

Product Transfer Tooling Redesign

As a Major Qualifying Project

Submitted to the faculty

Of the

Worcester Polytechnic Institute

Worcester, MA

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

On

26 April 2012

By

Stephanie Hoag

Matthew Kellas

Antonia La Bella

Mark Vanacore

Project Advisor: Professor Robert L. Norton

Department of Mechanical Engineering

Abstract

The sponsoring company for this project has a cartridge transfer station which uses a gripper loading mechanism to transfer their finished products from the assembly conveyor into their shipping and storage containers. Currently, this gripping mechanism is actuated by physical contact with the product, causing undesired surface deformations, shear marks and chipped product housings within the finished product. The project team developed and designed a new gripper loading mechanism, which utilizes a spring dampened toggle-linkage gripper to pick and place the product. This new linkage system is actuated by a pneumatic cylinder, a method currently being utilized by the sponsor. This new mechanism does not contact the product during its loading, completely eliminating the chance of physical deformation in the finished products.

Acknowledgements

The group would like to thank the following individuals for their contributions and help towards this project's success.

Christopher Brown

Martin D'Agostino

Michael Fagan

Loren Gjata

Corey Maynard

Finally we would like to express our sincerest thanks to our project advisor, Professor Robert L. Norton. His continued efforts and guidance was paramount in the success of the group's project.

Table of Contents

| | |
|-------------------------------------|-----|
| Abstract..... | ii |
| Acknowledgements | iii |
| Executive Summary | 1 |
| Background..... | 3 |
| Critical Motions | 4 |
| Upper Mechanism..... | 5 |
| Lower Mechanism..... | 7 |
| Gripping Tool | 9 |
| Physical Deformation Analysis | 11 |
| Problem Statement..... | 13 |
| Task Specifications | 14 |
| Design Process | 14 |
| Ideation..... | 14 |
| Realization..... | 15 |
| Creation | 15 |
| Final Design | 16 |
| New Parts | 18 |
| Cams | 20 |
| Modified Parts..... | 20 |

| | |
|---|----|
| Linkage Analysis..... | 24 |
| Spring Force Calculation | 28 |
| Pin Size Fatigue Optimization..... | 29 |
| Tear-out Calculations..... | 33 |
| Prototyping and Testing | 35 |
| Base Part..... | 35 |
| Pivoted gripping jaw..... | 36 |
| Links | 36 |
| Pins..... | 37 |
| Pivot Shoulder Screw | 37 |
| Spring and Pneumatic Cylinder | 38 |
| Acorn Nut..... | 38 |
| Base for Mounting Prototype | 38 |
| Conclusion | 40 |
| Appendix A: Spring Specification Sheet..... | 42 |
| Appendix B: Festo Air Cylinder Specification Sheet..... | 43 |
| Appendix C: Calculations for Tear-out Strength | 44 |
| Appendix D: Drawings for new parts | 51 |

Table of Figures

| | |
|---|----|
| Figure 1: Isometric view of the upper mechanism. Circled parts indicate the portions of the mechanism that contact the gripping tooling. | 5 |
| Figure 2: Timing diagram of the upper mechanism cam | 6 |
| Figure 3: Upper mechanism in its home position (left) and lowest position (right). Any parts circled indicate the gripping tooling, and are not fastened to the upper mechanism. | 6 |
| Figure 4: Isometric view of the lower mechanism. Parts circled indicate the portions of the mechanism that contact the gripping tooling. | 7 |
| Figure 5: Timing diagram of the lower mechanism cam..... | 8 |
| Figure 6: The separate stages of the bottom mechanism’s motion. Each position reflects different segments on the cam timing diagram. From left to right; 15° , 245° , 265° , 297° . | 9 |
| Figure 7: Isometric view of current gripping mechanism | 10 |
| Figure 8: Human eye view of select defective products. | 11 |
| Figure 9: Micrometer scale view of physical defect | 12 |
| Figure 10: Front view of the original gripper design on left and final gripper design on right. | 17 |
| Figure 11: Isometric view of a transmission link used in the actuation system..... | 18 |
| Figure 12: Isometric view of second link used in gripper actuation system | 19 |
| Figure 13: (From left to right) left pin, middle pin, and right pin | 20 |
| Figure 14: The previous and modified base plate for the gripper | 21 |
| Figure 15: The previous and modified left plate for the gripper | 22 |
| Figure 16: The previous and modified gripping jaw | 23 |

| | |
|--|----|
| Figure 17: The previous and modified upper tooling component of the CTS..... | 24 |
| Figure 18: Isometric view of final gripping assembly | 25 |
| Figure 19: Open and closed positions of the gripper assembly | 26 |
| Figure 20: Firing diagram for pneumatic cylinder actuation, imposed on the cam timing diagrams. | 28 |
| Figure 22: Fatigue analysis and safety calculations for transmission pins | 32 |
| Figure 23: Screenshot showing areas of interest for tear-out calculations | 33 |
| Figure 24: Radius to be determined in links by tear-out calculations | 34 |
| Figure 25: The rapid prototyped gripper block and actual gripper block..... | 36 |
| Figure 26: Isometric view of the base prototype testing assembly | 39 |
| Figure 27: Frontal view of the assembled prototype station | 40 |

Executive Summary

The goal was to redesign the current method and mechanisms used by the sponsor to physically transfer finished products from their production line to shipping containers. Currently, unwanted physical deformations are transferred to the products through the use of a current gripper design. In order to successfully eliminate these defects, we moved to not only identify the root cause of said defects, but also create a new gripping system to alleviate the cause of these deformations.

After receiving samples of defective products from the sponsor, the team analyzed and hypothesized on possible causes of defect creation. Upon first observations, apparent flaking of product housings and angled shear marks were transferred by the gripping mechanism to the finished product. Using a laser microscope, we took a much closer look at one of the most affected products. This image allowed us to confirm that the root cause of the physical deformations present was a downwards force transferred by the products physical contact with the actual gripping jaws.

The current gripping method involves contact with the product to open a spring actuated jaw lever. Application of contact force to the product spine pivots the gripping arm about a pin and compresses a spring allowing the jaws to open enough to hold onto the product. After gripping the product, the spring force in the gripper allows the jaws to hold onto the product while it travels around the overall mechanism's raceway. It is then deposited into a shipping tray.

The new gripping method uses a pneumatically driven linkage to open and close the gripping jaw around the sides of the product. When approaching the product, a pneumatic cylinder fires its piston into a transmission link, which in turn drives a larger linkage that causes a similar pivoting motion of the gripping jaw of that present in the current gripper. However, the jaw is actuated before it reaches the actual product, eliminating the risk of collision with the currently affected product spines. After clearing the product spine, the pneumatic cylinder retracts, and a spring forces the linkage back to its neutral position, which closes the jaws of the gripper around the product. By utilizing a toggle linkage design, the group ensured that the spring will always return the linkage to its neutral position, as long as it is not pushed past its toggle position. Careful positioning and tolerancing of the pneumatic cylinder stroke is paramount in ensuring the linkage does not switch its toggle position.

After prototyping and testing a similar gripping mechanism, the team observed that of the force involved in creating the physical deformations was eliminated. By eliminating the use of the product to open the jaws, the strong downwards impact force present in current operations was no longer present. The spring force present in the current gripper was replicated in the final design, to ensure that the product would be firmly gripped as it travels through the raceway of the mechanism to be deposited into the sponsor's shipping containers.

Background

The cartridge transfer station (CTS) is a combination of mechanisms utilized by the project's sponsoring corporation, which transfers acceptable product cartridges from an unloading conveyor system to their respective shipping containers. The CTS can bypass products that are unsuitable for consumer use. After a suitable cartridge is selected, it is inserted into one of the product transfer gripping tools. Once there are nine accepted cartridges, the group of grippers moves from the loading section of the product transfer machine to the unloading section of the machine, located opposite the loading conveyor. The grippers get to the unloading section of the machine by following the raceway, an overhead track used to guide the grippers throughout the entirety of the machine. At the unloading section, the nine cartridges are placed into dispenser cups to be taken to another station. Simultaneously, a second group of nine grippers loads with acceptable products, allowing more parts per minute to be processed.

When the product is transferred from the unloading conveyor system to the grippers at the loading station, two separate cams operate two mechanisms. The gripping jaws of the CTS have one pivot arm and one stationary arm. In order to properly grip the product at its center rib, the gripper jaws are physically forced onto the rib. At the unloading station, a servo motor is used instead of a cam to transfer the products from the gripper tools to the dispenser cups.

Within the CTS, unwanted physical deformations are transferred onto the product's rib via the transfer tooling. These deformations exist as shear marks displayed

on the rib of the product. These shear marks cause chipping on the critical section of the product, hindering the full functionality and appearance of the product.

Due to the observed angle and position of the deformations, it was assumed these deformations were caused by a downward force. This allowed numerous root causes to be identified for further investigation. The upper mechanism's cam has a quick downward motion, leading to an excess of downwards force, so a change in the cam profile may result in a smoother downward transition. The gripper jaws currently use the product rib to open the gripping jaw to hold the product as it travels around the raceway. By adjusting the way that these jaws open, the product might not need to be used to open the jaws. Also, another issue that must be addressed is if the tooling were misaligned. Even the smallest misalignment would result in deformations. Further investigation within the report determines the true cause of the deformations present on the product.

Critical Motions

In this section, the critical moments in the mechanisms operation cycle are analyzed. Details such as the motions of the upper and lower tooling mechanisms and the respective cam profiles were investigated. The physical actuation, loading, and unloading of the gripping tools were also examined to determine if these motions were causing the deformations on the product.

For the gripping tool to function properly, two separate mechanisms work in unison. One of these mechanisms has an end effector that is located above the product,

Lower Mechanism

The main drive shaft not only drives the upper mechanism's cam, but that of the lower mechanisms too. The lower mechanism raises its end effector in several stages to remove the product from the conveyor belt. Also present in the mechanism is a spring, which receives its loading force when the product is physically loaded into the gripper. Below, Figure 4 shows an isometric view of the lower mechanism.

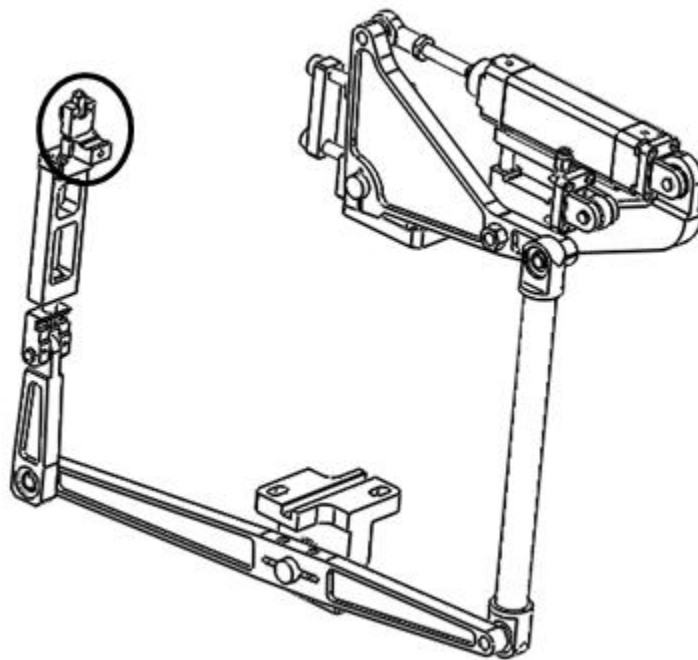


Figure 4: Isometric view of the lower mechanism. Parts circled indicate the portions of the mechanism that contact the gripping tooling.

Instead of a simple high dwell, fall, low dwell, rise, the lower mechanism cam has three separate stages to its fall. This protects the gripping tool from crashing into its end effector, and also allows the mechanism's spring to be loaded in a controlled manner.

The slope of the cam diagram is different in each fall segment, as seen below in Figure 5. A fall in the cam motion below translates to a rise in the end effector.

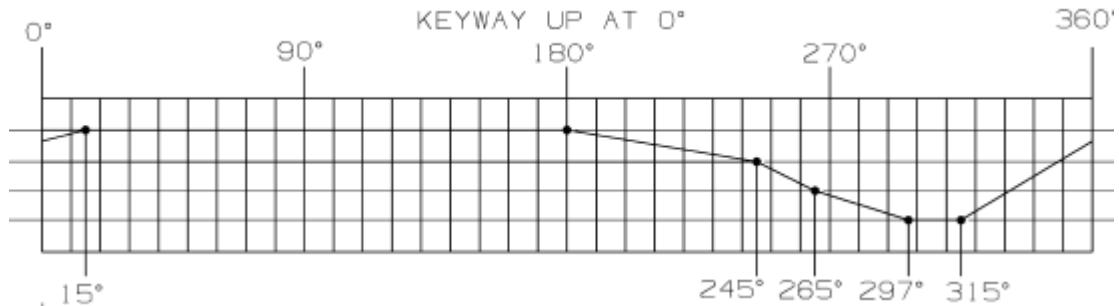


Figure 5: Timing diagram of the lower mechanism cam.

The segmented fall in the cam allows for a more controlled motion when the end effector contacts the products. By not using a single fall, the velocity and force can be minimized when the product is introduced into the mechanisms. Figure 6 below shows the numerous positions of the lower mechanism during the cam cycle, more specifically at the end of each cam segment. In the model, collision occurs within the gripping tool and end effector during the last fall segment (from 265° to 297°). The purpose of the aforementioned spring in the mechanism is to absorb this force and allow compression of the spring instead of physical collisions between end effectors.

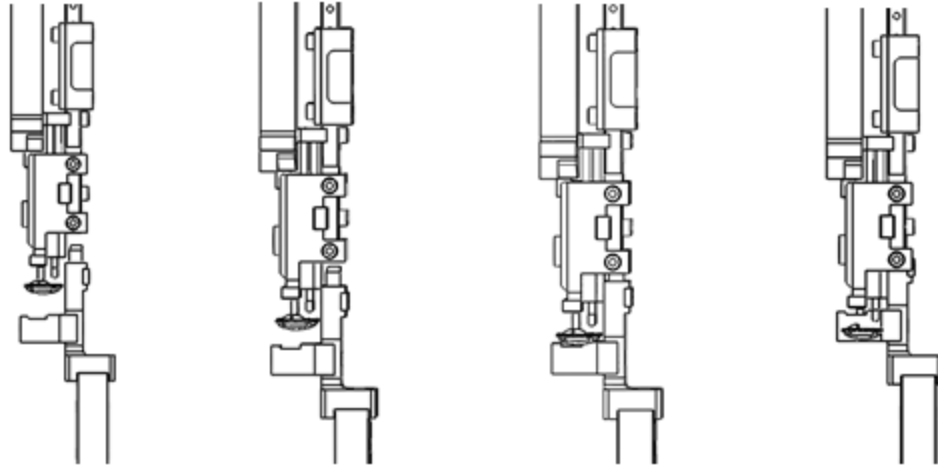


Figure 6: The separate stages of the bottom mechanism's motion. Each position reflects different segments on the cam timing diagram. From left to right; 15°, 245°, 265°, 297°.

Gripping Tool

The product gripper is the mechanism that picks up the product, moves to the drop off location and unloads the product into a dispenser cup. Within the mechanism two separate jaws work in conjunction. One of these jaws is grounded to the body of the gripper, and the other pivots around a central pin. The pivoting jaw is acted upon by a spring, located in the upper portion of the gripper's body. The force generated by the spring holds the tool in the closed position. To acquire the product, the tool is driven downwards onto a rib located in the center of the product. This rib forces the jaws of the tool open and the spring keeps the jaws pressing tightly on the center rib, allowing the tool to lift the product. A push bar on the back of the tool adds stability to the product while it is moving. Once the nine tools on either the top or bottom track are loaded, the whole set moves to the drop off location together. Figure 7 shows an isometric view of the gripper tool.

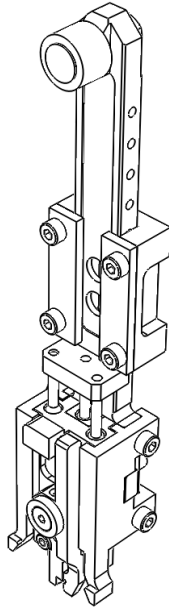


Figure 7: Isometric view of current gripping mechanism

Once the grippers reach the unloading position, a servo driven mechanism plunges all nine products into dispenser cups. Crush bumps designed into the dispenser cups allow the tool to drop off the product without actuating the jaws open. When the tool moves down to make the drop off, the gripper first makes contact with a cup locator. This contact prevents the jaws from moving too low and deforming the product or cup. The back of the product also comes in contact with the back of the cup at this time, preparing it for proper insertion. As the tool continues downward, one side of the product rests on a crush bump and rotates down to the bottom of the cup. When the tool reaches its lowest point, it seats the product at the proper final angle. Finally, the tool returns back to its highest position and the product is removed from the jaws from the friction force of the crush bumps.

Physical Deformation Analysis

As previously mentioned, unwanted physical deformations are created on the product's center rib via the transfer tool. These deformations occur in various severities but only on the right side of the product rib, demonstrating that only one of the gripper arms is causing these marks. Due to the observed angle and position of the deformations, we hypothesized that the shear marks resulted from a downward force. Two of the more extreme examples of this defect are shown in Figure 8, below.

