Automating the Handvalve Stem Assembly: Final Review Report

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12/15/2021

Executive Summary

Parker Hannifin is the world's leading diversified manufacturer of motion and control technologies and systems. In their Refrigeration Division, they assemble handvalve stems for industrial scale refrigeration by hand, wasting a total of 440 hours and $25,000 per year. Automation is becoming more important as the current assembly workforce is aging out and technology advances. Automating the assembly process would also decrease the time to produce a handvalve stem from 2 minutes to roughly 40 seconds.

The proposed design is to utilize a 6-axis collaborative robotic arm (cobot) so it is fully automated and requires no human intervention. The GoFa robot used in this design was determined by comparing factors, including: reach, max speed, price, degrees of freedom, and payload. The robotic arm will be used to move components and to position the mandrel over the disc carrier.

Grippers have been designed to attach to the robot and allow it to grab and release each component. Grippers and their fingers have been physically prototyped to confirm that one robot and two sets of grippers can be used to perform every movement task. They also grip firmly enough to securely hold every component, but not mar the teflon.

The crimping press uses a pneumatic cylinder to apply a downward force onto the disc carrier to crimp the spring into the stem. The robot places the stem into a molded stationary hole in the mounting plate, and places the wave spring then the disc carrier on top to ensure the parts are ready to crimp. The press applies the force to crimp the components and the molded hole provides stability in the stem so it is not overpressed through the table. The cobot will grab the crimped stem assembly and transport it to the snap ring press.

The snap-ring and mandrel sections were developed to integrate well with a cobot. A variety of mandrel designs were compared, settling on one that is held on the disc carrier with a spring pin so the outer diameter can perfectly match the diameter of the end of the disc carrier. The method chosen to apply the snap ring was by pressing it on with a new snap ring press.

The snap ring press is an automated pneumatic press using linear actuators to raise the already-crimped handvalve stem up to the mandrel, which gets placed on the disc carrier. The robot then feeds in the teflon and washer over the mandrel and an additional feeding system will add the snap ring. The linear actuator then extends further to the top of the press where an expanding collet will press the snap ring over the mandrel. Afterwards, the actuator will retract to a designated location for small actuated grippers to remove the mandrel, and then the linear actuator holding the handvalve will fully retract. The cobot will then reach in and take out the finished part.

Prototypes of feeding systems for the washers and Teflon were designed, assembled, and iterated to create simple designs that will aid the GoFa robot in the movement of parts. The simple feeding systems utilize inexpensive microcontrollers, such as the Arduino Uno, continuous servo motors, a wooden fixture for the parts to move through, photoresistors, and simple 3D prints. The prototypes showed great results when tested with the DOBOT, a small collaborative robot that was borrowed from the Mechanical Engineering department, and the grippers.

Parker is strongly considering completely redesigning the handvalve stem from scratch and will therefore not be moving forward with the design outlined in the report. While this project has been placed on hold, all designs have been documented in this report in case Parker finds a specific design that might be appropriate for the redesigned handvalve stem.

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Introduction

Parker Hannifin is the world's leading diversified manufacturer of motion and control technologies and systems. In their Refrigeration Division, they currently assemble handvalve stems for industrial scale refrigeration by hand, wasting a total of 440 hours and $25,000 per year. Automation is becoming more important as the current assembly workforce is aging out, and the newer generation is less interested in manual labor due to the monotonous nature of the job. With more than 5 workers retiring every year, automation is becoming more of a necessity than a luxury. Automating the assembly process would also decrease the time to produce a handvalve stem from 2 minutes to roughly 40 seconds. Furthermore, automation would also eliminate human intervention, thereby allowing the machines to run all day and increase production rates. One note is that current operators may have to undergo new training for any alternate tasks they might be assigned if their current role is automated.

The client requires the entire handvalve stem assembly process to be fully automated with an operator only needed to monitor operations. This design should also be able fit within a 15x15 ft cell and should meet the budget of $75,000. It is also preferable if the design could be easily customized so it could assemble two different length stems. In addition to these requirements, there are several others that can not be disclosed but are summarized in Appendix A with their respective methods for testing.

This report will cover Parker's current handvalve stem assembly process, the work that has been done on an automated design, and proposed steps for the future. The full assembly consists of six components being combined in two main stages: the crimping stage and the snap ring stage. The current process used to make this assembly will be expanded below. Then, the work done towards the proposed solution is split up into the layout, robot selection, gripper development, feeding system, the new crimping step, and the new snap ring step. Lastly, the report will be summarized and future steps condensed in the conclusion.

Current Assembly Process

The handvalves are composed of six separate components that require five different steps for assembly. Note that a figure of each of these components can be found in Appendix B: Assembly Components. The five components can also be seen below in Figure 1. The first step is to put the wave spring, as seen in Figure B-2, into the disc carrier, as seen in Figure B-3. Next, the stem of the hand valve, as seen in Figure B-5, is crimped into the disc carrier with the wave spring. After that the teflon, as seen in Figure B-6, and then the washer, as seen in Figure B-7, are slid over the bottom of the disc carrier. The bottom view of the disc carrier can be seen in Figure B-4. The final step is the snap ring, as seen in Figure B-8, which is clamped over the bottom of the disc carrier into a small groove.

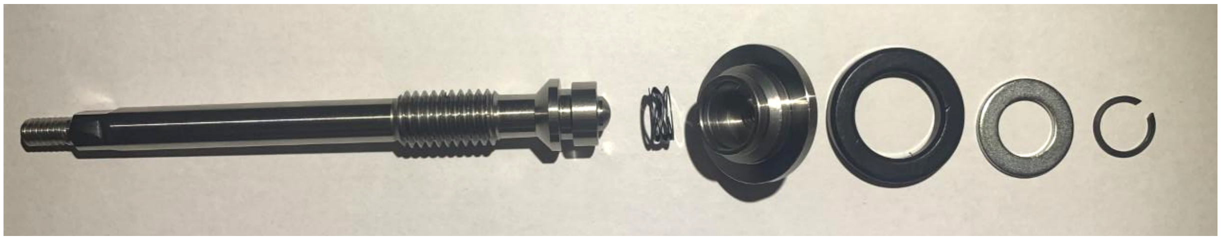


Figure 1. Each component of the hand valve in the order of how they are assembled.

Crimping Press

The current assembly process used at Parker utilizes a crimping press that applies a known force to a crimping coupling tool. CAD models of the crimping coupling tool placed onto the stem and the crimping press are shown in Figures 2 and 3, respectively.

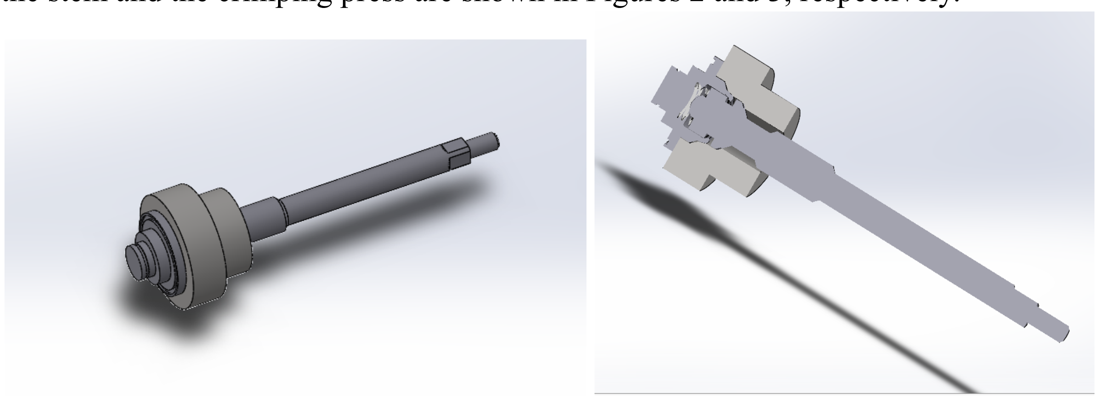


Figure 2. CAD model of crimping coupling tool placed on handvalve stem to crimp the spring on the left and cross-section of handvalve on the right.

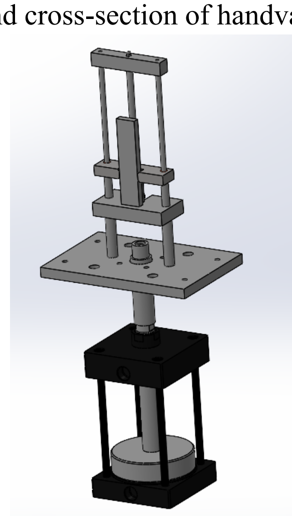


Figure 3. CAD model of crimping press.

The crimping press currently used at Parker applies a known force that is sufficient to allow the wave spring to be crimped. It also utilizes four separate sensors all work in conjunction with each other to offer a high level of safety for the assembler. Three of the sensors are ultrasonic while one is optical. There are two sensors, one ultrasonic and one optical, that are placed in front of the stem and the crimping coupling tool which detect both of those parts by measuring the distance between them and the sensors, respectively. There are also two sensors placed on the sides of the crimping press that detect whether there are any obstacles, such as the assembler's hand, in the way. Once all four of these sensors are in agreement, the crimping step begins. The crimping press also has a mold which ensures that the disc carrier is securely seated in the press and that disc carriers of various sizes due to tolerancing can fit.

Snap Ring Press

The current snap ring assembly process at Parker uses a manual press, as shown in Figure 4. The snap ring process is especially important because if the snap ring is not adequately secured, the hand valve assembly will fail. The snap ring fits over the bottom of the disc carrier and into a small groove, as seen below in Figure 5.

