Resistor Element Assembly – Pin Spacer

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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April 2018

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF DRAWINGS

LIST OF TABLES

ABSTRACT

With an emphasis on worker safety, Post Glover Resistors, Inc. (my employer) approached me to see if I would develop an automated solution for the repetitive and labor-intensive process of assembling small and sharp components. This pick-and-place process is known within the company as “pinning”, which is discussed in further detail in the problem statement and background sections of this report.

The company’s need for an automated solution for the pin spacer assembly problem was an interesting project because although the company has many machines that automate the fabrication of its components, assembly automation of its components is relatively new. Various issues with the purchased components arose whereas almost no issues occurred with the parts designed and manufactured in-house by Post Glover. Use of in-house tooling and fabrication capabilities greatly reduced the cost and lead time for the project.

The successful completion of this project depended upon completing the items listed in the Plan to finish section of this document, which were completed with considerable effort. Many hours were spent testing and redesigning components with cardboard prototypes created to verify designs as needed. Designs that were initially produced were slightly modified, whereas the overall concept was generally maintained.

This project also used a SCARA robot from ABB (1), which required me to learn how to program. This was a challenge of its own, but fortunately there were resources provided to me that limited the difficulty of this task. The end result was what was intended as the desired assembly was produced. The following sections provide detail into the initial design, and the CONCLUSION covers the design updates that were made to complete this project.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

The resistor element pin spacer assembly ("pinning") that is currently performed at Post Glover Resistors, Inc. is a physically taxing and time-consuming process that puts various unwanted physical stress on the assembler. Five parts are manually stacked and aligned, and then pressed together at various pressures due to this manual process. Two of the parts are sharp-edged stainless-steel plates that expose the worker to cut hazards, and these plates are held apart by a ceramic pin spacer that is held in place by push nuts on the outer faces of the plates. Due to the time-consuming nature of the current process, increased demand is an issue. This extends the lead time to fill existing orders, and limits the company's ability to pursue larger orders that require a shorter turnaround time.

BACKGROUND

In 2011, Post Glover Resistors, Inc. installed a new resistor element stamping machine to produce resistor elements for high power applications. The plates are assembled in pairs (Figure 1 - Element Assembly), then sent to the bank assemblers to stack them into banks of resistors (Figure 2 - Bank Assembly). The demand for this product has gradually increased over time, however the process for assembling these stainless-steel plates into pairs is still labor intensive. A full-time worker is allocated to perform the assembly of the plate pairs. This current process involves use of a bottom block with a hole in it, and a sheet metal shim with a hex nut welded to it (Figure 3 - Manual Assembly Block and Plate).

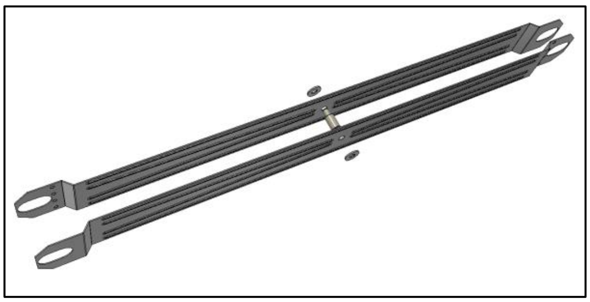


Figure 1 - Element Assembly

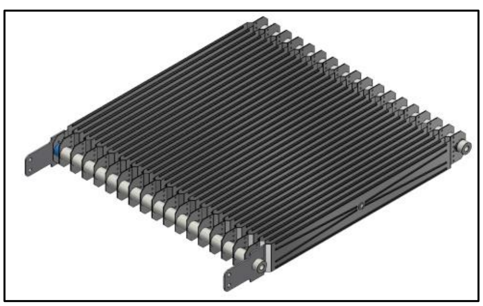


Figure 2 - Bank Assembly

Figure 3 - Manual Assembly Block and Plate

The current process leads to strain on the worker's wrists that can lead to permanent injury. Watching the assembler pick and place each component and manually press the shim onto the push nut was a bit painful. Because the yield strength of the push nut must be exceeded before the plate is secured to the pin spacer, each push nut must be pressed over the pin spacer one-at-a-time. This is achieved by flipping the first plate over after the first push nut is pressed onto the first element, then placing the second push nut on top of the second element and pressing that into place. Sometimes the plates get stuck to each other and must be pulled apart without the assembler getting cut by the exposed sharp edges. Figure 4 shows the actual completed assembled element pair:

Figure 4 - Completed Element Pair

RESEARCH

SCOPE OF THE PROBLEM

The specific resistor elements for this project are primarily used in mass transit applications for resistance braking. The current manual process does not produce a repeatable result in the pressure applied to the push nuts that secure the plates to the pin spacer. As stated in the previous section, the manual nature of the current assembly process places unwanted strain on the assembler. This problem is being addressed because the company would like to have a safe, cost-effective, and easy to use solution that will increase production.

What makes this project particularly important is that the current method used to assemble the element pairs will lead to permanent personal injury to the worker's wrists. The edges of the elements are sharp due to the thickness of the material required to make them, which falls in the range of 0.6mm to 1.5mm, depending on the application. Currently the manual process takes seven steps at about 40 seconds per element pair. Each bank assembly contains about 20 element pairs, and the current demand for more bank assemblies is increasing.

CURRENT STATE OF THE ART

Post Glover's parent company, TELEMA (https://www.telemait.com/en/index.html), uses a fully automated process to assemble the entire bank. However, this machine is permanently housed in their manufacturing facility in Italy. Also, TELEMA's machine was designed for a specific purpose with proprietary components, which is not desirable for Post Glover's solution due to long lead times for new or replacement components. Current price estimates for a similar machine exceed Post Glover's maximum budget of $50,000 (USD). Therefore, the company needs another cost-effective solution.

Current state of the art machines and components, other than TELEMA's, that may be used to place the components and press the assembly together include: bowl feeders (Figure 5 - Bowl Feeder), a SCARA robot (Figure 6 - SCARA Robot), a pneumatic plunger (Figure 7 - Pneumatic Plunger), various sensors and safety covers as needed to protect people around the work cell, and sensors as needed to signal the steps in the assembly process. For delivering and orienting the push nuts and pin spacer, three bowl feeders may be used. Extra tracks and selective geometry to reject parts back into the bowl must be designed, produced and attached to the bowls.

Figure 5 - Bowl Feeder

Figure 6 - SCARA Robot

For pressing the assembly together, use of a pneumatic plunger may be a satisfactory solution if the SCARA robot that can deliver the proper pressure to press the element pair together is too costly. However, if a SCARA robot is used, a special end effector may be designed that will pick up the elements plates as well as press the pieces together. A trigger force of 1.35 lb (6N) is required to press the push nuts into place (1). This load must be considered when selecting a solution.

Figure 7 - Pneumatic Plunger

Common threads between TELEMA's machine and what will be used for Post Glover's is the use of bowl feeders to deliver the push nuts and pin spacers. A SCARA robot would be an appropriate solution for picking and placing the elements for this project because it may be programmed to add additional assembly stations in the future. What is missing from the current state-of-the-art machine that TELEMA uses is a cost-effective, minimal maintenance solution.

END USER

The end user for this product is primarily the assembler. Instead of the assembler manually pressing the elements together at 40 seconds per element pair, the assembler will be removing the completed element pair in about fifteen seconds. When the lead assembler, Justin Gallacher, was interviewed, he stated that he did not want to handle each piece.

The other end user is the company, Post Glover Resistors, Inc. This is a product that will provide a safe, repeatable, and cost-effective solution.

CONCLUSIONS AND SUMMARY OF RESEARCH

The common themes for this project are safety, repeatability, and ease of use. Cost is also a concern for the company, but worker safety is paramount. By watching the assembler perform this task manually on only one element pair one can see the strain on the worker's wrists. Repeatability is needed to maintain product quality, and ease of use will lead to shorter lead times for future orders.

A minimal maintenance solution will also reduce unwanted downtime. The use of bowl feeders will aid in this. Utilizing a robot for part of the process will also help if the robot is a readily available product. The selection of components and design of this system must be geared toward safety and reliability.

CUSTOMER FEATURES

A brief survey was submitted via e-mail to the individuals who are currently most closely involved with the project. Screenshots of the replies are in APPENDIX A – SURVEY RESULTS. The following requirements were submitted for this survey with the request that the respondents rank them by importance:

- Safety
- Cost
- Ease of Use
- Repeatability
- Easy to Maintain
- Other (Please Specify)

The results of the survey provided the following ranking from most (1) to least (6) important:

1. Safety
2. Repeatability
3. Ease of Use
4. Cost
5. Easy to Maintain
6. Size (Floor Space)

During the interview with Mr. Gallacher, the desire to not handle each piece was defined, which would fall into Ease of Use. The strain on the worker's wrists must also be eliminated with a safe and easy to use solution.

The company's Maintenance Manager, Mike Simons, was also interviewed. His preference was to use existing power and air supplies, as well as to minimize the floor space for the solution. An easy to maintain and compact solution would be ideal from his viewpoint.

PRODUCT OBJECTIVES

The customer features listed in the previous section may be addressed by selecting components that are readily available where applicable, and fabricating non-standard components in-house using the company's existing capabilities. This would allow the product to be easily maintained by eliminating external procurement of fabricated component, and selecting purchased components that are readily available for replacement.

With safety being the most important aspect of the design, use of guards or light curtains to keep the workers clear of the hazardous aspects of the work area is suggested. Also, implementation of automatic shut-off when a worker enters the work area would be ideal. The components selected to perform these tasks should also be readily available or fabricated in-house.

Existing supply air up to 125psi, and power up to 240V supply may be used to power and supply the equipment. It is preferred to the assembler that manual handling of the push nuts and pin spacers be eliminated, and that these components be automatically oriented. This would provide an easy-to-use solution for these components.

Automatic orientation of the resistor elements is preferred. This is a pick-and-place function that should also be replaced by the product for safety and ease of use purposes. The cost of various alternatives to solve this problem must be considered. The overall size of the product is also dependent upon how this is handled.

QUALITY FUNCTION DEPLOYMENT

From the product objectives discussed in the previous section, several design features were determined. These features are listed below in the order of relative weight:

1. No Handling of Push Nuts and Pin Spacers
2. Pick and Place Element Plates
3. Guards (light curtains/worker screens)
4. Automatic Shut-Off When Worker Enters Work Area
5. Use Standard or Off-the-shelf Components
6. Uniform Pressure to Assemble Push Nuts to Pin Spacer
7. Automatically Orient Parts
8. Make non-standard components in-house
9. Use existing supply air/power

A House of Quality was created to assign importance to these features, and is in APPENDIX B – HOUSE OF QUALITY of this document.

DESIGN

DESIGN ALTERNATIVES AND SELECTION

The ideal solution for this project was to use a SCARA robot for the pick and place operations instead of designing special components that would incur long lead times. The focus was to find a robot that was cost effective and readily available.

Orienting the push nuts and pin spacer is to be performed by use of bowl feeders. Special adapters will be attached to accommodate the specific geometry of these components. These adapters will be designed and fabricated in-house by Post Glover.

For the work cell, most of the components are sheet metal, which will be fabricated in-house by Post Glover. The fixtures and parts are also assembled in-house.

Safety considerations were considered by selecting to use Lexan doors and covers to protect the worker. Light curtains were also considered; however, the work area is subjected to debris and dust from surrounding operations and machines. Lexan was chosen over Plexiglass to limit clouding.

Limit switches are also being used to detect whether a door is open or a cover is removed. If one is open or removed, the robot will stop. The robot must also stop if one of the bowl tracks is empty or jammed, or if one of the element stack stations is empty.

For picking and placing the elements, use of two suction cups will be incorporated, which is similar to the configuration on the element production line. To pick and place the pin spacer, a pneumatic gripper with in-house designed and fabricated fingers will be used. The picking and placing of the push nuts will be performed using suction as well.

Three layouts for the work cell were considered. Drawings of these layouts are in APPENDIX C – LAYOUT CONFIGURATIONSAPPENDIX C. Hand sketches for the specific design of the components are also included in APPENDIX D – HAND SKETCHES. The sketches were created in accordance with MP0213-L01, however most of the component designs ideas were still implemented.

COMPONENT SELECTION

As shown in APPENDIX C – LAYOUT CONFIGURATIONS, the third layout was selected. This layout will take more floor space, but also allows for twice as many element pairs to be assembled per load. An Alternative Configuration Evaluation is also included.

For this project, a SCARA robot was selected from ABB (model IRB 910 SC, 550mm (2)) because Post Glover already had an account with that company. Also, Post Glover already uses another ABB robot, model IRB 2600 (3), which uses the same pendant and controller software.

The bowl feeders selected for this project are the same as the bowl feeder that the company already uses for another work station, Part Feeders Inc. model V114 (4). The discharge track that comes with this bowl feeder will be replaced by specially designed discharge tracks for the push nuts and pin spacer.

The sheet metal components and fixtures are fabricated in-house, and have documentation that meets Post Glover’s requirements such as drawing format and tooling data. The documentation is stored in Post Glover’s documentation control software and can be recalled if a component is damaged and needs to be quickly replaced.

The Lexan doors and covers are to be outsourced to a local fabricator with which Post Glover already has an account. This reduces cost and lead time.

To limit cost, the components that do not come into contact with the push nuts, pin spacer and elements are to be fabricated from mill galvanized steel. This includes but is not limited to the frame and doors, top pan, table top and supports. The element stack stations, bowl tracks, end effector and exit track are all fabricated from 304 stainless steel to limit transfer of rust.

The limit switches being used for this project are from Eaton, model E47BCC07 (5), which the company already uses for various projects. To detect whether a push nut or pin spacer is present at the end of each bowl feeder track, a reflective sensor is used. This is Keyence model PR-FB30CP (6). Figure 8 – Track Sensors shows these components in red.

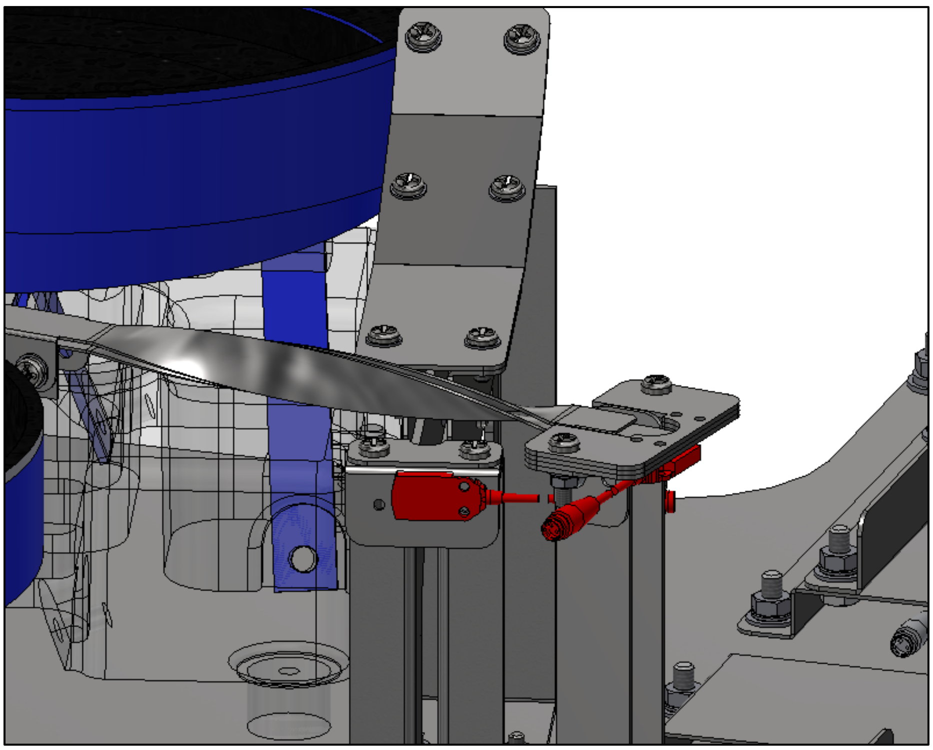


Figure 8 – Track Sensors

OPERATION

Before running the robot program, the doors of the work cell are opened and the stations are loaded. After loading the feeder bowls and stack stations, the doors are closed and the program is run from the robot pendant. The sequence of the robot follows the station numbers as shown in Figure 9 – Work Cell Stations. Here is the step-by-step sequence:

START: A to 1 (pick up first push nut)
1 to A (deliver first push nut)
A to 2 (pick up first element)
2 to A (deliver first element)
A to 3 (pick up pin spacer)
3 to A (deliver pin spacer and push into assembly)
A to 4 (pick up second element)
4 to A (deliver second element)
A to 5 (pick up second push nut)
5 to A (deliver second push nut and push into assembly)
A to A (push element pair together)
A to B (eject element pair)
B to A, then back to START

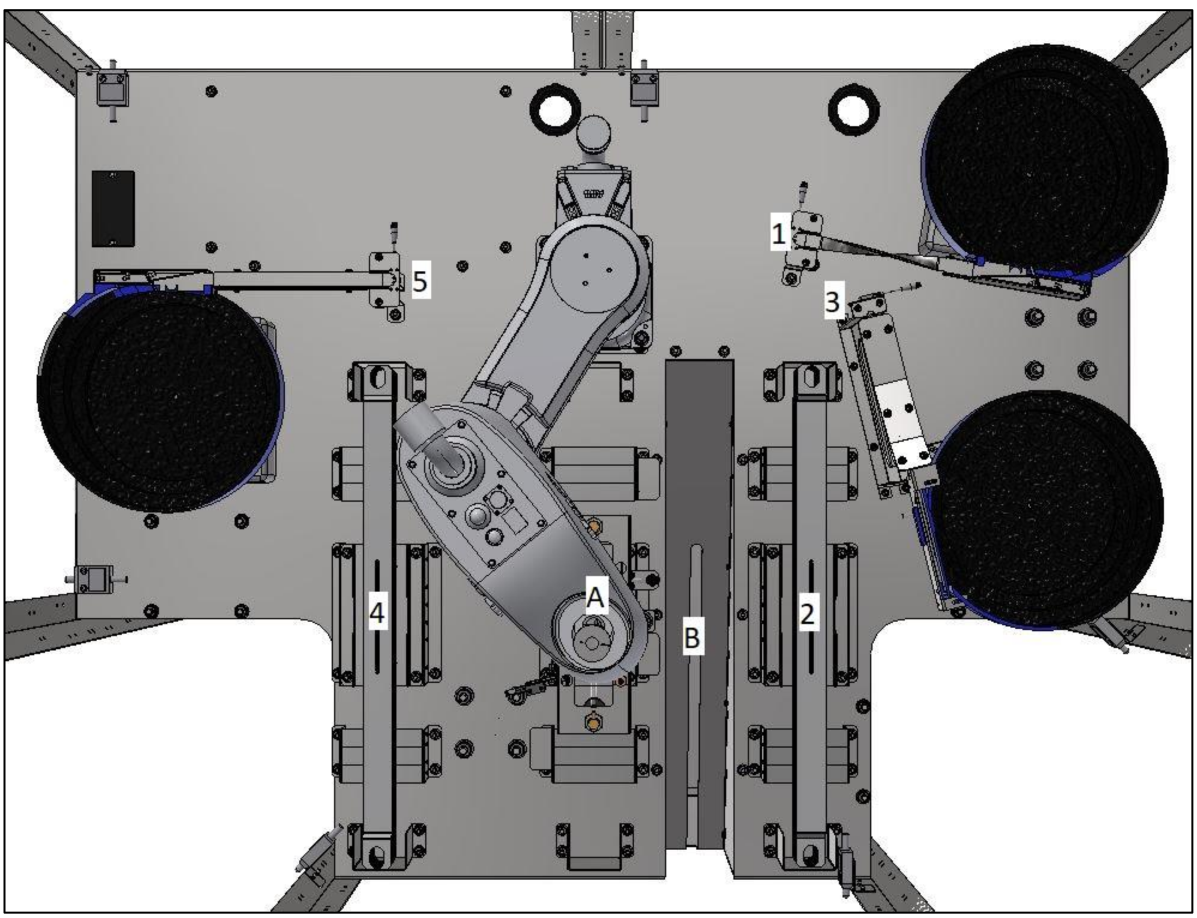


Figure 9 – Work Cell Stations

The element pair is assembled with the open sides of the push nuts facing outward. To get the correct orientation of the first push nut, the first bowl track is twisted to flip it after it exits the feeder bowl. This is shown in Figure 10 – First Bowl Feeder.