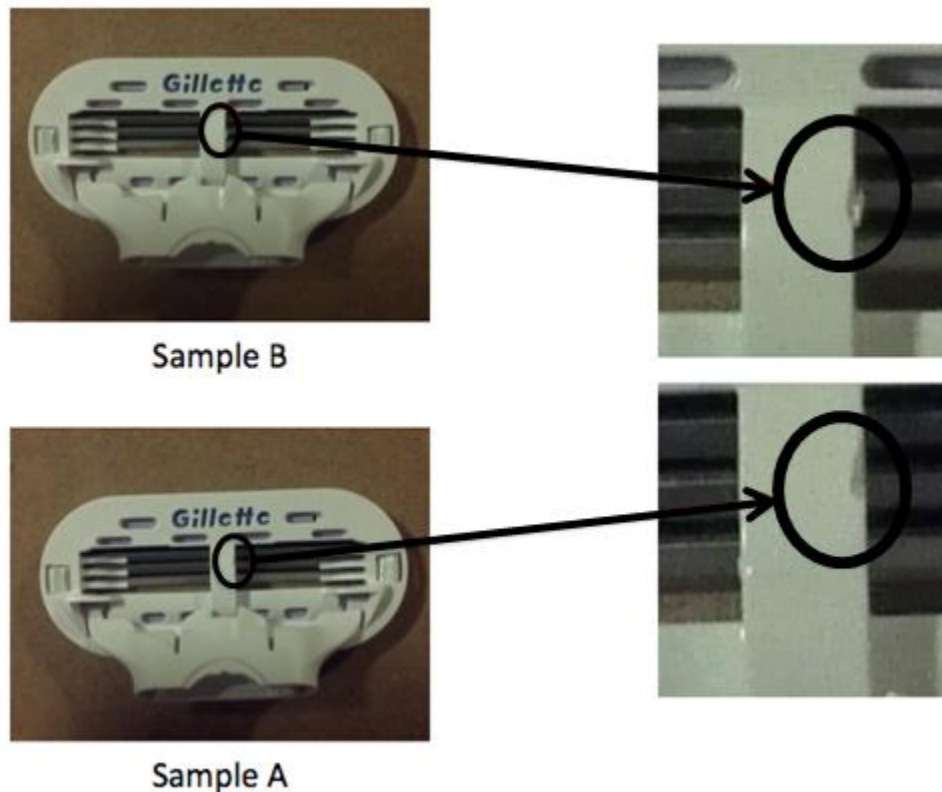


Figure 8: Human eye view of select defective products.

A closer examination of the defect was necessary to gain more information and to concretely determine a root cause. With the help of Professor Christopher A Brown

and the Olympus LEXT OLS4000 scanning-laser confocal microscope, the product chip was viewed at 10X magnification. A measurement region of 643x643µm was used with a height sampling grid of 1024x1024 height samples. There were three critical observations that led to the deformation conclusion. The shear crack in the middle of the chip has a downward slope. At the top edge of the chip on the top rib face the material slopes down over this edge. At the bottom of the chip, plastic deformations are observed due to material buckling. The laser microscope image displaying these observations and locations is shown in Figure 9.

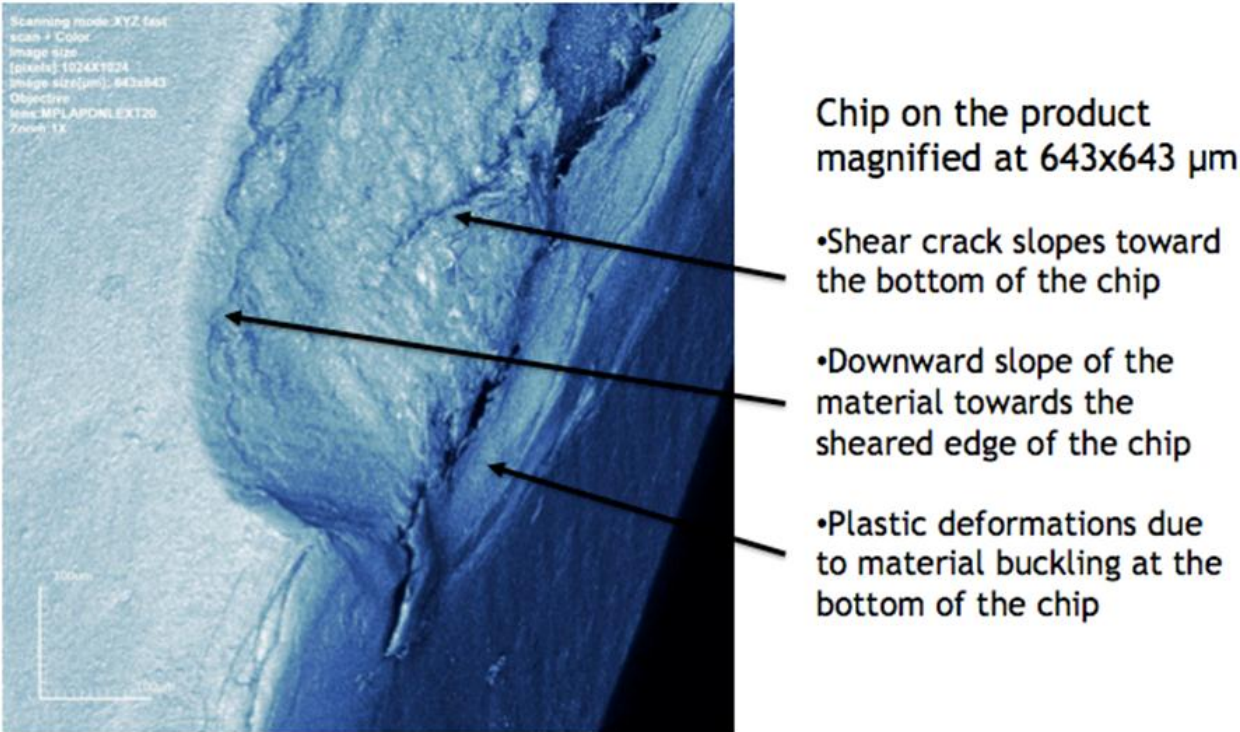


Figure 9: Micrometer scale view of physical defect

These observations confirm that the product chips are caused by a downward force. Therefore, the focus for the redesign is on the front loading area of the

mechanism. In order to ensure that the proposed design solutions function correctly we created a SolidWorks model with each design and observed any changes in the functioning of the back unloading area. This check would ensure that implementation of the final design would be possible.

After narrowing the projects focus to the loading mechanism, we identified numerous approaches to eliminate the root cause of the physical deformations. In order to create smoother velocity and acceleration transitions when the gripper and push pad contact, the cam profiles could be adjusted. Another strategy drew attention to the rate at which the gripper contacts the product. The cam motion could also be modified to allow for slower speeds just before contact. A third strategy is to redesign how the gripper arms actuate so that the product rib is not being utilized for this motion. By using these strategies, multiple prototypes were produced that could potentially reduce or eliminate the product's visible physical deformations.

Problem Statement

After analysis and discussion of the current standards used by the sponsor, we then moved to define the overall goal of the project. The forces causing the physical deformations would need to be eliminated, while maintaining full operation of all other tasks required of the CTS. The efforts of the project team would focus on the redesign of the physical gripping mechanisms. After combining these variables, the group set out to redesign various components of the product transfer machine to reduce or eliminate the product's visible deformations due to the transfer tooling.

Task Specifications

1. Gripper must not remove material from products
2. The proposed solution must require a simple process to minimize potential downtime for each machine
3. A minimum number of components of the machine must be modified
4. Design must be able to integrate with current products per minute speeds
5. Must align with preexisting servo motor profiles and speeds
6. Must maintain or enhance the machine's overall parts per minute performance
7. Can be reapplied to all preexisting gripper assemblies and configuration

Design Process

The problem presented by the sponsor was defined, and task specifications set; now a complete system that would fulfill all of these requirements needed to be designed.

Ideation

The brainstorming steps of the project led to many viable options and ideas which the project group could use. The first concepts proposed using current movements and forces present in the CTS mechanism. These designs used the contact of the lower mechanism and new gripper designs to actuate the gripper arm. However, by creating this new contact force, many components of the mechanism needed to be redesigned. The cams which drive the mechanism would need to be altered, along with several crucial pieces of the current gripper. After presenting four iterations of grippers

that were physically actuated by the lower mechanism of the CTS to the sponsor, we realized that this method may not be the best approach for accomplishing our tasks.

Realization

After receiving feedback from the sponsor, all design work shifted from using movements and forces currently present in the operation of the CTS. The mechanism as a whole is quite complex, and requires very tight tolerances and timing relationships to maintain the production speed and quality needed by the sponsor. Instead of altering these crucial factors, an independent method of actuating the new gripper was researched. Pneumatic cylinders are a modern method used by the sponsor in some of the assembly lines to accomplish a variety of tasks.

Creation

A linkage or lever system would be actuated to open and close a single gripping jaw around the side of the product spine, alleviating the issue of contacting the product from above and pushing down on it. All spring forces would need to remain the same as the previous gripper design so that after acquiring the product, it would not be released prematurely. In combination with the spring, an independent pneumatic system should be attached to the CTS mechanism and used as the primary actuation method.

Final Design

After further discussion with the sponsor, the approach for the final design involved a simple pneumatic actuation of the gripper. This choice allows for precise, repeatable motion and a small number of modifications to the existing system.

The proposed design for the gripper system involves the pneumatic actuation of a toggle-like linkage to open the gripper before inserting the product, then to close the gripper around the product once it is in place. This greatly improves upon the previous design of opening the gripper by contacting the product, by completely eliminating the downward force upon the product. Figure 10 below, shows a diagram of the original design at the left and the final design to the right. The linkage rests with the center pin higher than the outer pins. The outer pin on the right connects the linkage to the body of the gripper, and the left pin connects the linkage to the top of the movable gripper jaw. The center pin connects the two links together. The center pin is contacted by pneumatic actuator and pushed downwards, forcing the left outer pin to push the bottom of the movable gripper jaw outwards. This motion opens the gripper. Additionally, there is a small pin located below the center pin of the linkage, which is grounded to the body of the gripper. This pin acts as a hard stop to prevent the linkage from ever moving down past the toggle position. This also enables the machine to be cleaned and maintained by a person without being concerned with pushing the links past the toggle position. After the product has been inserted into the gripper, the actuator retracts and the spring located between the gripper arm and the side of the assembly forces the

gripper back to the closed position. The gripper is then sent to the other side of the transfer station where it drops off the product into its respective package container.

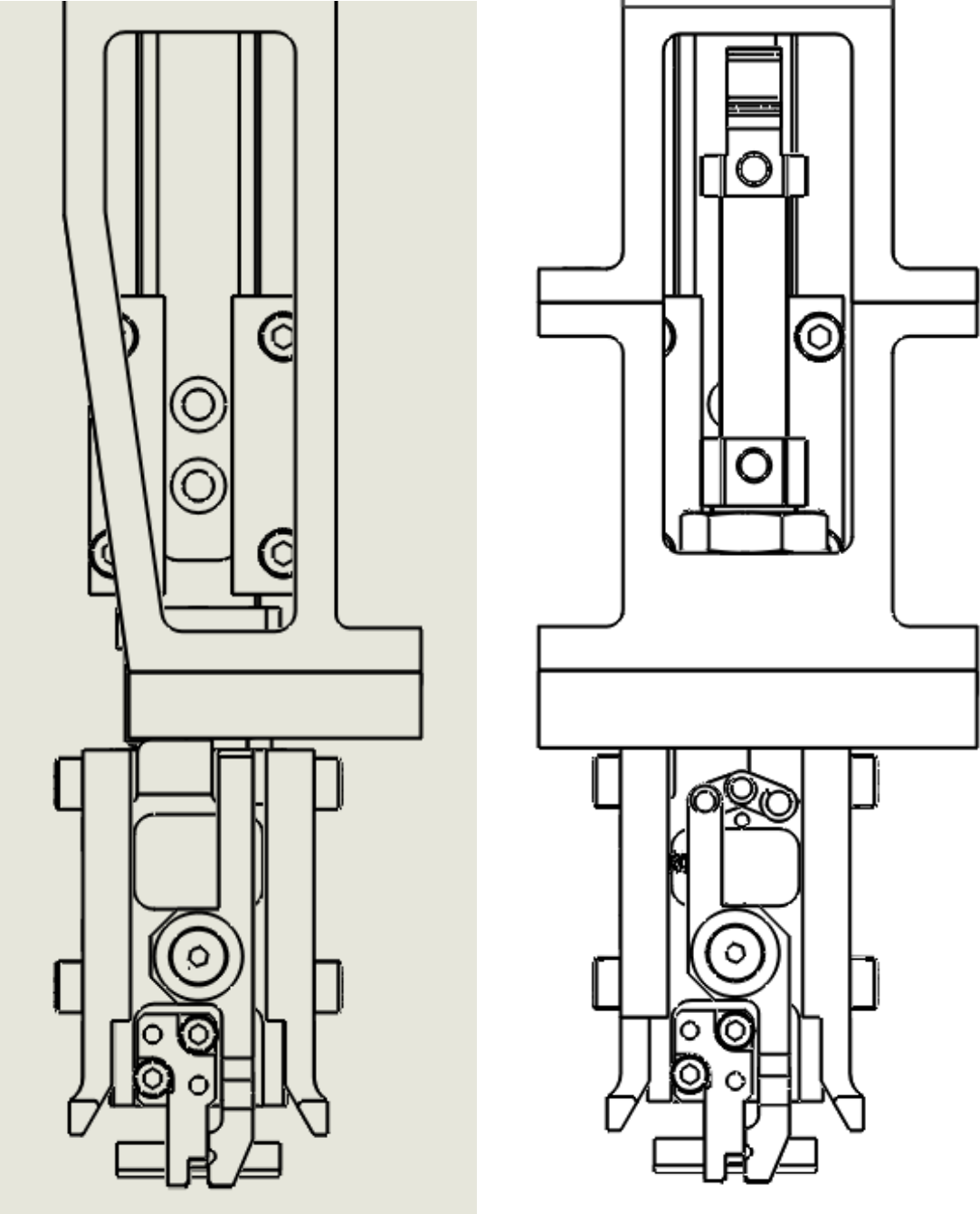


Figure 10: Front view of the original gripper design on left and final gripper design on right.

New Parts

For the final design, there are six new parts that need to be manufactured and five new parts that need to be purchased. All drawings for the parts are located in Appendix D at the end of this report.

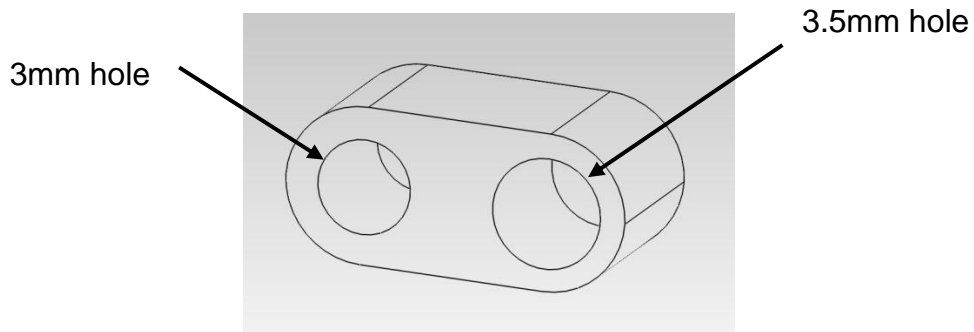


Figure 11: Isometric view of a transmission link used in the actuation system

There are two links to be manufactured. The first (Figure 11) is attached to the second link (Figure 12) by one pin and attached to the front of the gripper by another pin. This first link has two different size holes of 3mm and 3.5mm. The 3mm hole has the pin to attach to the second link and the 3.5mm hole is for the pin that attaches to the back of the gripper. The centers of the holes are 5.92mm away from each other. The length of the link is 11mm, the width is 5.5mm, and the height is 5mm.

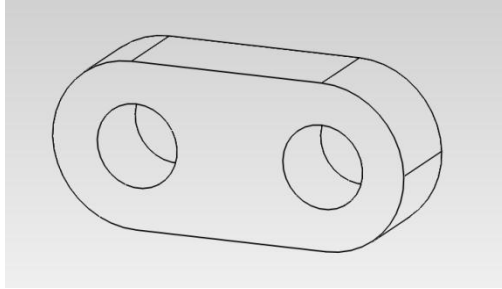
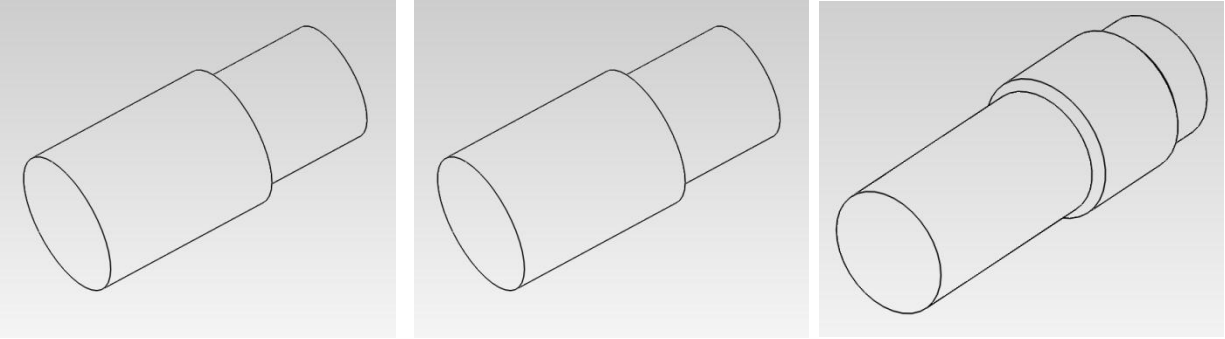


Figure 12: Isometric view of second link used in gripper actuation system

The second link (Figure 12) has two 2.5mm holes for pins to be press fit into them. One of the pins is attached to the first link and the other hole has a pin that attaches to the modified gripper jaw. The dimensions for the second link are a length of 11mm, width of 2.54mm and a height of 5mm.

