user to start the process. An original ladder logic (seen in Figure 13) was developed to organize thoughts of operation. An Allen Bradley MicroLogix 1100 was used to control the operations. A system reset was installed into the logic in order to return the system to its home position. This reset is activated by holding both push-buttons for five seconds. Note: Safety relays have not been added to the ladder below.

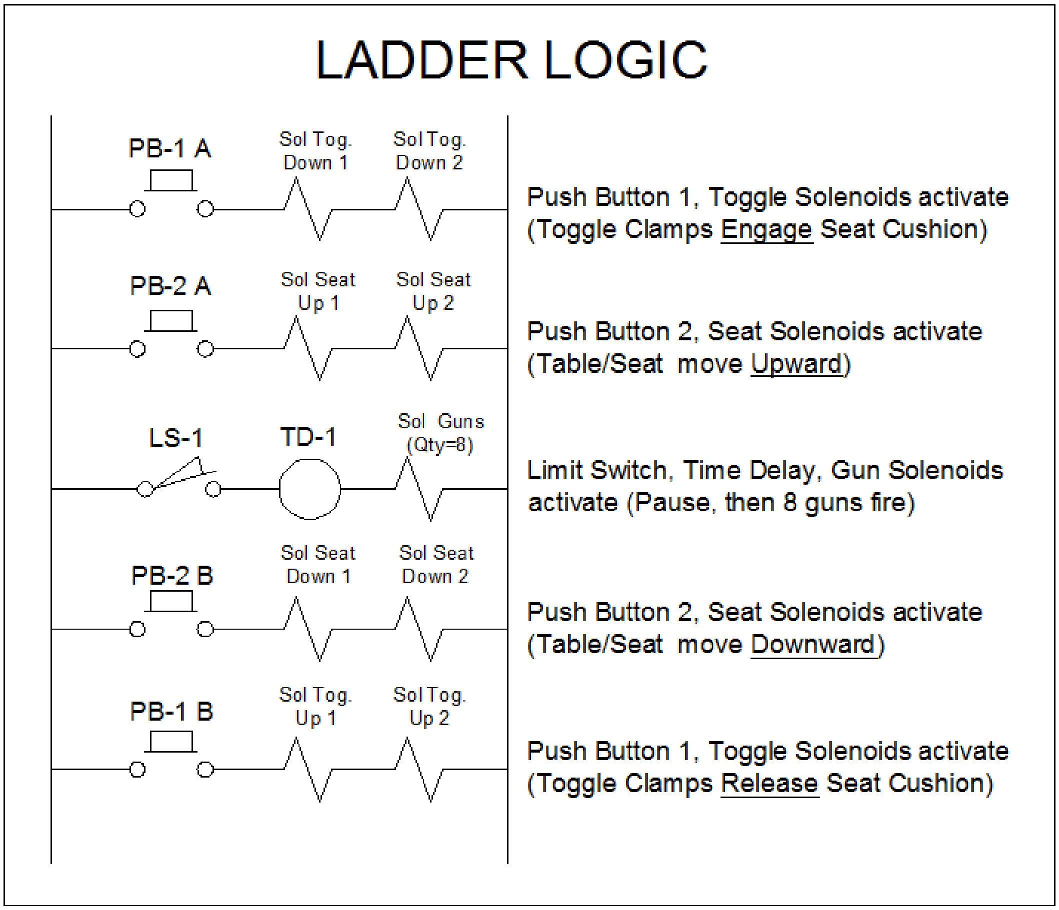

Figure 12: Ladder Logic

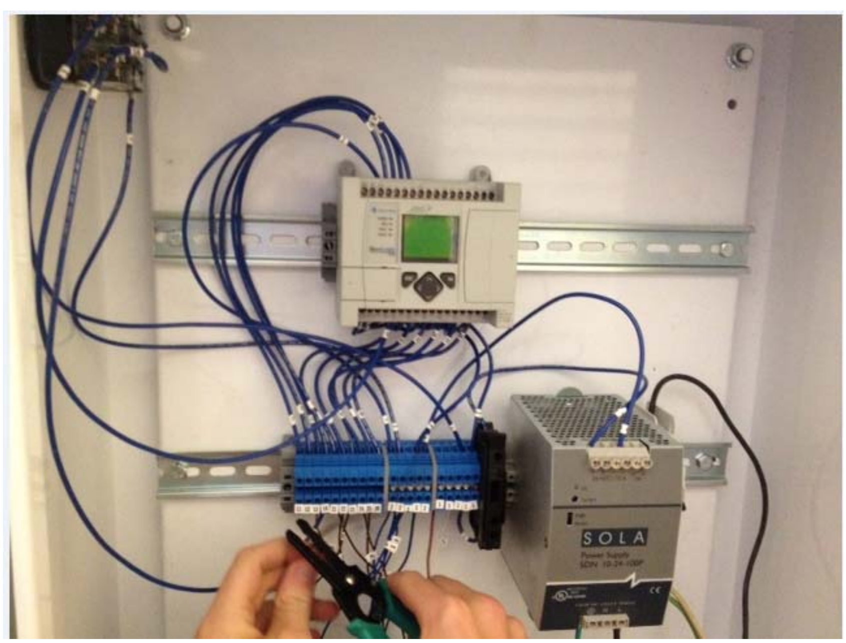

Figure 13: Micrologics Controller and Setup

Figure 14: Valves and Pressure Regulator Mounted

After feedback received from the CDR, we reduced the amount of solenoids needed from 5 to 3. The top valve in Figure 15, used for the outside cylinders on the stand, is 3 position, 4-way, double solenoid with a 3/8 inch port size. Flow regulators were installed on the air lines going into and leaving from the seat solenoid, however, they were adjusted to be fully open during testing. The middle valve in the figure, used for the guns, is a 2 position, 4-way, single solenoid with a 1/8 inch port size. Finally, the lowest valve in the figure, used for the toggle clamps, is a 2 position, 4-way, double solenoid with a 1/8 inch port size. The pressure regulator seen in Figure 15 is used to reduce the pressure going into the toggle clamps to 70 Psi. This reduction in pressure allows for the proper depression of the seat foam.

Figure 16 below shows the electrical schematic layout.