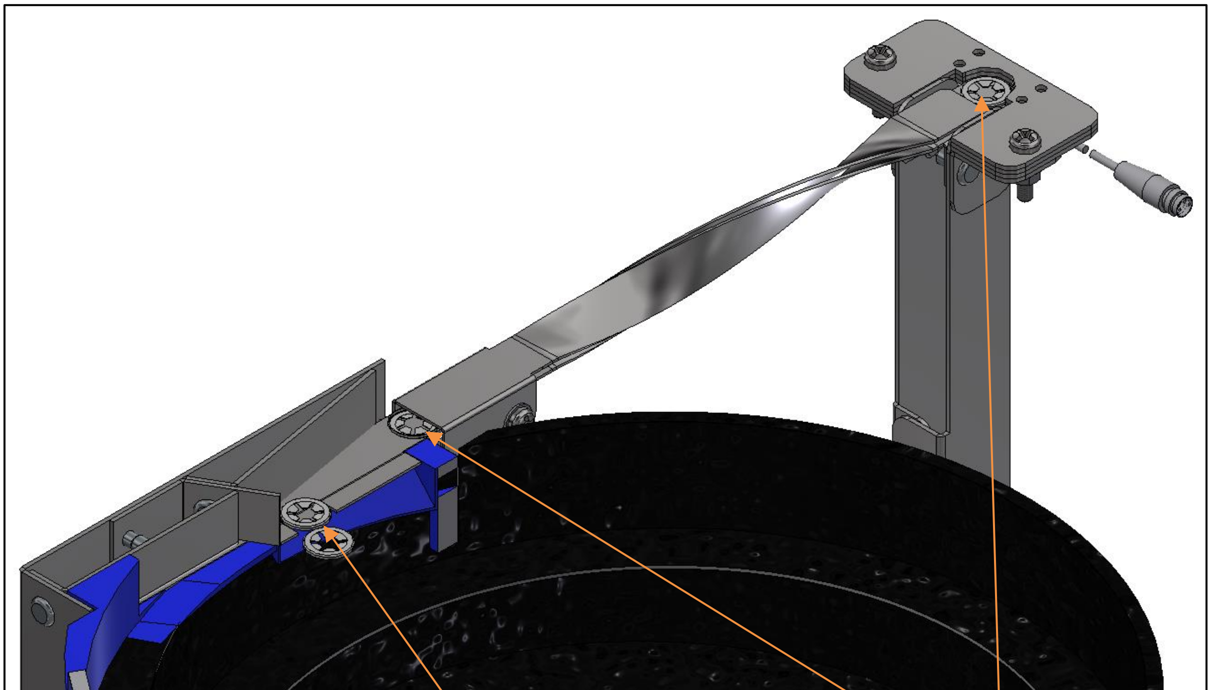


Figure 10 – First Bowl Feeder

The end effector is rotated and moved by the robot and uses suction to pick up the push nut. Then it is placed into the assembly fixture. The elements are lifted by use of two suction cups as shown in Drawing 2 – MP0213-05 – END EFFECTOR. These suction cups are also used to lift the element pair after assembly to the exit track at station B in Figure 9 – Work Cell Stations.

The pin spacer is moved by means of the pneumatic gripper also shown in Drawing 2 – MP0213-05 – END EFFECTOR. This is Festo model number 1310159 (7). The gripper may use up to 40 psi from the maximum supply of 125 psi. For the suction components, use of a vacuum generator is employed to deliver suction. This is ANVER model VR07 (8).

The remaining air supply will be used to reject the pin spacers that are not in the track as shown in Drawing 6 – MP0213-09 – FEEDER BOWL – PIN SPACER. This is further detailed in Figure 11 – Pin Spacer Rejection. The pin spacer in the track continues down the track whereas the incorrectly oriented pin spacers are blown back into the bowl feeder.

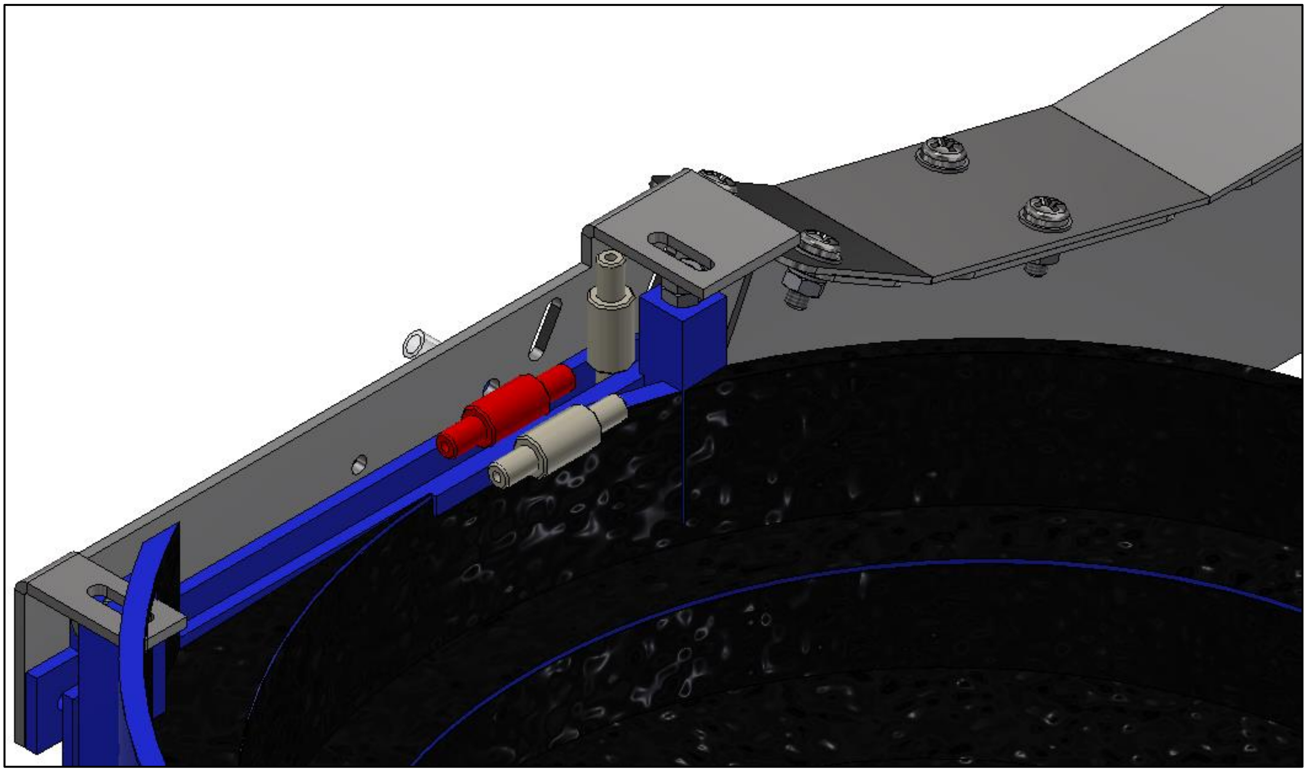
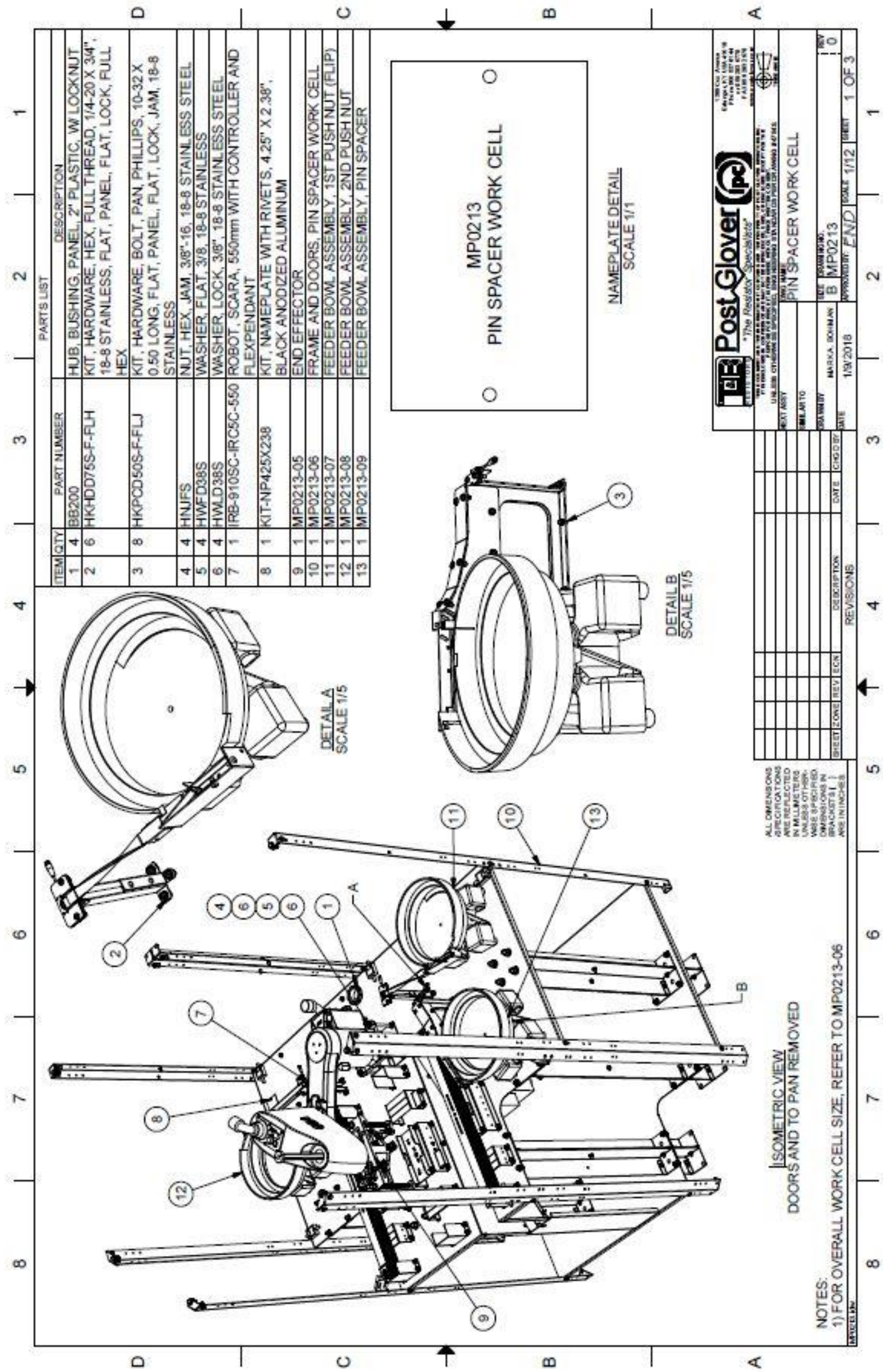
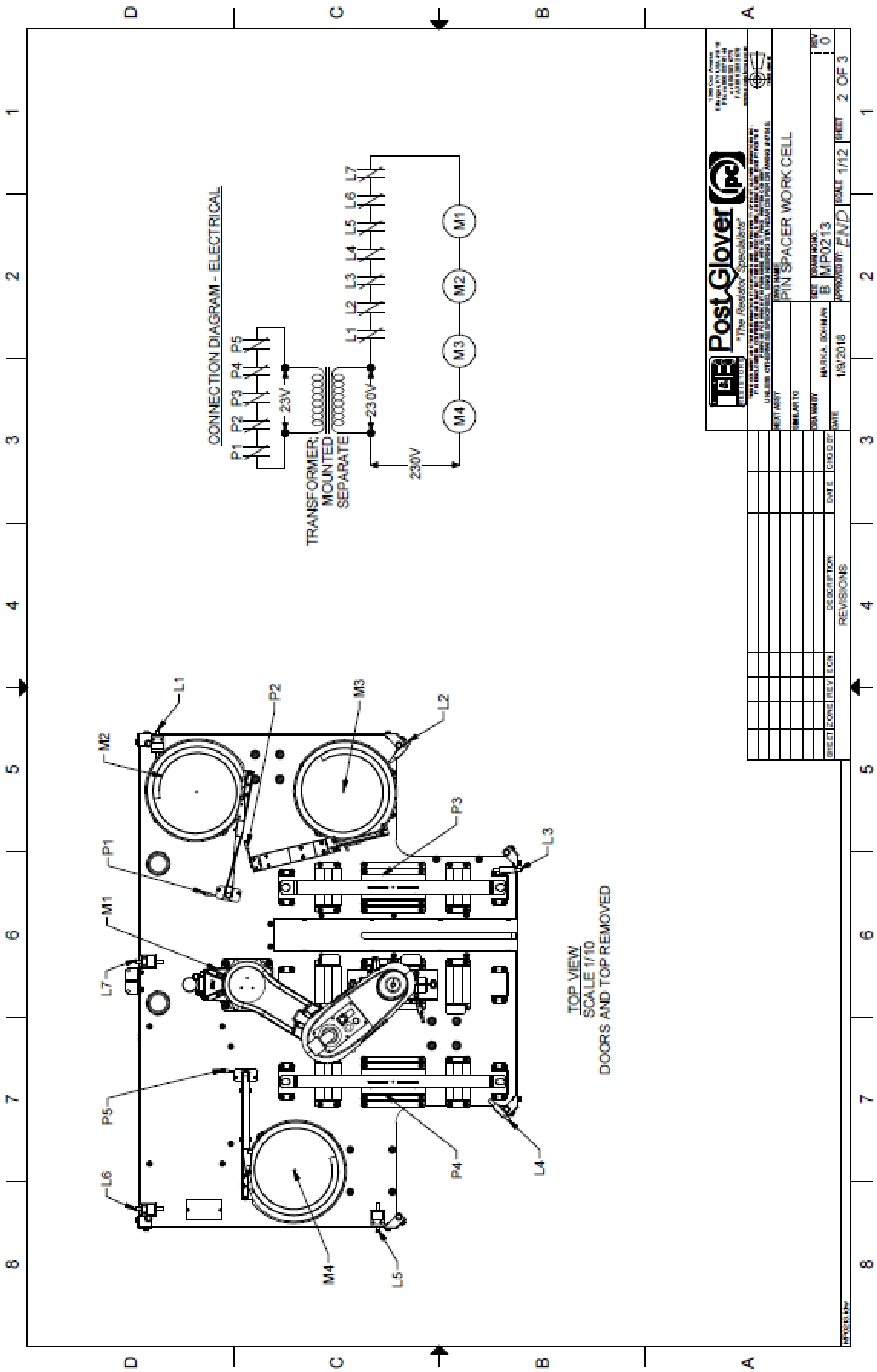


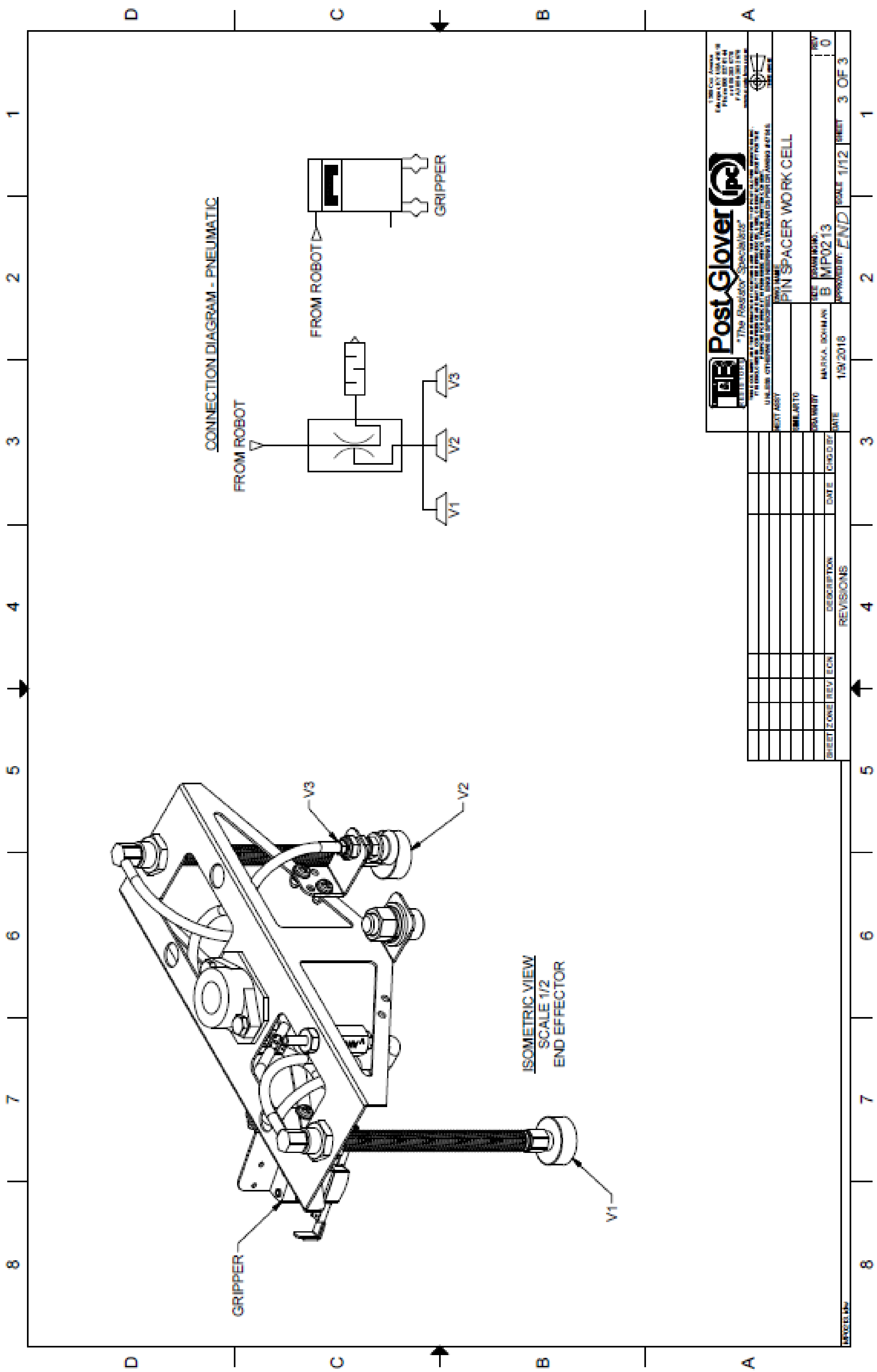
Figure 11 – Pin Spacer Rejection

DRAWINGS



Drawing 1 – MP0213 – WORK CELL


CONNECTION DIAGRAM - ELECTRICAL
P1 P2 P3 P4 P5
23V
230V
L1 L2 L3 L4 L5 L6 L7
M1
M2
M3
M4
230V
TRANSFORMER, MOUNTED SEPARATE
TOP VIEW
SCALE 1/10
DOORS AND TOP REMOVED
Post Glover
"The Resistor Specialists"
PIN SPACER WORK CELL
MARK A. BOHMAN
1/9/2018
B
MP0213
0
1/12
2 OF 3
REVISIONS
A B C D
1 2 3 4 5 6 7 8


