Robot Cell Infeed

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Jacob Mollman

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Thesis Advisor:

Dr. Janet Dong

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Problem Statement

At ADVICS there are machining lines that utilize a robot cell and an area for operators to work. For safety these areas are divided, and parts need to be passed from the operator area to the robot cell using a transfer station. The current transfer stations for the machine lines utilize casting datums on the raw bracket castings to locate onto the transfer sled that the operator places the parts onto to be sent into the cell. This way of locating is not ideal as the casting variation allows for the parts to not locate precisely, which prevents the robot picking up the parts from placing them precisely in the first machines. When this happens, the line is shut down and maintenance has to be called to enter the robot cell and re-place the parts and reset the robot alarm. This causes excessive downtime and costs operational availability.

I will design a new infeed that utilizes the machined datums for locating instead of the casting datums. This design may also include a new rotational component in order to ensure the correct orientation for the parts to be picked up by the robot. There will be new infeed structure and fixturing that will accommodate the changeover between two products on the machine line. The parts will be machined and any products for automation will be ordered to realize the new design. This new infeed will be assembled by myself and some technicians from ADVICS that are responsible for programing the PLC and Robots to work with the new design. After installation this new infeed will be tested to see if it accomplishes its task of allowing for more consistent and reliable loading of parts.

Research

Background of the Problem

ADVICS creates many original equipment braking components for the automotive industry including rear brake calipers in a dedicated building. This building has 2 separate factory lines for each brake caliper, a machining line that machines the caliper housing and bracket, and an assembly line that combines these machined components with other components such as the brake pads and electronic parking brake motor, to create a complete rear caliper. For the machining lines there is a hybrid of operator fed machines and robot fed machines. These areas have been split for safety with the robots being contained within a fenced in robot cell. The flow of parts begins and ends with the operator area with the first 2 machining operations being handled by the operators with the parts being transferred to the robot cell and finished parts from the robot cell being picked up by the operator to pack. “Part transfer can be a dull and tedious task and can also be injury-inducing part of the production process for human workers. By integrating robots into the parts transfer process, human workers are kept free of this hazardous environment.” (1). This transfer allows for parts to be safely picked up by the robot without a person entering a dangerous robot cell.

The input transfer is conducted using a sliding plate with fixtures that the operator places the parts onto. When the operator is finished loading the parts, they then activate a switch which then has the plate slide back into the robot cell where the robot arm then comes and picks up the parts to place within the first machine within the cell. The plate is controlled using a PLC system and a pneumatic cylinder is used to slide the plate from the operator into the cell. The robot is a pick and place 6 axis robot with grippers a set distance apart. “Pick and place automation speeds up the process of picking up parts or items and placing them in other locations. Automating this process helps to increase production rates. Pick and place robots handle repetitive tasks while freeing up human workers to focus on more complex work.” (2). Once the parts are taken by the robot, the plate slides back into the operator area.

For the input transfer stand it is critically important that the parts being transferred into the robot cell be the proper distance apart from each other otherwise the parts will not be picked up properly by the robot arm. “In simpler cells, accurate placement on the conveyor or in the pallet (and proper programming of the robot) is the key for the robot to find the workpiece.” (3) . When parts are not picked up properly by the robot, it will have trouble placing parts in the proper location within the first machine due to the machine requiring high locational control with the parts being placed on precision pins. If the parts are not placed properly the machine will create an alarm which shuts down the line until maintenance technicians can arrive and re-place the parts back properly in the machine. This problem occurs frequently, sometimes multiple times per hour and costs the company in operational availability for the machine lines. Production is not as efficient as it can be and the downtime can be over 10 minutes to find a maintenance technician and for the technician to get inside the robot cell using proper safety protocol.