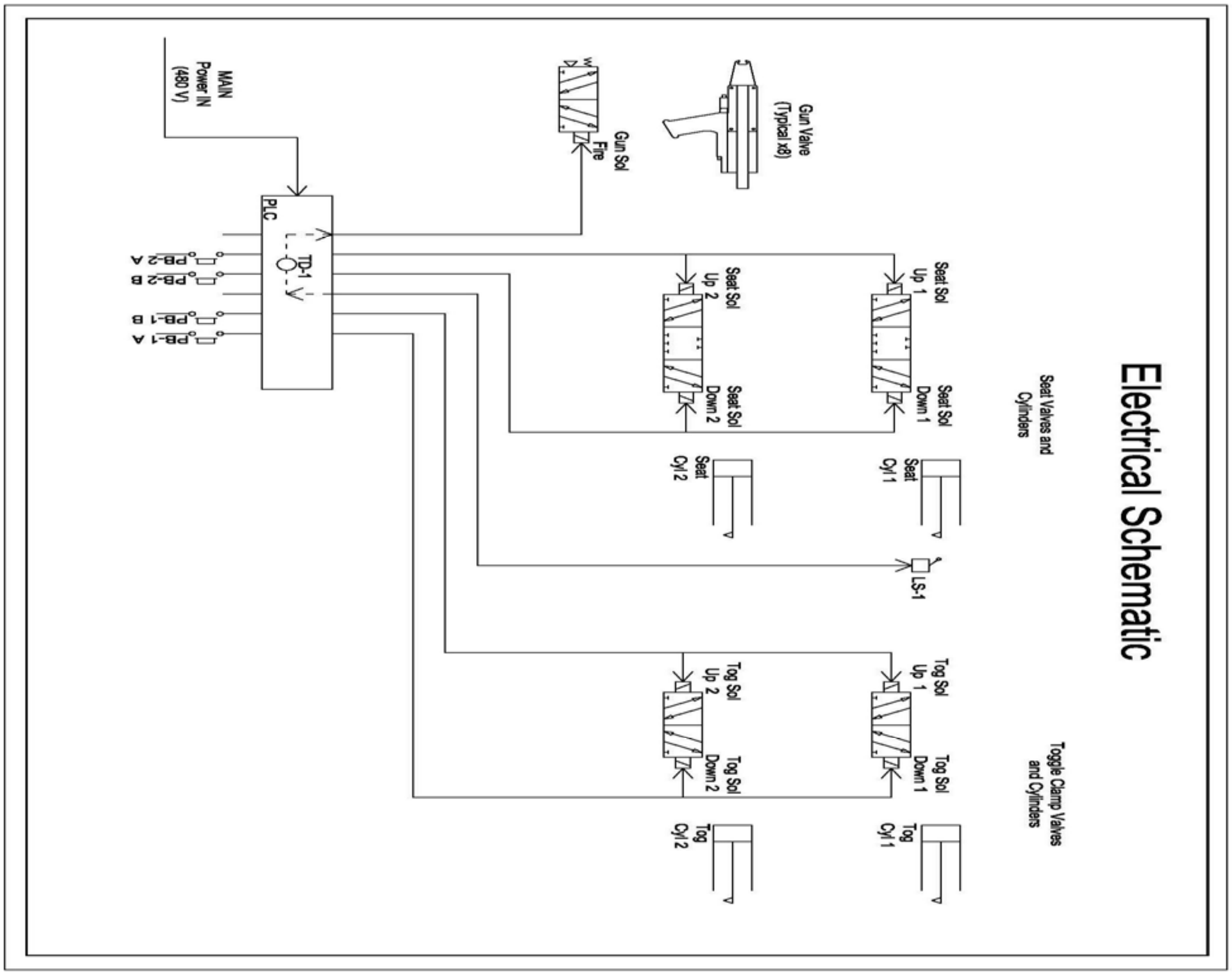

Figure 15: Electrical Schematic

Air Subsystem:

The stand will house two pneumatic cylinders, eight guns, and two toggle clamps, each requireing air lines and compressed air in order to function. The toggle clamps and guns use a ¼” air hose and fittings, while the seat cylinders use a 3/8” line to allow a greater flow rate which increases the speed of lifting the seat. The guns will need a 5/8” hose feeding into the handle and a ¼” hose feeding into the Bimba cylinder that was added. Figure 15 Shows the items needing air.