CONNECTION DIAGRAM - PNEUMATIC
FROM ROBOT
FROM ROBOT
GRIPPER
V1
V2
V3
ISOMETRIC VIEW
SCALE 1/2
END EFFECTOR
GRIPPER
V1
V2
V3
REVISIONS
Post Glover
"The Resistor Specialists"
PIN SPACER WORK CELL
B
MP0213
MARK A. BOHMAN
1/12
3 OF 3
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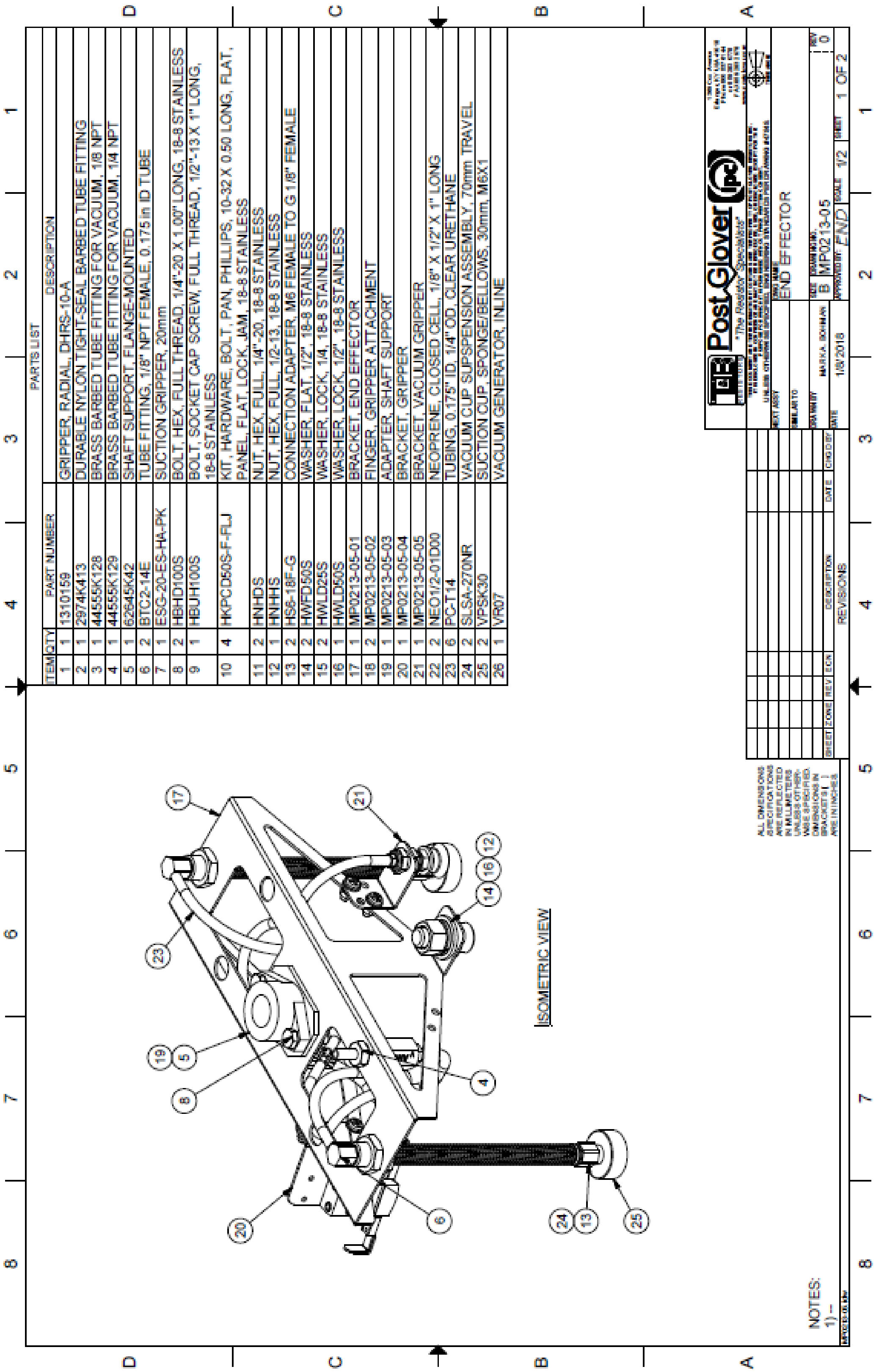
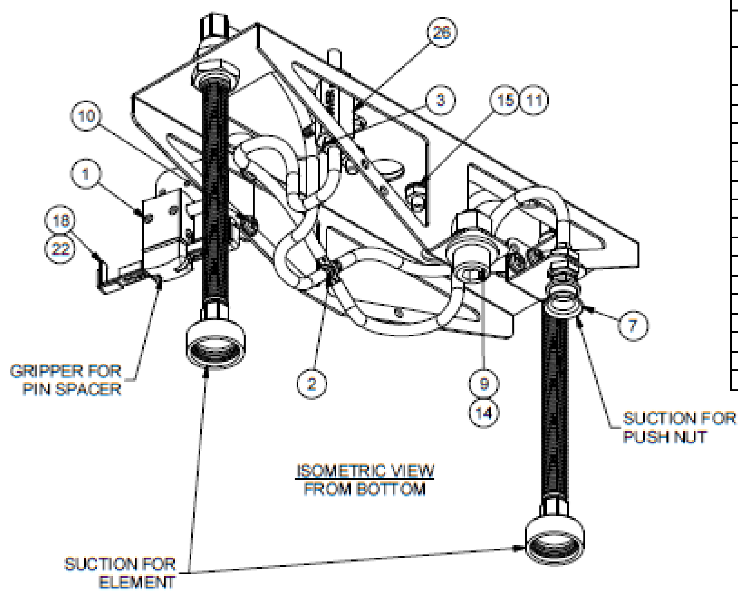


Drawing 2 – MP0213-05 – END EFFECTOR



ISOMETRIC VIEW
FROM BOTTOM

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	1310159	GRIPPER, RADIAL, DHRS-10-A
2	1	2974K413	DURABLE NYLON TIGHT-SEAL BARBED TUBE FITTING
3	1	44555K128	BRASS BARBED TUBE FITTING FOR VACUUM, 1/8 NPT
4	1	44555K129	BRASS BARBED TUBE FITTING FOR VACUUM, 1/4 NPT
5	1	62645K42	SHAFT SUPPORT, FLANGE-MOUNTED
6	2	BTC2-14E	TUBE FITTING, 1/8" NPT FEMALE, 0.175 in ID TUBE
7	1	ESG-20-ES-HA-PK	SUCTION GRIPPER, 20mm
8	2	HBHD100S	BOLT, HEX, FULL THREAD, 1/4"-20 X 1.00" LONG, 18-8 STAINLESS
9	1	HBUH100S	BOLT, SOCKET CAP SCREW, FULL THREAD, 1/2"-13 X 1" LONG, 18-8 STAINLESS
10	4	HKPCD50S-F-FLJ	KIT, HARDWARE, BOLT, PAN, PHILLIPS, 10-32 X 0.50 LONG, FLAT, PANEL, FLAT, LOCK, JAM, 18-8 STAINLESS
11	2	HNHDS	NUT, HEX, FULL, 1/4"-20, 18-8 STAINLESS
12	1	HNHHS	NUT, HEX, FULL, 1/2-13, 18-8 STAINLESS
13	2	HS6-18F-G	CONNECTION ADAPTER, M6 FEMALE TO G 1/8" FEMALE
14	2	HWFD50S	WASHER, FLAT, 1/2", 18-8 STAINLESS
15	2	HWLD25S	WASHER, LOCK, 1/4, 18-8 STAINLESS
16	1	HWLD50S	WASHER, LOCK, 1/2", 18-8 STAINLESS
17	1	MP0213-05-01	BRACKET, END EFFECTOR
18	2	MP0213-05-02	FINGER, GRIPPER ATTACHMENT
19	1	MP0213-05-03	ADAPTER, SHAFT SUPPORT
20	1	MP0213-05-04	BRACKET, GRIPPER
21	1	MP0213-05-05	BRACKET, VACUUM GRIPPER
22	2	NEO1/2-01D00	NEOPRENE, CLOSED CELL, 1/8" X 1/2" X 1" LONG
23	6	PC-T14	TUBING, 0.175" ID, 1/4" OD, CLEAR URETHANE
24	2	SLSA-270NR	VACUUM CUP SUPSPENSION ASSEMBLY, 70mm TRAVEL
25	2	VPSK30	SUCTION CUP, SPONGE/BELLOWS, 30mm, M6X1
26	1	VR07	VACUUM GENERATOR, INLINE

SHEET	ZONE	REV	ECN	DESCRIPTION	DATE	CHG'D BY

REVISIONS

Post Glover
"The Resistor Specialists"

UNLESS OTHERWISE SPECIFIED

NEXT ASSY	DWG NAME: END EFFECTOR
SIMILAR TO	
DRAWN BY: MARK A. BOHMAN	SIZE: B; DRAWING NO.: MP0213-05; REV: 0
DATE: 1/8/2018	APPROVED BY: END; SCALE: 1/2; SHEET: 2 OF 2

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	10	1151A81	HINGE, LIFT-OFF, LEFT HAND OPEN
2	5	1568A14	HANDLE, PULL, 4" X 1.88", ALUMINUM, 10-32 X 3/4" THREADED MOUNTING
3	10	97517A315	RIVET, 1/8" DIA, 0.126" - 0.187" GRIP RANGE, ALUMINUM WITH STEEL MANDREL
4	70	97525A490	RIVET, 3/16" DIA, 0.126" - 0.25" GRIP RANGE, 18-8 STAINLESS STEEL
5	7	E47BCC07	LIMIT SWITCH, COMPACT, PRE-WIRED
6	4	F60600-304	ROD, THREADED, 3/8-16 X 6.00", 304 STAINLESS STEEL
7	1	HBUH100S	BOLT, SOCKET CAP SCREW, FULL THREAD, 1/2"-13 X 1" LONG, 18-8 STAINLESS
8	124	HKHDD75S-F-FLH	KIT, HARDWARE, HEX, FULL THREAD, 1/4-20 X 3/4", 18-8 STAINLESS, FLAT, PANEL, FLAT, LOCK, FULL HEX
9	12	HKHDD75S-LF	KIT, HARDWARE, HEX, FULL THREAD, 1/4-20 X 0.75", 18-8 STAINLESS, LOCK, FLAT
10	34	HKHF100S-F-FLJ	KIT, HARDWARE, HEX, FULL THREAD, 3/8-16 X 1", 18-8 STAINLESS, FLAT, PANEL, FLAT, LOCK, JAM HEX NUT
11	8	HKHH150S-F-FLH	KIT, HARDWARE, HEX, FULL THREAD, 1/2-13 X 1 1/2", 18-8 STAINLESS, FLAT, PANEL, FLAT, LOCK, FULL HEX NUT
12	12	HKPCD50S-F-FLJ	KIT, HARDWARE, BOLT, PAN, PHILLIPS, 10-32 X 0.50 LONG, FLAT, PANEL, FLAT, LOCK, JAM, 18-8 STAINLESS
13	8	HKPCD75S-FLJ	KIT, HARDWARE, BOLT, PAN, PHILLIPS, 10-32 X 0.75 LONG, PANEL, FLAT, LOCK, JAM, 18-8 STAINLESS
14	1	HNHHS	NUT, HEX, FULL, 1/2-13, 18-8 STAINLESS
15	12	HNJFS	NUT, HEX, JAM, 3/8"-16, 18-8 STAINLESS STEEL
16	12	HNRDS-1	NUT, RIVET, HALF-HEX SHANK, 1/4"-20, 304 STAINLESS, 0.02-0.12" GRIP(24-11GA.), 0.354" HEX PUNCH
17	12	HWFD38S	WASHER, FLAT, 3/8, 18-8 STAINLESS
18	2	HWFD50S	WASHER, FLAT, 1/2", 18-8 STAINLESS
19	12	HWLD38S	WASHER, LOCK, 3/8", 18-8 STAINLESS STEEL
20	1	HWLD50S	WASHER, LOCK, 1/2", 18-8 STAINLESS
21	5	LHSS27-H-LH	LATCH, SPRING, LEFT HAND, 304 STAINLESS

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
22	3	MP0213-01	BRACKET, ELEMENT MOUNTING
23	6	MP0213-02	GUARD, ELEMENT PRESSING, SIDE
24	6	MP0213-03	GUARD, ELEMENT PRESSING, END
25	6	MP0213-04	BRACKET, ELEMENT RESTING
26	1	MP0213-06-01	TABLE TOP
27	4	MP0213-06-02	CORNER UPRIGHT
28	4	MP0213-06-03	CORNER UPRIGHT, FRONT
29	1	MP0213-06-04	BOTTOM SHELF
30	1	MP0213-06-05	TOP PAN
31	2	MP0213-06-06	DOOR, BOWL ACCESS
32	2	MP0213-06-07	DOOR, ELEMENT ACCESS
33	1	MP0213-06-08	DOOR, FRONT ACCESS
34	2	MP0213-06-09	COVER, REAR
35	1	MP0213-06-10	ROBOT MOUNT
36	4	MP0213-06-11	TABLE SUPPORT
37	4	MP0213-06-12	BASE SUPPORT
38	2	MP0213-06-13	TABLE SUPPORT, 1ST STACK
39	2	MP0213-06-14	BASE SUPPORT, 1ST STACK
40	1	MP0213-06-15	EXIT TRACK, INSIDE
41	1	MP0213-06-16	EXIT TRACK, OUTSIDE
42	1	MP0213-06-17	EXIT TRACK
43	1	MP0213-06-18	PENDANT SHELF
44	5	MP0213-06-19	LATCH BRACKET
45	3	MP0213-06-20	BRACKET, LIMIT SWITCH
46	2	MP0213-06-21	BRACKET, DOOR GUARD
47	2	MP0213-06-22	GUSSET, DOOR GUARD
48	4	MP0213-06-23	BRACKET, SUCTION PROTECTOR
49	1	MP0213-06-24	BRACKET, ELEMENT CENTER
50	18	NEOPRENE-04D50	NEOPRENE, CLOSED CELL, 1/8" X 1" X 4.50" LONG
51	2	PR-FB30CP	SENSOR, FLAT REFLECTIVE (BACKGROUND SUPPRESSION), M8 CONNECTOR TYPE, 30mm

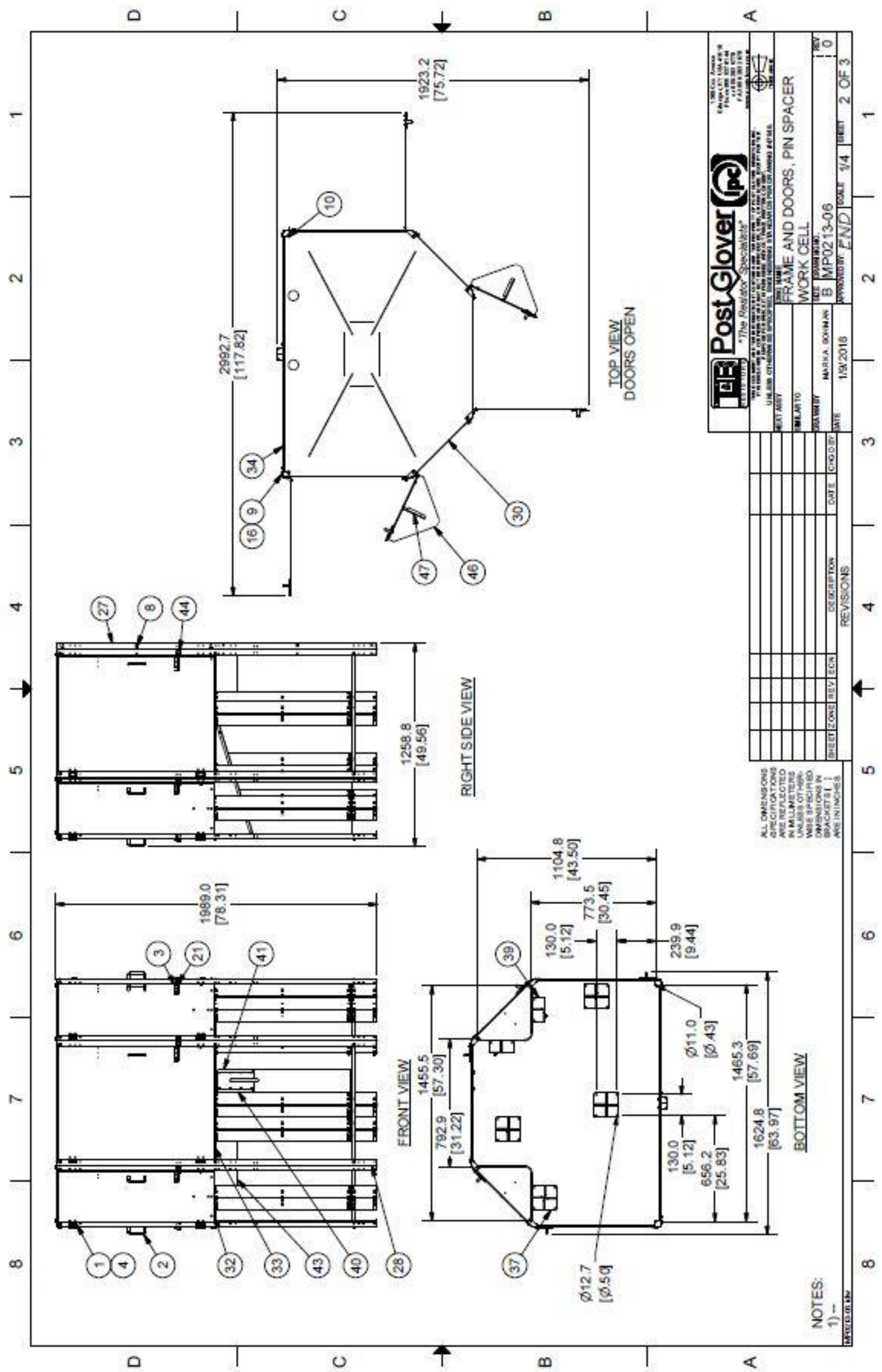
SHEET	ZONE	REV	ECN	DESCRIPTION	DATE	CHGD BY