Currently the fixturing on the transfer plate for the parts to locate on uses datums that are built within the castings themselves. These castings are unfortunately not held to high tolerances by the supplier and so this variation can cause the condition that prevents the robot from properly picking up the robot. “Many castings are eventually machined to create additional features or tighter tolerances that are beyond the capabilities of the casting process. To accomplish this machining, the castings must be located in a fixture. Surface errors on the casting will cause the position and orientation of the casting to be offset from the nominal” (4). This was confirmed by our QC lab which did a Coordinate Measuring Machine check on parts that were not properly placed. Also experiments on the line by Manufacturing Engineers to try and recreate the condition by loading different dimensioned parts showed that the current fixturing is not adequate for the tight precision of the robot within the cell. ADVICS also has a much tighter control on the machined features than the casting company does on the castings. Unfortunately, the casting datums currently used for location cannot be changed to be of tighter tolerance by the casting provider due to current business agreements.

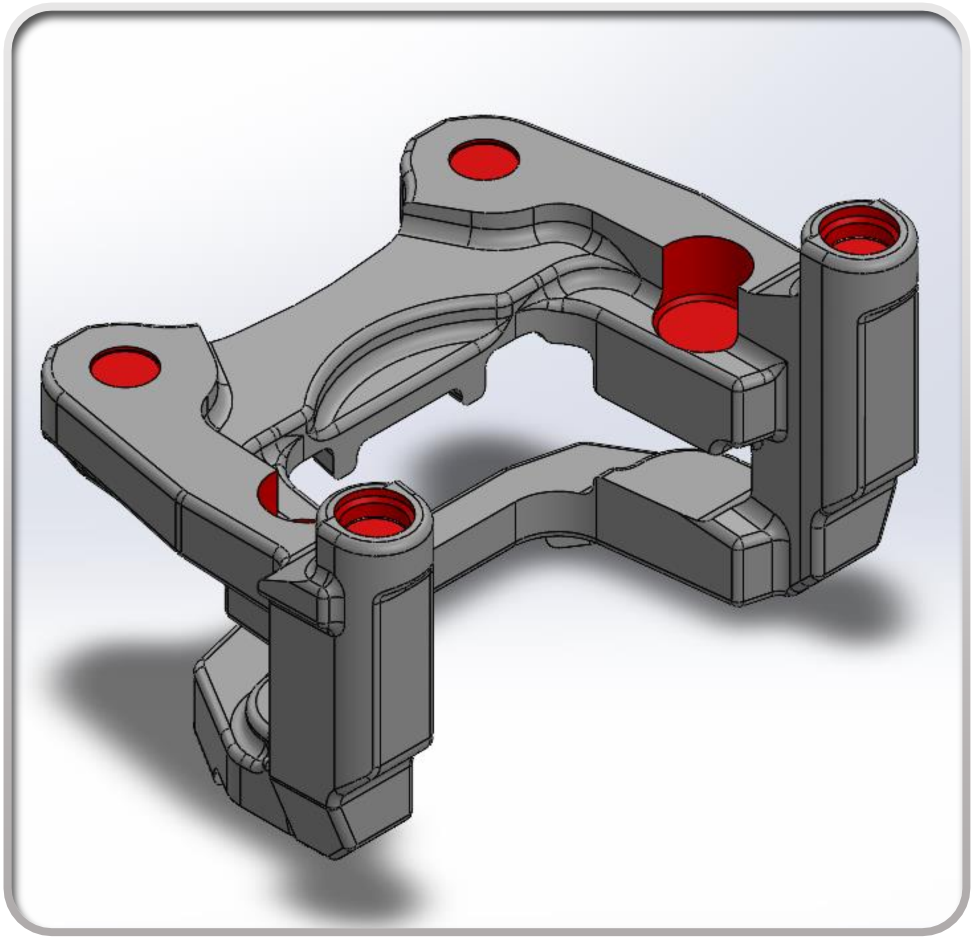

Figure 1 Datum Hole Locations In Red

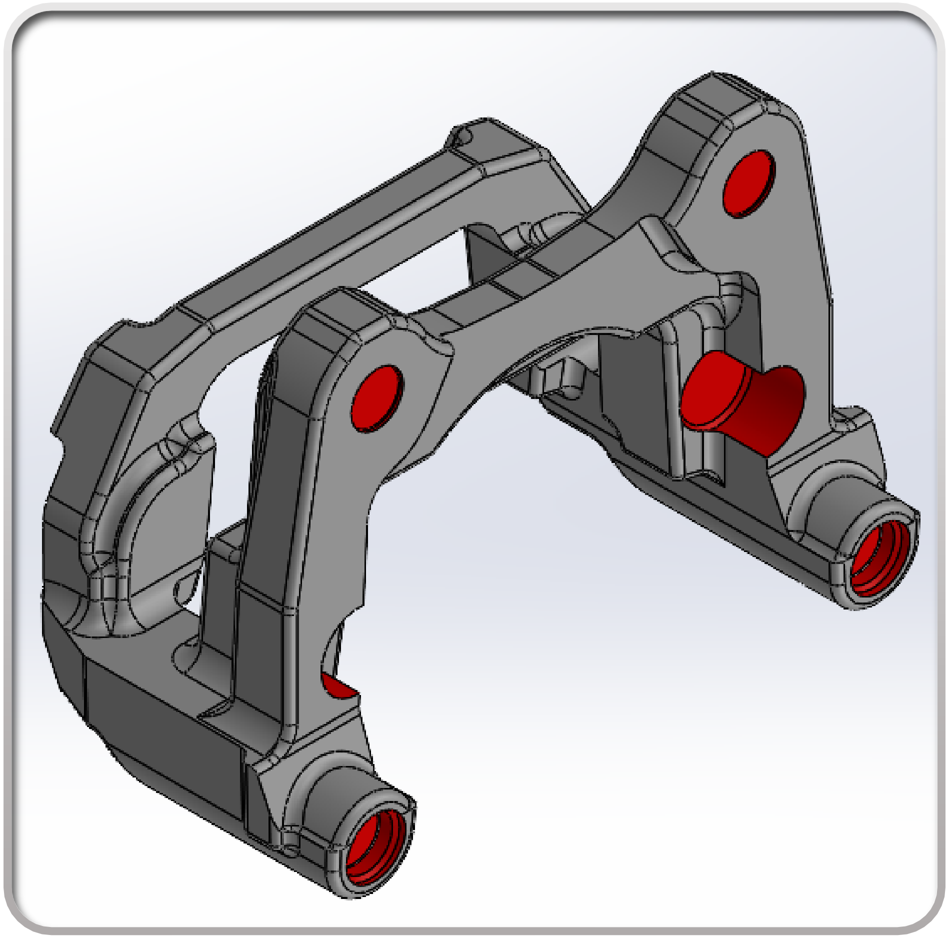

Figure 2 Casting Datum Fixturing Orientation

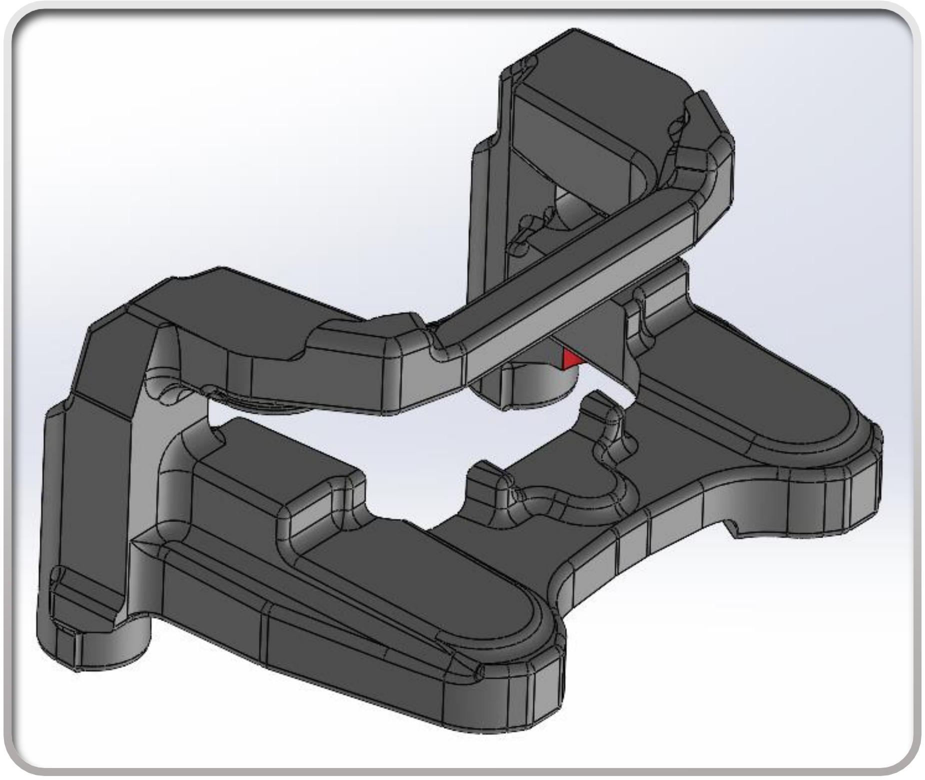

Figure 3 Orientation Using Machined Datums

Applicable Standards

- OSHA- There are United States applicable standards of safety which ADVICS have used for all their workers. (https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.212)
- ADVICS IGSS- ADVICS' own standard safety sheets that are applied to all machines and fixturing within the plant. This is an internal document, that cannot be viewed by people outside of ADVICS