There are three pins used in the new gripper design; the left pin (Figure 13.1) attaches the second link with the movable gripper jaw. It is a stepped pin with the diameter of 3mm for 4mm in length and the next diameter of 2.5mm for 2.54mm in length. The middle pin (Figure 13.2) attaches the first and second link together. It is also a stepped shaft with the diameter of 3mm for 6.5 mm in length and a diameter of 2.5mm for 2.54mm in length. The right pin (Figure 13.3) attaches the first link to the front of the gripper face. It is a three stepped shaft with the diameter of 3.5mm for 6.25 mm in length then a diameter of 4mm (determined from fatigue calculations) for 3.5mm in length and last a diameter of 3.5mm for 1.25mm in length. In addition to the pins, three snap retaining rings need to be purchased: two that fit around the 3mm pins and the third having to fit around the 3.5mm pin.



1 2 3

Figure 13: (From left to right) left pin, middle pin, and right pin

A spring that has a diameter of 2.007mm and a free length of 10.008mm with a spring rate of 0.567 N/mm needs to be purchased for the mechanism. The specification of this spring is found in Appendix A, and is purchased from the company Associated Spring Raymond.

Finally, an air cylinder needs to be purchased. A Festo company cylinder was found with a 10mm stroke and fits into our design. The specifications for this cylinder are contained within Appendix B of this report.

Cams

The current cams on the CTS machine can be used in this design because the air cylinder allows the group independent control regarding the actuation of the linkage system. While previous prototypes borrowed motion from tooling driven by the cams, this is no longer an issue, and allows for easier implementation of the pneumatic driven system.

Modified Parts

The final design modifies five existing parts of the gripper and transfer tooling machine. Because most of the existing parts are hardened tool steel, we recommend that replacing these parts by manufacturing new pieces would be best. Some modified details of these parts already require them to be manufactured from new material. They are presented as modified parts to convey the intent that as many features as possible have been left unchanged.

The body of the gripper as shown below in Figure 14 has only a few minor modifications. One hole has been added to the front face in the upper right corner, which holds the grounded stepped pin of the linkage. This pin is press fit into the body, and the link rotates around the protruding side of the pin. Another feature is the addition of the hole for the 2mm pin that prevents toggling for the linkage located in the middle upper portion of the base part. Also, the cavity which contained the original horizontal spring has been removed.

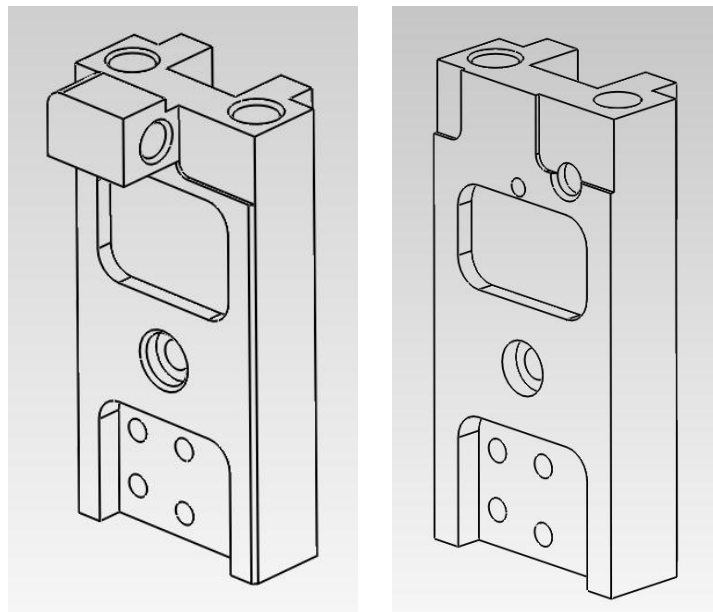


Figure 14: The previous and modified base plate for the gripper

The left side plate of the gripper as shown below in Figure 15 also features a new hole, which houses a small spring to keep the gripper closed at all times when the actuator is not exerting a force on the linkage. Additionally, the face on which the hole has been placed has been enlarged in order to provide a greater safety factor for the material around the hole. This added material provides enough clearance for the spring hole location.

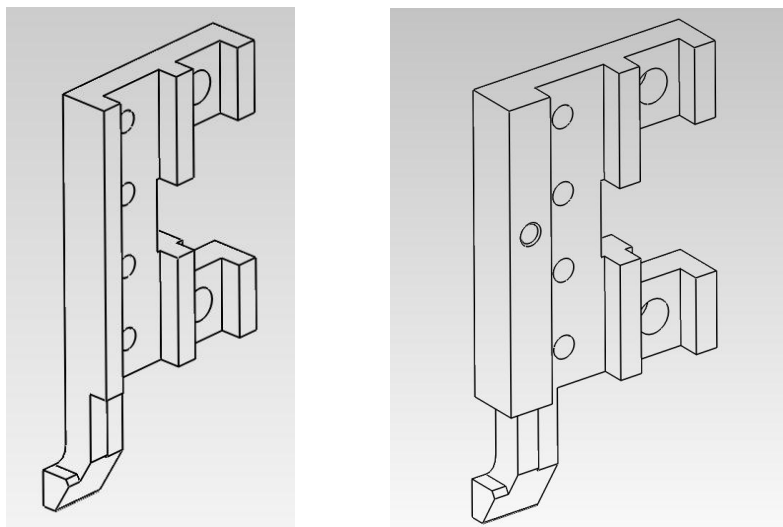


Figure 15: The previous and modified left plate for the gripper

The modified right jaw of the gripper, shown in Figure 16 below features its upper half on the opposite side of the pivot. This allows for the downward actuation of the pneumatic to cause the linkage to produce an opening motion at the tip of the jaws.

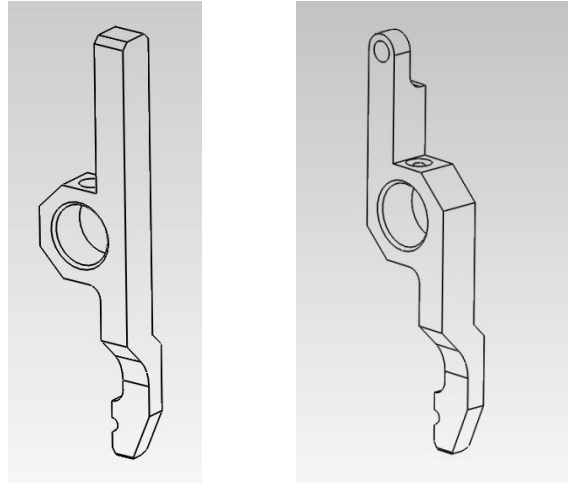


Figure 16: The previous and modified gripping jaw

The stabilizing plate is a small plate attached to the product pusher piece, which are both located on the upper cam mechanism of the CTS. As a gripper comes into the loading station of the CTS, it stops at the stabilizing plate assembly. This assembly then pushes the gripper down to retrieve the product. After the gripper has the product between its jaws, it moves around the raceway to the unloading area. Because this assembly is attached to the main CTS mechanism and pushes down on each gripper, there is only one of these groupings in the entire CTS mechanism. The product pusher piece on which the stabilizing plate attaches has been modified to house the pneumatic actuator, as shown below in Figure 17. To accommodate for the attachment of the two pieces, the part has been split into a top and bottom piece and flanges on either side have been added to support fasteners. A tapped hole centered at the bottom of each part interfaces with the male tapped end of the pneumatic actuator. This tapped hole also allows the piston rod of the cylinder to easily actuate the linkage system while also locating and stabilizing the linkage.

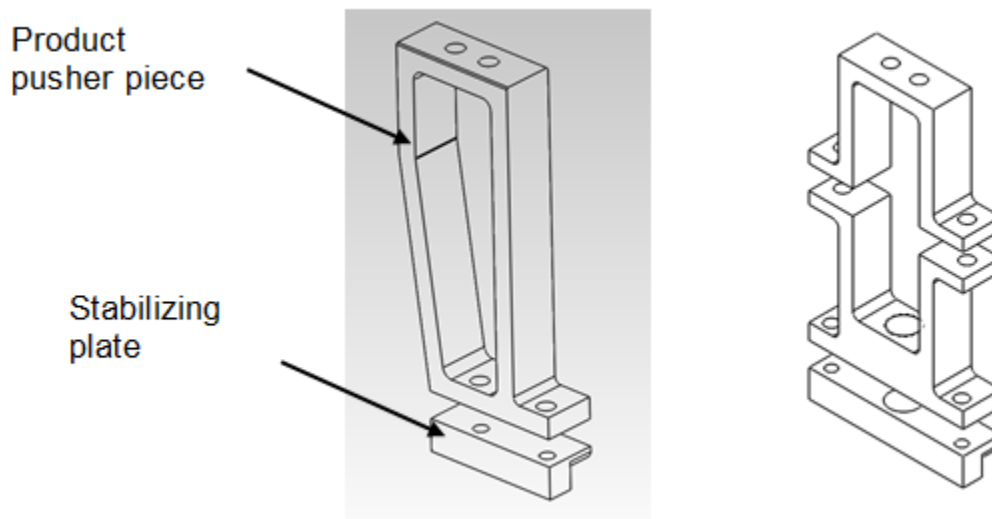


Figure 17: The previous and modified upper tooling component of the CTS

Linkage Analysis

The decision to actuate the gripper with a pneumatic cylinder (Festo Cylinder, Part Number DSNU-10-10-P-A) was made in order to have full control over the actuation and timing of the system, as well as decrease the complexity, precision and wear of the linkage mechanisms. A screenshot of the finalized gripper assembly is shown below in Figure 18. The Festo cylinder sits above the actual gripper components, chosen by the team based on its size and stroke length, which are further based on calculations.

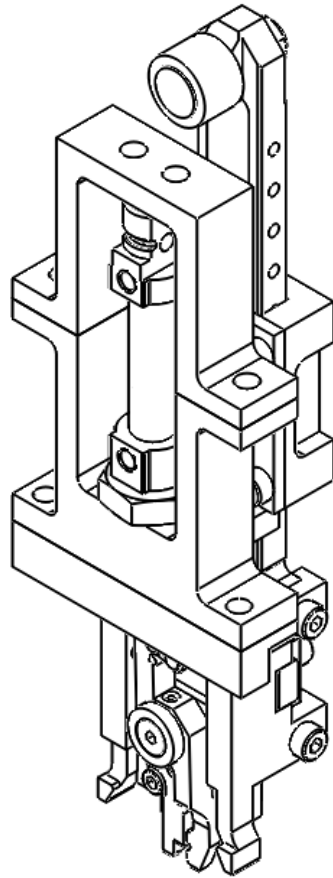


Figure 18: Isometric view of final gripping assembly

This new linkage system is actuated by the piston rod of the pneumatic cylinder pushing down on the linkage at the location of the pin that connects the two links (pin 2). The thickness of pin 1 was increased such that the actuator impacts only one of the links, creating a consistent collision for each cycle, and eliminating any unwanted variation of link stresses and fatigues. The mount for the pneumatic actuator consists of a few modified parts in the machine, which includes the stabilizing plate and the product pusher piece. Even though both the exterior and interior geometry changed for the

parts, the overall volume is similar. This ensures that these new pieces will not collide with any other components in the CTS. Both the stabilizing plate and product pusher piece have tapped holes at their bases to secure the cylinder. The two flanges on either side of the product pusher piece contain vertical holes that serve to secure the assembly rigidly, as well as allow the housing to break apart in order to insert the actuator.

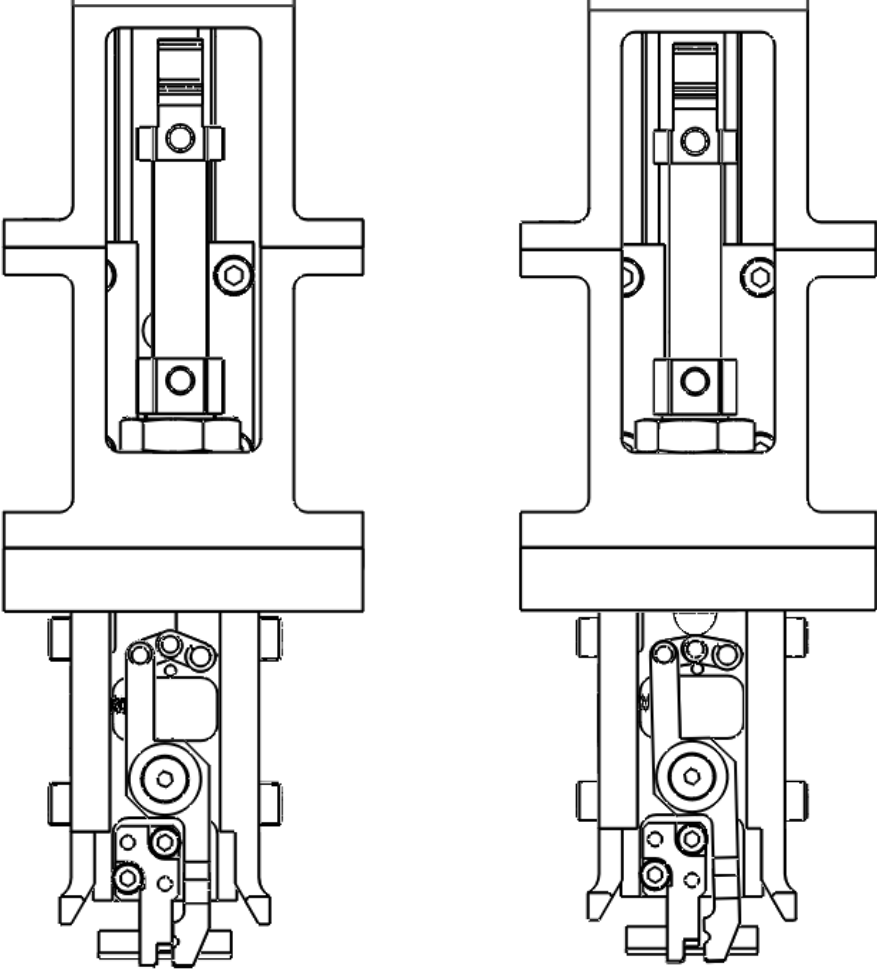


Figure 19: Open and closed positions of the gripper assembly

By actuating the linkage with a pneumatic piston, the system gains the desired consistency and repeatability for this machine. The way the linkage is designed, the piston moves the pin 2 down approximately 1.65 mm, which opens the tip of the jaw about 1.36 mm. This measurement was taken at the tip of the movable jaw in its closed position to the tip of the movable jaw when the linkage is fully actuated. This results in an overall mechanical advantage of 6:5 in this linkage. This actuation distance is shown above in Figure 19.

In order to demonstrate how this mechanism works, a simple mechanical flow of the CTS gripper is described. First, the gripper tool slides into the transfer station at the stabilizing plate. Immediately, the piston is actuated and pushes down on the linkage, allowing the movable gripper jaw to open. The entire gripper is then moved down, and the bottom cam of the CTS pushes the product up into the open gripper. The piston then retracts, and the spring closes the gripper around the product. The bottom station with the product nest drops away, allowing the gripper and product to return to its original vertical position. Finally, the tool moves around to the unloading station of the machine to create space for the next tool to come in, and the process is repeated. A cylinder firing diagram is shown below in Figure 20 and the dashed lines indicate the extension and retraction of the piston. These lines were placed on top of the original cam timing diagrams.

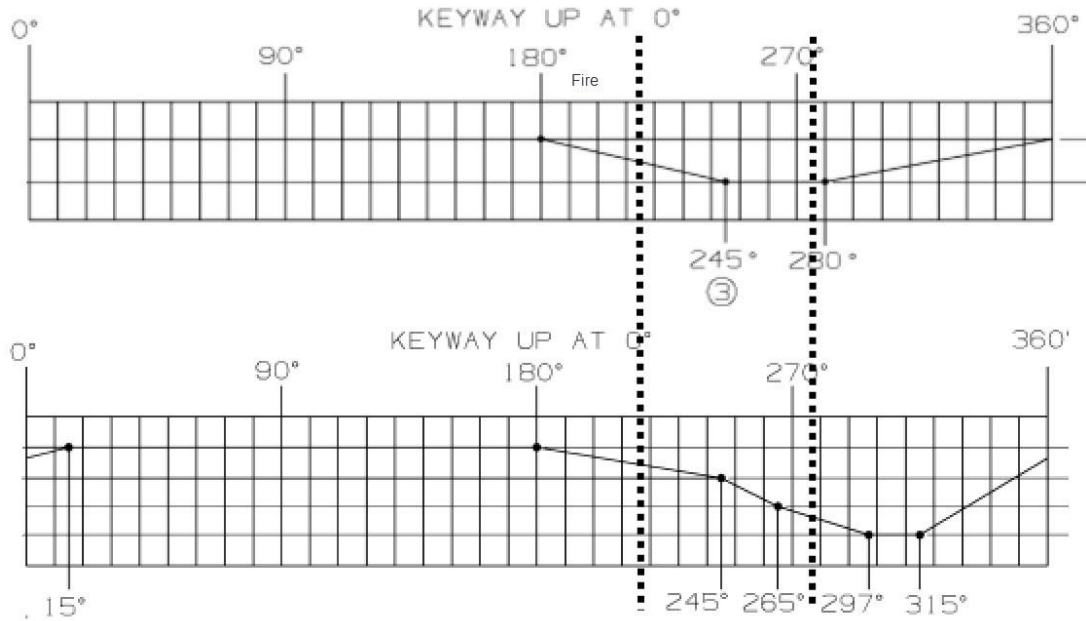


Figure 20: Firing diagram for pneumatic cylinder actuation, imposed on the cam timing diagrams.