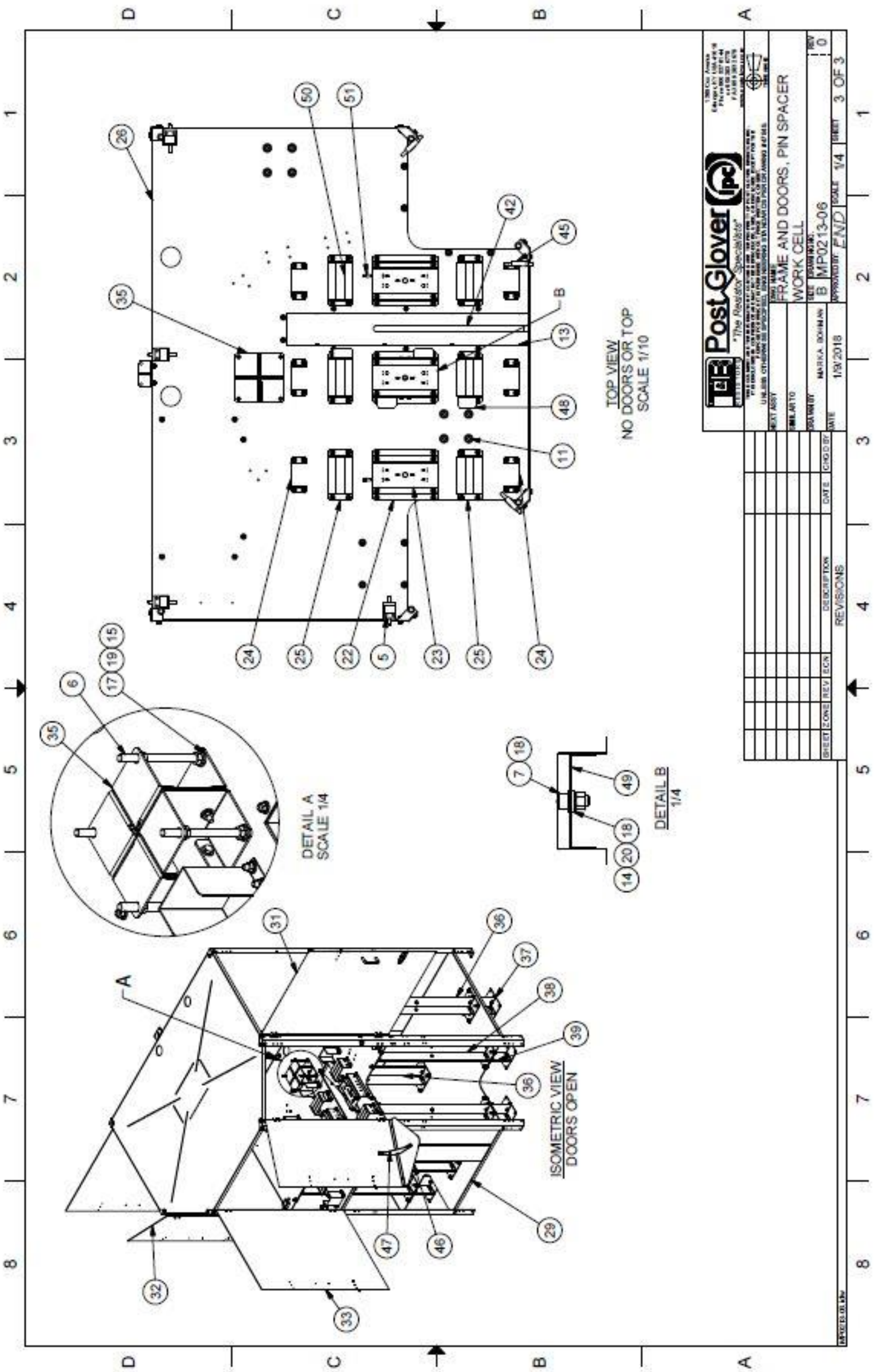
REVISIONS

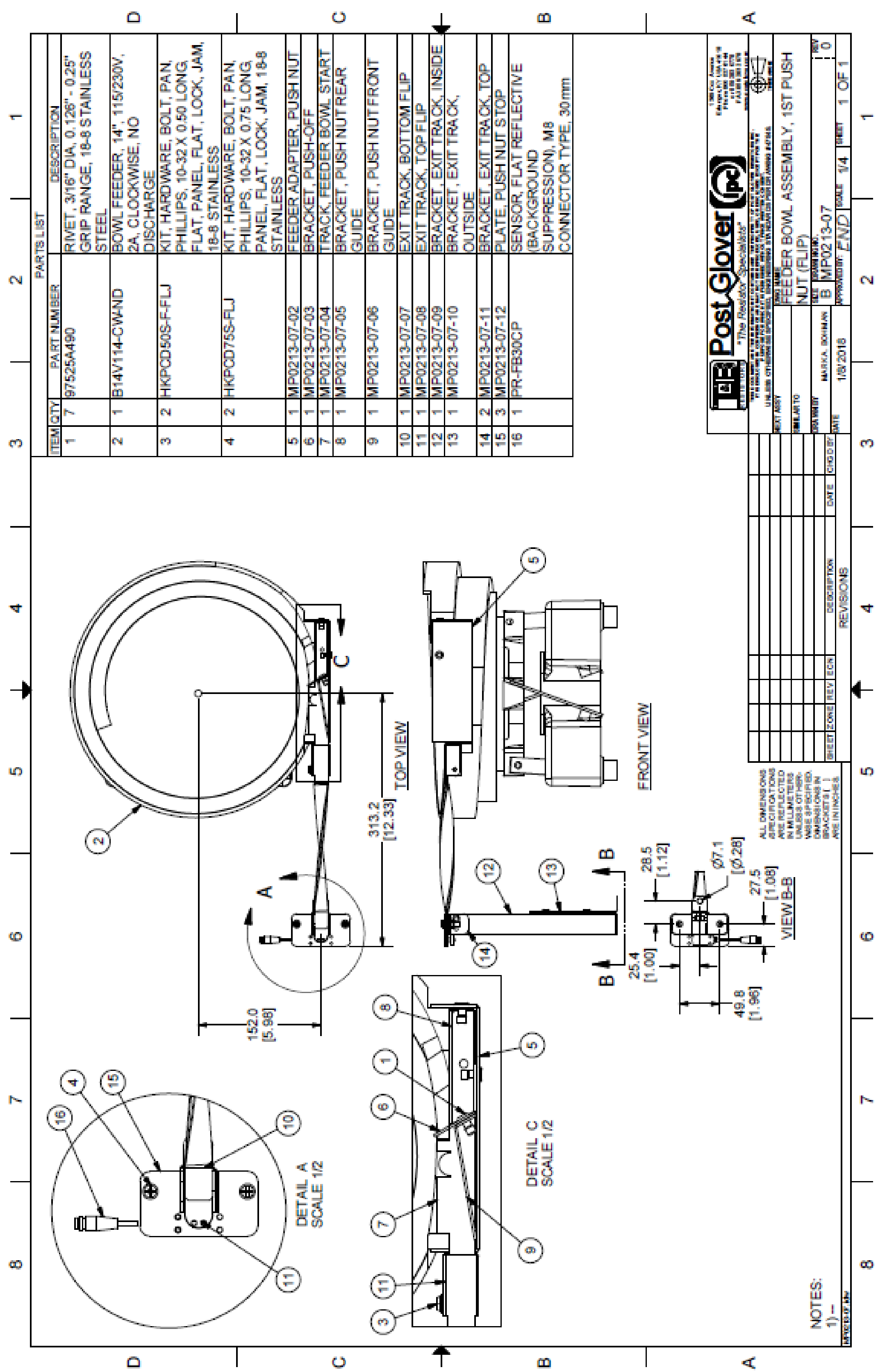
Post Glover "The Resistor Specialists"

DWG NAME: FRAME AND DOORS, PIN SPACER WORK CELL
DRAWN BY: MARK A. BOHMAN
DATE: 1/9/2018
SIZE: B DRAWING NO.: MP0213-06 REV: 0
SCALE: 1/4 SHEET: 1 OF 3

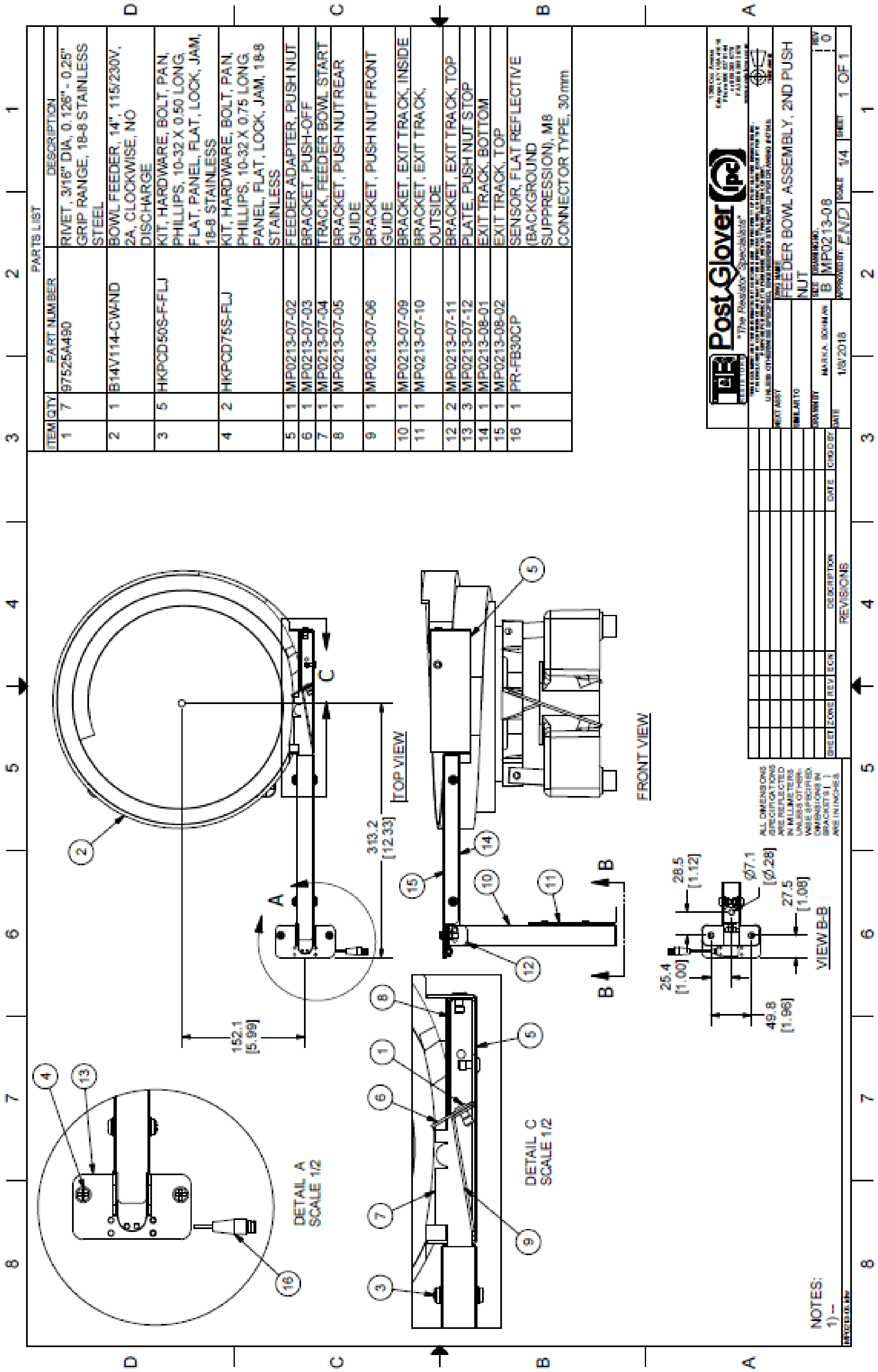
Drawing 3 – MP0213-06 – FRAME AND DOORS (TABLE ASSEMBLY)


TOP VIEW
DOORS OPEN
RIGHT SIDE VIEW
FRONT VIEW
BOTTOM VIEW
1923.2
[75.72]
2992.7
[117.82]
1258.8
[49.56]
1989.0
[78.31]
1104.8
[43.50]
773.5
[30.45]
130.0
[5.12]
239.9
[9.44]
Ø11.0
[Ø.43]
1455.5
[57.30]
792.9
[31.22]
656.2
[25.83]
1465.3
[57.69]
1624.8
[63.97]
Ø12.7
[Ø.50]
Post Glover
"The Resistor Specialists"
FRAME AND DOORS, PIN SPACER
WORK CELL
B MP0213-06
1/4
2 OF 3
MARK A. BOHMAN
1/9/2018
REVISIONS
NOTES:
1) --

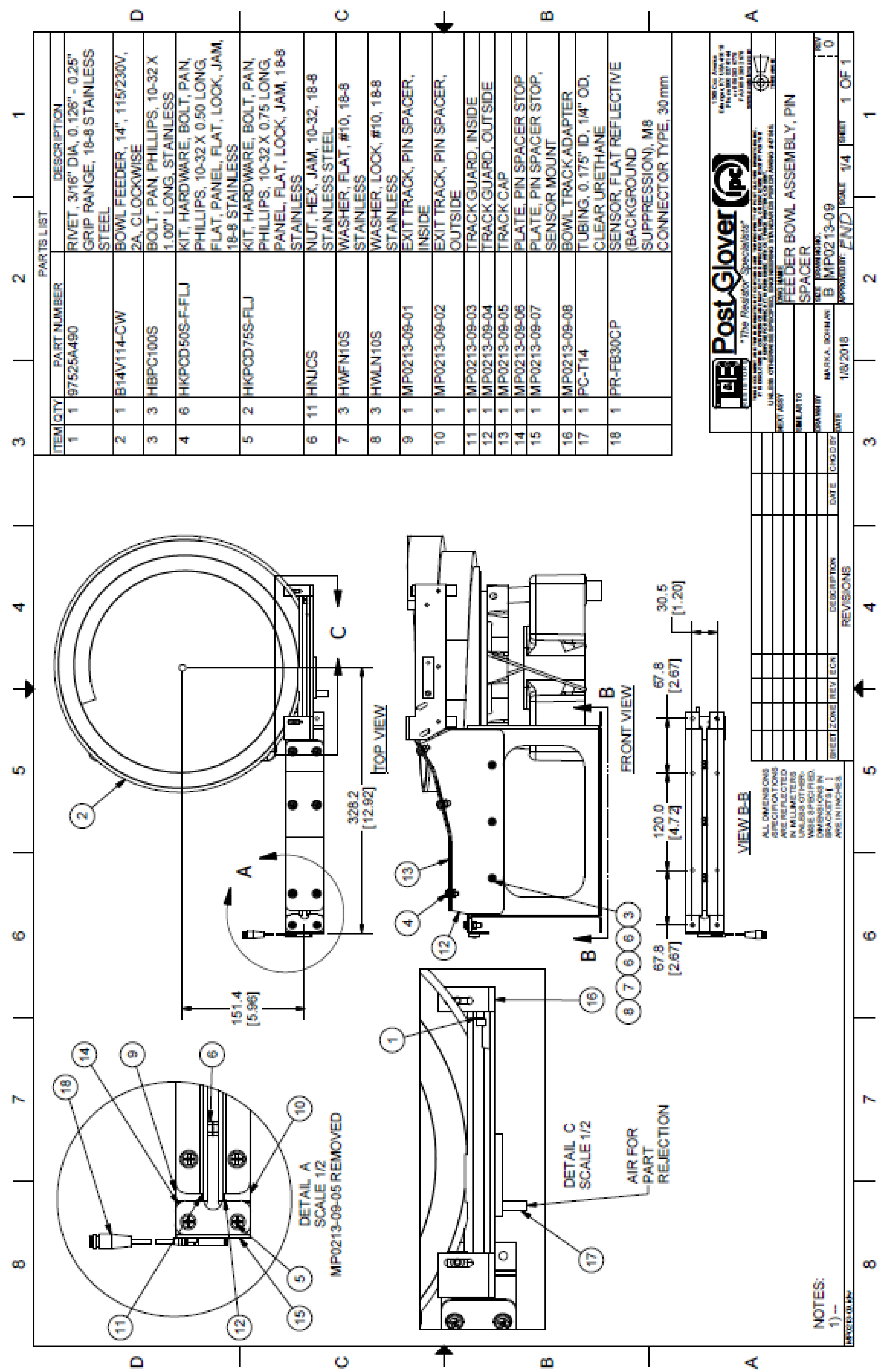

TOP VIEW
NO DOORS OR TOP
SCALE 1/10
DETAIL A
SCALE 1/4
DETAIL B
1/4
ISOMETRIC VIEW
DOORS OPEN
Post Glover
"The Resistor Specialists"
FRAME AND DOORS, PIN SPACER
WORK CELL
MP0213-06
MARKA BOHMAN
1/3/2018
3 OF 3
REVISIONS



Drawing 4 – MP0213-07 – FEEDER BOWL – FIRST PUSH NUT



Drawing 5 – MP0213-08 – FEEDER BOWL – SECOND PUSH NUT



Drawing 6 – MP0213-09 – FEEDER BOWL – PIN SPACER

LOADING CONDITIONS

As shown in Figure 12 - Loads, the bowl feeders and element stack stations will provide a load on the table surface of 60lbs each. The robot weighs 52lbs, and the load applied to the element pair is 6lbs maximum.