- ADVICS Engineering Design Standards- A set of design standards implemented by ADVICS' manufacturing engineers over the years in order to ensure consistency in safety and functionality across the plant. This is a set of informal standards for engineering that are not on paper, but will be used when consulting with the ADVICS engineers.

State of the Art

The current state of the art at ADVICS is a robot cell transfer station located between the operator area and the robot cell. This transfer is a plate that is mounted underneath at either end by liner motion rails, and a single pneumatic cylinder mounted at the robot side of the transfer and connected in the middle of said plate. This cylinder is activated by a PLC system within the robot cell to move the plate towards the cell in a linear way until it reaches the open side of the transfer stand within the robot cell. The plate has a product specific plate that is mounted on top of the main plate using locating dowel pins and holes, and this plate is being held to the main mounting plate by 2 thumb screws. This system allows for the fixturing to be swapped for different products when the machining line changes between different products. The fixturing itself is simple and uses the casting datums provided by the raw casting of the parts to locate onto the transfer plate. This mounting style allows for the operators to ergonomically place parts onto the transfer stand for their own health, and to have a good cycle time. This concern for ergonomics is also shown in the height of the transfer plate relative to the decking, which is standardized by ADVICS' ergonomic standards. Once the operator has set the parts onto the transfer plate, the operator then hits a simple and standard switch