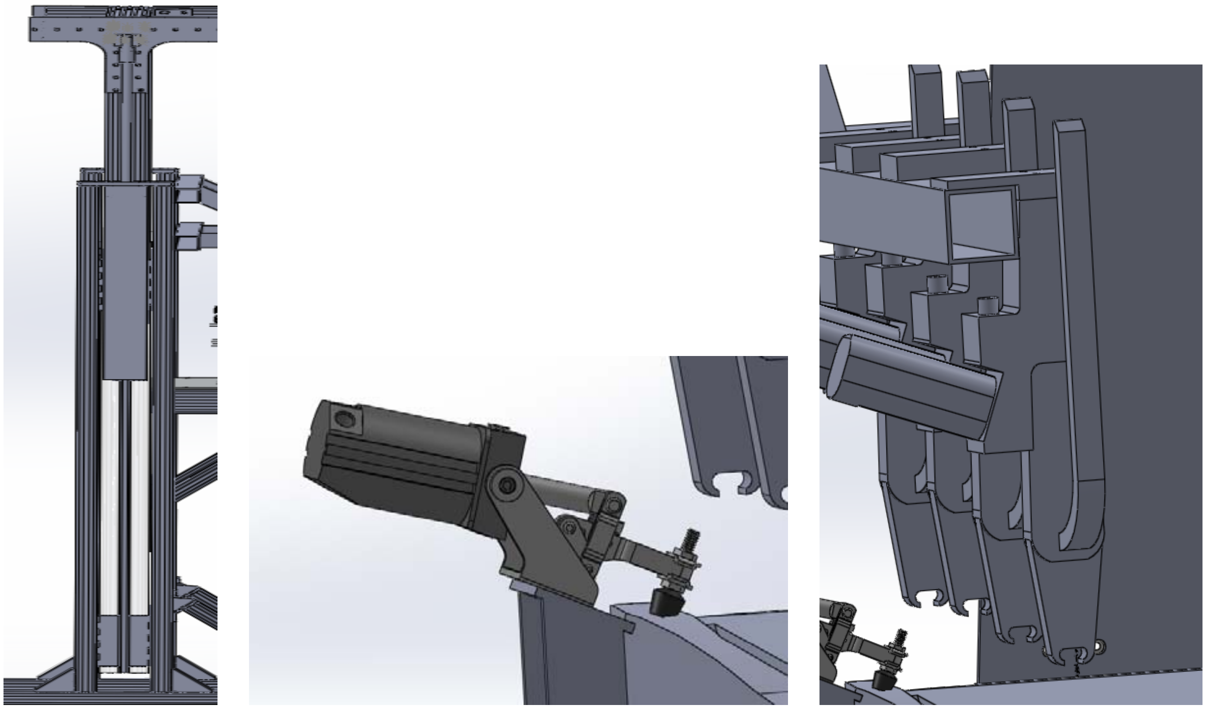

Figure 16: Objects Needing Air Supplies

A major supply of air will be inserted into the splitters already present on the stand. T-splitters will also be placed after air leaves the solenoids, in order to sync the two toggle clamps together, the two actuators together, and the guns together. Figure 16 provides a visual of a T-splitter used. Figure 17 on the following page is a schematic of air lines and solenoids.