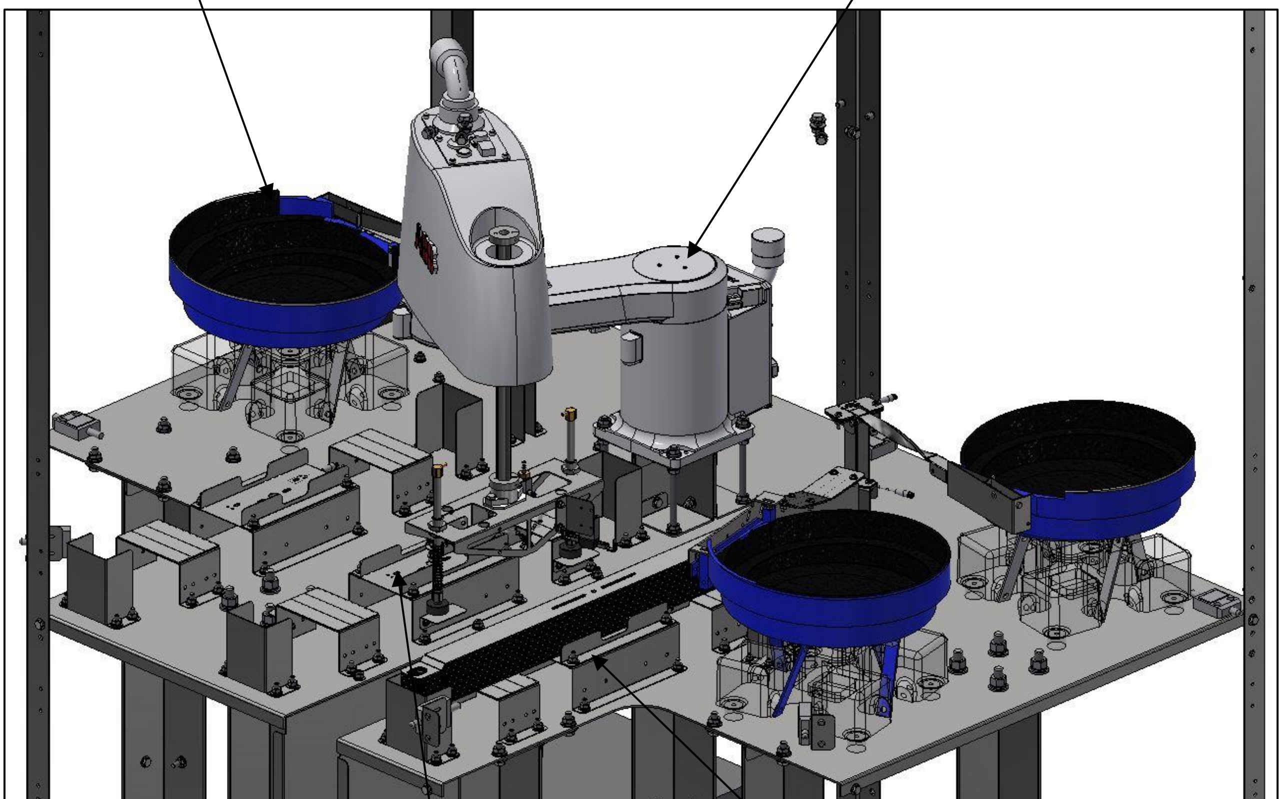


Figure 12 - Loads

For the end effector (MP0213-05), a load will be supplied to the head of the bolt as shown in Figure 13 – End Effector Load.

Figure 13 – End Effector Load

DESIGN ANALYSIS

A Finite Element Analysis (FEA) was performed on the table assembly (MP0213-06) using Autodesk Inventor 2018 Professional. Preprocessing of the 3D model was performed by removing the hardware and other components such as the doors and top pan. The loads listed in the previous section, LOADING CONDITIONS, are shown as the yellow arrows in Figure 14 – Table FEA.

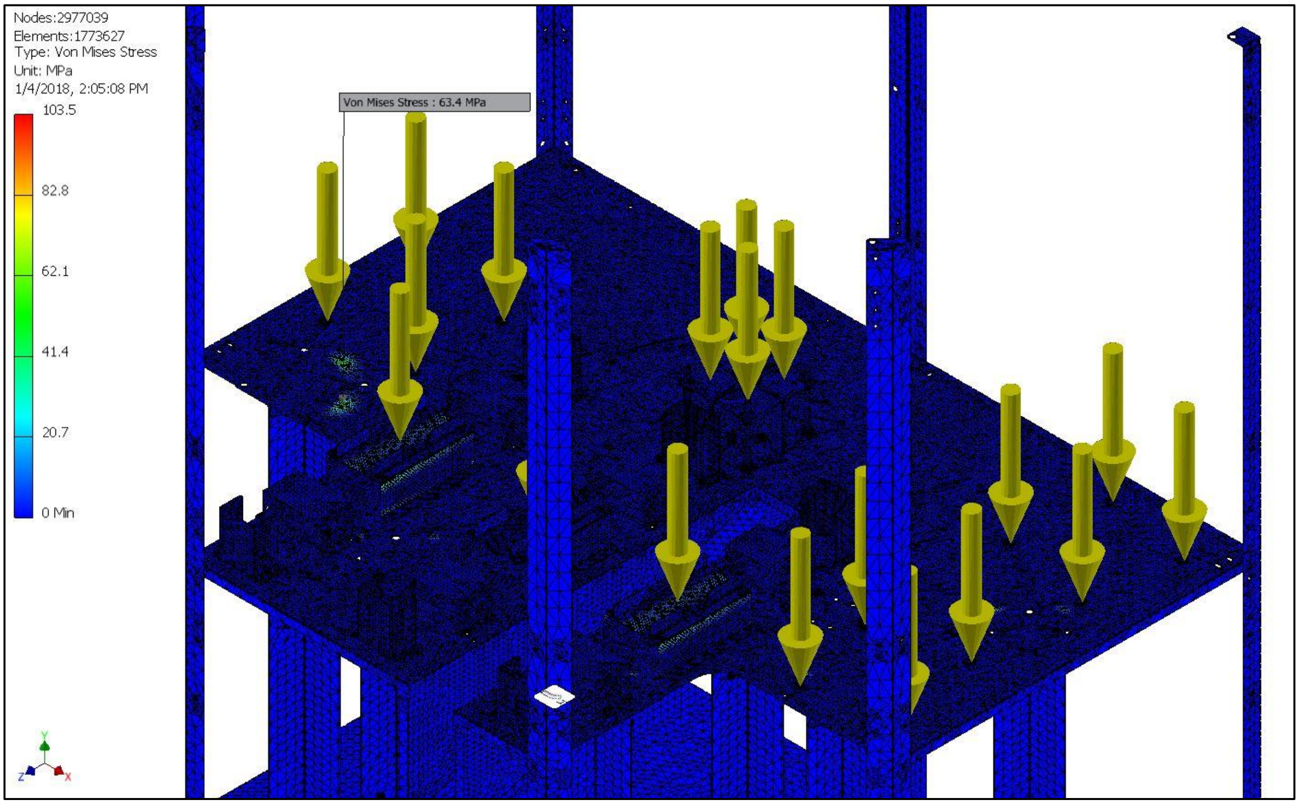


Figure 14 – Table FEA

The Von Mises Stress for the assembly is below 65 MPa, which is acceptable for this application because the yield stress for the material used is 207 MPa (mill galvanized steel – low carbon). This data is native to the CAD software.

The maximum displacement is under 1.0mm and is shown in Figure 15 – Table Displacement. This is also acceptable for the application.

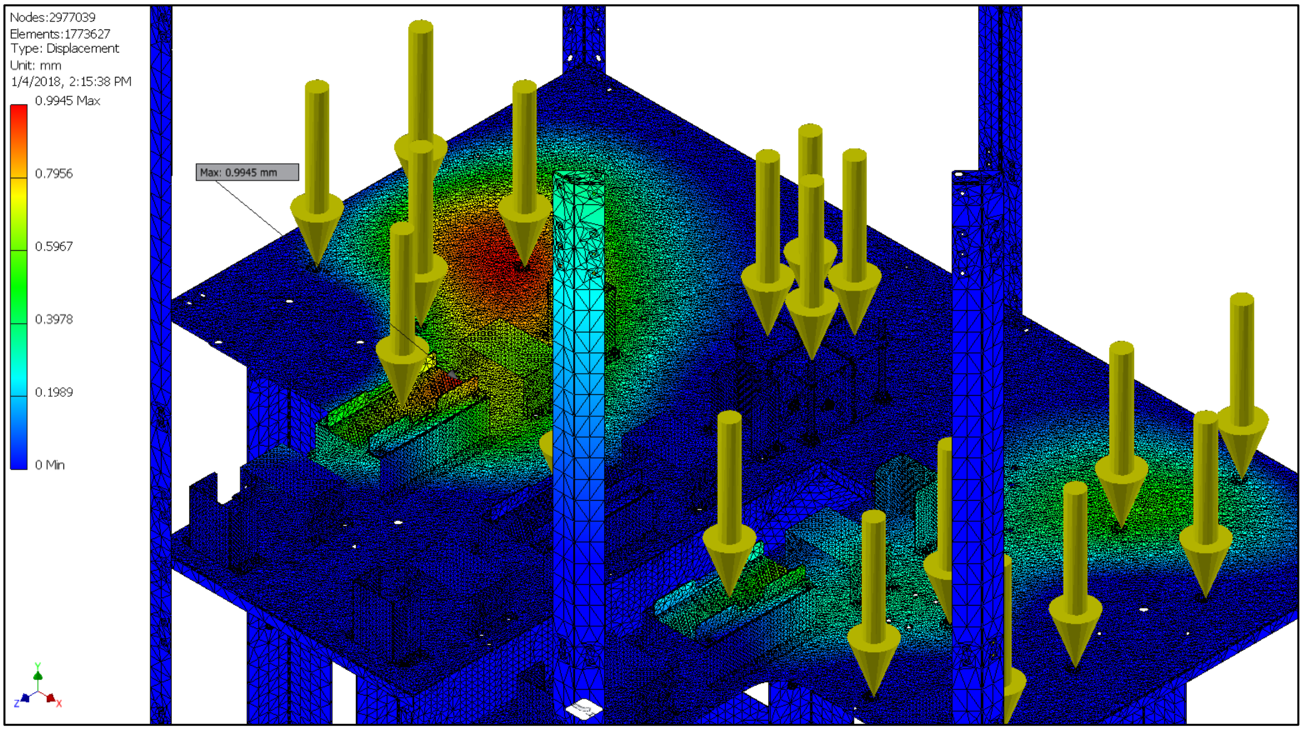


Figure 15 – Table Displacement

A Finite Element Analysis (FEA) was performed on the end effector (MP0213-05) as well. Preprocessing of the 3D model was performed by removing the hardware and other components such as the gripper and vacuums. The load listed in the previous section, LOADING CONDITIONS, is shown as the yellow arrow in Figure 16 – End Effector FEA.

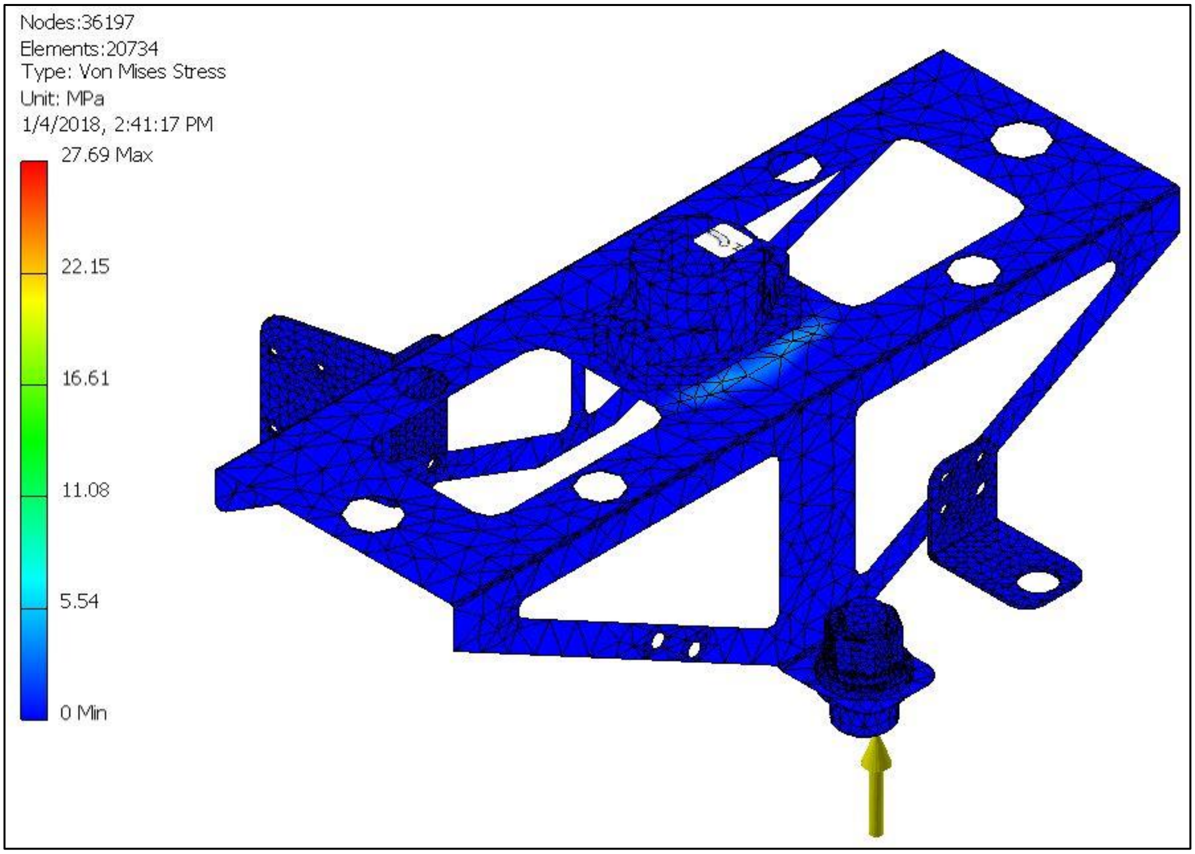


Figure 16 – End Effector FEA

The maximum stress of 27.69MPa is located between the threads of the bolt and nut as shown in Figure 17 - End Effector FEA Max Stress. This stress is also acceptable for this application because the yield stress of the hardware material is 215MPa (300 series stainless steel).

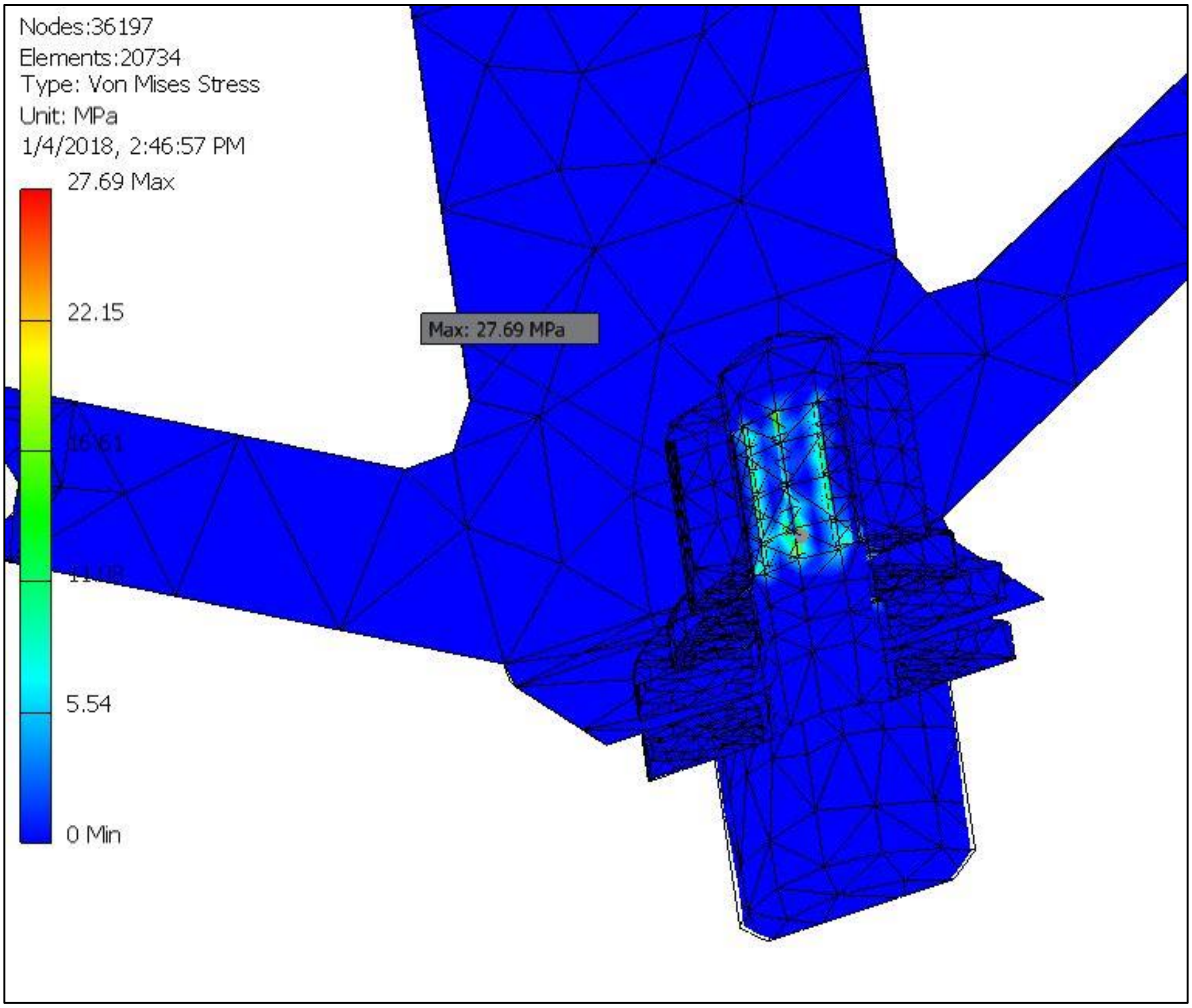


Figure 17 - End Effector FEA Max Stress

Displacement of the end effector under this load is under 0.2mm. This is acceptable for the application and is shown in Figure 18 – End Effector Displacement.