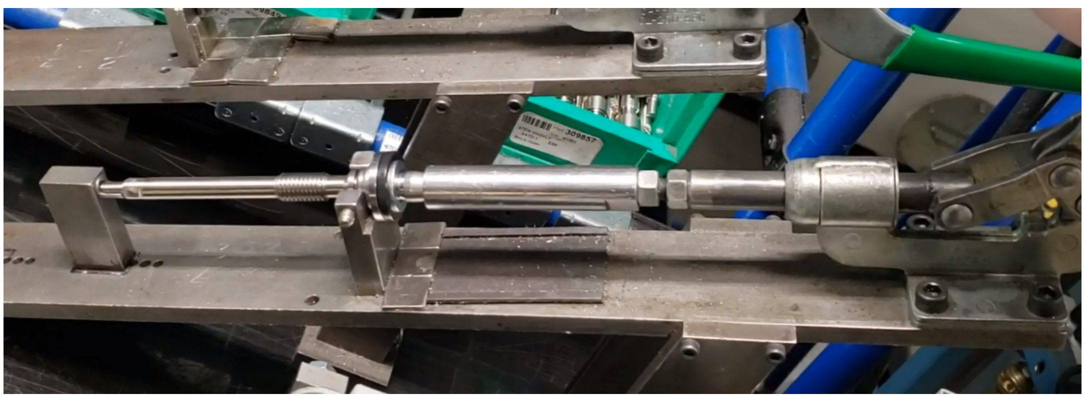


Figure 4. Current snap ring press system.

Figure 5. Side view of the disc carrier to see the snap ring groove. The groove is the small indented section at the bottom of the disc carrier.

Regarding the preparation for placing the snap ring, the teflon will go first, and then the washer after. The current process for adding these components is for the operator to reach into small plastic bins, pick out the parts, and place them onto the bottom of the disc carrier. The stem assembly is placed into the press, while the operator uses a small mandrel to place the ring onto. The mandrel and ring are placed towards the top of the press and lined up for crimping from a collet. The operator crimps it down with a lever-activated force and checks by observing that the ring will hold in that groove.

Snap rings are very rigid pieces and therefore require some force to stretch them over the bottom of the disc carrier. However, the rings cannot be stretched too much, otherwise they might permanently deform, thus becoming too loose, and falling out of the groove. This was an important factor when designing the solution.

Proposed Solution

The proposed solution follows similar steps to the current assembly process, building off of what works well for Parker, and revising where improvements can be made. It will consist of the components passing through a feeding system, then being moved into a crimping step, then a snap ring press step, and ending being output from the process. The product architecture is shown below in figure 6.

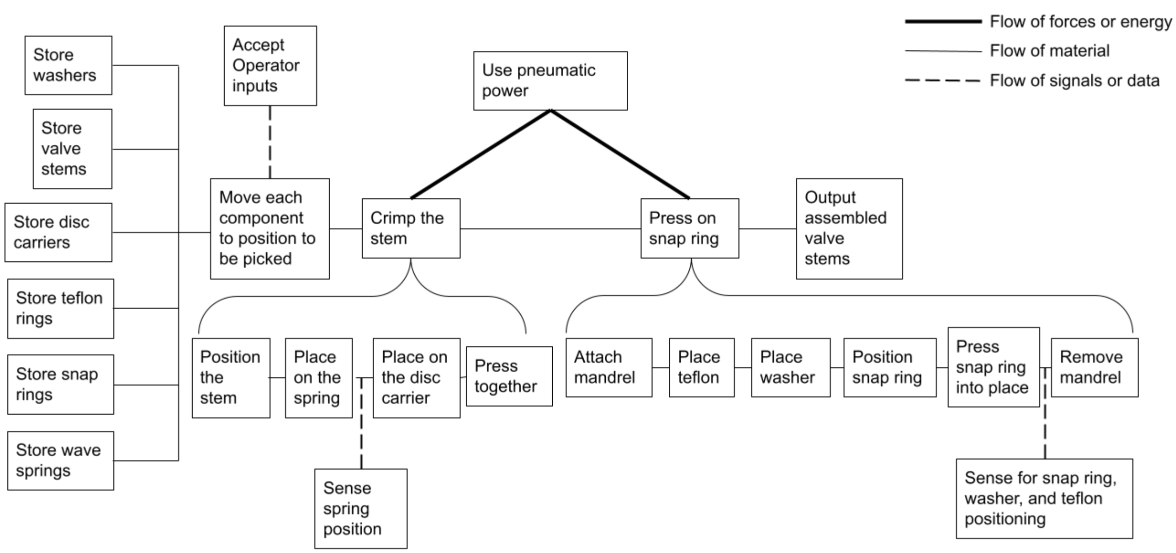


Figure 6. Product architecture showing the process flow for an automated crimping press.

To fully automate the system, a robot should be used to pick and place each component from the end of the feeding system to their spot on the assembly. It will also move each assembly between the stages of the process. This would remove the need for a human operator and increase production time, both goals Parker has for this project. Each process will be explained in more depth in their subsection below.

Layout

The layout of the assembly is a vital component of the design as it could drastically decrease the assembly time for each part. Figure 7 shows the current layout of the proposed design. The optimal layout would have all of the feeding systems supplying their respective parts as close to the robotic arm as possible.

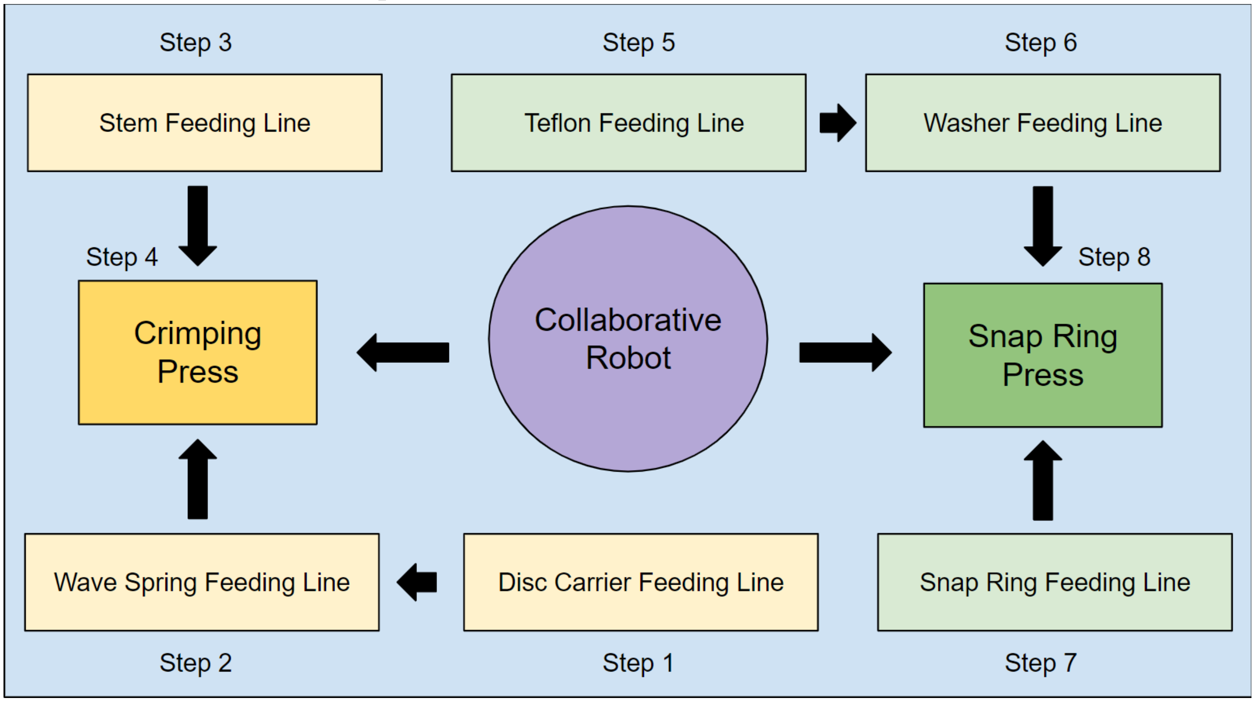


Figure 7. Layout for proposed solution.

Figure 7 shows how the proposed design will be laid in the cell. The collaborative robot will be located at the center of the design, allowing it to be in all of the feeding lines' proximity. The left-hand side is associated with the crimping step while the right handside is associated with the snap ring step. The feeding lines have been chosen to minimize the distance that the robot has to move for each step, thereby reducing assembling time.

The robot will grab a stem and place it in the crimping press mold, followed by the wave spring and the disc carrier (Steps 1-3). The crimping press would then be triggered by the sensors, allowing the wave spring to be crimped (Step 4). The robot would then grab the assembly by the top of the disc carrier, and place it in the snap ring press. The snap ring press would have a hole cut into it to match the shape of the disc carrier and prevent it from tipping. With the part securely seated on the fixture, it would raise the assembly up to mate with a mandrel on top to guide the Teflon, washer, and snap ring over the disc carrier. Then, the robot will place the Teflon and then washer onto the disc carrier (Steps 5-8). Then a feeding system will add the snap ring onto the mandrel and the press will then push the snap ring into place. Once all of the parts are in place, the press will lower and remove the mandrel. Finally, the robot will place the entire assembled part into a designated section.

This is the first design for the layout and can be easily modified to optimize the assembly process. Depending on the robot's reach, the feeding lines could be placed closer to each other, allowing the robot to travel less distance and therefore complete the assembly process faster. The timing of each process could also be optimized so the robot could carry out other tasks when the crimping press or snap ring press is in motion.

Robotic Arm

It was decided that only one 6-axis collaborative robotic arm, cobot, is necessary due to the robot's large range. The main functions of the cobot will be to move components to different stations and into the crimping press, adding and removing the mandrel, and pressing on the snap ring. The reason a collaborative robot was chosen instead of an industrial robot is because it's much safer in the presence of a human worker due to its lower speed and thus force if it were to hit something/someone. There are many safety standards set by ISO/TS 15066 for collaborative robots, including limitations on end effectors and body inertia to calculate constraints on speed and force [1]. Since collaborative robots are meant to work alongside people, as suggested by their name, it is important to consider the structure of the body and end effectors for any safety hazards, such as pinching. Additionally, if the cobot went out of control, it should still operate at a low enough speed that if it were to ram into a person, the person would not get too injured. The operating speed standard for ABB robotics is 250 millimeters per second when humans are in the collaborative workspace [2].