next to the open side of the transfer, which then tells the robot cell PLC to move the parts into the cell. There are optical sensors on the stand which determine if both parts are placed onto the stand, and the PLC has logic which looks at whether there are any parts in the stand to transfer, and if so, activates the pneumatic cylinder to pull the parts into the cell. Once inside the cell the first robot closest to the stand will then pick up the part using specially designed end effectors, and then orient and place the parts within the first machine. Once the PLC has seen that the robot has picked up the parts, it activates the pneumatic cylinder again which pushes the plate back into its original position on the operator side of the transfer station.

This current solution has some strengths to its design. Its simple pneumatic actuation allows it to be easy to control by PLC and is adjustable. The fixturing plate that is held on top with thumb screws, located on the main plate by dowel pins and has handles on top allow for the quick and easy change over from one product to another by simply removing the thumb screws, pulling off the top plate and putting on the new plate and tightening down the thumb screws. Using the casting datums to locate the parts within the fixturing of the transfer, allows for the operator to simply place the parts onto the transfer stand, quickly and ergonomically. This fixturing is seen in Figure 7 Right Side Fixture Up Close. The simple programming for the PLC also ensures reliable movement of the stand from operator to robot and back again with the use of a simple black switch seen just to the left of the opening in Figure 4 Transfer Stand Operator Side. The current stand also meets ADVICS' and OSHA's safety standards and ADVICS' own standards on operator ergonomics of lifting parts.