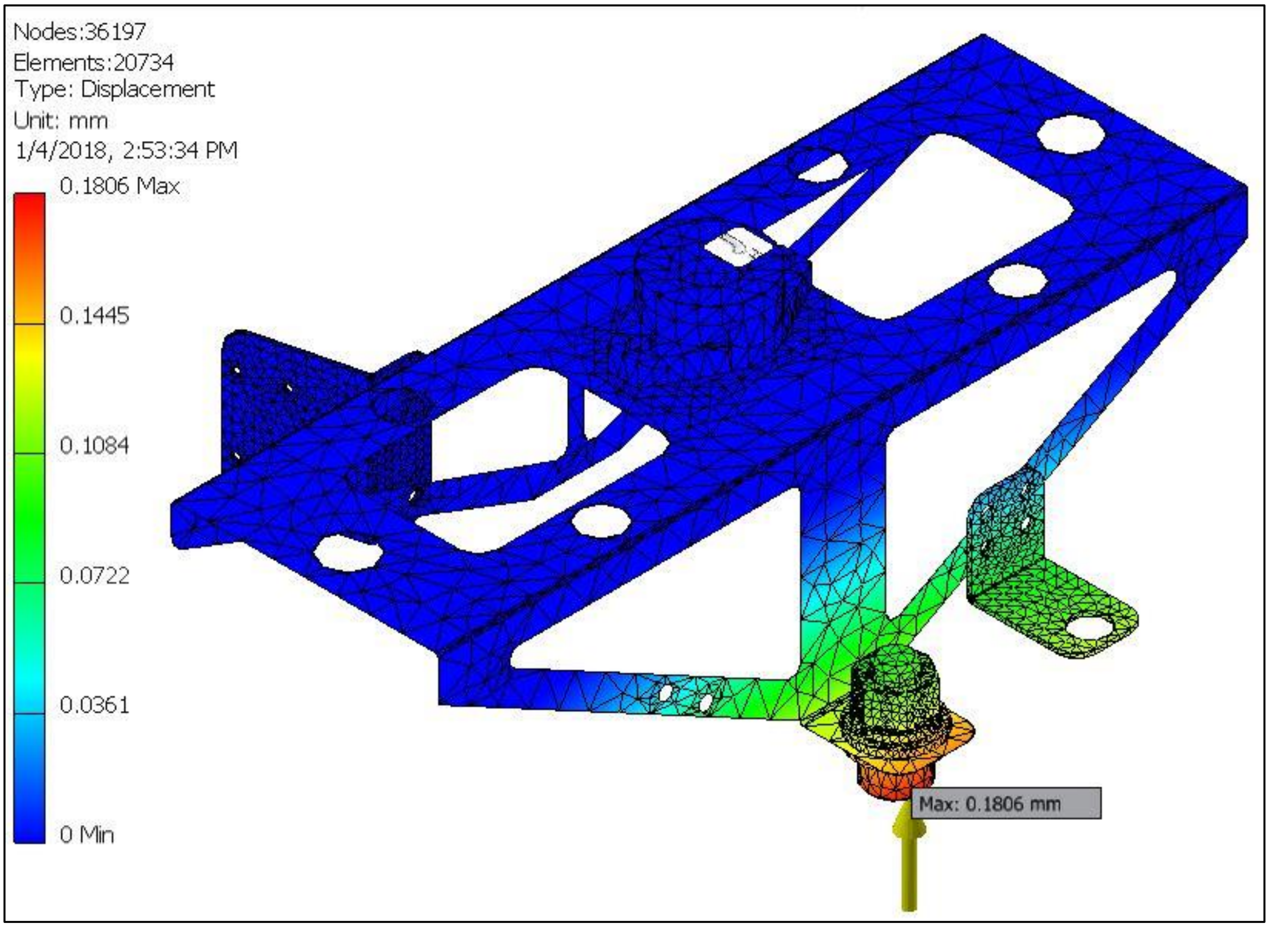


Figure 18 – End Effector Displacement

FACTORS OF CONCERN

Testing of the feeder bowl assemblies will be the first concern. The twisted track for the first push nut will be studied and updated as needed. The other two bowl feeder assemblies must also be tested and updated accordingly because the 3D model that was supplied does not contain the proper exit track details.

Clearances for the robot will also be vetted once the assembly of the frame is complete. The model doesn’t currently show any interference errors, and will be used as a basis for creating the program for the robot.

As for the ability to lift, move and assemble the components, hand calculations were performed and provided in HAND CALCULATIONS.

HAND CALCULATIONS

Supply air = 125psi – 10psi = 115psi
Note: 10psi for pin spacer rejection.
Limit of vacuum generator = 72.5psi (for element and push nut suction)

Element suction area:
1in diameter >> 0.5in radius
Quantity = 2

$2((0.5in)^2 \times \pi) = 1.57in^2$

Push nut suction area:
0.787in diameter >> 0.393in radius

$(0.393in)^2 \times \pi = 0.486in^2$

Total suction capacity:
$72.5psi / (1.57in^2 + 0.486in^2) = 35.26$ lb

Element suction = $1.57in^2 / (1.57in^2 + 0.486in^2) * 35.26$ lb = ***26.9 lb***
Need 2.75 lb to lift the assembled element pair. This value is good.

Push nut suction = $0.486in^2 / (1.57in^2 + 0.486in^2) * 35.26$ lb = ***8.3 lb***
Need 0.001 lb to lift the push nut. This value is good.

Gripper: (Festo part number 1310159 (7))
x = 30mm (distance from gripper finger joint to pin spacer)
115psi – 72.5psi = 42.5psi = 2.9 bar (red star location in Figure 19 – Gripper Performance)
FH = 1.5N = ***0.33lbf***
Need 0.004lbf for pin spacer. This value is good.

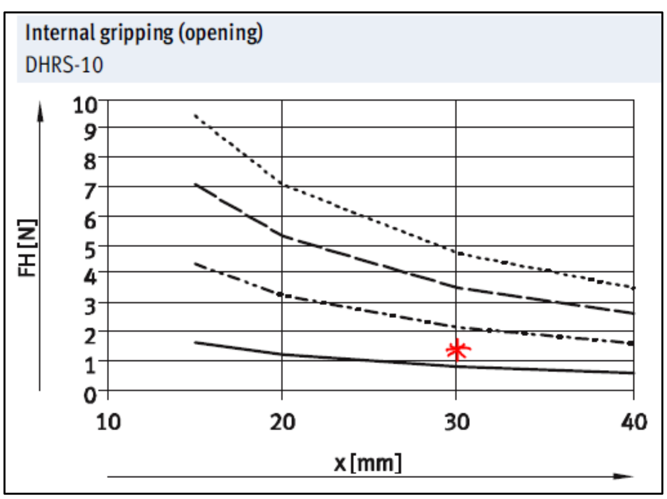


Figure 19 – Gripper Performance (7)

Robot payload = 3kg = 6.6lb
End effector = 2.5lb
Element pair maximum = 2.75lb

6.6lb – 2.5lb – 2.75lb = ***1.35lb***
This value is good.

This provides a safety factor of 6.6lb/5.25lb = 1.25
The maximum robot payload is 6kg. Ultimate safety factor = 13.2lb/5.25lb = 2.5

BILL OF MATERIAL

The breakdown of the component costs in accordance with the top-level assembly, Drawing 1 – MP0213 – WORK CELL, is shown in the following bill of material.

BOM Level	Item ID	Name	Quantity Per	Cost	Total
0	BB200	KIT, HUB, BUSHING, PANEL, 2" PLASTIC, W/ LOCKNUT	4	$6.35	$25.40
0	HKHDD75S-F-FLH	KIT, HARDWARE, HEX, FULL THREAD, 1/4-20 X 3/4", 18-8 STAINLESS	6	$0.17	$1.00
0	HKPCD50S-F-FLJ	KIT, HARDWARE, BOLT, PAN, PHILLIPS, 10-32 X 0.50 LONG, 18-8 STAINLESS	8	$0.03	$0.27
0	HNJFS	NUT, HEX, JAM, 3/8"-16, 18-8 STAINLESS STEEL	4	$0.08	$0.31
0	HWFD38S	WASHER, FLAT, 3/8, 18-8 STAINLESS	4	$0.05	$0.19
0	HWLD38S	WASHER, LOCK, 3/8", 18-8 STAINLESS STEEL	4	$0.06	$0.24
0	IRB-910SC-IRC5C-550	ROBOT, SCARA, 550mm WITH CONTROLLER AND FLEXPENDANT	1	$20,000.00	$20,000.00
0	KIT-NP425X238	KIT, NAMEPLATE WITH RIVETS, 4.25" X 2.38", BLACK ANODIZED ALUMINUM	1	$0.49	$0.49
0	MP0213-05	END EFFECTOR	1	$1,043.65	$1,043.65
1	IN-HOUSE	IN-HOUSE COMPONENTS	1	$6.34	--
1	62645K42	SHAFT SUPPORT, FLANGE-MOUNTED	1	$21.93	--
1	HS6-18F-G	CONNECTION ADAPTER, M6 FEMALE TO G 1/8" FEMALE	2	$4.25	--
1	SLSA-270NR	VACUUM CUP SUPSPENSION ASSEMBLY, 70mm TRAVEL	2	$33.99	--
1	VR07	VACUUM GENERATOR, INLINE	1	$24.00	--
1	PC-T14	TUBING, 0.175" ID, 1/4" OD, CLEAR URETHANE	50	$2.40	--
1	BTC2-14E	TUBE FITTING, 1/8" NPT FEMALE, 0.175 in ID TUBE	2	$5.25	--
1	ESG-20-ES-HA-PK	SUCTION GRIPPER, 20mm	1	$62.00	--
1	1310159	GRIPPER, RADIAL, DHRS-10-A	1	$674.50	--
1	2974K413	DURABLE NYLON TIGHT-SEAL BARBED TUBE FITTING	1	$1.46	--
1	44555K128	BRASS BARBED TUBE FITTING FOR VACUUM, 1/8 NPT	1	$1.26	--
1	44555K129	BRASS BARBED TUBE FITTING FOR VACUUM, 1/4 NPT	1	$2.86	--
1	VPSK30	SUCTION CUP, SPONGE/BELLOWS, 30mm, M6X1	2	$21.16	--
0	MP0213-06	FRAME AND DOORS, PIN SPACER WORK CELL	1	$3,087.80	$3,087.80
0	MP0213-07	FEEDER BOWL ASSEMBLY, 1ST PUSH NUT (FLIP)	1	$2,015.00	$2,015.00
0	MP0213-08	FEEDER BOWL ASSEMBLY, 2ND PUSH NUT	1	$2,015.00	$2,015.00
0	MP0213-09	FEEDER BOWL ASSEMBLY, PIN SPACER	1	$2,770.00	$2,770.00
				TOTAL	$30,959.33

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Post Glover's maximum budget for this project is $50,000 (USD). Here is the proposed breakdown of this budget into the design features listed in the previous sections:

DESIGN FEATURE	PROPOSED BUDGET	ACTUAL
No Handling of Push Nuts and Pin Spacers	$4,000.00	$5,000.00
Pick and Place Element Plates	$35,000.00	$20,000.00
Guards (light curtains/worker screens)	$2,500.00	$1,750.00
Automatic Shut-Off When Worker Enters Work Area	$1,000.00	$1,000.00
Use Standard or Off-the-shelf Components	$1,200.00	$1500.00
Uniform Pressure to Assemble Push Nuts to Pin Spacer	$2,000.00	$200.00
Automatically Orient Parts	$1,600.00	$500.00
Make non-standard components in-house	$1,000.00	$1,200.00
Use existing supply air/power	$500.00	$1,500.00
Testing and Rework	$1,200.00	$1,200.00
TOTAL	**$50,000.00**	**$33,850.00**

Table 1 – Budget

Additional cost has been added to the ACTUAL column values to cover rework. Funding and support for this project is supplied by Post Glover. See APPENDIX E – LETTER OF SUPPORT for further detail.

SCHEDULE, PROPOSED /ACTUAL

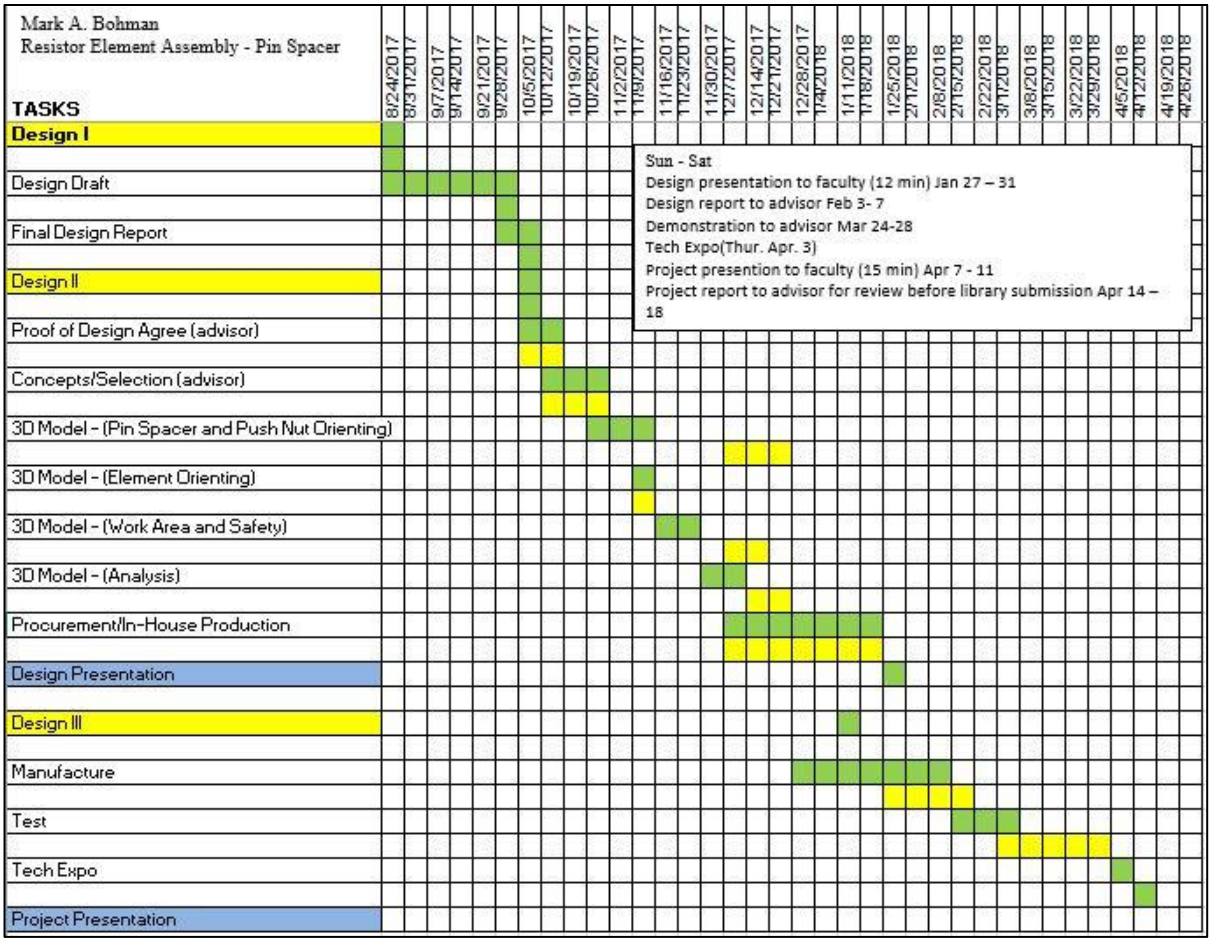


Figure 20 – Schedule
Green = Proposed; Yellow = Actual

PLAN TO FINISH

The following steps are to be completed:

1] Meet with the Manufacturing team to discuss the project and address concerns.
2] Purchase remaining items (non-long-lead)
3] Build the frame Drawing 3 – MP0213-06 – FRAME AND DOORS (TABLE ASSEMBLY)
4] Build the bowl feeder assemblies
5] Test the bowl feeder assemblies
6] Assemble the robot to its mounting base in the frame.
7] Run power and air to components
8] Assemble the end effector to the robot
9] Program the robot
10] Test the robot program

Once an element pair is successfully assembled and ejected, the project is complete. A PLC may also be added for further control of the work cell later.

CONCLUSION

The feeder tracks were specially designed for this project and work fairly well. No jamming issues on the top push nut track and pin spacer track exist, however the first push nut track design had to be changed. Figure 10 – First Bowl Feeder shows the first design attempt for flipping the bottom push nut. This was changed to make it easier to bend the sheet metal while using the center of gravity of the push nut to flip it. It works, but will need adjustment to ensure the push nut always flips over properly. The current design is shown in Figure 21 – First Bowl Feeder Flip Track.

Figure 21 – First Bowl Feeder Flip Track

The sheet metal fabrication by the Manufacturing team at Post Glover was excellent for this project. The design called for over 30 new sheet metal parts that were all produced within the company's standard tolerances. This was no small feat because many of these parts have overlapping bends. Due to the quality of the parts, building the stand per Drawing 3 – MP0213-06 – FRAME AND DOORS (TABLE ASSEMBLY) was completed without much of an issue. A photo of the completed stand is shown in Figure 23 – Completed Stand.

For the purchased components, the bowl feeders posed the largest hurdle for the project because the 3D model that was supplied did not match the actual bowl feeders. This caused delays to the schedule in the form of remodeling the exit portion of the bowl feeder. The height was off by over 12mm, which lead to the redesign of all three exit track designs.

Testing for the bowl feeders was time consuming because the first designs required updating to get the components (push nuts and pin spacer) to be properly delivered to the appropriate locations in a repeatable manner. Once the track geometry was updated for each bowl feeder, adjusting the vibration for each feeder was easily done by using the dial on each feeder cube (see Figure 24 – Feeder Cubes). The updated pin spacer track is also shown in Figure 25 – Pin Spacer Track.

The robot programming was done both manually and via ABB's RobotStudio (9) and the FlexPendant. The program tracks the pick and place locations and includes wait times to allow for the parts to reach the pick up locations. This was done using the supplied manual from ABB and with help from Randy Lecher, the company's Process Improvement & Safety Engineer. Some of the code from the prototype program is shown in Figure 22 – Robot Program.

```
    MoveJ *, v1000, z50, tool0;
    WaitTime 0.5;
    MoveJ *, v1000, z50, tool0;
    MoveL *, v1000, z50, tool0;
    MoveJ *, v1000, z50, tool0;
    WaitTime 1;
    MoveL *, v1000, z50, tool0;
    MoveJ *, v1000, z50, tool0;
    MoveJ *, v1000, z50, tool0;
    MoveJ *, v1000, z50, tool0;
    WaitTime 0.5;
    MoveJ *, v1000, z50, tool0;
    RETURN;
ENDPROC
```

Figure 22 – Robot Program

When testing the end effector, it was determined that a separate vacuum generator was required for the push nuts, which was added (Figure 26 – End Effector). The gripper also required an extra air supply line to reopen. This lead to the use of all four air lines on the robot. The robot itself does not contain internal valves to open and close the four air lines. To prove the concept, manual push-to-connect valves were installed to control the four air inputs (Figure 27 – Manual Valves).

After some manual manipulation an element pair was produced. As for this project, the concept was proven, and this phase is complete. Moving forward, the suction for the push nuts needs modification to adjust for the hole in the push nut. A PLC won't be required because the ABB FlexPendant can be used to send and receive signals once the robot controller is updated with the proper communication card. The manual valves will also be replaced with solenoid valves. This will allow for the valves and photo sensors to be mapped into the robot program to achieve full automation. The limit switches and Lexan doors will be installed last to ensure worker safety.