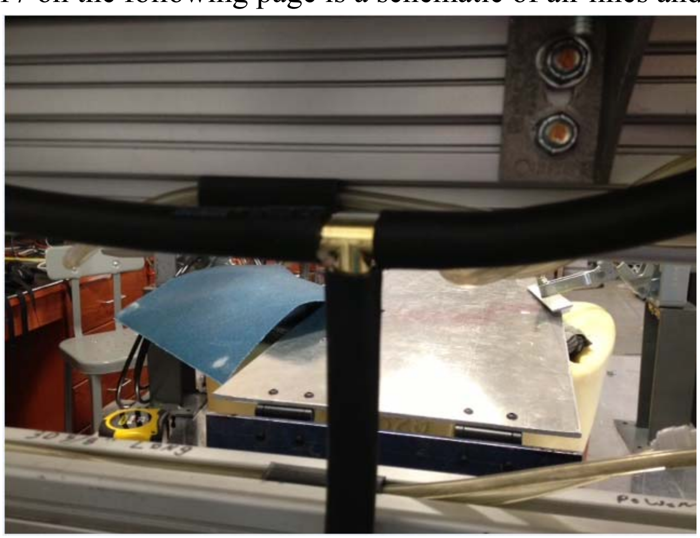

Figure 17: T-splitter

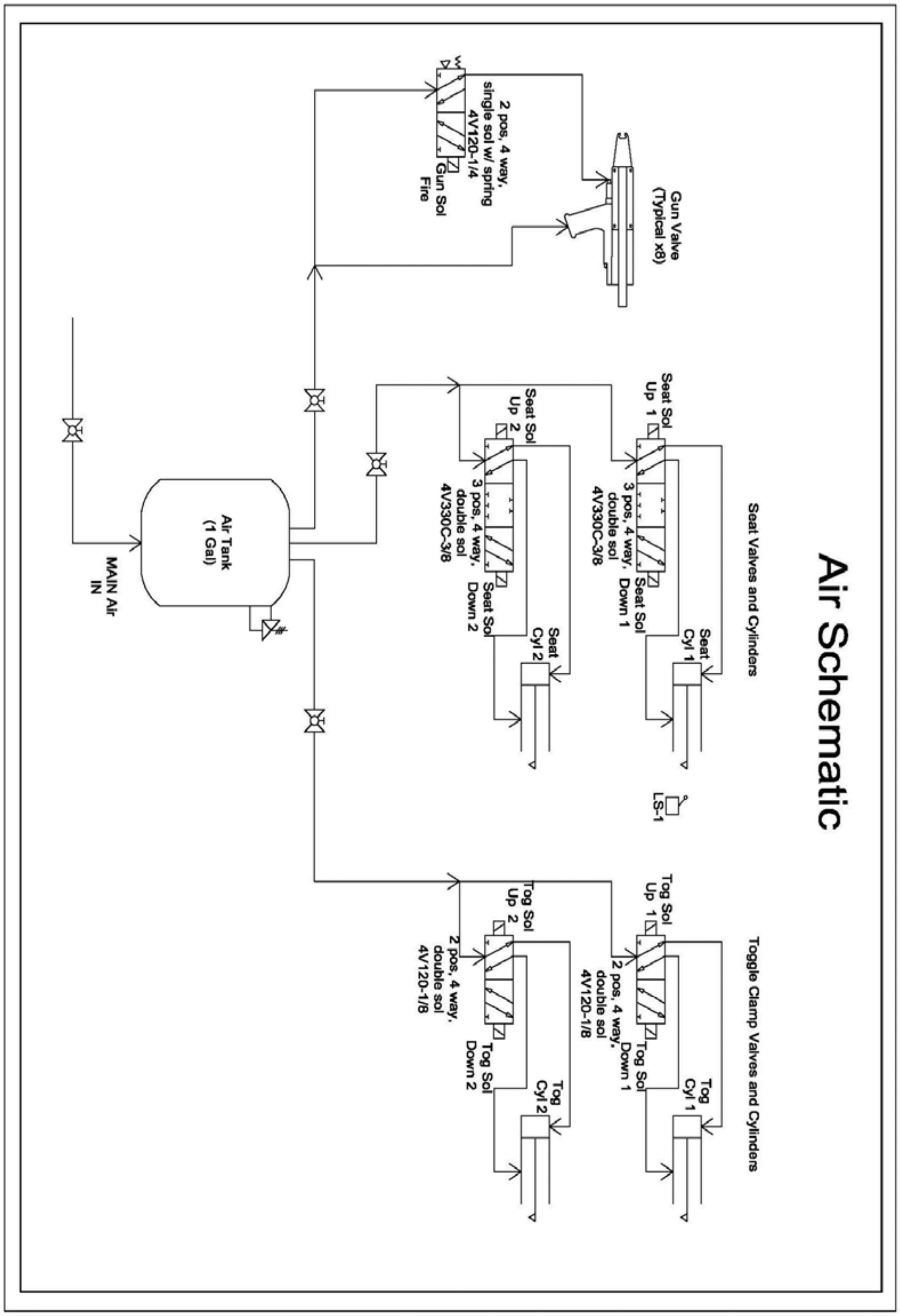

Figure 18: Air Schematic

Concept of Operations:

Time-Ordered Sequence of Events:

1. Place foam and fabric, with existing hog-rings in center six locations, in the nest
2. Restrain excess fabric by folding down fabric restraint
3. Tuck extruded listings into the foam valleys
4. Activate solenoid to send air to toggle clamps by contacting right finger swipe
5. Activate solenoid to send air to lift cylinders, in order to raise nest and foam, by contacting left finger swipe
6. Fire guns by contacting left finger swipe
7. Activate solenoid to exhaust air from lift cylinders to lower nest and foam by contacting left finger swipe
8. Activate solenoid to exhaust air from toggle clamps by contacting right finger swipe
9. Raise fabric restraint
10. Remove married foam and upholstery from nest

Validate and Verify

In order to verify that our design is meeting the requirements, each subsystem will be tested as it is built and as it is integrated into the system. This will ensure that the system is up to date upon completion of assembly. For this project, initial testing is the most important and time consuming phase. The design of the apparatus depended on the results of the tests performed.

3.3.2 Goals of Gun Test Station

Resolve the following issues with the automated process:

1. Hog ring gun catching on trim tab during extraction
2. Hog ring gun mounting details (angle, motion, etc..)
3. Hog ring gun entry into cushion wire cavity
4. Alignment of trim tab holes

Test the following mission critical concepts/system proof of concept:

1. Hog ring gun entry angles
2. Accuracy and repeatability of automated gun movement

3. Repeatability of trim tab position/alignment
4. Force on gun required to mate trim tab to cushion wire
5. Cushion side restraints
6. Cushion alignment pegs

2.3.2 Testing Data

Initial Testing (to determine dimensions of stand)

The entry angle and repeatability of the gun movement was tested by mounting the gun and arm over the seat. The gun was able to slide on a track towards the foam, while varying its angle of entry relative to the seat. The optimum angle was found to be -3.8° relative to the horizontal plane above the arm; After determining this angle, the process was repeated in order to see if the motion was predictable, and therefore, repeatable.

The sides of the seat were flattened at different angles in order to find the best foam angle for gun entry. The stapling process was performed at different foam angles to see if the crevices were widened enough to permit gun entry. After this requirement was met, the entire side of the seat was stapled in order to ensure that the restraints did not produce wrinkles in the fabric.

A basic structure of our concept was originally built in order to solve some key design issues. Once those were resolved, a more mature version of the original test site was built; the gun was mounted to side arms which were angled towards the center at 84° (alpha equals 84° in Figure 17); and the pre-existing actuators on the test stand were used.

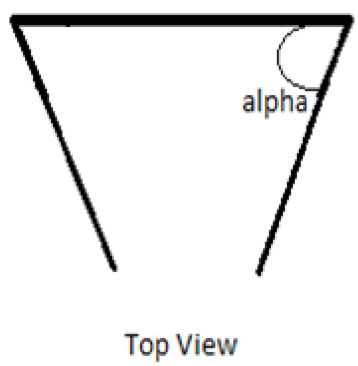

Figure 19: Set-up Angle

Multiple values of Beta (As seen in Figure 18) were tested throughout the process, but the final value in the design was set at -3.8° from the vertical.

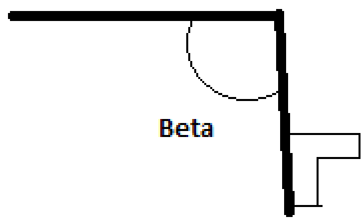

Figure 20: Set-up Gun Angle

The holes were numbered as follows in Figure 19 in order to keep an organized account of the data

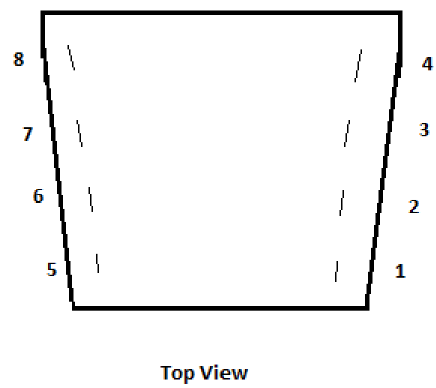

Figure 21: Set-up Numbering System

The height difference from the bottom of the cushion to the tip of the gun was important to keep track of because it effected the time needed to complete the operation. The distanced used for testing was 10.41 inches, as seen in Figure 20. The set distance for the final stand allows for the foam cushion to easily slide onto the nest.