Although the standards put in place for collaborative robots make a safe work environment, Parker-Hannifin would still like to add an enclosure around the entire system just to add that extra piece of safety. This way, someone does not risk getting hit if they are walking by and not paying attention to the robot movements or cannot anticipate the next move. Furthermore, when a person is within a specified area, collaborative robots are signaled to slow down. Therefore, by adding an enclosure and keeping people away from the cobot, it will be allowed to operate at its maximum speed and therefore increase part output.

After researching for cobots to use in the design, the choices were between GoFa from ABB, Swifti from ABB, and UR5-e from Universal Robotics, which can be seen below in Figure 9. The parameters to analyze these three robotic arms are shown below in Table 1. The calculations for speed can be found in Appendix C-3.

Figure 9. GoFa from ABB is the robotic arm on the left [3]. Swifti from ABB is next in the middle [4]. Finally, UR5-e from Universal Robotics is on the right [5].

Table 1. Parameters of three different collaborative robotic arms [3], [4], [5].

Parameters	GoFa	Swifti	UR5-e
Payload [kg]	5	4	5
DOF	6	6	6
Reach [mm]	950	475 and 580	850
Max Speed [m/s]	2.2	5.05	1

When deciding between the three collaborative robotic arms, a decision matrix was created to analyze the important factors and help decide which robot should be purchased, as shown in Table 2.

Table 2. Decision Matrix for Robot Selection

Criteria	Weight	GoFa (ABB)	Swifit (ABB)	UR5-e (Universal Robotics)
Payload	10%	5	4	5
DOF	15%	5	5	5
Reach	30%	5	3	4
Max speed	20%	3	5	1

Price	20%	5	3	4
Familiarity	5%	5	4	2
Overall Score	**100%**	**4.6**	**3.8**	**3.65**

The first is GoFa from ABB robotics, and it has a payload of 5kg, 6 degrees of freedom, reach of 950mm, and a max speed of 2.2m/sec. The second is Swifti from ABB robotics, and it has a payload of 4kg, 6 degrees of freedom, a reach of 475mm and 580mm, and a max speed of 5.05m/sec. The third is the UR5-e collaborative robot from Universal Robotics, and it has a payload of 5kg, 6 degrees of freedom, and a reach of 850mm. Since Parker has a contract with ABB robotics, the decision leaned towards purchasing a robotic arm from ABB robotics. The decision matrix, shown in Table 2, consists of a variety of variables that played a role in the final decision, such as; payload, degrees of freedom, reach, max speed, price, and familiarity with the robot's company.

The payload was given a 10% weight which is relatively insignificant because most of the parts in this assembly are relatively lightweight. The DOF was given a 15% weight because the robot is not expected to do any highly precise movements. The reach was the most important aspect of this decision as the robot needed to move from various stations easily. Complimenting the reach, relatively high speed was required so the robot can move from various stations quickly. The reach and speed were given weights of 30% and 25%, respectively. Since Parker has a good relationship with ABB robotics, familiarity was given a 10% weight. As shown in the decision matrix in Table 2, the best robot for such an application and client was the GoFa ABB robot.

Grippers

In order to use a robot to automate the assembly, it needs grippers attached to the end to actually pick up components. The criteria used to develop the grippers were that they had to be strong enough to hold each component, but not too strong that they would damage components. They also needed a stroke long enough to grab every component. Lastly, they needed to be commercially available and easy to repair because they are heavily used and can wear down. There are gippers available in most styles that can reach all of those goals, so the criteria was narrowed [6].

The overall gripper system was selected by the power system, then by type of gripper, then by number of grippers needed. Parker has easily accessible compressed air lines in their facility, and cobots commonly have pneumatic hookups for their end of arm tooling (EOAT), so this project focused on pneumatic grippers. From there, parallel grippers were the option that provided the most stability and consistency for grabbing parts, and the replaceable gripper fingers made them an easy part to replace if they are damaged. Then from prototyping it was decided that the range of parts needed to be grabbed was too diverse for a single gripper, so two grippers should be attached to a plate at the end of the robot arm. The original gripper prototype can be seen in figure 10.

Figure 10. First physical gripper prototype. Could grab each component by the outer diameter.

The original gripper prototype had the strength to hold every component, but it required very specific angles to approach the components which would make staging the parts very difficult. There were also concerns with how securely it could hold the thin components.

To alleviate the concerns from the first prototype, the design switched to a two gripper assembly so that each gripper can be designed more specifically to the parts it will pick up. The two gripper designs can be seen in figure 11 below.

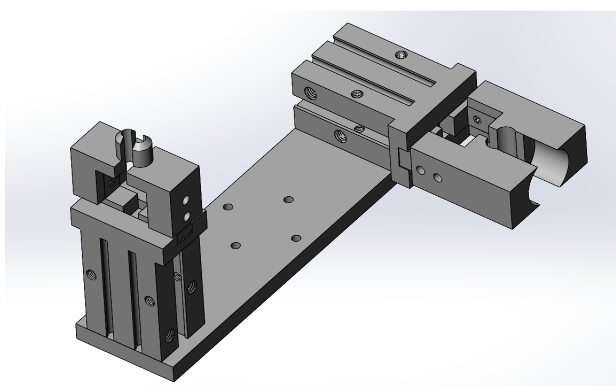


Figure 11. The two gripper assembly to be attached to a robot arm. One inner diameter gripper (left) and one outer diameter gripper (right).

The two gripper design uses an inner diameter gripper to grab the washer, teflon, and wave spring. It uses an outer diameter gripper to grab the stem and the disc carrier. The snap ring was decided to be too fragile, and will be applied with a separate device. The recommended pneumatic grippers also have a larger stroke so that each set of fingers only needs one contour that can grab every component.

The inner diameter design was tested with the original prototype gripper body to confirm that the two gripper design will work. The inner diameter grippers are in figure 12.

Figure 12. The prototype inner diameter grippers being tested with a robot.

The prototyped inner diameter grippers needed multiple steps cut into them because the gripper stroke is very small. The recommended grippers will have a larger stroke so the fingers can be simpler. The inner diameter prototype grippers were able to be tested with the DOBOT, a 4-axis educational robot, and they could securely grab and move the teflon, washer, and wave spring. The outer diameter gripper had no trouble moving the stem and disc carrier. Therefore the two gripper design should be a successful and robust solution for Parker.

Feeding System

The only feeding systems designed were for the Teflon and Washer parts. This is due to their uniform cross-sections which simplifies their dynamics and makes it easier to move across the assembly. After many feeding system iterations, the one shown in Figure 13 is the simplest design given the equipment we had invested in when pursuing previous iterations. While a linear actuator would be simpler, utilizing the servo motors which had been purchased would be more efficient than purchasing linear actuators.

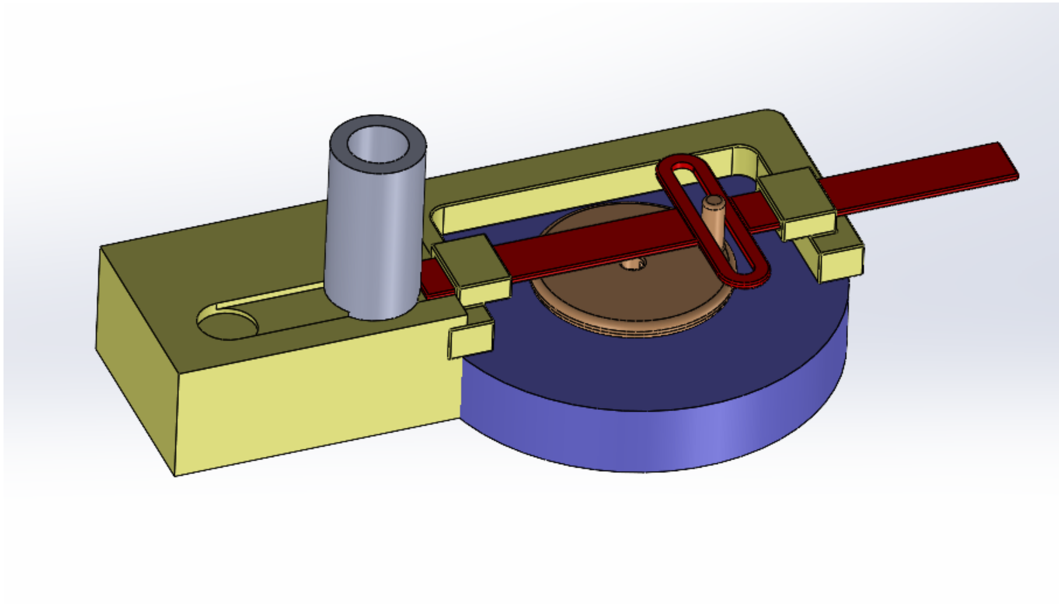


Figure 13. SolidWorks model of entire feeding system using Scotch Yoke mechanism

This design uses a simple Scotch Yoke mechanism that converts the rotational motion into linear motion using a continuous servo motor, tubes that hold stacks of each part with a cutout equivalent to the thickness of each part, and photoresistors to automate the feeding process. The figures detailing such a design are all SolidWorks files which could be easily altered to the specific dimensions of the part under consideration. The first feature of this design is the servo motor cutout which can mount a servo motor in the bottom of the fixture, as shown in Figure 14.

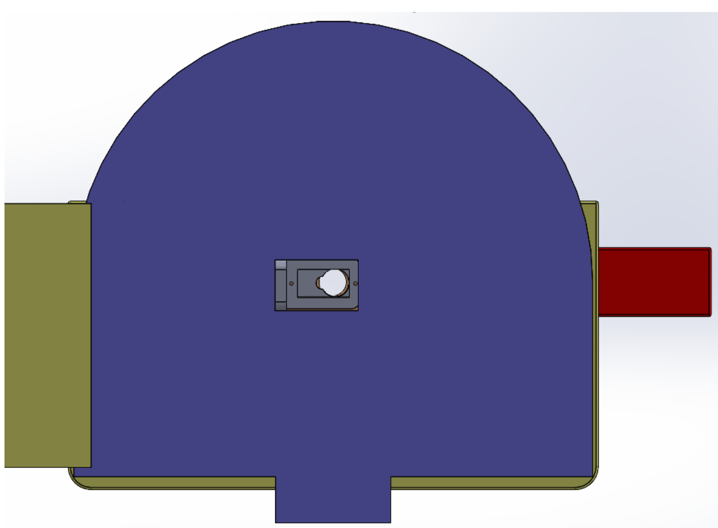


Figure 14. Servo motor mount cutout in feeding system

In addition to the servo motor mount cutout, there is a servo motor horn cutout in the crank to transmit torque from the servo motor to the feeding mechanism.