Spring Force Calculation

The main parameter for selecting a spring for the design was to have the same force on the product as the original design. Because the spring was moved down to the side of the gripper jaw, the new spring was determined based on the original spring force from the existing gripper. This is necessary so the product would not fall out of the jaws while going around the carousel. This also insures no changes need to be made on the unloading portion of the CTS.

The first calculations were to find the force from the original gripper on the product, based on the geometry of the existing CTS grippers. After that, the calculation for the new spring coefficient was completed, in order to ensure proper gripping force. Both these calculations are shown below in Figure 21.

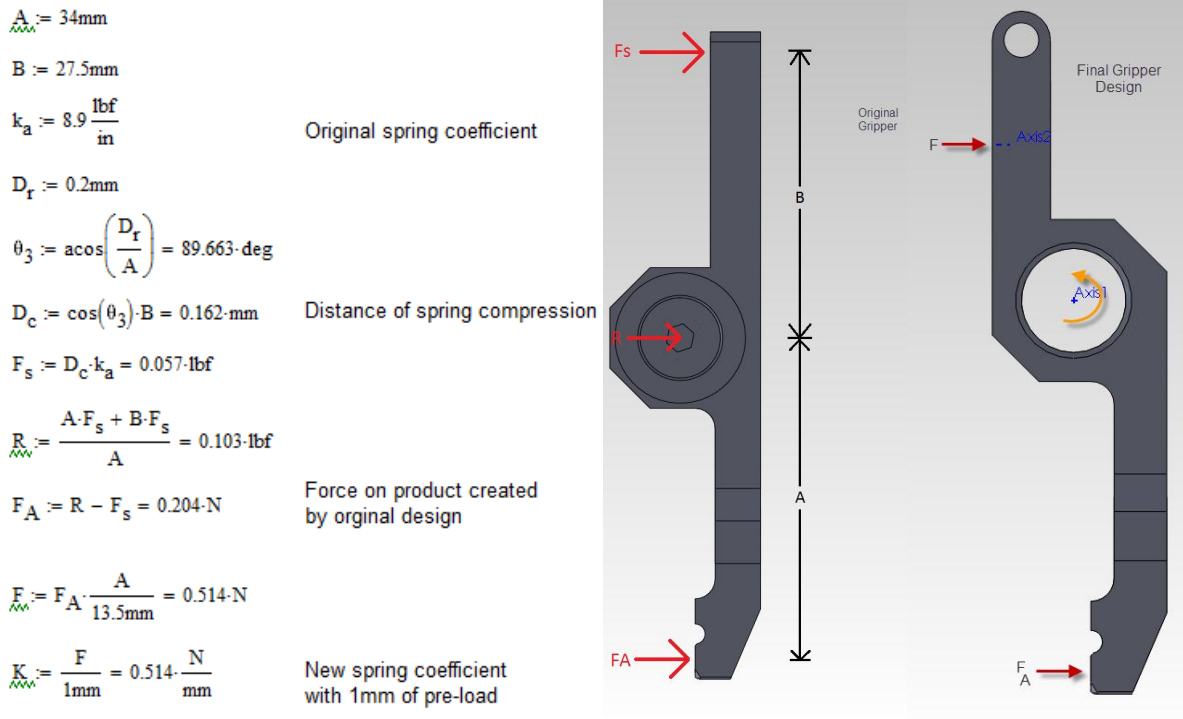


Figure 21: Calculations and FBDs used to determine final spring constant

The new spring coefficient for the final gripper is 0.514 N/mm with a 1mm pre-load. The space in between the gripper jaw and side of the gripper is 9mm including the wells or holes. The spring chosen for final use had a 10.008mm free length and a spring coefficient of 0.567 (see Appendix A for the specification sheet of this spring.)

Pin Size Fatigue Optimization

By referring to the static analysis of the gripper and the specification sheet of the Festo air cylinder (provided in Appendix B), we moved forward with determining the optimal pin size to use in the linkage system. This was done by adjusting the material

strength of the pins, and determining a safety factor in the pins for an infinite life cycle. The strength adjustments and corresponding fatigue analysis was completed in the program MathCAD and is presented below in Figure 22. By using 3.5 millimeter pins, we obtained a safety factor of 2.385 for infinite life cycles.

Fluctuating Stress Components

Initial Loading and Stresses

$$\min := 0 \text{ ksi}$$

$$\max := .396 \text{ ksi}$$

$$d := \max - \min = 396 \text{ psi}$$

$$a := \frac{\max - \min}{2} = 198 \text{ psi}$$

$$m := \frac{\max + \min}{2} = 198 \text{ psi}$$

$$\frac{R}{W} := \frac{\min}{\max} = 0$$

$$\frac{A}{W} := \frac{a}{m} = 1$$

Strength Adjustment Factors

$$S_{ep} := .5S_{ut} = 51.5 \text{ ksi}$$

$$C_{load} := .70$$

Loading Type = Bending

$$C_{size} := 1$$

Small diameter

$$C_{surf} := 2.7 \cdot (103)^{-.265} = 0.791$$

Surface Adjustment

$$C_{temp} := 1$$

Operating Temperature

$$C_{reliab} := .753$$

99.9% Reliability

$$S_m := .95S_{ut} = 97.85 \text{ ksi}$$

Adjusted Strength

$$S_e := C_{load} \cdot C_{size} \cdot C_{surf} \cdot C_{temp} \cdot C_{reliab} \cdot S_{ep} = 21.462 \text{ ksi}$$

Material Information

A-8 Tool Steel

$$S_{ut} := 103 \text{ ksi}$$

$$S_y := 448 \text{ ksi}$$

Radius of Pin Steps

$$d := 3.5\text{mm} \quad D := 4\text{mm}$$

$$I := \frac{(d)^4}{64} = 7.366 \times 10^{-12} \text{m}^4 \quad \text{Izz Axis}$$

$$c := \frac{d}{2} = 1.75 \times 10^{-3} \text{m} \quad \text{Center of Pin}$$

$$r := .25\text{mm} \quad \text{Shoulder Radius}$$

$$\sigma_{\text{anom}} := \frac{M_a \cdot c}{I} = 3.019 \times 10^7 \text{Pa} \quad \text{Nominal Alternating and Mean Stresses}$$

$$\sigma_{\text{mnom}} := \frac{M_m \cdot c}{I} = 3.019 \times 10^7 \text{Pa}$$

Geometric Ratios

$$\frac{D}{d} = 1.143$$

$$\frac{r}{d} = 0.071$$

$$A := .95000 \quad b := -.28000 \quad a := .060^2 \text{m}$$

$$K_t := \left[A \cdot \left(\frac{r}{d} \right)^b \right] = 2.124$$

$$q := \frac{1}{1 + \frac{\sqrt{a}}{\sqrt{r}}} = 0.623$$

$$K_f := 1 + q \cdot (K_t - 1) = 1.7$$

$$K_{f \cdot \text{max}} = 4.643 \times 10^6 \text{Pa}$$

$$K_{\text{fim}} := K_f = 1.7$$

$$\sigma_{\text{max}} := K_{f \cdot \text{max}} \cdot \sigma_{\text{anom}} = 5.133 \times 10^7 \text{Pa}$$

$$\sigma_{\text{max}} := K_{\text{fim}} \cdot \sigma_{\text{mnom}} = 5.133 \times 10^7 \text{Pa}$$

Final Safety Factor for Pins

$$N_{f3} := \frac{S_e \cdot S_{ut}}{a \cdot S_{ut} + m \cdot S_e} = 2.385$$

Figure 22: Fatigue analysis and safety calculations for transmission pins

Tear-out Calculations

Tear-out calculations were performed on the links to determine the smallest area between the pin and the edge of the link that would insure function without failure. This method calculates the radius of the end of the link starting at the center of the pin location, as shown in Figure 24. Since both pin locations on the thinner link and pin three location on the larger link would have the possibility of breaking in these thinner areas, the minimum tear-out area was calculated for these three locations, shown in Figure 23.

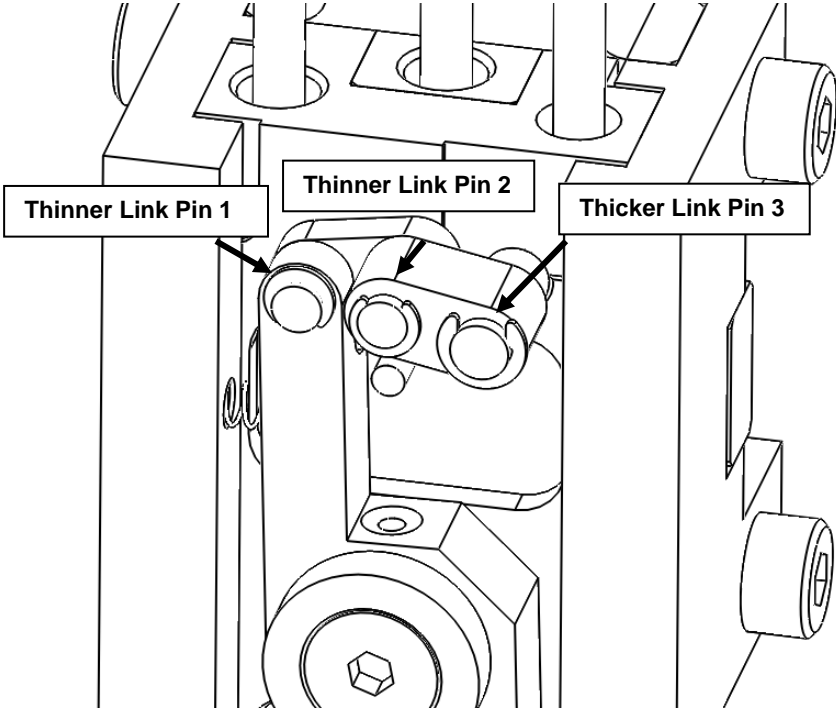


Figure 23: Screenshot showing areas of interest for tear-out calculations

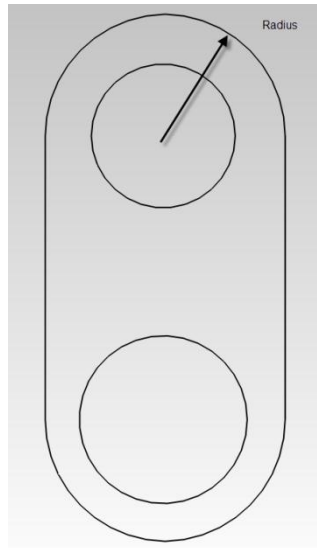


Figure 24: Radius to be determined in links by tear-out calculations

Based on the free body diagrams of the links, the forces on each link and pin were calculated. These forces were used to determine the maximum and minimum forces at each pin location, which were then used to find the alternating and mean forces. The pins are in double shear and there are no stress concentrations. For the final product, it was determined that these links would be manufactured from A-6 tool steel because the material has a high ultimate tensile strength. From the material strength, the modified endurance limit was calculated. The diameters of the pins were calculated and sized against fatigue in the previous section, which determined the safety factor that was used for the tear-out calculations. A modified Goodman-failure Case 3 Process was used to determine the radius size. Case 3 was used because the ratio between the mean and alternating von Mises stresses is a constant value. By using the safety factor of 2.385 (previously determined by the fatigue analysis) and a

modified Goodman failure with case 3, the tear-out radius for each pin location was calculated and presented below.

The minimum radius for pin 2 on the thinner link is 1.252mm, for pin 1 on the thinner link is 1.251mm and for pin 3 on the thicker link is 1.75mm. Because each link was created larger than these values for manufacturing and tolerance purposes, they would be able to function without fatigue failure. The tear-out calculations are presented in their entirety in Appendix C.

Prototyping and Testing

In order to demonstrate the functionality and positioning of the various components of the gripper in relation to each other without using the entire transfer station, a prototype is necessary. Many components were modified so that the geometry could be simplified for manufacturing purposes. This also allows for use of simpler, cheaper processes and materials to make each part.

Base Part

The final designed base part was modified to be close to a simple block for ease of rapid prototyping (RP). The RP machine layers thin treads of plastic to make a part. Any unnecessary cavities and extended pieces were excluded from the design, allowing less material overall for the block piece. Such as the two extended legs on the side pieces are used in the final design for placement purposes. The two spring holes on the top and the cavity in the front were altered along with the bolts and holes on the stationary gripper arm. This gripper arm piece was not modified for the unique geometry utilized on the bottom where it contacts the product.

In the original design, all of these components had a clearance between them, which resulted in large gaps. To make this part one solid block, all of these gaps were “filled in” in the prototype piece in SolidWorks. When this block is then sent to the RP printer, it will be one solid piece of plastic. Figure 25 shows this simplification.

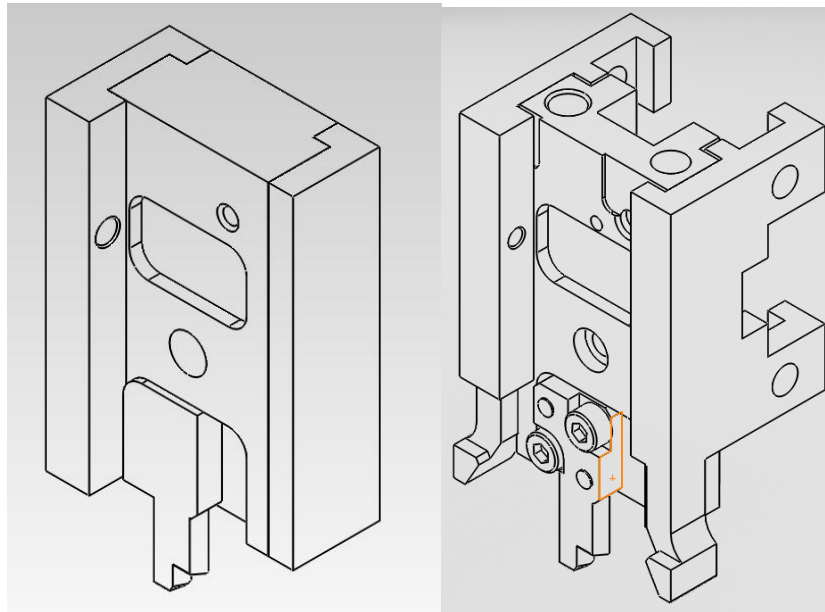


Figure 25: The rapid prototyped gripper block and actual gripper block
Pivoted gripping jaw

The gripper arm that is not stationary contains unique geometry of chamfers and curves similar to the other gripper arm. This ensures that the contact between both grippers is uniform and very similar to the existing geometry. The mobile gripper arm was selected to be rapid prototyped separately. This enabled us to maintain the geometry of the part, and no additional changes were made between the designed gripper arm and the prototype gripper arm.

Links

The links in the design contain very small geometry. In order to use the same diameter pins, the diameters of the holes in the links were made to be the same at 4mm diameter. This allowed the team to use the same diameter pins for all links and components in the gripper. We utilized a laser cutter to achieve the correct thickness and geometry of the links. Acrylic was used as the material for the links. Even though acrylic is not a strong material when it is thin, it is a cheaper and easy-to-manufacture alternative to other materials.

Pins

The pins used to connect the links together and to the base part were manufactured in two separate ways. Pin numbers 1 and 2 were made from cutting a 4mm diameter 12L14 carbon steel metric rod into lengths of 9 mm segments. This allowed for pin 1 to be connected to the gripper arm and pin 2 to connect both links. The other pin, pin 3 (refer to Figure 13), used a standard shoulder screw to connect the thicker link to the base part. This shoulder screw was an 18-8 metric stainless steel precision socket screw hex, 4mm shoulder diameter, 10mm shoulder length and M3 thread. The 10mm length allowed the screw to go into the base part, which was to be tapped to the M3 thread of the shoulder screw.

Pivot Shoulder Screw

The shoulder screw that is in the original design was not changed drastically for the prototype. Because the same dimensions were necessary to rotate the gripper link, the overall dimensions were unchanged. To allow the screw to be fully attached to the base, the length of the screw was increased. An alloy steel shoulder screw with a 6mm shoulder diameter, 20mm shoulder length and M5 thread was used. The 20mm

shoulder length allowed the screw to go through the base part on the prototype, which could then be bolted in the back.

Spring and Pneumatic Cylinder

From the final design, a spring and a pneumatic cylinder were specified. Because the spring that was in the final design would not be able to be delivered from the company for six weeks, a similar spring was purchased from a different company that would provide the same motion and force on the pivoting gripper arm. The pneumatic cylinder is the same as in the final design.

Acorn Nut

In order for the cylinder to contact the links, it was necessary to have an attachment at its end. For the final design, a standard acorn nut was used, which is the same as the prototype. This part is an 18-8 stainless steel acorn nut with an M4 thread, 0.7mm pitch, 7mm width and 8mm height.