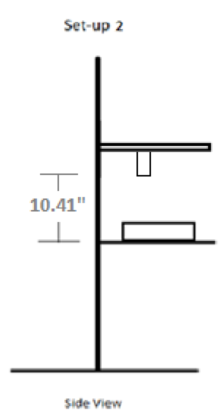

Figure 22: Set-up 2 Height

The side arms were 6 ½ inches from the outer vertical bars, as seen in Figure 21 (measured from the inside edges). This allowed for a steeper angle to enter the foam.

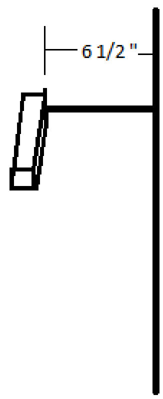

Figure 23: Set-up Sidearm Distance

Figure 24: Final Vertical Setup

During the second test run in Table 2, the stapling of site 1 pulled the listing to a different location, and therefore, site 2 was not aligned correctly. But all of the guns will be entering into the crevice at the same time, so this was determined as an invalid result. Test run 1, however, proved successful.

Table 2: Test Runs with Vertical Position

Test Run	Alpha	Beta	Issues
1	84.2°	3.8°	slight hang up on 2 and 3.
			1 and 4 were great
2	84.2°	3.8°	1 got caught.
			2 didn't go into the hole because 1 was stapled

The setup of test run 4 in Table 3 included two guns on one arm. The staple magazines on the guns were on opposite sides and rubbing against each other, so the adjacent holes could not be tested.

Table 3: Vertical Test Runs with 2 Guns

Test Run	Alpha	Beta	Issues
3	84.2°	3.8°	Question of Speed
			Good results
4			
gun 1	84.2°	3.8°	when stapling sites 1 and 3 at the same time,
gun 2	84.2°	3.8°	Successful.

Final Testing (After fabrication of stand)

The seat cylinders were the first to be mounted to the stand. Air lines were connected and they were tested to see if the new mounts allowed them to move up and down the proper distance.

The first gun was mounted to the aluminum arm, and aligned with the nest and foam. The second gun was mounted to the tubing into its proper place by moving the seat up towards the arms and placing the gun around the wire. Its simultaneous location on the arms was marked, and then it was mounted. After both guns were mounted, the nest was moved up and down in order to verify that they were in the correct locations.

After the nest and guns had a permanent spot on the stand, the toggle clamps were mounted. They were aligned so that they would hit the highest point on the side of the cushion; their locations were marked, and then they were mounted. Air lines were connected to the clamps in order to test their location, as well. The toggle clamps were closing too far which could have possibly damaged the seat, therefore, the air pressure going into the clamps was reduced.

The fabric restrainer plate was mounted after the nest. It was tested to see if it would interfere with the guns, as well as if it would completely retain the excess trim.

When all the electrical and pneumatic components were mounted, the lines were disconnected from their respective parts. We ran through the PLC program to validate that air was coming from the proper lines when expected. This showed that the solenoid valves and the PLC program were working as they should. Once this was complete, all components were attached and the stand was complete.

Testing Data

Table 4 below shows some testing results of the final stand.

Table 4: Final Testing

Test Run	Comments
1	Right gun at 2nd hole got in while the trim was laying out flat
	Left gun was 1 cm to the right of the tab hole
2	Right gun made it again, but did not close all the way
	Left gun hits perfectly around the wire (fabric was pulled out of the way for this run)
3	Right gun did not fire, but it did not make the tab hole
	Left made hold and wire
4	Time: 33 sec
	Right did not fire, might be too low on staples
	Left fired and missed
5	Right missed tab hole
	Left fired and missed
6	Both made it in tab hole and wire
	Time: 31 seconds
	tabs were pushed into the crevice prior to firing
7	Both guns made it again
	tabs were again stuck into the crevice prior to starting
8	Time from putting the cushion into the nest: 40 sec
	both guns made it again

Pressure Setting for each:

Guns = 80 Psi

Stand Cylinder = 80 Psi

Toggle Clamps = 70 Psi

2.4 Mission Environment

The environment of the manufacturing plant has a small role in the design of our product. The air is kept at a constant temperature and moisture content. The only restraint is that the new station needs to be about the same size as the current one. This means that the station must be about 4ft by 4ft, and the operator must be able to reach the gun.

Our design may require more electricity to be wired to the area, but this is readily available and will not affect the plant. A separate air tank will sit near or underneath the stand in order to provide an adequate amount of air to operate the guns.

2.5 Risk Management

An assessment of possible issues is listed below in Table 5, with their solution and level of importance.