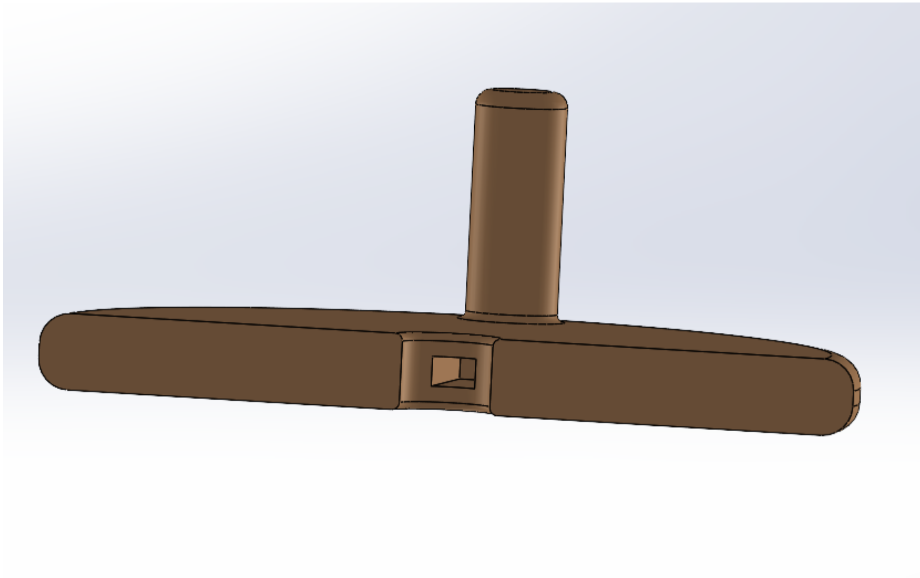


Figure 15. Horn cutout to transmit torque from servo motor to feeding system

When the servo motor rotates, the crank converts the rotation into linear motion, allowing the slider to slide linearly. When the crank is in its original position, the crank is not in contact with any of the parts being fed, however, as the servo motor rotates, the slider moves forward and pushes one part from the stack forward. Only one part moves forward, because the tube has a cutout at the bottom equivalent to the thickness of the part being fed, as shown in Figure 16. The servo motors currently under consideration are Hiwonder's 20 KG Digital Continuous Servo motors due to their cheap price and high torque [7]. The need for a high torque is to ensure that the parts always reach the desired location regardless of the stack size above them.

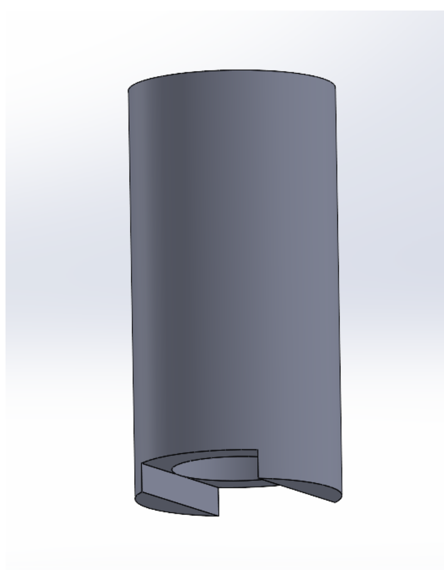


Figure 16. Feeding system tube with cutout equivalent to the thickness of one part

The crank continues moving forward until the servo motor has rotated 180 degrees from its initial position at which point the part reaches the end of the path and falls into a pocket for the robot to then pick up. The servo motor continues to rotate, causing the slider to move back, eventually returning to its original position and causing the next part to fall down to the bottom of the tube. As mentioned earlier, the servo motors could easily be replaced by connecting the slider to a linear actuator thereby reducing complexity and the chance of failure.

This entire process will be automated by integrating photoresistors into the pockets for each part which will be able to sense whether a part is present or not. When a part is not present, the photoresistor will trigger the servo motor to start rotating, allowing a part to be fed for the robot to pick up. Utilizing these photoresistors is more effective than using timed delays because there is a chance that the robot's grippers drop a part, forcing the robot to return to pick up a new one. The photoresistors under consideration are the Rectangular photoelectric sensor LR-X series because of their small size and cheap price [8].

Unfortunately, a physical prototype of such a design was not created and tested, however, an animation of the proposed design can be shown in this video [9]. Various physical prototypes of previous design iterations were made, however, they all failed due to their complexity and that is why such a simple design was pursued. Complexities included relying on the servo motor to consistently position the part in the correct position and predicting if the part will be misaligned when it lands in the pocket. This design will satisfy Parker's feeding system design requirements as it will be fast, autonomous and robust thereby requiring little maintenance. The system is also controlled by microcontrollers and can therefore be integrated into the design using PLCs. As for materials, all of the parts could be 3D printed as opposed to being fabricated using aluminum or steel. This is because the feeding system only has to apply a small amount of force to push the parts out of the stack and into the negative mold. Once such a design has been tested, Parker should consider fabricating the design for a more durable system.

Crimping Step

The current crimping press that Parker uses for the disc carrier and wave spring applies a known force in an upward motion to fully crimp the stem into the disc carrier. The process is slightly tedious for the worker, who has to place the components into a coupling tool for each time a part is made. The new crimping press design eliminates this type of setup for the part and also provides the necessary leeway for the crimped part to be removed from the press without any obstructions. The new solution is a multi-step automated pneumatic press that includes a solid mounting plate with a molded stationary hole to hold the part in place. The layout of the new crimping press is shown in Figure 17.

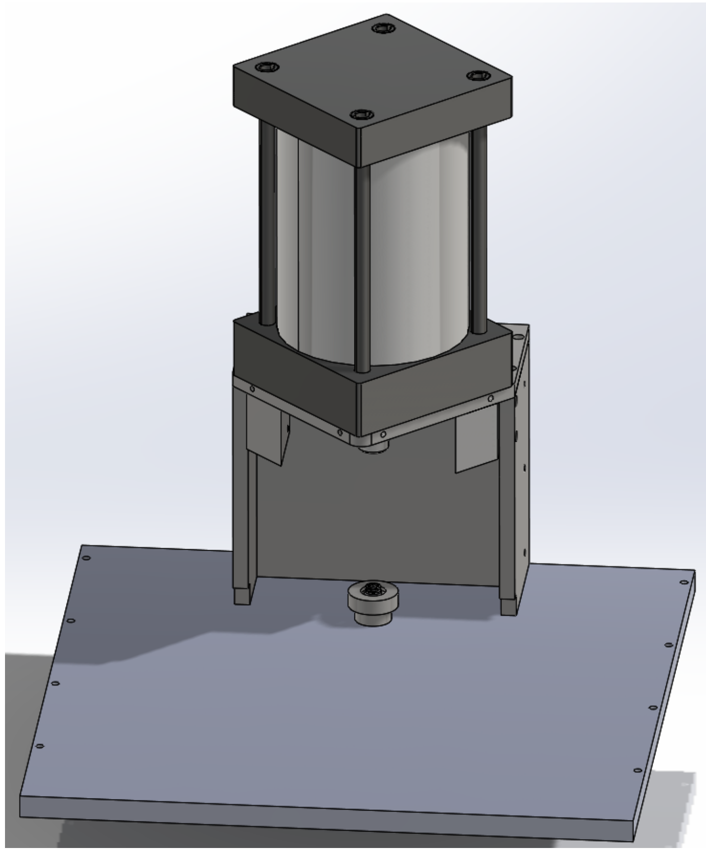


Figure 17. Solidworks assembly of the proposed solution for the crimping press.

The crimping utilizes a linear pneumatic cylinder that was configured off of Parker's website [10]. The stem and disc carrier requires a couple thousand pounds of force to crimp together, so a large pneumatic cylinder can provide more than enough force to achieve this. The cylinder has a six inch stroke to allow enough free space for the robot to smoothly place parts and remove the completed modified stem assembly. Side mount inlet air ports on the cylinder provide an easier setup when mounting on a support plate for tabletop usage. The inlet air must provide at least 100 psi to power the 6-inch bore cylinder to achieve the crimping press force.

The mounting plate will screw into the table top and is made out of ¾" thick steel to ensure that the plate won't fail from the constant pressure of the press. The plate is narrower than the previous design, so the robot will be within reach of the press. A rotating index system was considered for the purpose of holding the parts, but was deemed unnecessary since one handvalve is made at a time. Instead of the rotating system, a single molded hole will be installed directly underneath the cylinder to hold the stem in place. The mold will be above the plate with internal indented ribs to hold the part in place and prevent it from pushing down through the hole. The internal design of the stationary molded hole is shown in Figure 18. The stem is placed in the hole by the robot, while the wave spring and disc carrier are placed on top of the stem by the robot as well. Once the components are in the appropriate orientation and position, the part is ready to be crimped, which is illustrated in Figure 19.

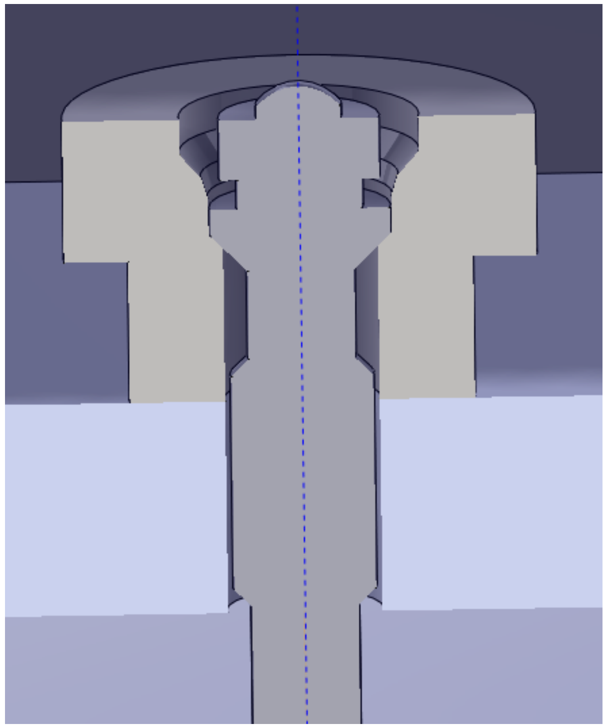


Figure 18. Internal rib design of the molded stem holder.