Base for Mounting Prototype

Instead of using the entire tooling transfer machine to mount the prototype, an acrylic unit was created for demonstration purposes. This unit contained two levels: one to hold the cylinder and one to hold the rest of the gripper. In order to mount the cylinder, one of the sheets of acrylic was created with a tapped hole for the cylinder. This kept the cylinder in an upright position. Below this sheet of acrylic, the gripper linkage was placed in this area. There was a slot cut into the acrylic sheet below it to allow the gripper arms to go through it into the next volume of space. This bottom space is where the gripper arms would contact the cartridge. All sheets were separated using

a threaded pipe and CPVC tubes were placed around these threaded rods. The teams utilized bolts to fix the unit together and were applied directly to the threaded rod. A simple assembly screenshot of this base station is shown in Figure 26. A frontal image of the assembled prototype is shown in Figure 27.

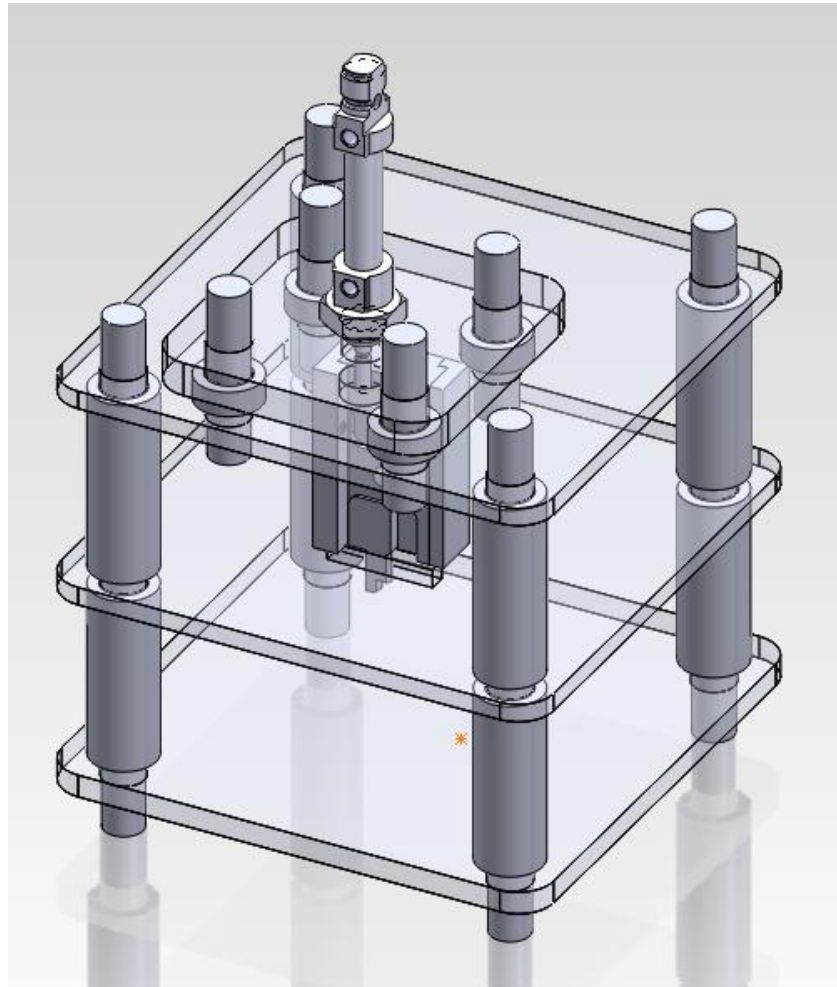


Figure 26: Isometric view of the base prototype testing assembly

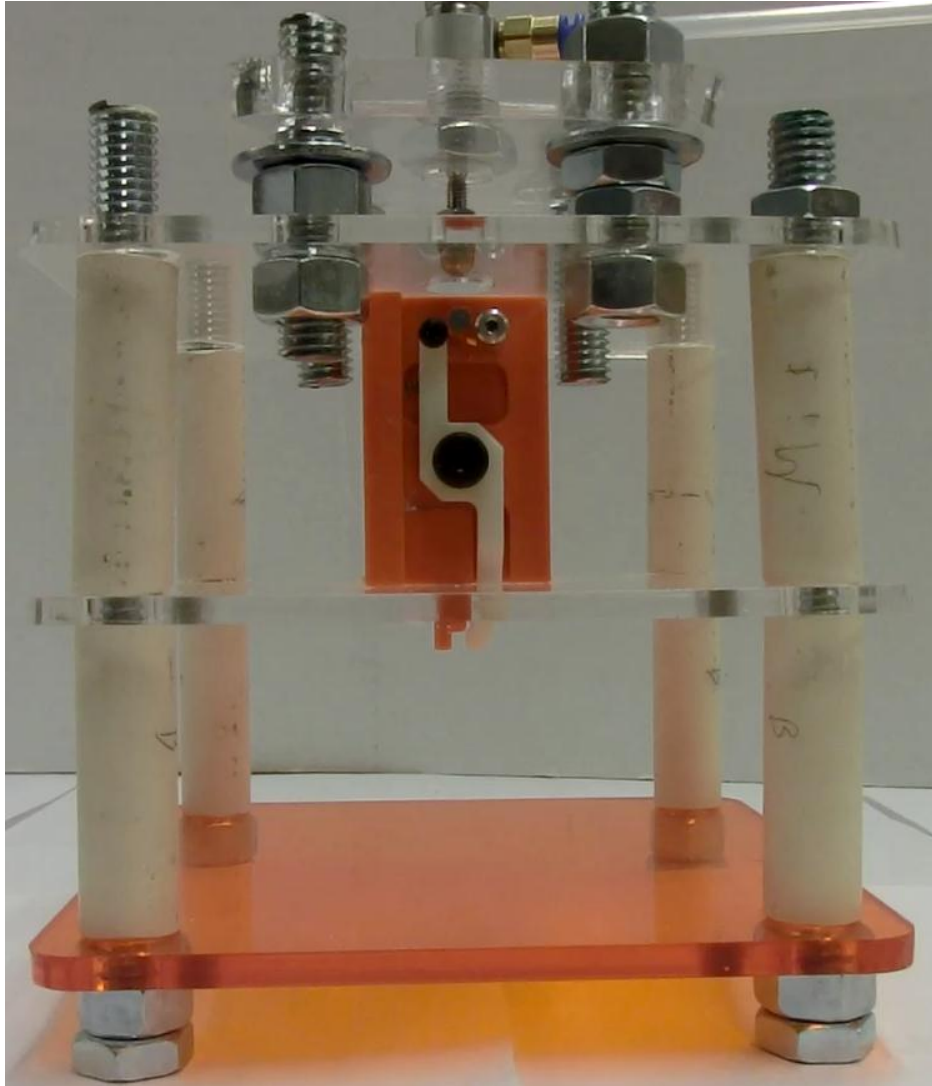


Figure 27: Frontal view of the assembled prototype station

Conclusion

The task specifications as defined by the team and the sponsor were all satisfied through modifying the original gripper. The new gripper design eliminates any deformations that were present on products. There are only eighteen grippers on the CTS, so by only modifying a few parts, many existing gripper components can stay the

same to keep manufacturing costs low. Only a few parts were modified on the machine. Because these parts were on the main machine, only one of each part needs to be manufactured. The ability to independently control the gripper motion with the pneumatic cylinder insures that production speeds of the machine can stay the same. Calculations, modeling, and testing of the prototype showed that the new gripper functions properly. By effectively eliminating the chance of causing deformations of the product during the transfer process, the new gripper design would be a valuable modification to the CTS mechanism.

.

Appendix A: Spring Specification Sheet

Associated Spring Raymond:

[High Performance](#)

| Order Item | Show CAD | Catalog Number | Outside Diameter [OD] (mm) | Wire Diameter [d] (mm) | Free Length [L] (mm) | Fits In Hole Size [H] (mm) | Fits Over Shaft [R] (mm) | Length [E] (mm) | Solid Height [Sh] (mm) | Load (P) at L [P] (N) | Spring Rate [R] (N/mm) | Coil Direction (L) |
|--------------|------------|----------------|----------------------------|------------------------|----------------------|----------------------------|--------------------------|-----------------|------------------------|-----------------------|------------------------|--------------------|
| Order | CAD | C00200003010 | 2.007 | 0.254 | 10.008 | 2.108 | 1.397 | 6.2 | 3.988 | 2.158 | 0.567 | LH |

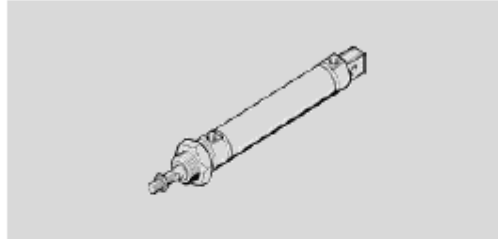
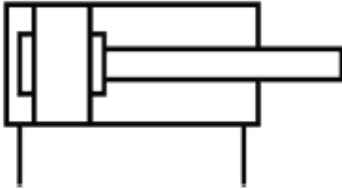
1

Appendix B: Festo Air Cylinder Specification Sheet

Data sheet: Standard cylinder DSN-10-10-P – #5040

FESTO

Function



| Feature | values |
|--|---|
| Stroke | 10 mm |
| Piston diameter | 10 mm |
| Piston rod thread | M4 |
| Cushioning | P: Flexible cushioning rings/plates at both ends |
| Assembly position | Any |
| Conforms to standard | CETOP RP 52 P ISO 6432 |
| Piston-rod end | Male thread |
| Design structure | Piston Piston rod Cylinder barrel |
| Position detection | No |
| Variants | Single-ended piston rod |
| Working pressure | 1.5 ... 10 bar |
| Mode of operation | double-acting |
| Operating medium | Compressed air in accordance with ISO8573-1:2010 [7:4:4] |
| Note on operating and pilot medium | Lubricated operation possible (subsequently required for further operation) |
| Corrosion resistance classification CRC | 2 |
| Ambient temperature | -20 ... 80 °C |
| Impact energy in end positions | 0.05 J |
| Theoretical force at 6 bar, return stroke | 39.6 N |
| Theoretical force at 6 bar, advance stroke | 47.1 N |
| Moving mass with 0 mm stroke | 8.5 g |
| Additional weight per 10 mm stroke | 2.7 g |
| Basic weight for 0 mm stroke | 37.3 g |
| Additional mass factor per 10 mm of stroke | 1 g |
| Mounting type | with accessories |
| Pneumatic connection | M5 |
| Materials note | Conforms to RoHS |
| Materials information for cover | Wrought Aluminum alloy neutral anodization |
| Materials information for seals | NBR TPE-U(PU) |
| Materials information for piston rod | High alloy steel, non-corrosive |
| Materials information for cylinder barrel | High alloy steel, non-corrosive |

Appendix C: Calculations for Tear-out Strength

Tearout for thinner link, pin 2

$$\underline{\text{kip}} := 10^3 \cdot \text{lbf} \quad \underline{\text{ksi}} := 10^3 \cdot \text{psi}$$

$$t_1 := 2.54 \text{ mm}$$

thickness of link

$$d := 2.5 \text{ mm}$$

diameter of pin

$$A_{\text{tear1}}(R) := t_1 \cdot \sqrt{R^2 - (0.5 \cdot d)^2}$$

alternating and mean components of forces on link and pin

$$P_{\text{max}} := 47 \text{ N}$$

$$P_{\text{min}} := 0 \text{ N}$$

$$P_a := \frac{P_{\text{max}} - P_{\text{min}}}{2}$$

$$P_a = 5.283 \times 10^{-3} \cdot \text{kip}$$

$$P_m := \frac{P_{\text{max}} + P_{\text{min}}}{2}$$

$$P_m = 5.283 \times 10^{-3} \cdot \text{kip}$$

The pin is in double shear and there is no stress-concentration. The alternating and mean loads at one section on the pin are

$$\tau_a = \frac{1}{2} \cdot \frac{P_a}{A_{\text{pin}}}$$

$$\tau_m = \frac{1}{2} \cdot \frac{P_m}{A_{\text{pin}}}$$

The cross-section area of the pin is

$$A_{\text{pin}}(d) := \frac{\pi \cdot d^2}{4}$$

The alternating and mean shear stresses and von Mises stresses are

$$\tau_a(d) := \frac{P_a}{2 \cdot A_{\text{pin}}(d)}$$

$$\tau_m(d) := \frac{P_m}{2 \cdot A_{\text{pin}}(d)}$$

$$\sigma'_a(d) := \sqrt{3} \cdot \tau_a(d)$$

$$\sigma'_m(d) := \sqrt{3} \cdot \tau_m(d)$$

$$\underline{\tau_a}(R) := \frac{P_a}{4 \cdot A_{\text{tear1}}(R)}$$

$$\underline{\tau_m}(R) := \frac{P_m}{4 \cdot A_{\text{tear1}}(R)}$$

$$\underline{\sigma'_a}(R) := \sqrt{3} \cdot \tau_a(R)$$

$$\underline{\sigma'_m}(R) := \sqrt{3} \cdot \tau_m(R)$$

ultimate strength of pin using A-8 tool steel

$$S_{\text{utc}} := 103 \text{ ksi}$$

unmodified endurance limit of pin

$$S'_{\text{ec}} := 0.5 \cdot S_{\text{utc}} = 51.5 \cdot \text{ksi}$$

endurance limit modification factor for nonrotating rectangular shear area (uniformly stressed)

Load $C_{\text{load}} := 0.7$

Size $A_{95}(\text{R}) := A_{\text{tear1}}(\text{R})$

$$d_{\text{equiv}}(\text{R}) := \sqrt{\frac{A_{95}(\text{R})}{0.0766}}$$

$$C_{\text{size}}(\text{R}) := 0.869 \cdot \left(\frac{d_{\text{equiv}}(\text{R})}{\text{in}} \right)^{-0.097}$$

Surface $A := 2.70$ $b := -0.265$

$$C_{\text{surf}} := A \cdot \left(\frac{S_{\text{utc}}}{\text{ksi}} \right)^b$$

Temperature $C_{\text{temp}} := 1$

Reliability $C_{\text{reliab}} := 0.753$ 99.9% reliability

modified endurance limit

$$S_{\text{ec}}(\text{R}) := C_{\text{load}} \cdot C_{\text{size}}(\text{R}) \cdot C_{\text{surf}} \cdot C_{\text{temp}} \cdot C_{\text{reliab}} \cdot S'_{\text{ec}}$$

modified goodman failure with case 3, safety factor

$N_f := 2.385$ from diameter calcs

$$N_f = \frac{S_e \cdot S_{\text{ut}}}{\sigma'_a \cdot S_{\text{ut}} + \sigma'_m \cdot S_e}$$

guess

$$R := 2.5\text{mm}$$

Given

$$N_f = \frac{S_{ec}(R) \cdot S_{utc}}{\sigma'_a(R) \cdot S_{utc} + \sigma'_m(R) \cdot S_{ec}(R)}$$

$$\text{Find}(R) = 1.252\text{-mm}$$

Tearout for thinner link, pin 1

$$t_1 := 2.54\text{mm}$$

thickness of link

$$d := 2.5\text{mm}$$

diameter of pin

$$A_{tear1}(R) := t_1 \cdot \sqrt{R^2 - (0.5 \cdot d)^2}$$

alternating and mean components of forces on link and pin

$$P_{max} := 25.415\text{N}$$

$$P_{min} := 0\text{N}$$

$$P_a := \frac{P_{max} - P_{min}}{2}$$

$$P_a = 2.857 \times 10^{-3} \cdot \text{kip}$$

$$P_m := \frac{P_{max} + P_{min}}{2}$$

$$P_m = 2.857 \times 10^{-3} \cdot \text{kip}$$

The pin is in double shear and there is no stress-concentration. The alternating and mean loads at one section on the pin are

$$\tau_a = \frac{1}{2} \cdot \frac{P_a}{A_{pin}}$$

$$\tau_m = \frac{1}{2} \cdot \frac{P_m}{A_{pin}}$$

The cross-section area of the pin is

$$A_{pin}(d) := \frac{\pi \cdot d^2}{4}$$

The alternating and mean shear stresses and von Mises stresses are

$$\tau_a(d) := \frac{P_a}{2 \cdot A_{\text{pin}}(d)} \quad \tau_m(d) := \frac{P_m}{2 \cdot A_{\text{pin}}(d)}$$

$$\sigma'_a(d) := \sqrt{3} \cdot \tau_a(d) \quad \sigma'_m(d) := \sqrt{3} \cdot \tau_m(d)$$

$$\tau_a(R) := \frac{P_a}{4 \cdot A_{\text{tear1}}(R)} \quad \tau_m(R) := \frac{P_m}{4 \cdot A_{\text{tear1}}(R)}$$

$$\sigma'_a(R) := \sqrt{3} \cdot \tau_a(R) \quad \sigma'_m(R) := \sqrt{3} \cdot \tau_m(R)$$

ultimate strength of pin using tool steel

$$S_{\text{utc}} := 103 \text{ ksi}$$

unmodified endurance limit of pin

$$S'_{\text{ec}} := 0.5 \cdot S_{\text{utc}} = 51.5 \text{ ksi}$$

endurance limit modification factor for nonrotating rectangular shear area (uniformly stressed)

Load $C_{\text{load}} := 0.7$

Size $A_{0.5}(R) := A_{\text{tear1}}(R)$

$$d_{\text{equiv}}(R) := \sqrt{\frac{A_{0.5}(R)}{0.0766}}$$

$$C_{\text{size}}(R) := 0.869 \cdot \left(\frac{d_{\text{equiv}}(R)}{\text{in}} \right)^{-0.097}$$