Table 5: Risk Assessment

Rank	Risk Title	Risk Exp.	Action	Risk Type	Solution
5	Gun Jam	Likelihood: Mod Consequence: Low	Watch	Technical	Remove Jammed Hog Ring
1	Loss of Power	Likelihood: Low Consequence: High	Watch	Electrical	Check for Shorted Wire / Flipped Breaker
2	Loss of Air Pressure	Likelihood: Low Consequence: Mod/High	Watch	Technical	Check Hose Connection/ Compressor
6	Gun Misfire	Likelihood: Mod Consequence: Low	Watch	Technical	Check for Jam or Possibility of Reload
7	Misalignment	Likelihood: Low Consequence: Low	Inspect	Technical/Alignment	Adjust Alignment Constraints
3	Gun Caught on Material	Likelihood: Mod Consequence: Mod	Watch	Technical/Alignment	Adjust Alignment Constraints
4	Seize in Track	Likelihood: Low Consequence: Mod	Watch	Technical/Lubrication	Lubricate Track / Actuator

3.0 Project Management

Currently, all tasks have been met on time. Each person was assigned a responsibility which was met by the deadline. Nate has worked on the programming logic and will continue to develop a code to control our system functions. Robert has researched the optimal way to actuate the triggering of the guns. He will also cut and weld some of the steel components of the workstation. Hark and Josh worked on the material list and assembling the 3D model of the workstation. Molly worked on the Critical Design review report and drafted components of the work stand. The budget for this project was not given to us by Johnson Controls.

4.0 Conclusions

The prototype still needs adjustments in the design in order to become production floor ready. The position of the trim and cushion is very sensitive. Further modification is needed to make the process more repeatable. We found that tucking the extruded listing into the crease prior to gun firing resulted in better accuracy. Also, the process of welding the aluminum tubing needs to be more accurate, for the design requires specific angles.

For future recommendations: the clamps should move to a vertical position to allow for easier placement of the foam onto the nest. Larger diameter air lines should be used for the seat cylinders to increase the speed of travel. Light curtains and other safety guards should be implemented. The PLC program should be reconfigured to use one finger swipe which will reduce cycle time.

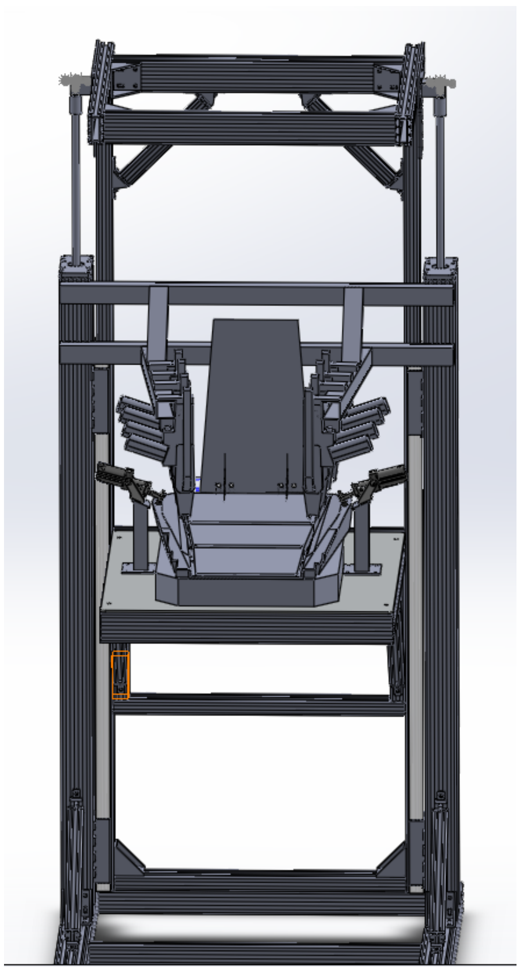

Figure 25: Final Apparatus

6.0 Appendix

Toggle Clamps:

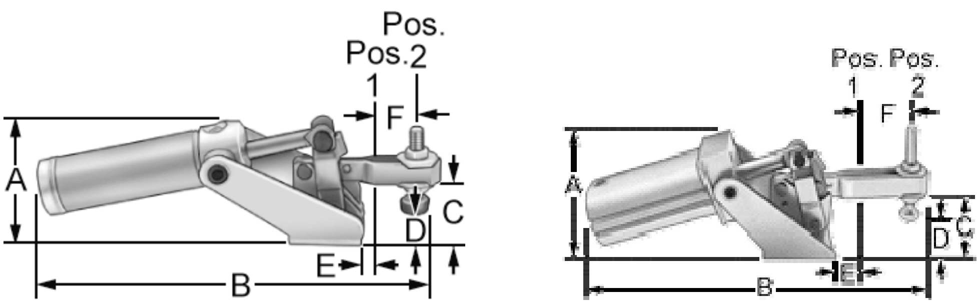

Figure 26: Toggle Clamp Example

When clamp is disengaged, spindle arm opens a min. of 88° for easy work piece removal. Spindle moves easily to any position along the U-shaped, open spindle arm. 5174A35 and 5129A21 have a molded neoprene-tipped spindle; 5129A22, 5129A23, and 5129A24 a hex head cap screw spindle.