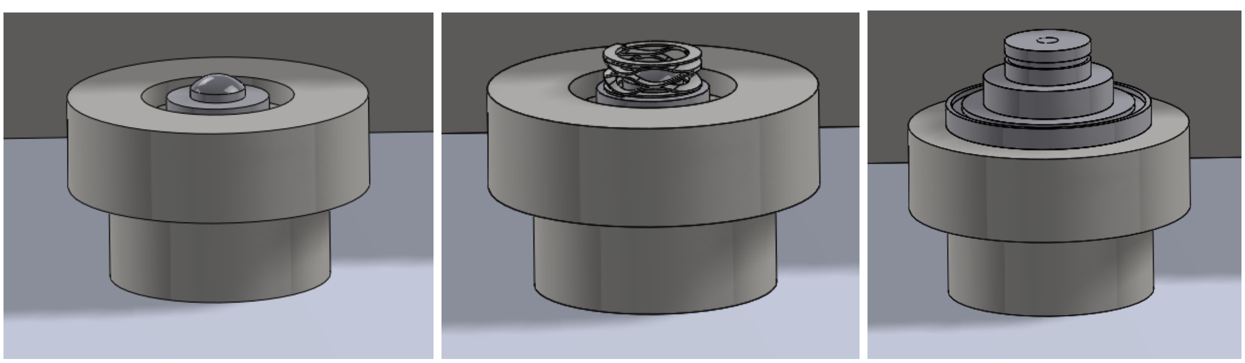
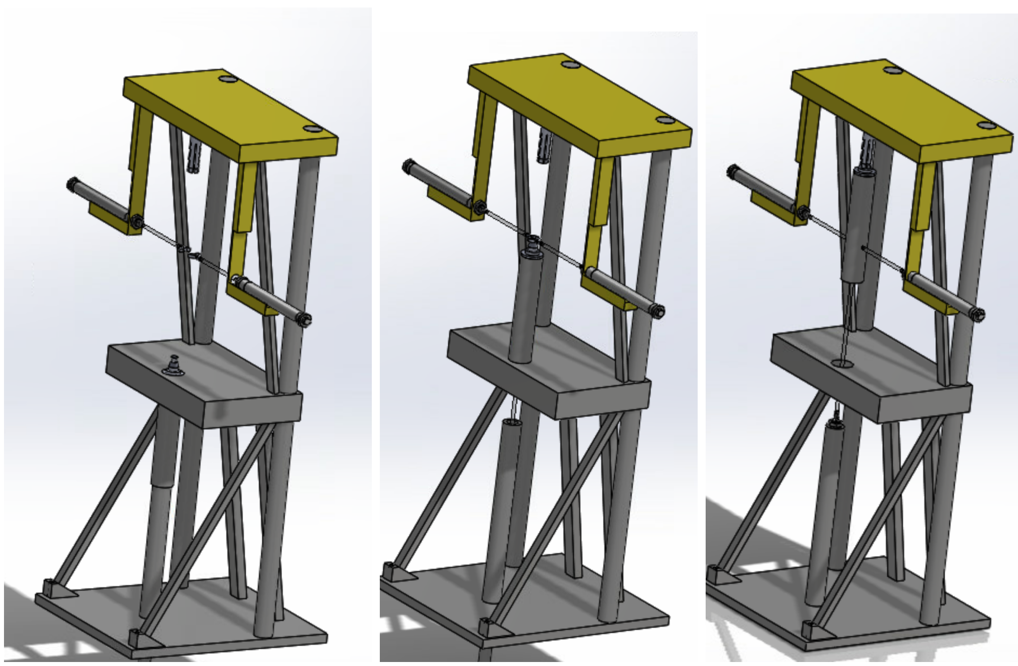


Figure 19. Process of placing components into the molded hole.

The crimping press was originally going to remain unchanged, but our client wanted an upgrade of the design. Utilizing a pneumatic cylinder provides a constant applied force with consequence and the molded stationary hole eliminates the manual labor of the coupling tool. The stem orientation is flipped to ensure the internal ribs mate with the angle of top of the stem. The floating hole through the table allows the disc carrier to bottom out before the stem is pushed past the failure limit through the table. A physical prototype was not created because Parker prefers to make the press in house, but this improved crimping press design satisfies Parker's crimping design requirements by creating an autonomous process with no need for human contact.

Snap-ring Step

The new solution is a multi-step automated pneumatic press, that consists of linear actuators and an expanding collet. The overall purpose of this press is to clamp the snap ring onto the handvalve so that the teflon and washer components stay on the disc carrier securely. In this press, the teflon, washer, and snap ring will be added to the already-crimped handvalve stem. The full layout of the press can be seen below in Figure 20.

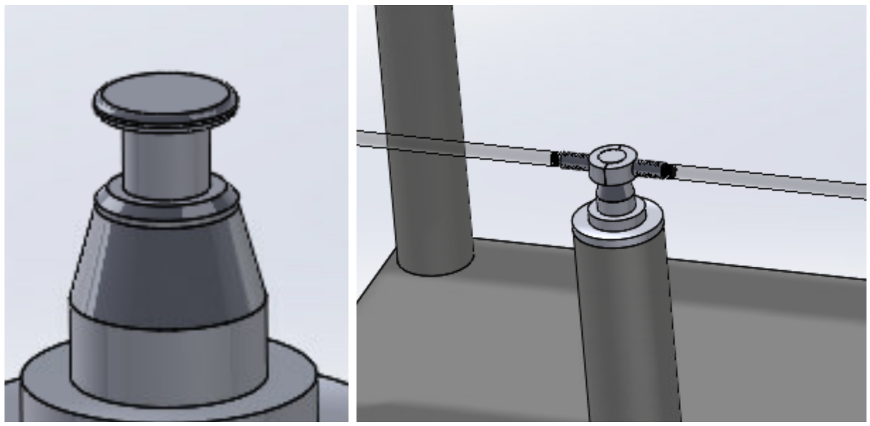


(b) Initial Position (b) Middle Position (c) Final Position

Figure 20. Proposed pneumatic snap ring press that contains three subfigures.

The initial position can be seen in image (a) of Figure A. This is where the cobot places the crimped handvalve stem in the holder, which is fully retracted. Then, the bottom linear actuator extends to the middle position, image (b) in Figure A. This linear actuator has a sensor in it, which allows there to be an intermediate position for the actuator to stop at. This is where the mandrel is held up by the two side actuators. Once the handvalve reaches the mandrel, the mandrel is seated on top of the disc carrier. Then, the two side actuators retract and the cobot comes into the press and places the teflon and washer over the mandrel onto the disc carrier. Then, a feeding system will add the snap ring onto the mandrel. Once all three components have been added and the cobot is out of the way, the sensor in the linear actuator will fully extend to the final position, image (c) in Figure A. This is where the expanding collet at the top of the press will push the snap ring over the mandrel, and into the groove of the disc carrier. Then, the handvalve will retract back to the middle position, where the two side linear actuators extend to grab the mandrel off of the disc carrier. Finally, the handvalve will fully retract and the cobot will reach in and grab the fully finished handvalve part.

Seen below in Figure 21 is a closer view of the mandrel and the linear actuator grippers at the middle position of the system, image (b) in Figure 20.



(a) Mandrel (b) Linear actuator grippers of the press

Figure 21. New mandrel design on the right in image (a) and linear actuator grippers of the press on the left in image (b).

The linear actuator grippers are each a half circle that wrap around the sides of the mandrel. The mandrel has a small overhang on the top and bottom of the cylindrical area the grippers grab onto. This allows for pressure to add force down to place the mandrel onto or take the mandrel off of the handvalve. The two side linear actuators will be fully extended while holding the mandrel. Additionally, the mandrel has a small pin in the bottom that will sit in a small hole drilled into the disc carrier. This, plus the alignment of the grippers, will ensure that the mandrel always sits on the disc carrier in the same position.

This overall design went through multiple iterations, including different linear actuators and mandrels. This design was ultimately decided on because these actuators are small and lightweight, and the mandrels allow for an easy gripping force for the actuators. The most significant part of the mandrel design is the cylindrical part in the middle, where the grippers hold the mandrel. This is because this part is not on a slope like the rest of the part, so the grippers will not slide off. Another big design consideration was the fatigue life, due to the height of the press. Even though the force required for the snap ring is small, which is 9lbf as seen in Appendix C-2, one concern was the amount of potential bending of the press overtime. Therefore, calculations were performed to analyze the fatigue life, as seen in Appendix C-1. These calculations were to determine whether it was necessary to add support structures. While it was proven that the press would not require supports, they were added anyway in order to ensure a long-lasting snap ring press.

Assembly Costs

The final valve stem assembly device should combine each component described above, and refine the prototype materials to more robust versions. The overall cost is expected to be around $37,680. The largest cost will be the GoFa at $36,167. Pneumatic components are expected to cost $760, electric components should be around $144, and the other material costs should be around $610. The specific components can be seen below in table 3, the bill of materials.

Table 3. Bill of Materials

Part Number	Description	Quantity	Unit Cost	Cost
100	ABB GoFa	1	$36,167	$36,167
200	Pneumatic grippers	2	$230.00 [11]	$460.00
201	ID gripper finger	2	$37.50	$75.00 [11]
202	OD gripper finger	2	$37.50	$75.00 [11]
300	Snap ring press driving cylinder	1	$73.34	$73.34 [12]
301	Snap ring press mandrel cylinder	2	$73.31	$146.62 [12]
400	Crimping press driving cylinder	1	$79.95	$79.95 [10]
505	20KG Digital Continuous Servo motors [7]	2	$16.99	$33.98
506	Rectangular photoelectric sensors LR-X series for feeding system [8]	2	$54.99	$109.98
300 & 305	Aluminum Stock for Fabrication	1	$57.49	$57.49 [13]
-	Stainless Steel Stock for Fabrication	-	$400	$400 [11]
Total	-	-	-	$37,678.36

As seen from the bill of materials, the cobot is by far the most expensive component for the automated assembly system, and if Parker can justify the cost of it then the other components are a drop in the bucket.