Surface $A := 2.70 \quad b := -0.265$

$$C_{\text{surf}} := A \cdot \left(\frac{S_{\text{utc}}}{\text{ksi}} \right)^b$$

Temperature $C_{\text{temp}} := 1$

Reliability $C_{\text{reliab}} := 0.753$ 99.9% reliability

modified endurance limit

$$S_{\text{ec}}(R) := C_{\text{load}} \cdot C_{\text{size}}(R) \cdot C_{\text{surf}} \cdot C_{\text{temp}} \cdot C_{\text{reliab}} \cdot S'_{\text{ec}}$$

modified goodman failure with case 3, safety factor

$$N_f = \frac{S_e \cdot S_{ut}}{\sigma'_a \cdot S_{ut} + \sigma'_m \cdot S_e} \quad N_e := 2.385 \text{ from diameter calcs}$$

guess

$$R := 2.5 \text{ mm}$$

Given

$$N_f = \frac{S_{ec}(R) \cdot S_{utc}}{\sigma'_a(R) \cdot S_{utc} + \sigma'_m(R) \cdot S_{ec}(R)}$$

$$\text{Find}(R) = 1.251 \text{ mm}$$

Tearout for thicker link, pin 3

$$t_1 := 5.50 \text{ mm} \quad \text{thickness of link}$$

$$d := 3.5 \text{ mm} \quad \text{diameter of pin}$$

$$A_{\text{tear}}(R) := t_1 \cdot \sqrt{R^2 - (0.5 \cdot d)^2}$$

alternating and mean components of forces on link and pin

$$P_{\text{max}} := 25.415 \text{ N}$$

$$P_{\text{min}} := 0 \text{ N}$$

$$P_a := \frac{P_{\text{max}} - P_{\text{min}}}{2} \quad P_a = 2.857 \times 10^{-3} \cdot \text{kip}$$

$$P_m := \frac{P_{\text{max}} + P_{\text{min}}}{2} \quad P_m = 2.857 \times 10^{-3} \cdot \text{kip}$$

The pin is in double shear and there is no stress-concentration. The alternating and mean loads at one section on the pin are

$$\tau_a = \frac{1}{2} \cdot \frac{P_a}{A_{pin}} \qquad \tau_m = \frac{1}{2} \cdot \frac{P_m}{A_{pin}}$$

The cross-section area of the pin is $A_{pin}(d) := \frac{\pi \cdot d^2}{4}$

The alternating and mean shear stresses and von Mises stresses are

$$\tau_a(d) := \frac{P_a}{2 \cdot A_{pin}(d)} \qquad \tau_m(d) := \frac{P_m}{2 \cdot A_{pin}(d)}$$

$$\sigma'_a(d) := \sqrt{3} \cdot \tau_a(d) \qquad \sigma'_m(d) := \sqrt{3} \cdot \tau_m(d)$$

$$\tau_a(R) := \frac{P_a}{4 \cdot A_{tear1}(R)} \qquad \tau_m(R) := \frac{P_m}{4 \cdot A_{tear1}(R)}$$

$$\sigma'_a(R) := \sqrt{3} \cdot \tau_a(R) \qquad \sigma'_m(R) := \sqrt{3} \cdot \tau_m(R)$$

ultimate strength of pin using tool steel

$$S_{ute} := 103 \text{ ksi}$$

unmodified endurance limit of pin

$$S'_{eq} := 0.5 \cdot S_{ute} = 51.5 \text{ ksi}$$

endurance limit modification factor for nonrotating rectangular shear area (uniformly stressed)

Load $C_{load} := 0.7$

Size $A_{95}(R) := A_{tear1}(R)$

$$C_{size}(R) := 0.869 \cdot \left(\frac{d_{equiv}(R)}{\text{in}} \right)^{-0.097} \qquad d_{equiv}(R) := \sqrt{\frac{A_{95}(R)}{0.0766}}$$

Surface $A := 2.70$ $b := -0.265$

$$C_{surf} := A \cdot \left(\frac{S_{ute}}{\text{ksi}} \right)^b$$

Temperature $C_{temp} := 1$

Reliability $C_{\text{reliab}} := 0.753$ 99.9% reliability

modified endurance limit

$$S_{ec}(R) := C_{\text{load}} \cdot C_{\text{size}}(R) \cdot C_{\text{surf}} \cdot C_{\text{temp}} \cdot C_{\text{reliab}} \cdot S'_e$$

modified goodman failure with case 3, safety factor

$$N_f = \frac{S_e \cdot S_{ut}}{\sigma'_a \cdot S_{ut} + \sigma'_m \cdot S_e} \quad N_f := 2.385 \text{ from diameter calcs}$$

guess

$$R := 2.5 \text{ mm}$$

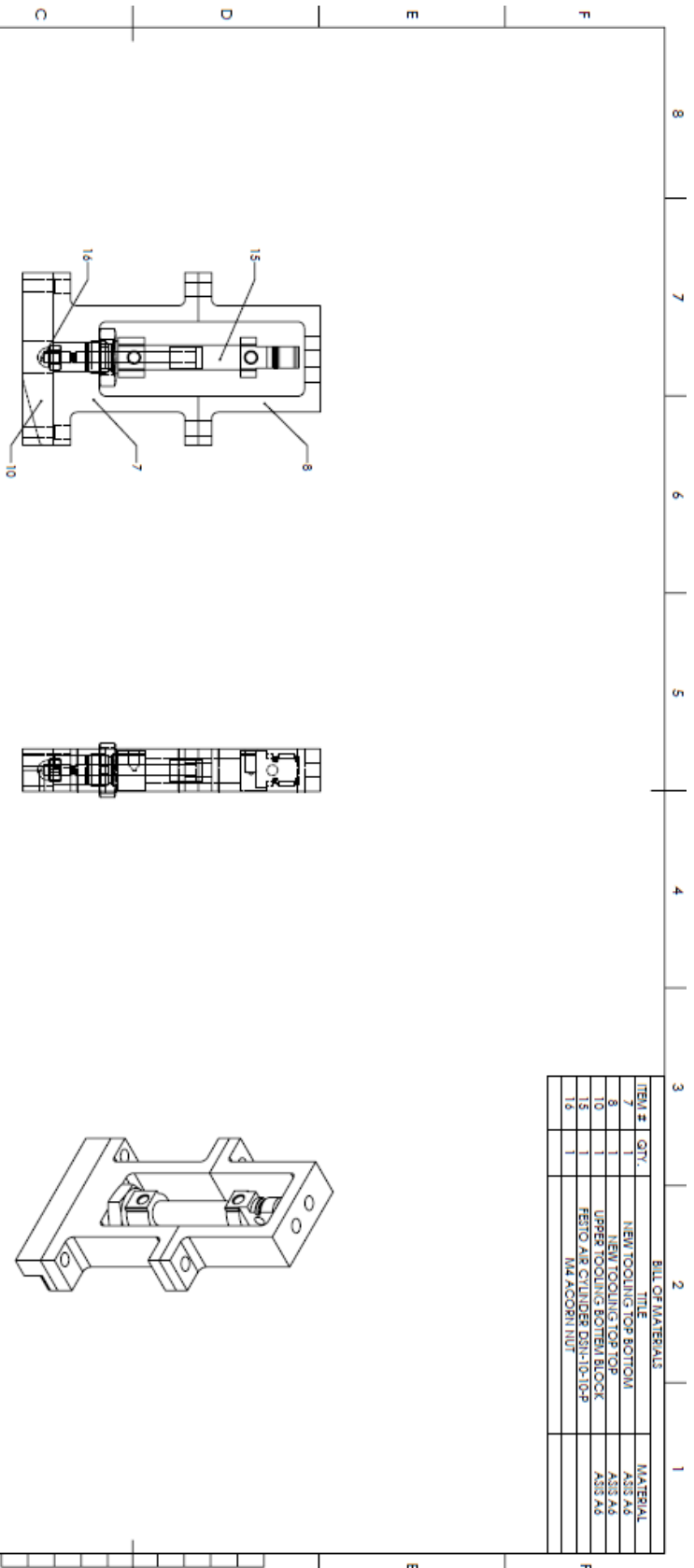
Given

$$N_f = \frac{S_{ec}(R) \cdot S_{utc}}{\sigma'_a(R) \cdot S_{utc} + \sigma'_m(R) \cdot S_{ec}(R)}$$

$$\text{Find}(R) = 1.75 \text{ mm}$$

Appendix D: Drawings for new parts

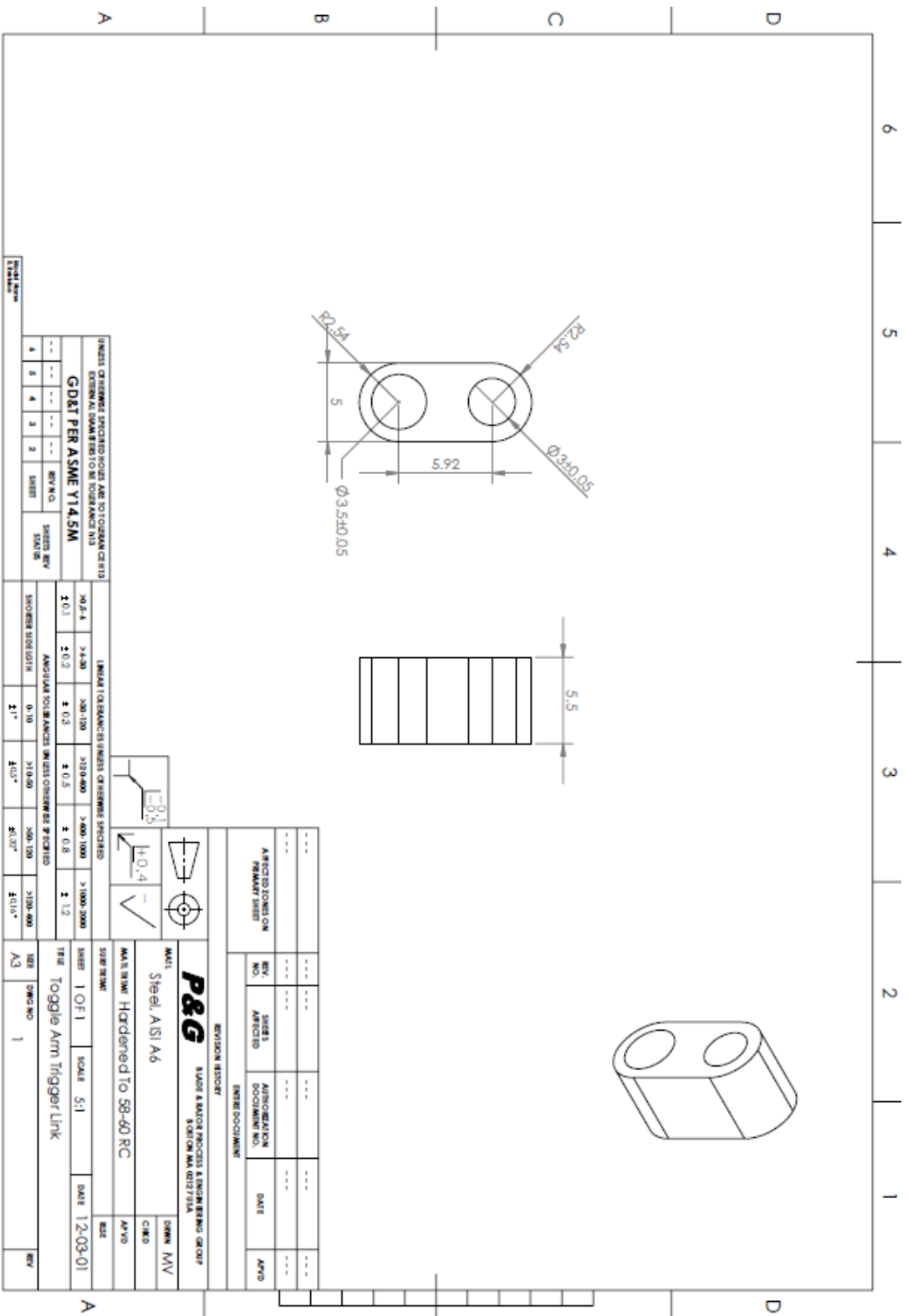
| BILL OF MATERIALS | | 1 |
|-------------------|------|---------------------------------|
| ITEM # | QTY. | MATERIAL |
| 7 | 1 | NEW TOOLING TOP BOTTOM |
| 8 | 1 | ASS. A6 |
| 10 | 1 | NEW TOOLING TOP TOP |
| 15 | 1 | UPPER TOOLING BOTTOM BLOCK |
| 15 | 1 | FESTO AIR CYLINDER DS1H-10-10-P |
| 16 | 1 | M4 ACORN NUT |



| REV | DATE | BY | CHKD | DESCRIPTION |
|-----|------|----|------|-------------------------------------|
| 1 | | | | INITIAL TOOLING BLOCKS (COMPONENTS) |
| 2 | | | | INITIAL TOOLING BLOCKS (COMPONENTS) |
| 3 | | | | INITIAL TOOLING BLOCKS (COMPONENTS) |
| 4 | | | | INITIAL TOOLING BLOCKS (COMPONENTS) |
| 5 | | | | INITIAL TOOLING BLOCKS (COMPONENTS) |
| 6 | | | | INITIAL TOOLING BLOCKS (COMPONENTS) |
| 7 | | | | INITIAL TOOLING BLOCKS (COMPONENTS) |
| 8 | | | | INITIAL TOOLING BLOCKS (COMPONENTS) |

NOTICE: This drawing is the property of P&G. It is to be used for the design and construction of the equipment described herein. It is not to be used for any other purpose without the written consent of P&G. The design is subject to change without notice.

DATE: 10/10/10
 DRAWN BY: [Name]
 CHECKED BY: [Name]
 APPROVED BY: [Name]



| REV. NO. | SHEET NO. | SHEET REV. | DESCRIPTION |
|----------|-----------|------------|-------------|
| 4 | 5 | 4 | |
| 3 | 4 | 3 | |
| 2 | 3 | 2 | |
| 1 | 2 | 1 | |

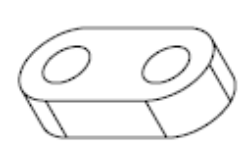
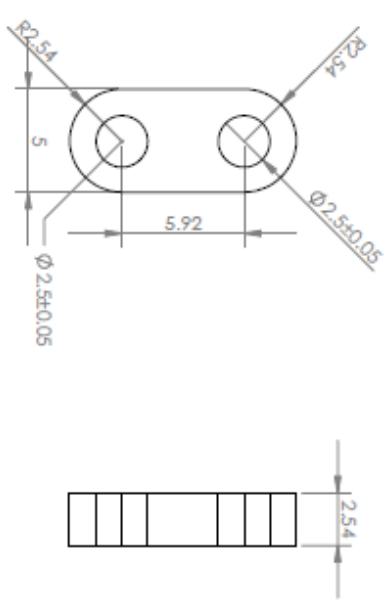
| LINEAR TOLERANCES UNLESS OTHERWISE SPECIFIED | ANGULAR TOLERANCES UNLESS OTHERWISE SPECIFIED |
|--|---|
| ±0.1 | ±1° |
| ±0.2 | ±1.5° |
| ±0.3 | ±2.0° |
| ±0.5 | ±3.0° |
| ±0.8 | ±4.5° |
| ±1.2 | ±7.0° |

| | | | |
|--|--|--|--|
| P&G MAJOR & MAJOR PROCESS ENGINEERING GROUP 3000 MA 00127 USA | | SHEET 1 OF 1 SCALE 5:1 DATE 12-03-01 | |
| TITLE Toggle Arm Trigger Link | | SIZE A3 | |
| MATERIAL Steel, AISI A6 Heat Treat Hardened To 58-60 RC | | DRAWN MV | |
| CHECKED AVD | | DATE | |

| REV. | DATE | BY | APP. | DESCRIPTION |
|------|------|-----|------|-------------|
| --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- |

NOTICE: This drawing and the information disclosed hereon, without prejudice, is the confidential property of the drafter. No part of this drawing, including the information disclosed hereon, shall be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or by any information storage and retrieval system, without the prior written permission of the drafter.

6 5 4 3 2 1



| APPROVED FOR CONSTRUCTION | | APPROVED FOR CONSTRUCTION | |
|---------------------------|---------------|---------------------------|---------------|
| REV. NO. | SHEET AFFICHS | REV. NO. | SHEET AFFICHS |
| --- | --- | --- | --- |
| --- | --- | --- | --- |
| --- | --- | --- | --- |

| | | | |
|---|------------------|------------------|----------------|
| | | | |
| REVISION HISTORY MAKE & MATCH PROCESS & ENGINEERING GROUP SCHEM MA 00127151A | | | |
| MAKE Steel, AISI A6 | DRAWN MV | DATE 12-03-01 | CHECKED AVB |
| MATERIAL Hardened To S8-60 RC | SCALE 1:1 | DATE 12-03-01 | CHECKED AVB |
| SIZE A3 | DRAWING NO. 2 | DATE 12-03-01 | CHECKED AVB |

| | | | |
|---|--|---|--|
| UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 | | UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 | |
| G.D&T PER ASME Y14.5M | | | |
| DIMENSIONS TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 | DIMENSIONS TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 | DIMENSIONS TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 | DIMENSIONS TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 |
| DIMENSIONS TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 | DIMENSIONS TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 | DIMENSIONS TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 | DIMENSIONS TO TOLERANCES INDICATED EXTERNAL DIMENSIONS TO NEAREST 0.015 |

NOTICE: This drawing and the subject matter disclosed therein, and the proprietary information which is the confidential property of the P&G Company, hereof, is hereby copied, reproduced, disclosed to others, published or used in whole or in part for any purpose, without the express permission of the P&G Company. This drawing is subject to modification by the P&G Company or any firm.