Solenoids

Figure 27: Solenoid Example

Figure 28: Allen Bradley MicroLogix

This is a rough estimate of what the entire structure would cost without having any materials beforehand. A more detailed bill of materials will be provided as the detailed designed is developed further.

Gantt Chart

Version 1.7.3

To unlock this spreadsheet, purchase Gantt Chart Template Pro: http://www.vertex42.com/ExcelTemplates/excel-gantt-chart.html

Johnson Controls

Today's Date: 11/12/2012 Monday
(vertical red line)

Project Lead: Brandon Hughey
Start Date: 8/20/2012 Monday

First Day of Week (Mon=2): 2

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Design	Team	1/9/13	2/22/13	45	100%	33	45	0
1.1	Cad	Josh/Hark	1/10/13	1/29/13	20	100%	14	20	0
1.2	Automate Trigger	Robert	1/15/12	1/24/12	10	100%	7	10	0
1.3	PLC	Nate	1/9/13	2/12/13	35	100%	25	35	0
1.4	Cad	Josh/Hark	1/29/13	2/17/13	20	100%	14	20	0
1.5	PowerPoint	Brandon	2/17/13	2/19/13	3	100%	2	3	0
1.6	Report	Molly	2/17/13	2/26/13	10	100%	7	10	0
2	JC Meeting	Team	2/27/13	2/27/13	1	100%	1	1	0
2.1	Add new parts	Team	3/4/13	3/4/13	1	100%	1	1	0
2.2	Test	Team	3/4/13	3/11/13	8	100%	6	8	0
2.3	Research parts	Team	3/11/13	3/14/13	4	85%	4	3	1
2.4	Order Parts	Team	3/14/13	3/14/13	1	85%	1	0	1
2.5	Spring Break	Team	3/18/13	3/25/13	8	100%	6	8	0
2.6	Wait on parts	Team	3/25/13	3/29/13	5	75%	5	3	2
3	Start Building	Team	4/1/13	4/29/13	29	100%	21	29	0
3.1	Order Parts	Team	4/1/13	4/5/13	5	75%	5	3	2
3.2	Manufacturing	Team	4/8/13	4/12/13	5	75%	5	3	2
3.3	Test	Team	4/15/13	4/21/13	7	100%	5	7	0
3.4	Manufacturing	Team	4/15/13	4/21/13	7	100%	5	7	0
3.5	Test	Team	4/27/13	4/28/13	2	100%	0	2	0
4	Final Presentation	Team	4/29/13	4/29/13	1	100%	1	1	0
5	Detailed Design Report	Team	4/29/13	5/1/13	3	100%	3	3	0

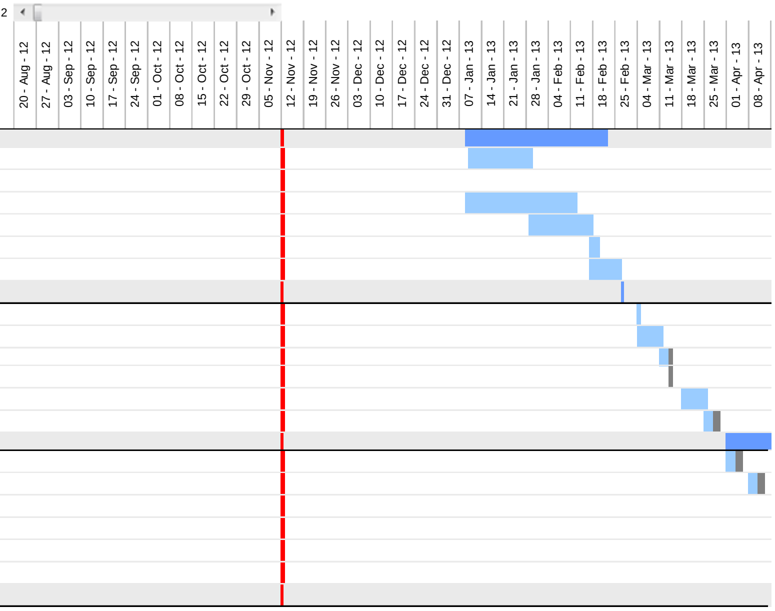

Figure 29: Gantt Chart

The bill of materials, gas accounts, and drafts of subassemblies are attached.