Conclusion

This project aimed to automate the handvalve stem assembly process for Parker. It found that for the current handvalve stem design, the best way to automate is with a collaborative robot based system that can interact with the peripheral systems much like a human, but at a faster rate and lower safety risks. A feeding system was implemented to reduce preparation times. The crimping press was improved to simplify the fixturing required before the press. The snap-ring process was improved by automating the press using sensor-driven actuators and improving the mandrel so all components stay contained in their subassembly. While Parker Hannifin has decided to move in a different direction with regards to this project, all the designs outlined in this report are variable and could therefore accommodate a variety of processes that Parker might want to pursue in the future. Since this project had so many diverse components, Parker could implement some of the components to semi-automate their system until the decision of a new direction has been made. The work done throughout this past year can be especially helpful since Parker has been on back-order recently and anything to increase the speed of assembly would be helpful.

Appendix A:
Design Specifications

Client Needs
Client Need Statement
Parker needs a way to fully automate the assembly of their handvalve stems because it will save them 440 hours and $25,000 savings per year.
List of client needs (in their words)
Fully automate the process, with only an operator needed to monitor operations.
It should ideally fit in a 15x15 ft. cell, but they can find more room if needed.
The crimping step needs enough force so the parts cannot be pulled apart.
The snap ring cannot experience permanent deformation from the assembly process.
Aim for $75,000 as the budget, but less than that would be nice.
It would be convenient if it could assemble two different length stems.

Engineering Specifications					
Specification description	**Target**	**Unit**	**Test method**	**Rank**	**Met**
Category 1: Performance					
Crimping press force	*	lbf	Pull out test, tensile test	Must	
Snap ring deflection	0.035	in	Observation, Deflection test	Must	
Production time	40	units/hr minimum	Observation	Must	
Hopper capacity	230t	units each	Product specs, Observation	Should	
Category 2: Cost					
Cost	75000	USD	Accounting	Should	
Category 3: Safety					
Safety barriers/sensors	as many as needed	-	Visually assess safety coverage	Should	
Category 4: Operations					
Run time	2080	hrs/year	Observation	Must	
Assembly footprint	15	ft^2	CAD model	Nice	

*Non-disclosable but known value

Appendix B:
Assembly Components

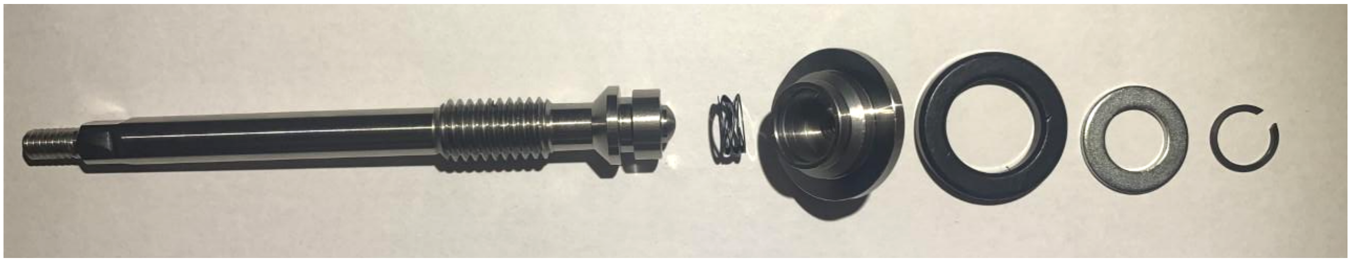


Figure B-1. Each component of the hand valve in the order of how they are assembled.

Figure B-2. The wave spring, which goes into the disc carrier before crimping.

Figure B-3. The disc carrier with the wave spring in it.

Figure B-4. The bottom of the disc carrier, where the teflon, washer, snap ring, and mandrel attach.

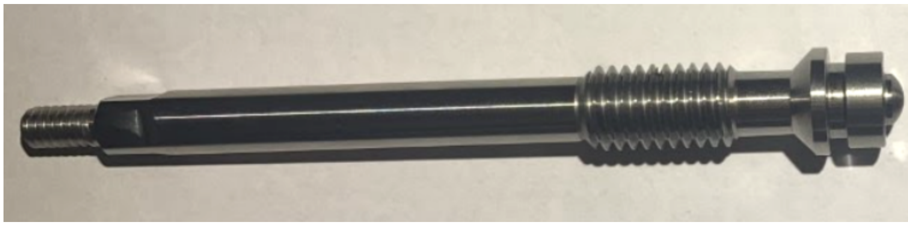


Figure B-5. The stem of the handvalve.

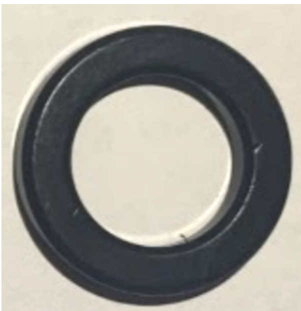


Figure B-6. The teflon, which goes onto the disc carrier.

Figure B-7. The washer, which goes onto the disc carrier after the teflon.

Figure B-8. The snap ring that prevents the washer and teflon from falling off of the disc carrier.

Appendix C:
Calculation Used for Decisions

C-1: Bending of shaft supports for snap ring press.

Bending Load:

$$S_n = S_n' C_L C_G C_S C_T C_R \quad (1)$$

Aluminum yield and ultimate stress [14]:

$$S_n' = 4.5\ ksi$$

$$S_u = 12\ ksi$$

From the Juvinall textbook [14]:

$$C_L = 1,\ C_G = 0.9,\ C_S = 0.8,\ C_T = 1,\ C_R = 1$$

From equation 1…

$$S_n = S_n' C_L C_G C_S C_T C_R = (4.5)(1)(0.9)(0.8)(1)(1) = 3.24\ ksi$$

Bending Stress:

$$\boldsymbol{\sigma}_{nom} = Mc/I \quad (2)$$

Where the bending moment,

$$M = F * x = 9.47[lb] * 5[in] = 47.35[lb - in] \quad (3)$$

The moment of inertia about the neutral axis,

$$I = 0.5 * m * r^2 = 0.5 * 1.11 * 0.5^2 = 0.1388\ [in^4] \quad (4)$$

The distance from the neutral axis,

$$c = 0.5\ [in] \quad (5)$$

Resulting in a bending stress of 170.6 [psi]

Axial Load:

$$\boldsymbol{\sigma}_a = F/A = mg/A = (11.7lb)(32.174ft/s^2)/(3.1415 * (0.5^2)) = 479.29\ psi \quad (6)$$

Goodman's:

$$(\sigma_a/S_n) + (\sigma_m/S_u) = 1/n \quad (7)$$

$$(479.29/(3.24 * 10^3)) + (170.63/(12 * 10^3)) = 1/n$$

$$n = 6.181\ SF$$

This demonstrates that support structures are not required, however it would be beneficial as the support structures will improve stability and reduce the chances of failure.

C-2: Force analysis on snap ring.

The equations and calculations used to find the downward force needed to be applied to attach the snap ring, F, is below. They are in part based off of the geometry from figure J.

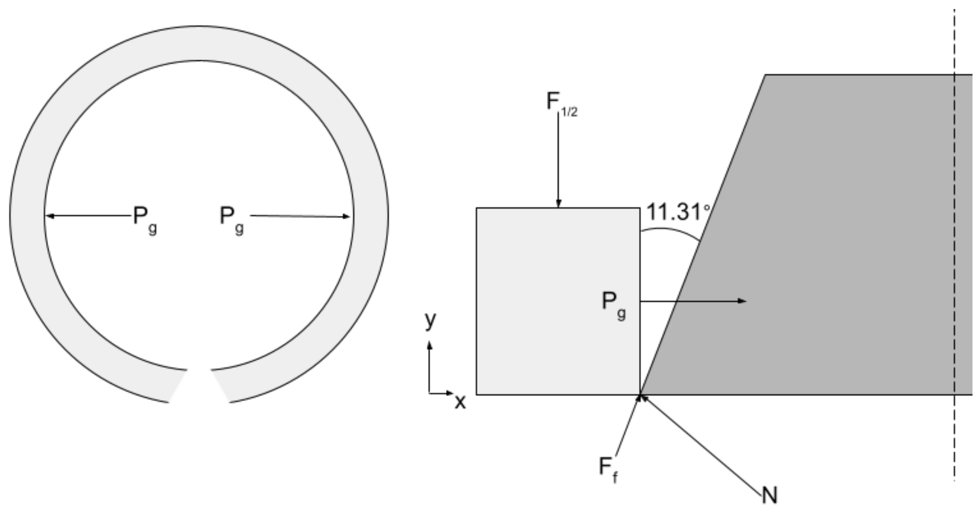


Figure C2-1. Free body diagram of significant forces to apply the snap ring.

$$P_g = \frac{4Etb^3 f}{3\pi D^3} \quad (8)$$

$$\sum F_x = 0 \quad (9)$$

$$\sum F_y = 0 \quad (10)$$

$$F = 2F_{\frac{1}{2}} \quad (11)$$

To balance the forces in the x and y directions the friction force, F_f, is needed.

$$F_f = \mu_k N \quad (12)$$

N_x, N_y, F_{fx}, and F_{fy} will also be used. They are the components of N and F_f in the x and y directions. From geometry,

$$N_x = N\cos(11.31) \quad N_y = N\sin(11.31)$$
$$F_{fx} = \mu_k N\sin(11.31) \quad F_{fy} = \mu_k N\cos(11.31)$$

For the snap ring which is spring steel, E = 30*10^6 psi, t = 0.035 in, b = 0.048 in, and D = 0.488 in. At the widest portion of the mandrel, f = 0.0165 in, and the coefficient of kinetic friction, μ_k for steel on steel is 0.42. The coefficient of kinetic friction is used because at the widest part of the mandrel the snap ring will already be in motion from the robot's push, and the snap ring and mandrel will both be made of steel. The complete calculations are below.

$$P_g = \frac{4(30*10^6[psi])*0.035[in]*0.048[in]^3*0.0165[in]}{3\pi*0.488[in]^3} = 7[lbf]$$

$$\sum F_x = 0 = P_g + F_{fx} - N_x = P_g + \mu_k N\sin(11.31) - N\cos(11.31)$$

$$N = \frac{P_g}{\cos(11.31) - \mu_k \sin(11.31)} = \frac{7[lb]}{\cos(11.31) - 0.42\sin(11.31)} = 7.79[lbf]$$

$$\sum F_y = 0 = F_{fy} + N_y - F_{1/2} = \mu_k N\cos(11.31) + N\sin(11.31) - F_{1/2}$$

$F_{1/2} = \mu_k N\cos(11.31) + N\sin(11.31) = 0.42 * 7.79[lbf] * \cos(11.31) + 7.79[lbf] * \sin(11.31) =$ 4.736[lbf]

$$F = 2F_{\frac{1}{2}} = 2 * 4.736[lbf] = 9.47[lbf]$$

9.47[lbf] converts to a 4.3 [kg] load that needs to be applied to the snap ring.