6 5 4 3 2 1



| APPROVED FOR CONSTRUCTION | | APPROVED FOR PRODUCTION | |
|---------------------------|------|-------------------------|------|
| REV. | DATE | REV. | DATE |
| --- | --- | --- | --- |
| --- | --- | --- | --- |

REVISION HISTORY

P&G SHOCK & VIBRATION PROCESS & ENGINEERING GROUP
SCOTTON, MA 02173 USA

MAKE: Steel, AISI A6

MATERIAL: Hardened to S8-60 RC

SIZE: 1 OF 1

SCALE: 1:5

DATE: 12-03-01

DESIGNER: MV

CHECKER: AVB

| FINISH TOLERANCES UNLESS OTHERWISE SPECIFIED | | FINISH TOLERANCES UNLESS OTHERWISE SPECIFIED | |
|--|-----------|--|-----------|
| SIZE | TOLERANCE | SIZE | TOLERANCE |
| 0.075 - 0.125 | ± 0.01 | 0.125 - 0.1875 | ± 0.015 |
| 0.125 - 0.1875 | ± 0.015 | 0.1875 - 0.25 | ± 0.02 |
| 0.1875 - 0.25 | ± 0.02 | 0.25 - 0.3125 | ± 0.025 |
| 0.25 - 0.3125 | ± 0.025 | 0.3125 - 0.375 | ± 0.03 |
| 0.3125 - 0.375 | ± 0.03 | 0.375 - 0.4375 | ± 0.035 |
| 0.375 - 0.4375 | ± 0.035 | 0.4375 - 0.5 | ± 0.04 |
| 0.4375 - 0.5 | ± 0.04 | 0.5 - 0.5625 | ± 0.045 |
| 0.5 - 0.5625 | ± 0.045 | 0.5625 - 0.625 | ± 0.05 |
| 0.5625 - 0.625 | ± 0.05 | 0.625 - 0.6875 | ± 0.055 |
| 0.625 - 0.6875 | ± 0.055 | 0.6875 - 0.75 | ± 0.06 |
| 0.6875 - 0.75 | ± 0.06 | 0.75 - 0.8125 | ± 0.065 |
| 0.75 - 0.8125 | ± 0.065 | 0.8125 - 0.875 | ± 0.07 |
| 0.8125 - 0.875 | ± 0.07 | 0.875 - 0.9375 | ± 0.075 |
| 0.875 - 0.9375 | ± 0.075 | 0.9375 - 1.0 | ± 0.08 |
| 0.9375 - 1.0 | ± 0.08 | | |

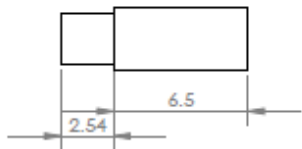
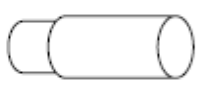
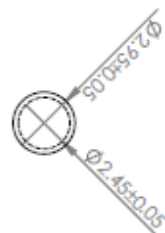
Sheet Name

NOTICE: The drawing and the subject matter disclosed therein, embody proprietary information which is the confidential property of the P&G Company. The drawing is subject to modification by the P&G Company or any firm.

A B C D

A

6 5 4 3 2 1



| APPROVED FOR CONSTRUCTION | | APPROVED FOR PRODUCTION | | DATE | |
|---------------------------|-------|-------------------------|-------|------|------|
| REV. NO. | SHEET | REV. NO. | SHEET | DATE | DATE |
| --- | --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- | --- |

REVISION HISTORY

P&G SHAFT & MOTOR PROCESS & ENGINEERING GROUP
SCOTTON, MA 02175 USA

MATERIAL: Steel, AISI A6
MATERIAL: Hardened to S8-60 RC

SIZE: A3
DWG NO: 4

SCALE: 1:1
DATE: 12-03-01

| UNITS TO DIMENSIONS UNLESS OTHERWISE SPECIFIED | | DIMENSIONS UNLESS OTHERWISE SPECIFIED | |
|--|-------------|---------------------------------------|-------------|
| INCHES | MILLIMETERS | INCHES | MILLIMETERS |
| ±0.004 | ±0.10 | ±0.001 | ±0.025 |
| ±0.001 | ±0.025 | ±0.0005 | ±0.0125 |
| ±0.0005 | ±0.0125 | ±0.0002 | ±0.005 |
| ±0.0002 | ±0.005 | ±0.0001 | ±0.0025 |
| ±0.0001 | ±0.0025 | ±0.00005 | ±0.00125 |

NOTICE: The drawing and the subject matter disclosed herein, in whole or in part, are the confidential property of the Company. The drawing is subject to modification without notice. Reproduction, distribution, or use of this drawing in whole or in part for any purpose, without the express advance written permission of the Company, is strictly prohibited.

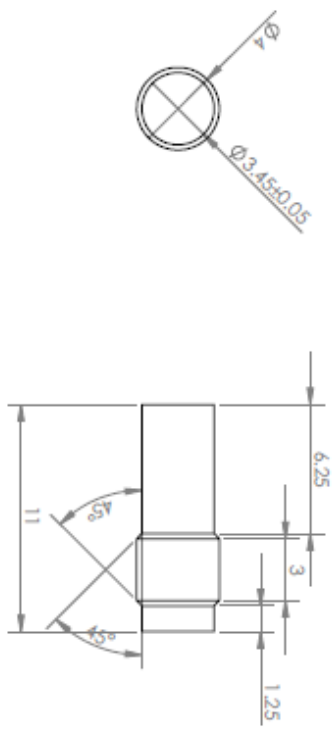
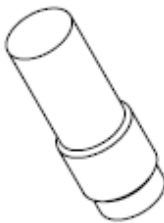
A A

B B

C C

D D

6 5 4 3 2 1



| AFFECTED WORK ON PREVIOUS SHEET | | AUTORIZATION DOCUMENT NO. | | DATE | |
|---------------------------------|-----|---------------------------|-----|------|-----|
| --- | --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- | --- |

| REVISION HISTORY | | DATE | |
|------------------|-----|------|-----|
| --- | --- | --- | --- |
| --- | --- | --- | --- |

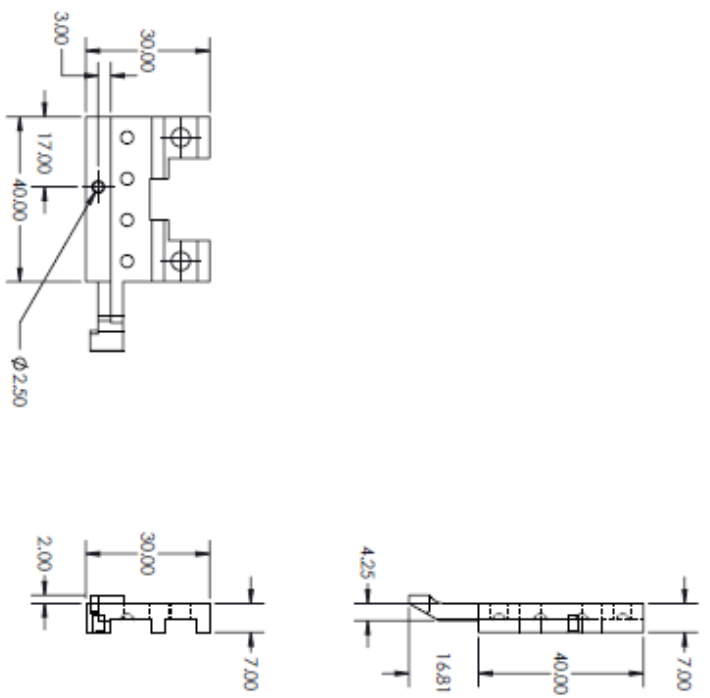
| | | | |
|----------|----------------|---------|----------------------|
| MATERIAL | Steel, AISI A6 | FINISH | Hardened To 58-60 RC |
| SCALE | 1:1 | DATE | 12-03-01 |
| SIZE | A3 | DWG NO. | 5 |
| REV | | | |

| UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE TO DIMENSIONS UNLESS OTHERWISE SPECIFIED | |
|---|------|
| 30.5 - 4 | ±0.1 |
| 76.2 - 30 | ±0.2 |
| 30.5 - 120 | ±0.3 |
| 76.2 - 400 | ±0.5 |
| 30.5 - 1000 | ±0.8 |
| > 1000 - 2000 | ±1.2 |

NOTICE: This drawing and the subject matter disclosed therein, and the proprietary information which is the confidential property of the P&G Company, hereof, which is hereby copied, reproduced, displayed to others, published, or used in whole or in part for any purpose, without the express permission written or printed on or a duly authorized agent of the Company. This drawing is subject to modification by the P&G Company at any time.

A B C D

6 5 4 3 2 1

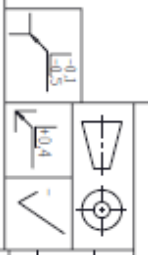


ALL OTHER DIMENSIONS SAME AS ORIGINAL PART

| UNLESS OTHERWISE SPECIFIED HOLES ARE TO TOLERANCE H13 | | LINEAR TOLERANCES UNLESS OTHERWISE SPECIFIED | |
|---|------------|---|-------|
| EXTERNAL DIMENSIONS TO BE TOLERANCED TO | | ANGULAR TOLERANCES UNLESS OTHERWISE SPECIFIED | |
| GD&T PER ASME Y14.5M | | SHEETER SIZE (LTH) | |
| REV NO. | SHEETS REV | 30-30 | 30-30 |
| 6 | 5 | 4 | 3 |
| 1 | 2 | 11° | 11° |
| 2 | 3 | 10.5° | 10.5° |
| 3 | 4 | 10.0° | 10.0° |
| 4 | 5 | 9.5° | 9.5° |
| 5 | 6 | 9.0° | 9.0° |

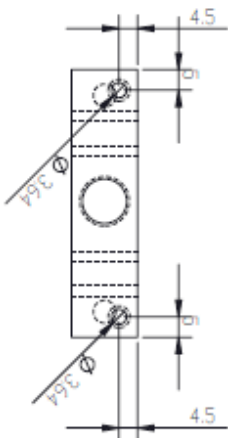
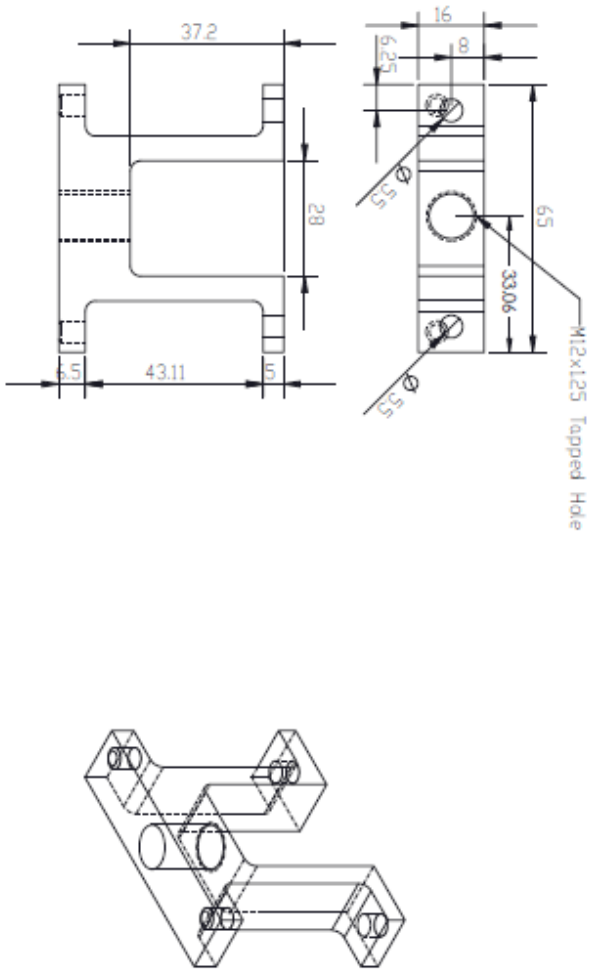
NOTE: This drawing and the subject matter disclosed therein embody proprietary information which is the confidential property of the P&G/QuVo. None of which shall be copied, reproduced, disclosed to others, published, or used, in whole or in part for any purpose, without the express advance written permission of the Company. This drawing is subject to recall by the P&G/QuVo at any time.

| AFFECTED DIMENSION | REV NO. | SHEETS AFFECTED | AUTOMATIC DIMENSION NO. | DATE | BY |
|--------------------|---------|-----------------|-------------------------|------|-----|
| --- | --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- | --- |



| REVISION HISTORY | | SHEET TITLE | |
|------------------------------------|--|-------------------|--|
| P&G | | Left Gripper Body | |
| MATERIAL: Steel, AISI A6 | | SCALE: 1:1 | |
| HARDNESS: Heat Treated To 58-60 RC | | DATE: 12-03-01 | |
| DRAWN BY: SRH | | CHECKED BY: APV3 | |
| DATE: 12-03-01 | | REV: 6 | |

6 5 4 3 2 1



| REV | DATE | DESCRIPTION |
|-----|------|-------------|
| --- | --- | --- |
| --- | --- | --- |
| --- | --- | --- |

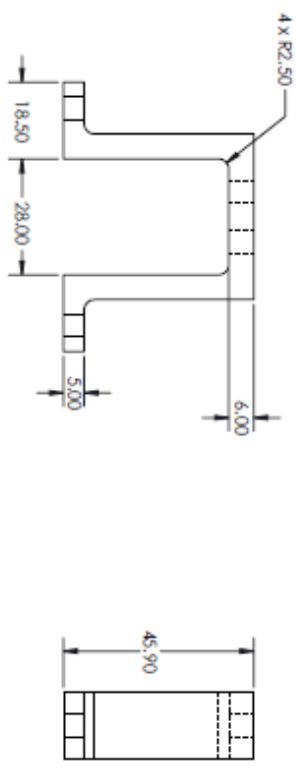
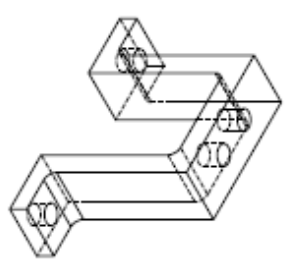
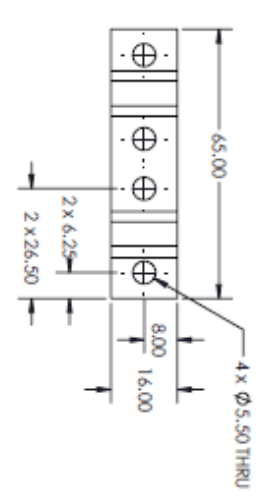
| REV | DATE | DESCRIPTION |
|-----|------|-------------|
| --- | --- | --- |
| --- | --- | --- |
| --- | --- | --- |

| | | | |
|-----------|----------------|--------|-----|
| MATERIAL | Steel, AISI A6 | FINISH | SRH |
| HARDENING | Oil | TEMP | --- |
| ANNEALING | --- | TEMP | --- |
| TEMP | --- | TEMP | --- |
| TEMP | --- | TEMP | --- |
| TEMP | --- | TEMP | --- |

| UNLESS OTHERWISE SPECIFIED HOLES ARE TO TOLERANCE H3 | | LINEAR TOLERANCES UNLESS OTHERWISE SPECIFIED | | SURF. FINISH | |
|--|-------------------|---|-------|--------------|-----------|
| EXCEPT DIMENSIONS TO HOLE DIMENSION | | 0.05-0.6 | ±0.08 | 0.08-0.08 | 0.08-0.08 |
| | | 0.6-3.0 | ±0.12 | 0.12-0.12 | 0.12-0.12 |
| | | 3.0-6.0 | ±0.15 | 0.15-0.15 | 0.15-0.15 |
| | | 6.0-30.0 | ±0.20 | 0.20-0.20 | 0.20-0.20 |
| | | >30.0 | ±0.25 | 0.25-0.25 | 0.25-0.25 |
| HOLE PER ASME Y14.5M | | ANGULAR TOLERANCES UNLESS OTHERWISE SPECIFIED | | SIZE | |
| REV NO. | SHEETS REV STATUS | 0-90 | ±0.5° | 3/16 IN | 7 |
| 6 | 5 | 4 | 3 | 2 | 1 |

NOTE: This drawing and the subject matter disclosed therein embody proprietary information which is the confidential property of the P&G/QuVo. None of which shall be copied, reproduced, disclosed to others, published, or used, in whole or in part, for any purpose, without the express advance written permission of the Company. This drawing is subject to recall by the P&G/QuVo at any time.