REFERENCES

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12. **Incorporated, Vibratory Feeders.** [Online] Vibratory Feeders, Incorporated, 2016. [Cited: 09 14, 2017.] http://www.vibratoryfeeders.com/cascade-bowls.html.
13. **Velvac.** [Online] [Cited: 09 14, 2017.] https://www.velvac.com/products/air-produts/air-cylinders.

APPENDIX A – SURVEY RESULTS

Original survey e-mail:

Please rank the following aspects for the pin spacer machine from most (1) to least (6) important:

- Safety
- Cost
- Ease of Use
- Repeatability
- Easy to Maintain
- Other (Please Specify)

Responses:

1. Safety
2. Repeatability
3. Ease of use
4. Cost
5. Easy to maintain
6. Size (floor space).

Mike Simons, Maintenance Manager

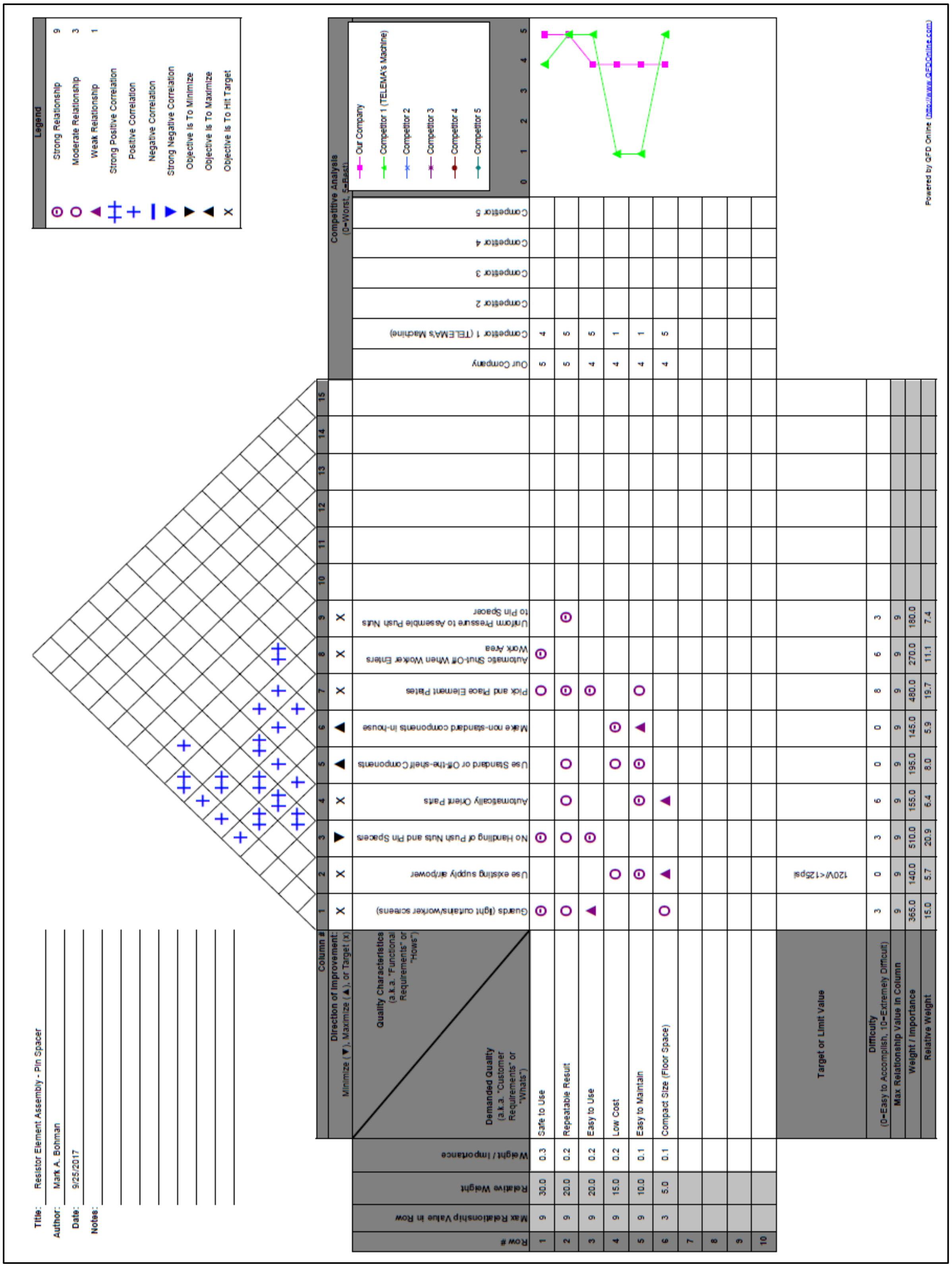
1. Safety
2. Repeatability
3. Ease of use
4. Easy to maintain
5. Cost

Randy Lecher, Process Engineer
David Hall, VP Manufacturing

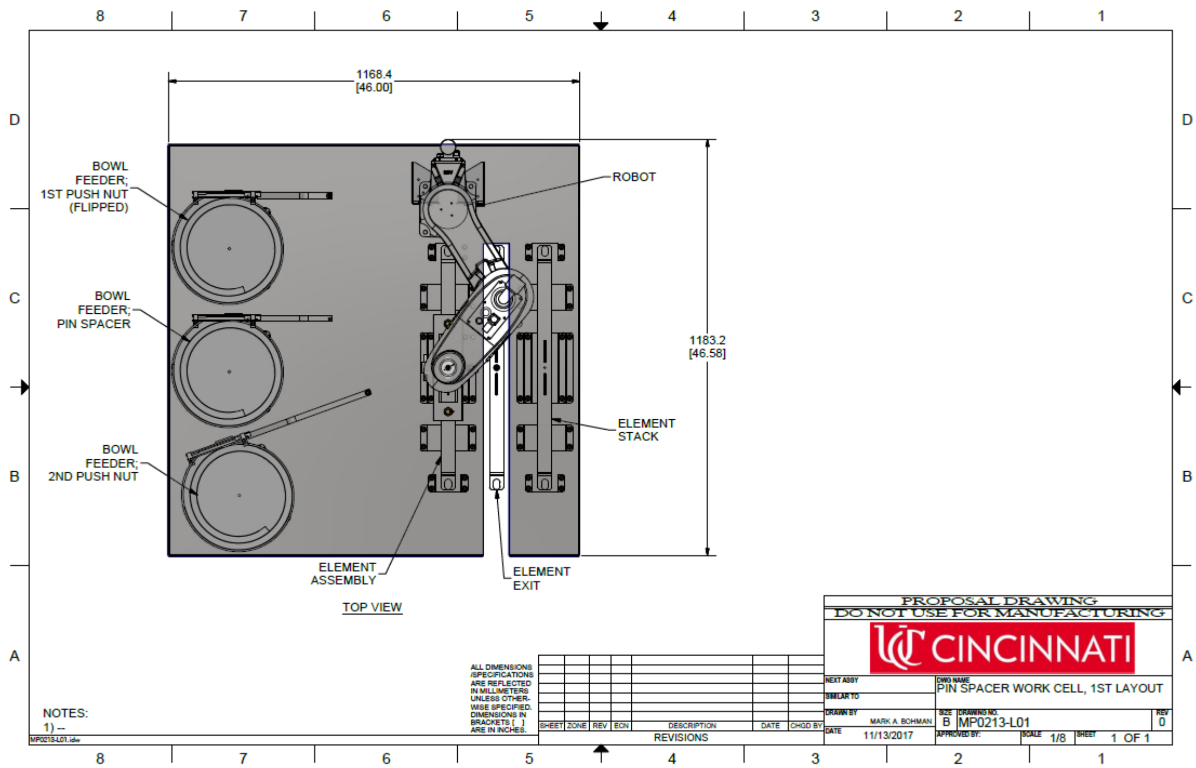
- Safety - 1
- Cost - 5
- Ease of Use - 2
- Repeatability - 3
- Easy to Maintain - 4
- Other (Please Specify)