C-3: Speed Analysis on Cobots.

The speed calculations for the robots are based on each stop being evenly spaced 36° (π/5 radians) apart, and the robot having to travel along 36 of these 36° segments at their furthest reach. An image of this layout can be seen below in Figure C3-1.

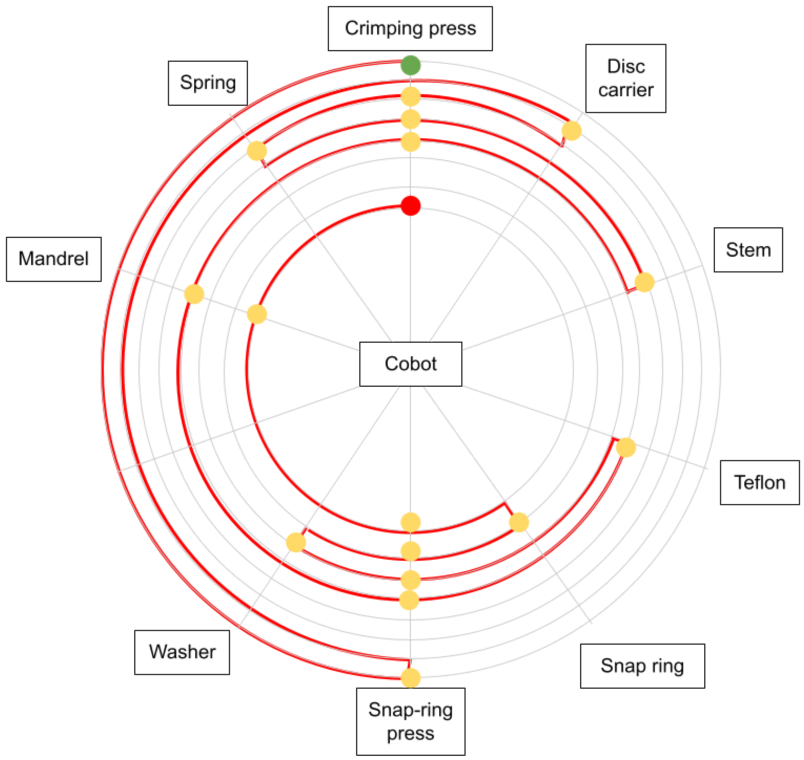


Figure C3-1. Potential path of the robot end of arm tooling throughout the assembly process. It begins at the green circle, ends at the red circle, and each yellow dot is a stopping place.

The time it takes for the cobot to produce one part, t, is shown below in Equation 13.

$$t = \frac{36\pi R}{5V} \tag{13}$$

From there, Equation 14 was used to find the number of stems made in one hour, N. It assumes that 18 seconds are added to the time in motion to account for the gippers opening or closing at each stop. There are 18 stops that should each take about 1 second.

$$N = \frac{3600\,[s]}{t+18[s]} \tag{14}$$

For GoFa, R = 950mm and V=2.2m/s. This leads to the calculations below.

$$t = 36\left(\frac{950[mm]\pi}{5}\right)\left(\frac{1[m]}{1000[mm]}\right)\frac{1}{2.2[m/s]} = 9.77[s]$$

$$N = \frac{3600\,[s]}{9.77+18[s]} = 129\ parts\ per\ hour$$

For Swifti, R=580mm and V=5.05m/s. This leads to the calculation below.

$$t = 36\left(\frac{580[mm]\pi}{5}\right)\left(\frac{1[m]}{1000[mm]}\right)\frac{1}{5.05[m/s]} = 2.60[s]$$