There are some downsides to this design. The current design is creating a situation occasionally where the robot will be able to successfully pick up the parts from the stand but will fail to load the parts within the first machine. This suggests that the transfer station's method of using the casting datums of the part to locate on the fixturing as faulty, and therefore a more precise locating is needed to reduce robot failures. The optical sensors that work with the PLC to ensure that parts are on the transfer station are not precise enough to ensure that not only are there 2 parts on the stand, but that those parts are in precisely the right location for the robot to pick and place them. The robot is also unable to determine whether or not the parts that it has picked up are in the correct orientation and pitch in order to successfully place parts inside the first machine.

Due to the custom nature of this particular kind of part infeed system, there are no off the shelf solutions that can feed these particular parts into the robot cell. I could not find any off the shelf solution that works with the type of parts flow that ADVICS has or be able to work with the particular shape of the bracket part, that will be transferred. ADVICS' system of flow is one that needs to remain the same as the current system, so the new infeed will need to be custom made.

Figure 4 Transfer Stand Operator Side

Figure 5 Infeed Transfer Up Close

Figure 6 Raw Casting of a Bracket Part

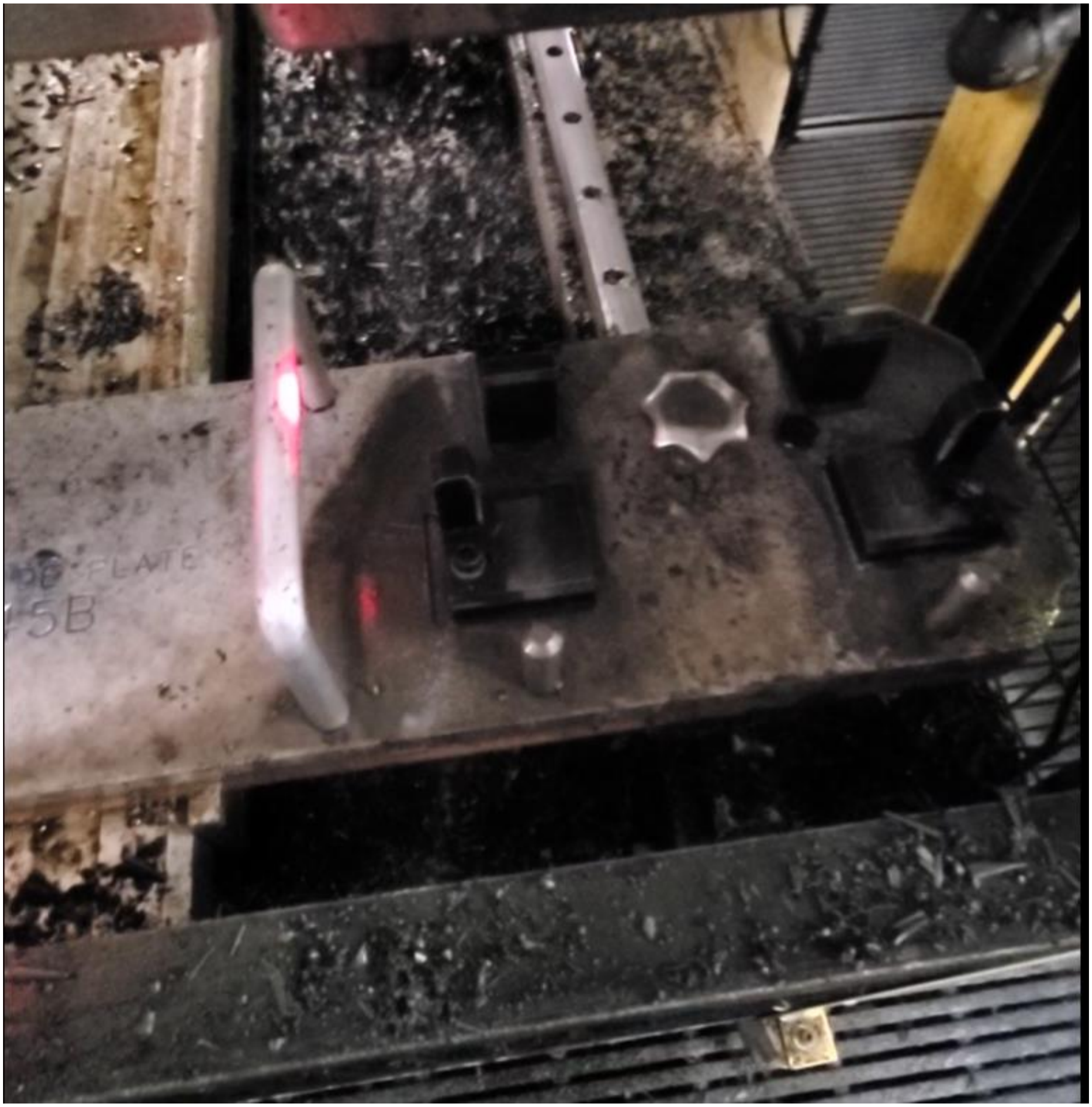

Figure 7 Right Side Fixture Up Close

Figure 8 Robot

End User

The end users of the transfer stand is specifically ADVICS and the operators that work on the line, the maintenance technicians who fix any problems with the line, the manufacturing engineers who oversee the line, and the robots that use the transfer stand to move parts within the robot cell. The operators generally are unskilled laborers, who pass parts from the first two machines onto the transfer stand and pick up and pack parts that the robot cell is finished with. Therefore, the technology that the operators encounter, needs to be simple to operate and use, and can be easy enough to repeat for hours on end. This includes ensuring that the ergonomics of placing parts onto the transfer stand are as good as the current system. The maintenance technicians are semi-skilled laborers who usually have technical knowledge that fix the machines and robots when they go down. It would be beneficial to them to make changing over the products easy to do and make the design easy to access all the critical components in case of repair. The manufacturing engineers are skilled laborers with degrees in engineering, who's main concern is the consistent and efficient running of the machine lines. They would like to see results when it comes to fixing any downtime due to maintenance, and reductions in cycle time to increase production efficiency. Finally, the robot that handles the parts within the cell is a simple pick and place robot which has no vision system and instead runs on a path set by the robot cell PLC. The robot therefore needs parts to be precise in order to load parts into the first machine in the correct orientation.