6 5 4 3 2 1

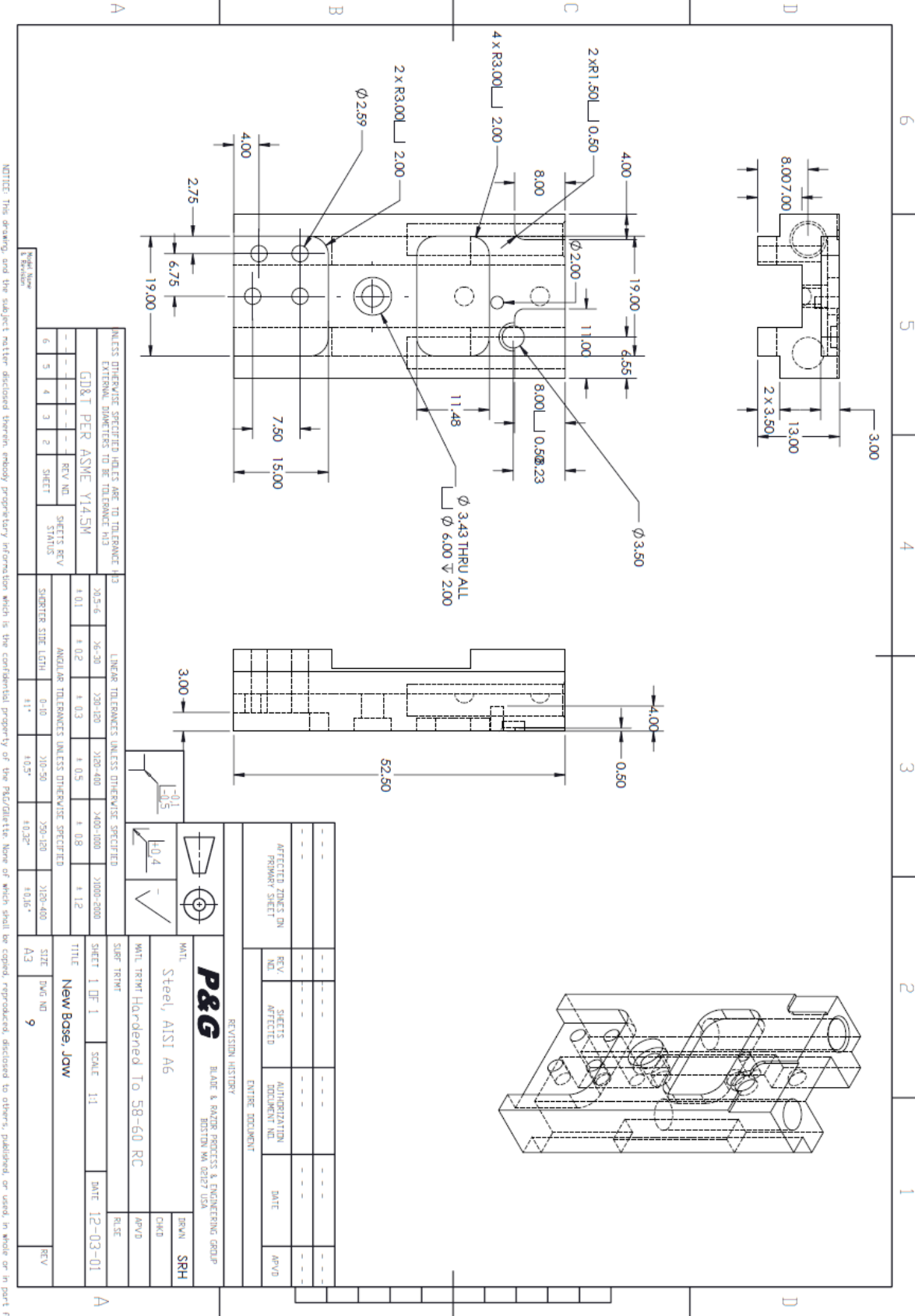


| REVISION HISTORY | | | |
|------------------|----------|----------------|------|
| REV | DATE | DESCRIPTION | BY |
| 1 | 12-03-01 | INITIAL DESIGN | APV3 |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |

| | | |
|--|--|---------------|
| P&G <small>MADE IN FRANCE PROCESS & ENGINEERING GROUP RENTON WA 98127 USA</small> | | 3POM SRH |
| MTL Steel, A51 A6 | | CMB APV3 |
| MAT. TREAT. Hardened To 58-60 RC | | RSE |
| SURF. TREAT. | | RSE |
| SHEET 1 OF 1 | | SCALE 1:1 |
| DATE 12-03-01 | | DATE 12-03-01 |

| UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE TO UNLESS OTHERWISE SPECIFIED | | LINEAR TOLERANCES, UNLESS OTHERWISE SPECIFIED | |
|--|-------|---|---------|
| 305-6 | 36-30 | 30-50 | 300-300 |
| 4.01 | 4.02 | 4.03 | 4.05 |
| ANGULAR TOLERANCES UNLESS OTHERWISE SPECIFIED | | 30-50 | 300-300 |
| 6 | 5 | 4 | 3 |
| 2 | 2 | 2 | 2 |
| SHEETS REV | | SHEETS STATUS | |
| 1 | | 1 | |
| 2 | | 2 | |
| 3 | | 3 | |
| 4 | | 4 | |
| 5 | | 5 | |
| 6 | | 6 | |

NOTE: This drawing and the subject matter disclosed therein embody proprietary information which is the confidential property of the P&G/PGI. None of which shall be copied, reproduced, disclosed to others, published or used, in whole or in part, without the express advance written permission of a duly authorized agent of the Company. This drawing is subject to recall by the P&G/PGI at any time.



NOTICE: This drawing, and the subject matter disclosed therein, embody proprietary information which is the confidential property of the P&G/Alltel. None of which shall be copied, reproduced, disclosed to others, published, or used, in whole or in part.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE TO TOLERANCE UNLESS OTHERWISE SPECIFIED

| SIZE | TOLERANCE |
|---------------|-----------|
| 0.125 - 0.250 | ± 0.01 |
| 0.250 - 0.375 | ± 0.02 |
| 0.375 - 0.625 | ± 0.03 |
| 0.625 - 1.250 | ± 0.05 |
| 1.250 - 2.000 | ± 0.08 |
| 2.000 - 3.000 | ± 0.12 |

CH8T PER ASME Y14.5M

| REV NO | DATE | BY | CHKD | APP'D |
|--------|------|----|------|-------|
| 6 | 3 | 4 | 3 | 2 |
| 5 | 4 | 3 | 2 | 1 |
| 4 | 3 | 2 | 1 | 0 |
| 3 | 2 | 1 | 0 | -1 |
| 2 | 1 | 0 | -1 | -2 |
| 1 | 0 | -1 | -2 | -3 |

LINEAR TOLERANCES UNLESS OTHERWISE SPECIFIED

| SIZE | TOLERANCE |
|---------------|-----------|
| 0.125 - 0.250 | ± 0.01 |
| 0.250 - 0.375 | ± 0.02 |
| 0.375 - 0.625 | ± 0.03 |
| 0.625 - 1.250 | ± 0.05 |
| 1.250 - 2.000 | ± 0.08 |
| 2.000 - 3.000 | ± 0.12 |

ANGULAR TOLERANCES UNLESS OTHERWISE SPECIFIED

| ANGLE | TOLERANCE |
|------------|-----------|
| 0 - 45° | ± 0.05° |
| 45 - 90° | ± 0.10° |
| 90 - 120° | ± 0.20° |
| 120 - 180° | ± 0.30° |

REVISION HISTORY

| NO. | DATE | DESCRIPTION |
|-----|----------|-------------|
| 1 | 12-03-01 | DATE |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |

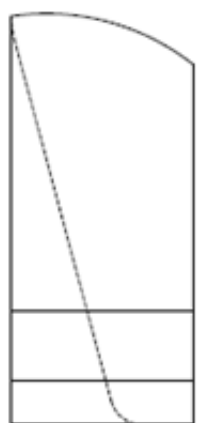
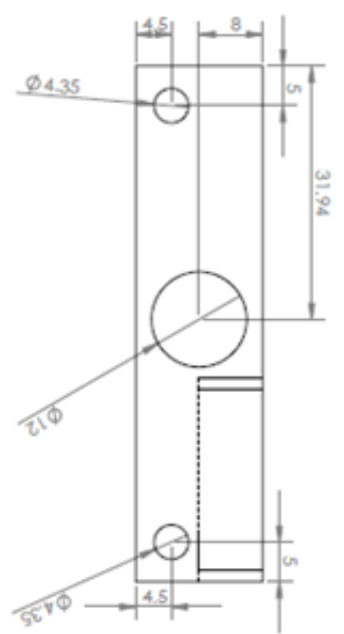
ENTIRE DOCUMENT

| | | | |
|-----------|-------------------------------|------|----------|
| MATERIAL | Steel, AISI A6 | DATE | |
| TREATMENT | MtL TRMT Hardened To 58-60 RC | DATE | |
| SCALE | 1:1 | DATE | 12-03-01 |
| SIZE | DWG NO 9 | DATE | |
| SIZE | A3 | DATE | |

P&G BLADE & RAZOR PROCESS & ENGINEERING GROUP
 BOSTON MA 02127 USA

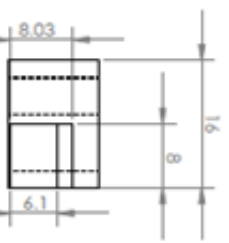
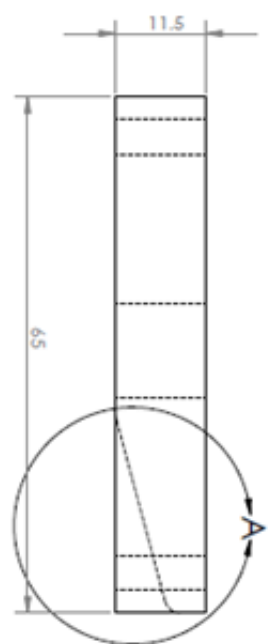
SRB SRH
 CHKD
 APP'D

6 5 4 3 2 1



DETAIL A
SCALE 4:1

GEOMETRY IS SAME AS PREVIOUS PART



| REV. | DESCRIPTION | DATE | APP. |
|------|-------------|------|------|
| ... | ... | ... | ... |
| ... | ... | ... | ... |
| ... | ... | ... | ... |
| ... | ... | ... | ... |

REVISION HISTORY

P&G MADE & BUILT PROCESS & ENGINEERING GROUP
NORTH MA 01875/MA

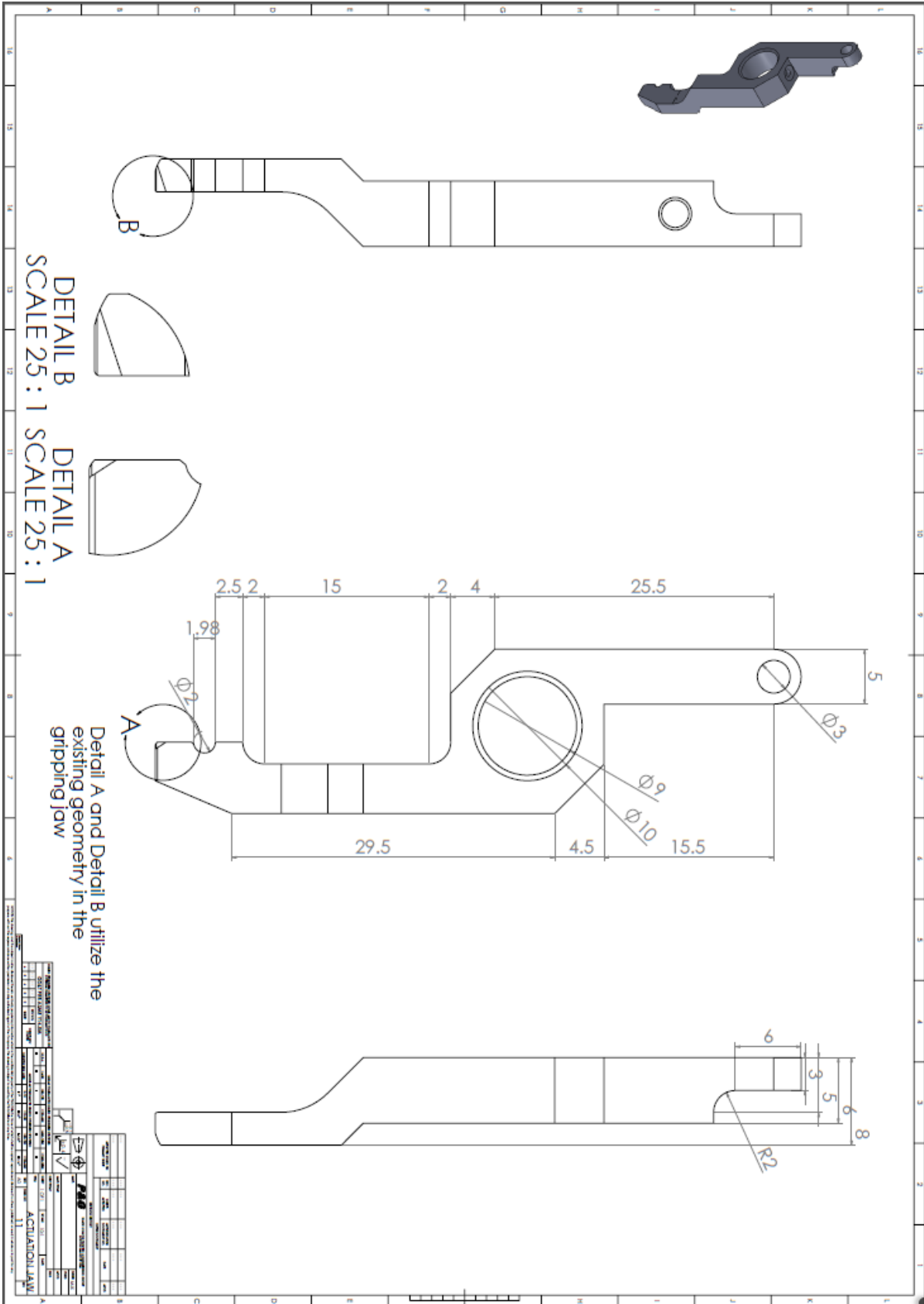
MATERIAL: Steel, AISI A6
MATERIAL: Hardened to S8-40 RC

DATE: 3-2-2012

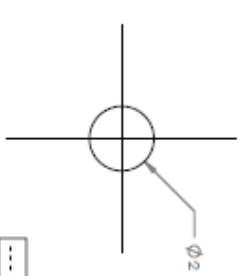
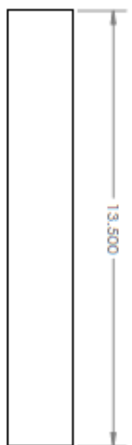
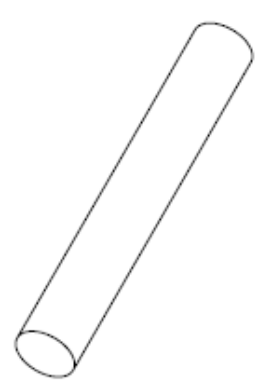
| NO. | DATE | BY | CHKD | APP. | DESCRIPTION |
|-----|----------|-----|------|------|-------------|
| 1 | 3-2-2012 | ... | ... | ... | ... |
| 2 | ... | ... | ... | ... | ... |
| 3 | ... | ... | ... | ... | ... |
| 4 | ... | ... | ... | ... | ... |

NOTE: The drawing of this abstract design is not intended to be construed as a contract. The drawing is subject to change without notice. The drawing is not to be used for manufacturing or construction purposes without the express written permission of the Company. This drawing is subject to review by the Engineering or Quality departments.

10



6 5 4 3 2 1



| REVISION HISTORY | | | |
|---------------------------------|----------|-----------------|------|
| AFFECTED ZONES ON PRIMARY SHEET | REV. NO. | SHEETS AFFECTED | DATE |
| ... | ... | ... | ... |
| ... | ... | ... | ... |
| ... | ... | ... | ... |

| ENGINE DOCUMENT | | | |
|-----------------|-------------|------|-------|
| REV. NO. | DESCRIPTION | DATE | APPD. |
| ... | ... | ... | ... |
| ... | ... | ... | ... |
| ... | ... | ... | ... |

| | | | |
|------------------------|----------------------|----------|----------|
| MATERIAL | Steel, AISI A6 | DRAWN BY | MV |
| MATERIAL TREATMENT | Hardened To S8-60 RC | CHECKED | AND |
| MATERIAL SPECIFICATION | SAE J423 | DATE | 12-04-21 |
| TITLE | Stopper Pin | SCALE | 8:1 |
| SHEET NO. | 1 OF 1 | DATE | 12-04-21 |
| SIZE | DWG NO 17 | REV | |

| UNLESS OTHERWISE SPECIFIED | | | |
|----------------------------|--------------------|--------------|------------|
| LINEAR DIMENSIONS | ANGULAR DIMENSIONS | FINISH | TOLERANCES |
| >0.4 - ± 0.1 | >0.2 - ± 0.2 | AS SPECIFIED | ± 0.1 |
| 0.4 - ± 0.2 | 0.2 - ± 0.3 | AS SPECIFIED | ± 0.2 |
| 0.2 - ± 0.3 | 0.3 - ± 0.5 | AS SPECIFIED | ± 0.3 |
| 0.1 - ± 0.4 | 0.5 - ± 0.8 | AS SPECIFIED | ± 0.4 |
| 0.05 - ± 0.5 | 0.8 - ± 1.2 | AS SPECIFIED | ± 0.5 |
| 0.02 - ± 0.6 | 1.2 - ± 1.5 | AS SPECIFIED | ± 0.6 |

| UNLESS OTHERWISE SPECIFIED | | | |
|----------------------------|------|-------------|-------|
| REV. NO. | DATE | DESCRIPTION | APPD. |
| 4 | 5 | 4 | 3 |
| 3 | 2 | 1 | |

NOTICE: This drawing and the subject matter disclosed herein, without proprietary information which is the confidential property of the P&G/Shell, or of which it may be copied, reproduced, disclosed to others, published, or used, in whole or in part for any purpose, without the express advance written permission of a duly authorized agent of the Company. This drawing is subject to modification without notice.