$$N = \frac{3600\,[s]}{2.60+18[s]} = 174\ parts\ per\ hour$$

Appendix D:
Engineering Drawings

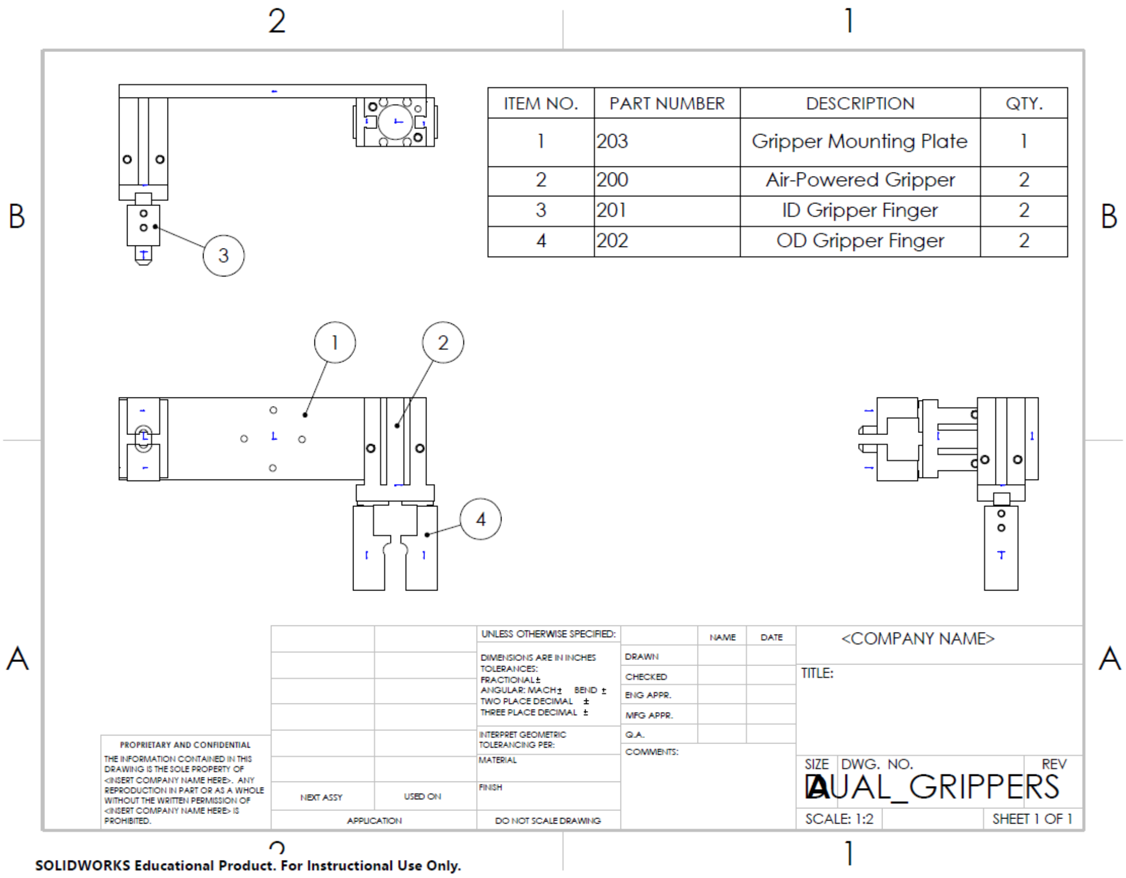


Figure D-1. Gripper sub-assembly engineering drawing and BOM

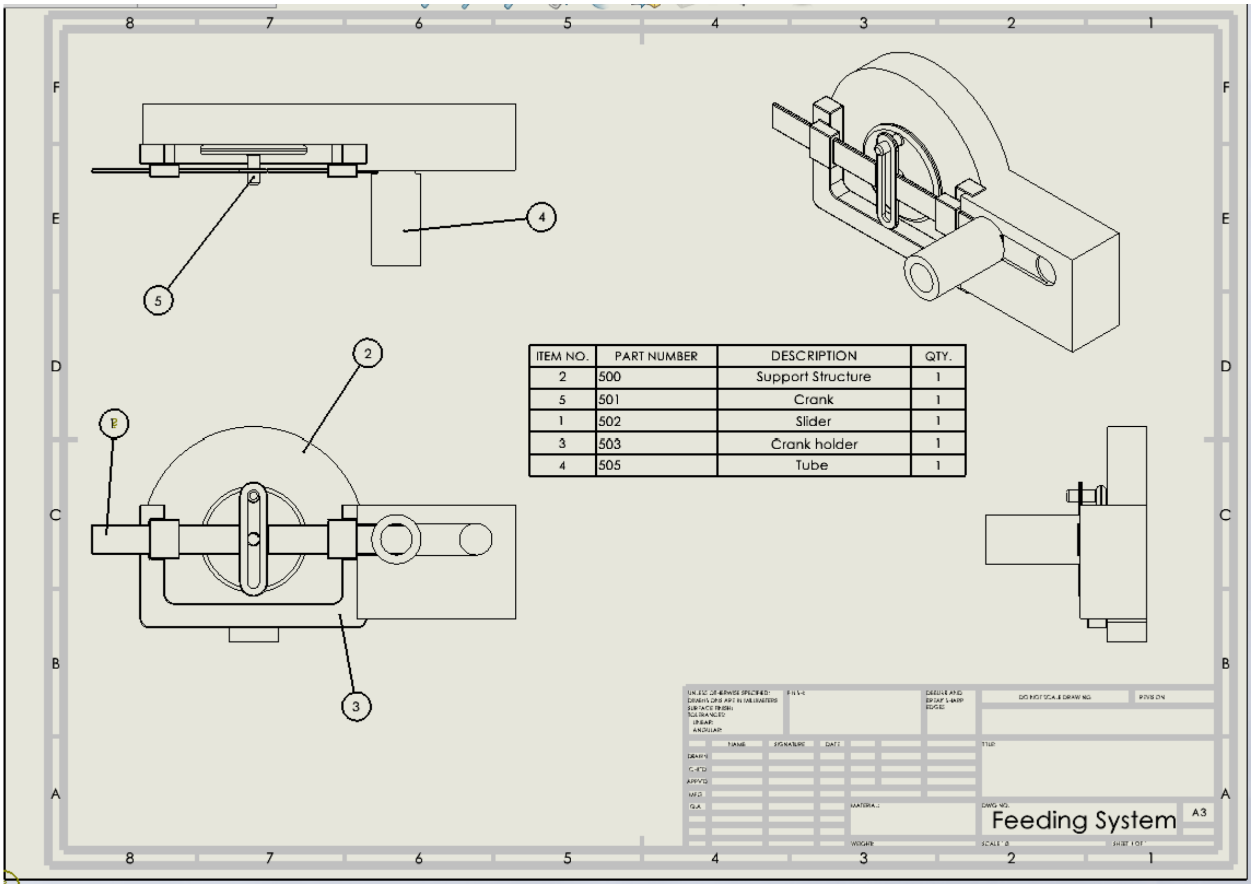
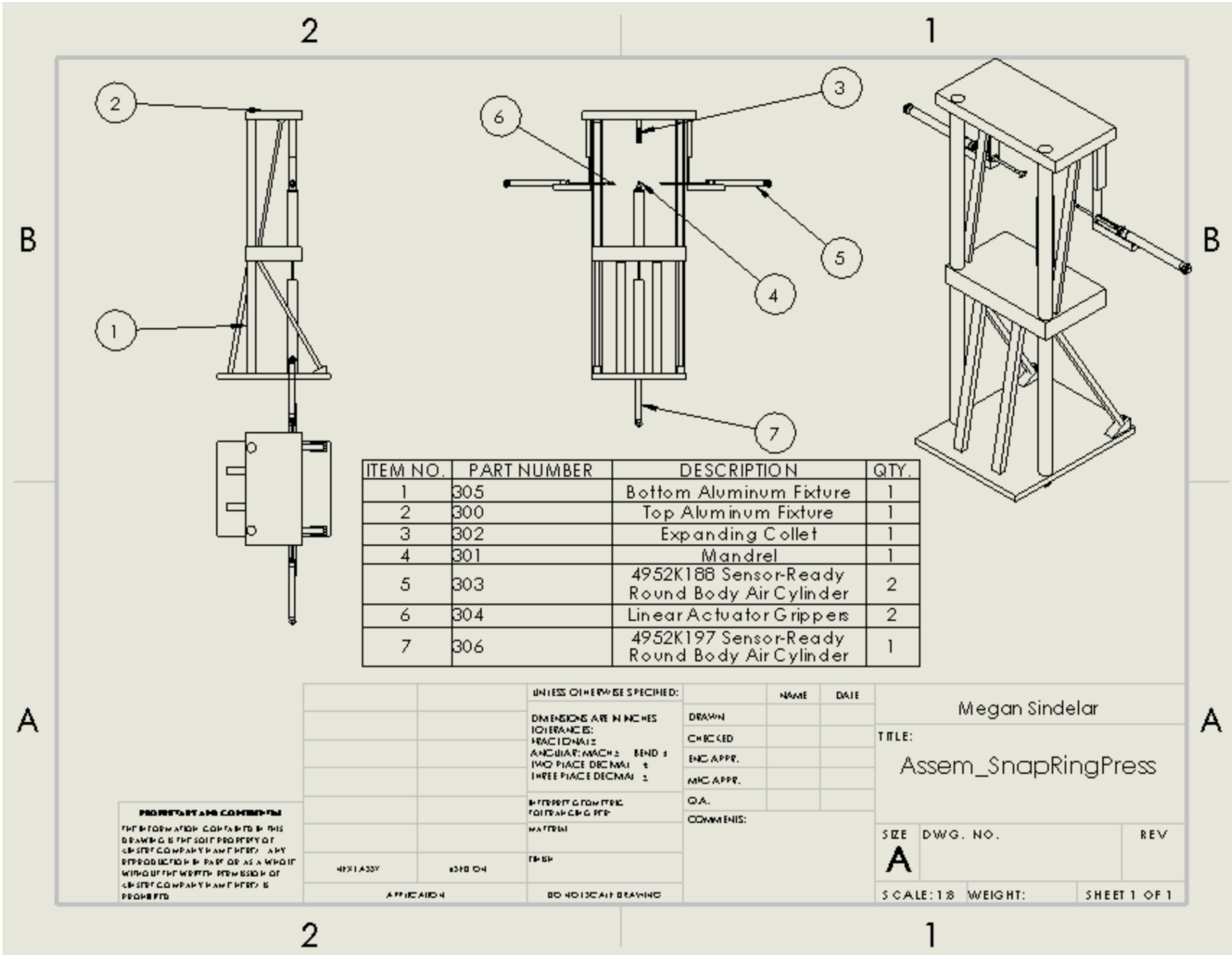
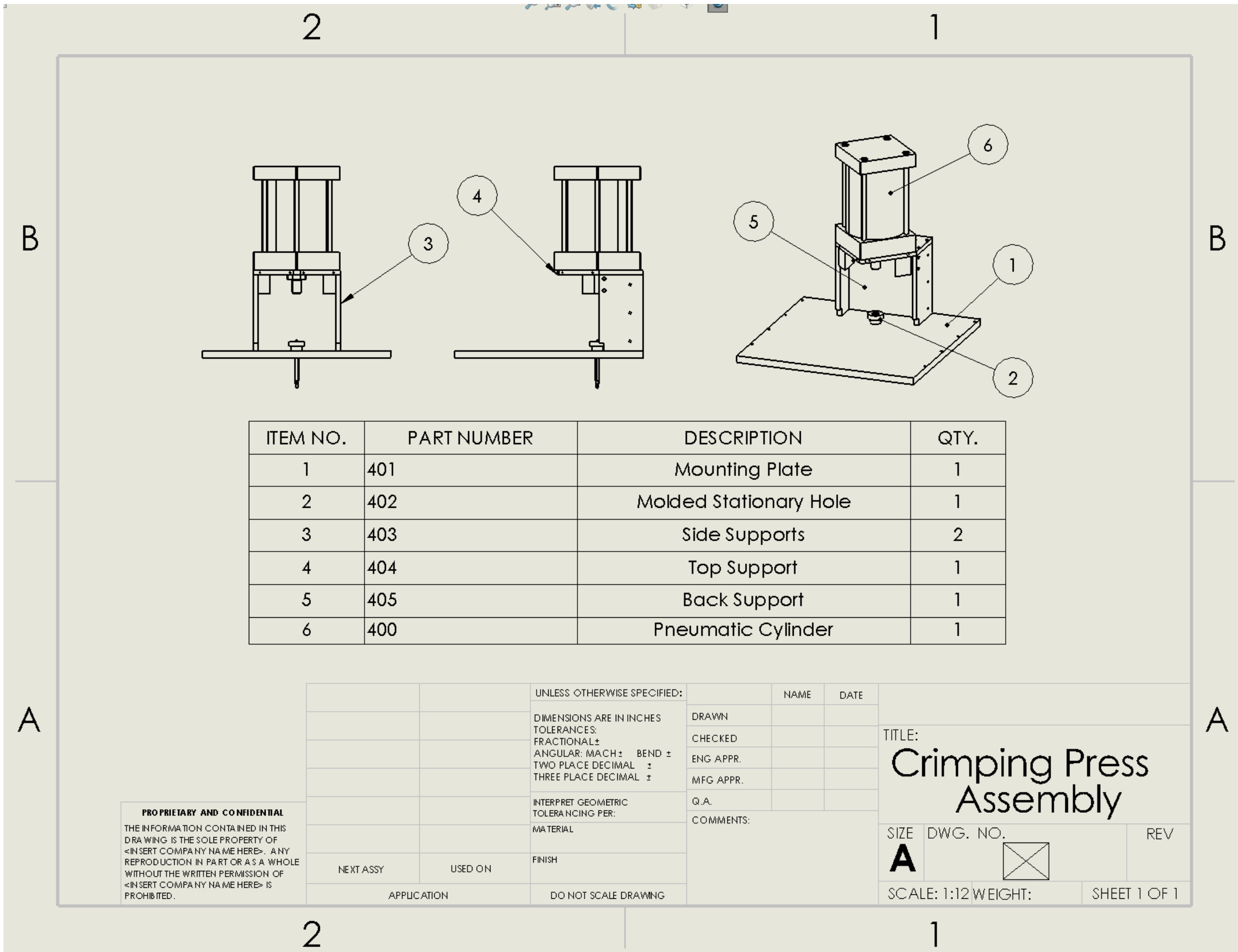


Figure D-2. Engineering drawing and BOM for feeding system sub-assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	305	Bottom Aluminum Fixture	1
2	300	Top Aluminum Fixture	1
3	302	Expanding Collet	1
4	301	Mandrel	1
5	303	4952K188 Sensor-Ready Round Body Air Cylinder	2
6	304	Linear Actuator Grippers	2
7	306	4952K197 Sensor-Ready Round Body Air Cylinder	1

Figure D-3. Engineering drawing and BOM for snap ring press assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	401	Mounting Plate	1
2	402	Molded Stationary Hole	1
3	403	Side Supports	2
4	404	Top Support	1
5	405	Back Support	1
6	400	Pneumatic Cylinder	1

Figure D-4. Engineering drawing and BOM for the crimping press assembly

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