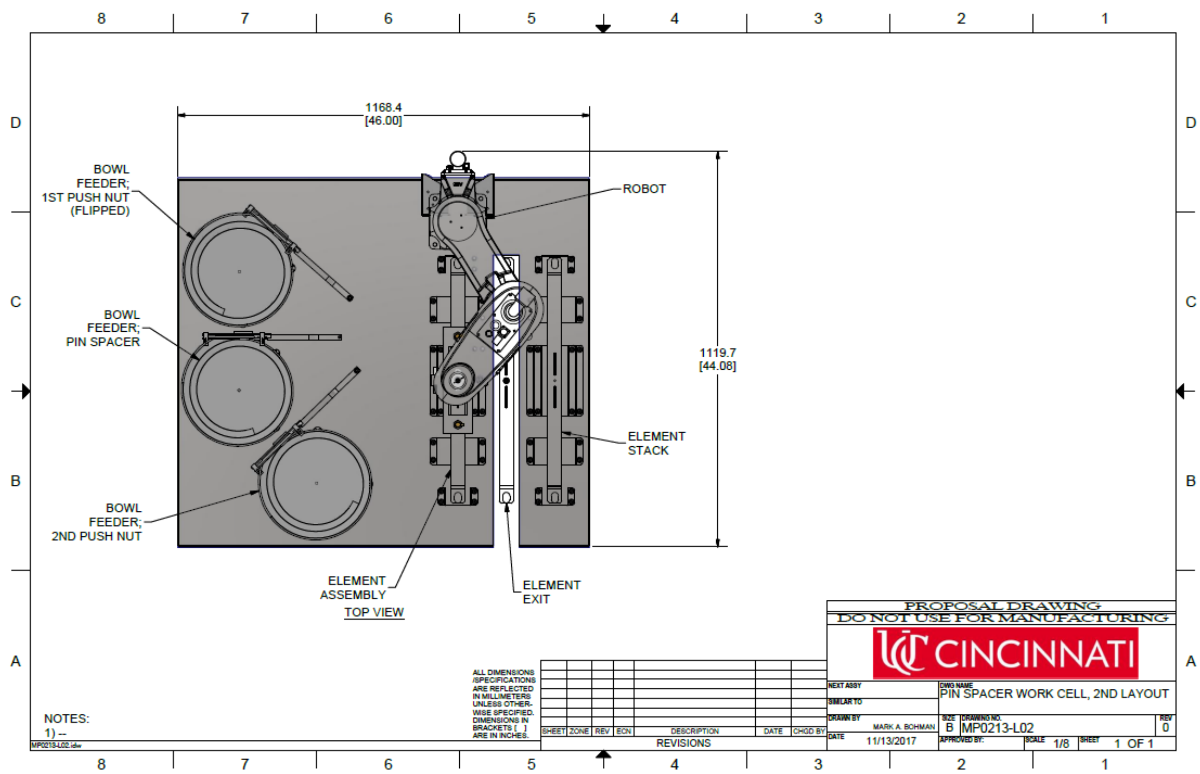
Bob Berger, VP Engineering

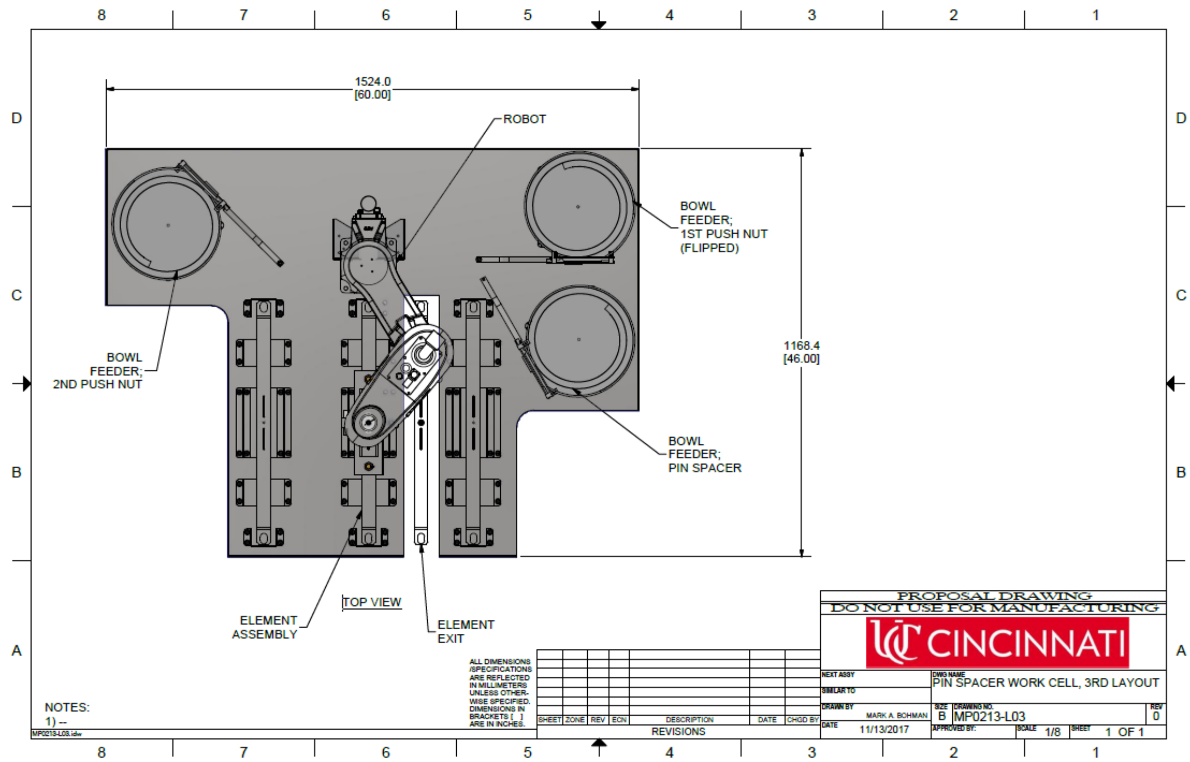
APPENDIX B – HOUSE OF QUALITY



APPENDIX C – LAYOUT CONFIGURATIONS

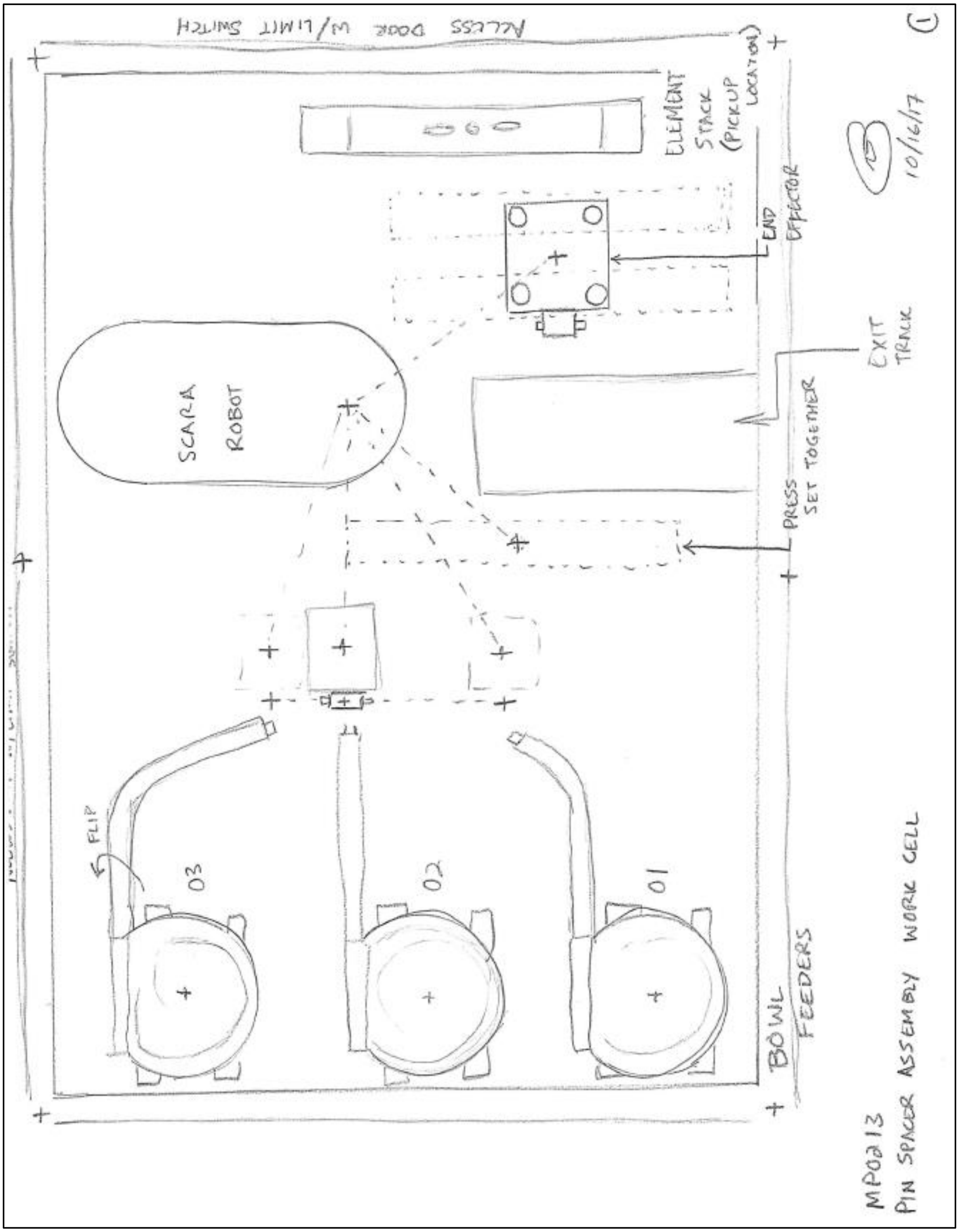


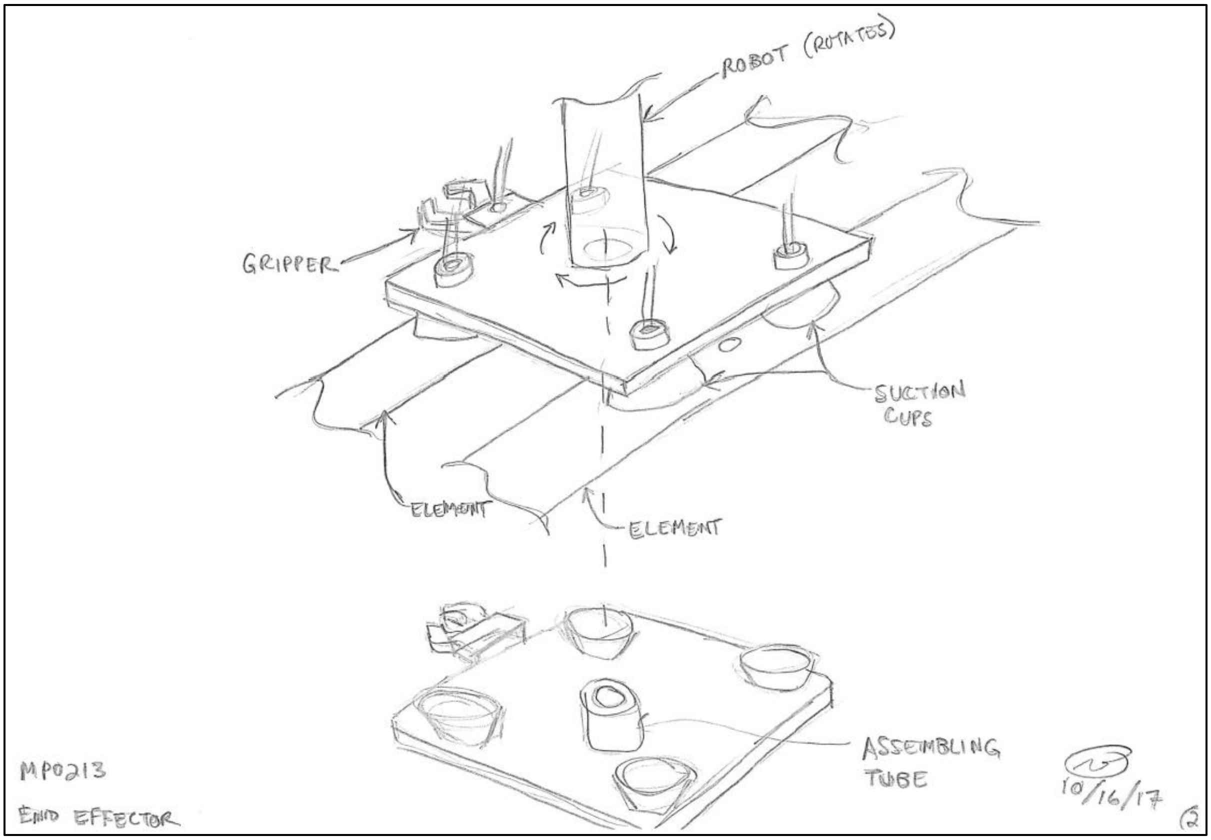


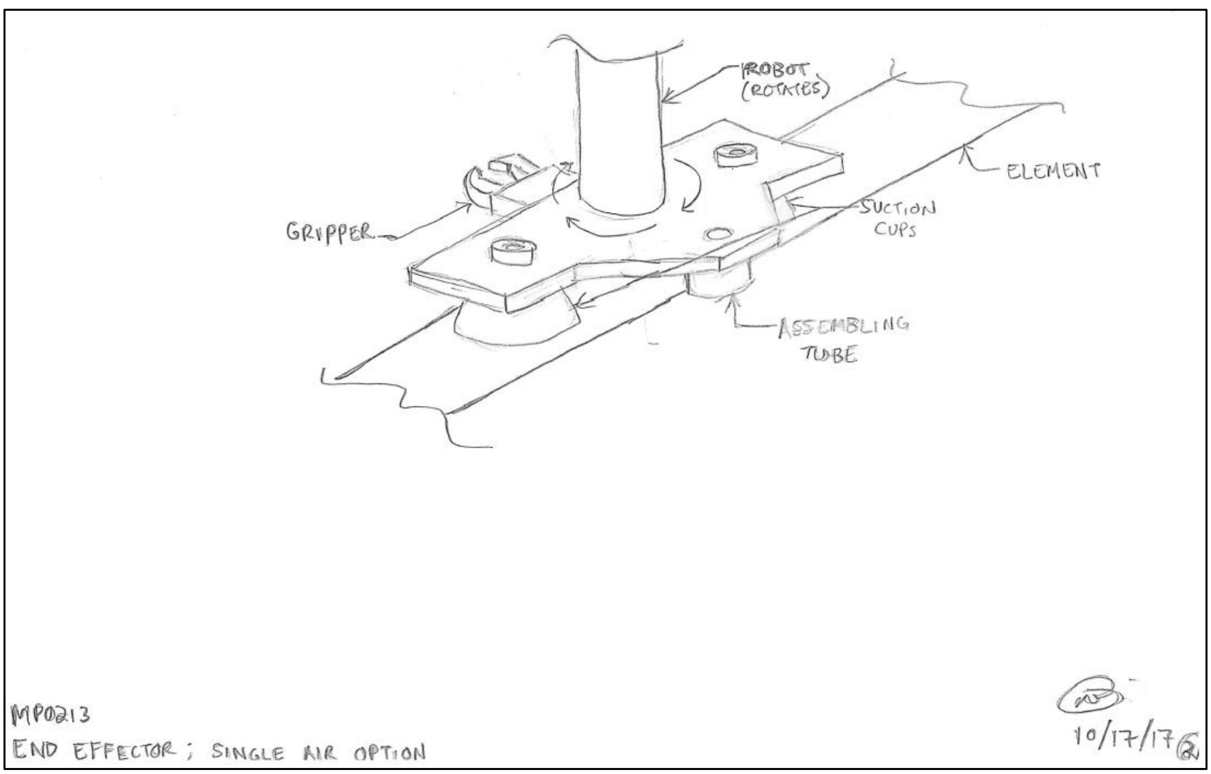


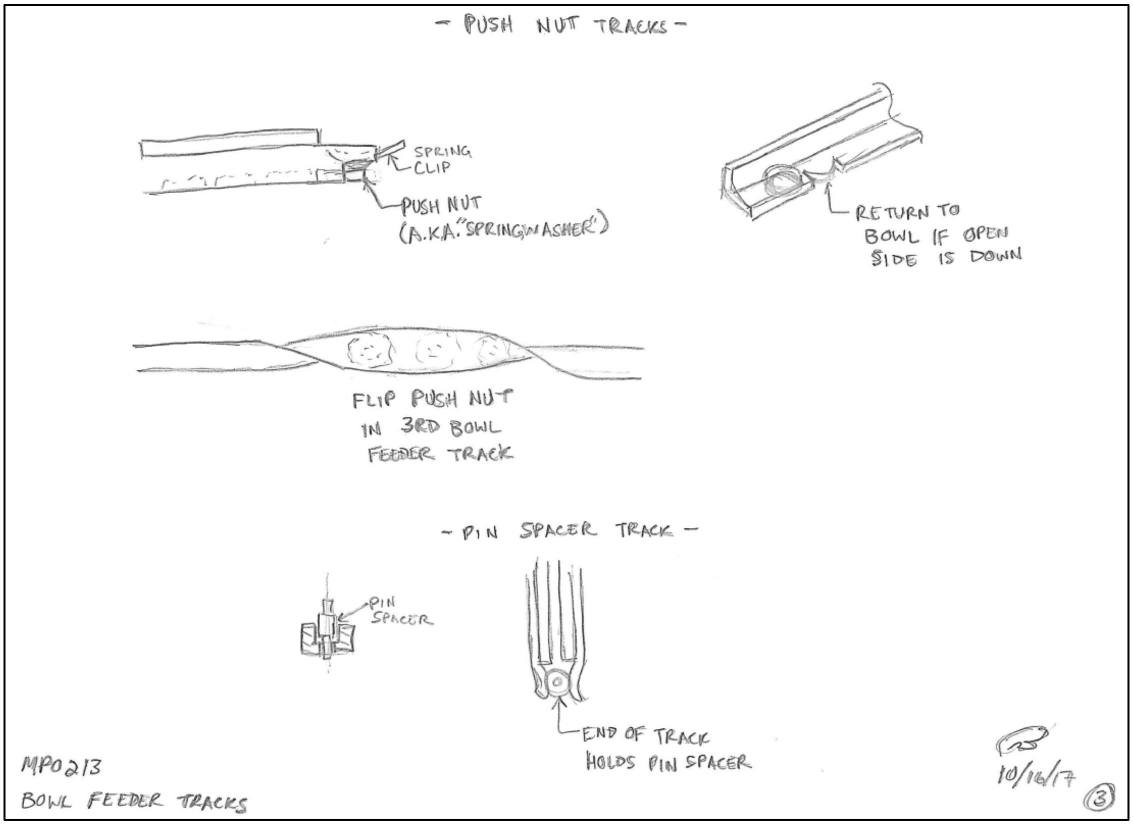
MP0213 PIN SPACER WORK CELL – ALTERNATIVE CONFIGURATION EVALUATION							
Criteria	Importance Weight	MP0213-L01: Bowl Feeders In-Line		MP0213-L02: Bowl Feeders In Arc		MP0213-L03: Two Element Stacks	
		Rating	Wt. Rating	Rating	Wt. Rating	Rating	Wt. Rating
Function							
limit loading steps	10%	2	0.20	1	0.10	4	0.40
assemble more pairs	15%	1	0.15	2	0.30	4	0.60
limit floor space	5%	3	0.15	3	0.15	2	0.10
robot utilization	20%	1	0.20	2	0.40	3	0.60
Manufacture							
material usage	10%	2	0.20	3	0.30	4	0.40
tooling costs	10%	3	0.30	3	0.30	3	0.30
processing costs	10%	3	0.30	3	0.30	2	0.20
Assembly							
handling	5%	3	0.15	3	0.15	3	0.15
insertion	5%	3	0.15	3	0.15	3	0.15
number of parts	10%	4	0.40	3	0.30	2	0.20
	100%						
Weighted Rating			2.20		2.45		3.10

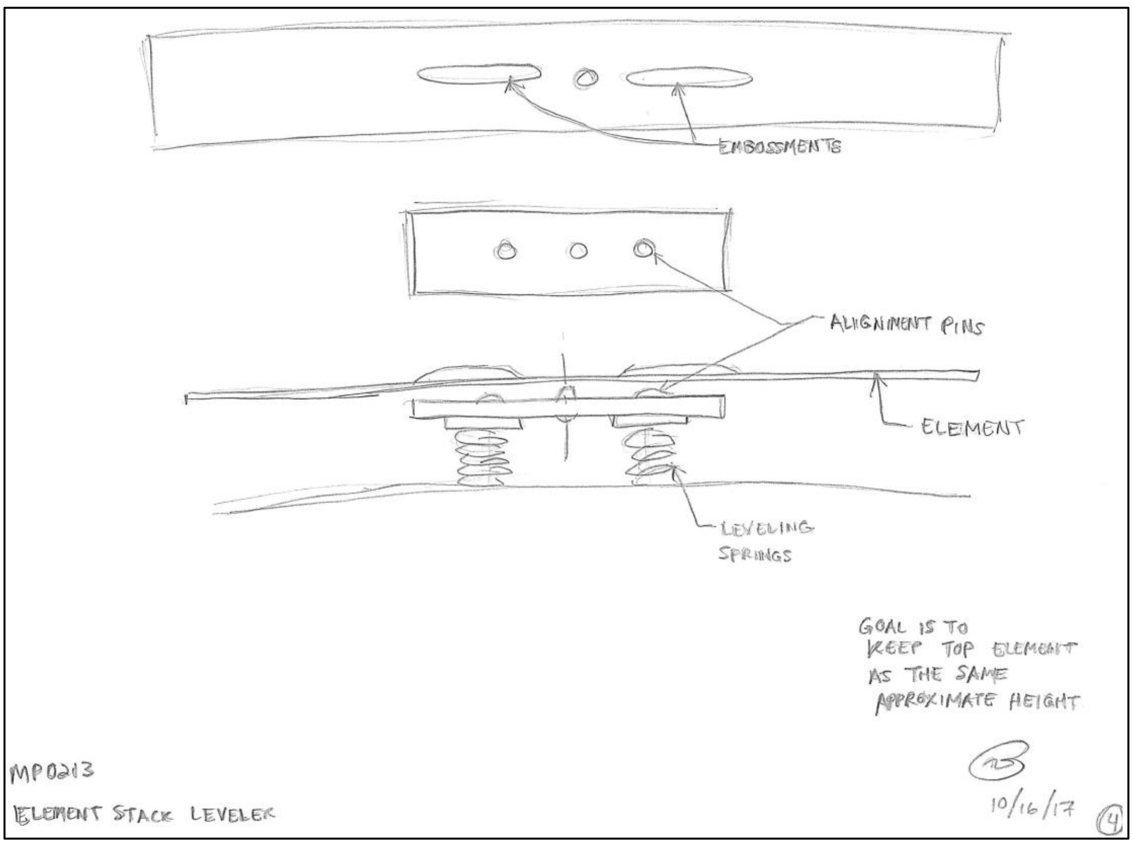
APPENDIX D – HAND SKETCHES

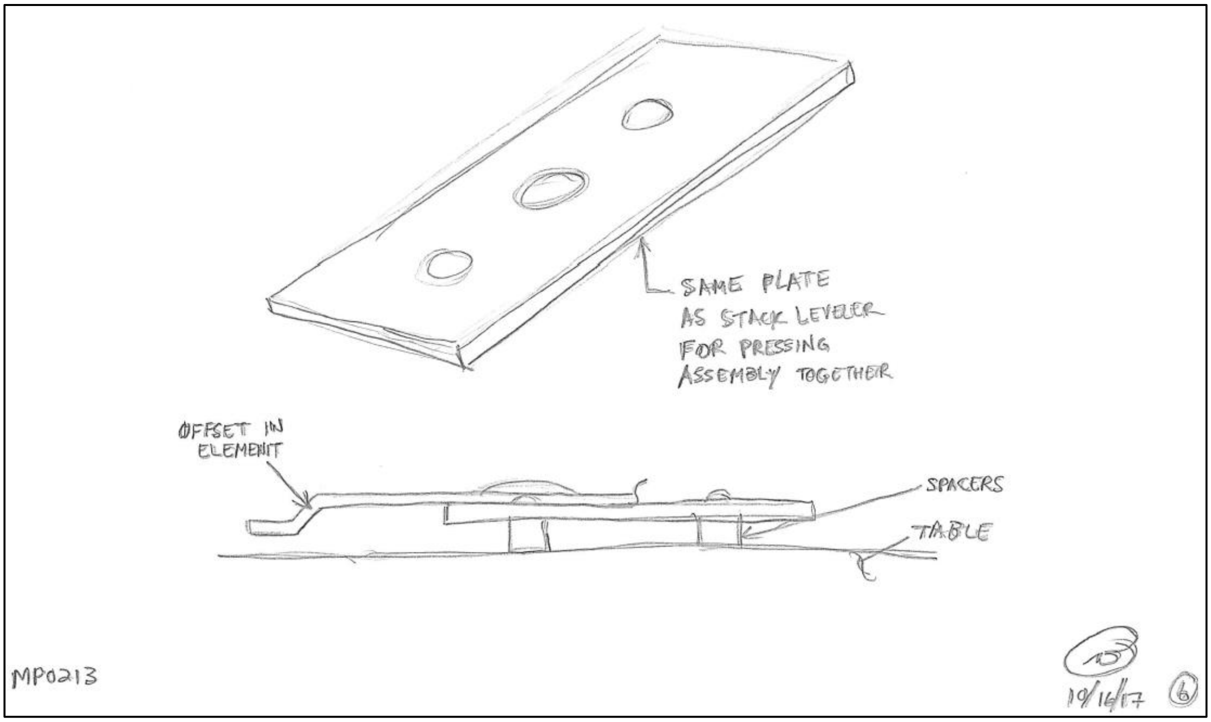



ROBOT (ROTATES)
GRIPPER
SUCTION CUPS
ELEMENT
ELEMENT
ASSEMBLING TUBE
MP0213
END EFFECTOR
10/16/17


ROBOT (ROTATES)
ELEMENT
SUCTION CUPS
GRIPPER
ASSEMBLING TUBE
MP0213
END EFFECTOR ; SINGLE AIR OPTION
10/17/17


- PUSH NUT TRACKS -
SPRING CLIP
PUSH NUT (A.K.A. "SPRINGWASHER")
RETURN TO BOWL IF OPEN SIDE IS DOWN
FLIP PUSH NUT IN 3RD BOWL FEEDER TRACK
- PIN SPACER TRACK -
PIN SPACER
END OF TRACK HOLDS PIN SPACER
MP0213
BOWL FEEDER TRACKS
10/16/17
③


EMBOSSMENTS
ALIGNMENT PINS
ELEMENT
LEVELING SPRINGS
GOAL IS TO KEEP TOP ELEMENT AS THE SAME APPROXIMATE HEIGHT
MP0213
ELEMENT STACK LEVELER
10/16/17
④


SAME PLATE
AS STACK LEVELER
FOR PRESSING
ASSEMBLY TOGETHER
OFFSET IN
ELEMENT
SPACERS
TABLE
MP0213
10/16/17

APPENDIX E – LETTER OF SUPPORT

Post Glover

"The Resistor Specialists"

LETTER OF SUPPORT

The following project has been approved with a proposed budget of $50,000 (USD):

Project Name: Pin Spacer Work Cell
Post Glover Job Number: 97714

The following support will be provided by the company:

- Funding
- Fabrication
- Assembly
- Testing
- Installation

The Engineering design, testing and setup is to be completed by Mark A. Bohman. Further assistance may be provided as needed.

Richard Field
Company President

1/9/18
Date

1

APPENDIX F – ACTUAL ASSEMBLY PHOTOS

Figure 23 – Completed Stand

Figure 24 – Feeder Cubes


Figure 25 – Pin Spacer Track

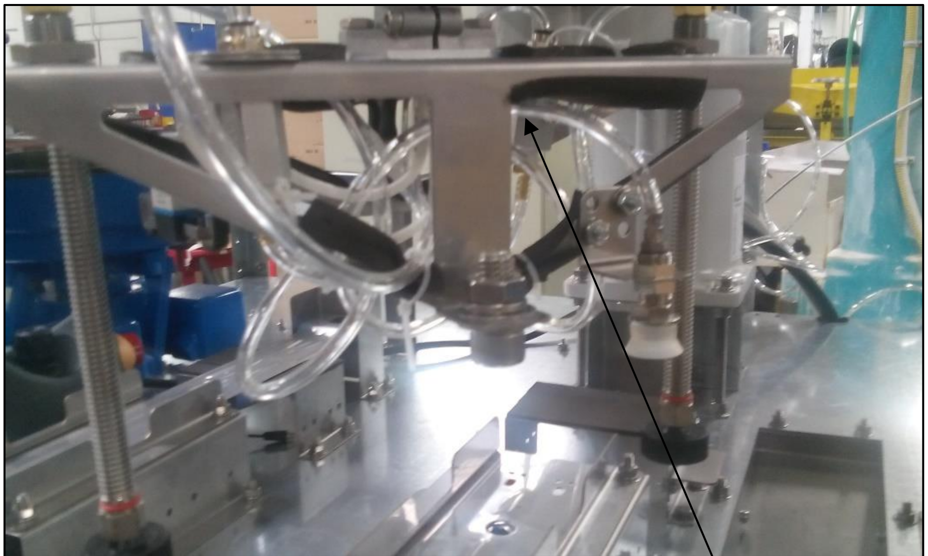


Figure 26 – End Effector

Figure 27 – Manual Valves

Figure 28 – Work Cell with Robot and Bowl Feeders