ADVICS would like me to produce a new designed part transfer that satisfies all the end users. This means that the part transfer should be simple to operate and maintain the standards of ergonomics that are already in place with the current solution. The new design should also be just as easy for maintenance to fix any issues with the transfer, as well as allowing for the change over of products to be just as smooth as the current plate system. The engineering group would like to see an improvement in the amount of pick and place failures by the robot, while maintaining or exceeding the current cycle time. To accomplish this the new transfer stand should make the pitch of the parts for the robot the same, while also increasing the precision of the parts location on the stand. ADVICS currently has no statistics that this new transfer should meet other than the above considerations.

Summary of Research

Transfer stands between operators and an automated robot cell need to be simple for operators to use, but precise enough for the robots to pick and place parts from the transfer into the first machine. The current solution implemented by ADVICS achieves the main part of this function but fails to allow a precise locating of parts for the robot. This new transfer stand must improve on the precision of locating by using the machined datums on the part done by the operator's machines. It must also be able to keep the same standards of safety by OSHA and IGSS, and maintain the ergonomic requirements met by ADVICS' operator standards. This new design should also be easy to change over to different products and fix. It should also be simple to operate and use by the operators, taking into account that this stand will be used constantly for hours on end. There should also be a marked improvement in robot pick and place reliability by decreasing downtime due to pick and place failures, and an increase in the efficiency of the line by maintaining or exceeding the cycle time of the transfer.

Quality Function Deployment

Customer Features

- **Worker Safety**
- **Reliability of Operation**
- **Ease of Change Over**
- **Operator Ergonomics**
- **Integration with Current System (Pneumatics, Electronics, etc…)**
- **Cost of Materials**
- **Ease of Installation/ Future maintenance**

Engineering Characteristics

- **Pneumatic Actuator Selection**
- **Material Selection**
- **Structure Shape**
- **Change Over Plate Design**
- **Type of Fasteners**
- **Use Of Existing Pneumatics and Controllers**

House of Quality

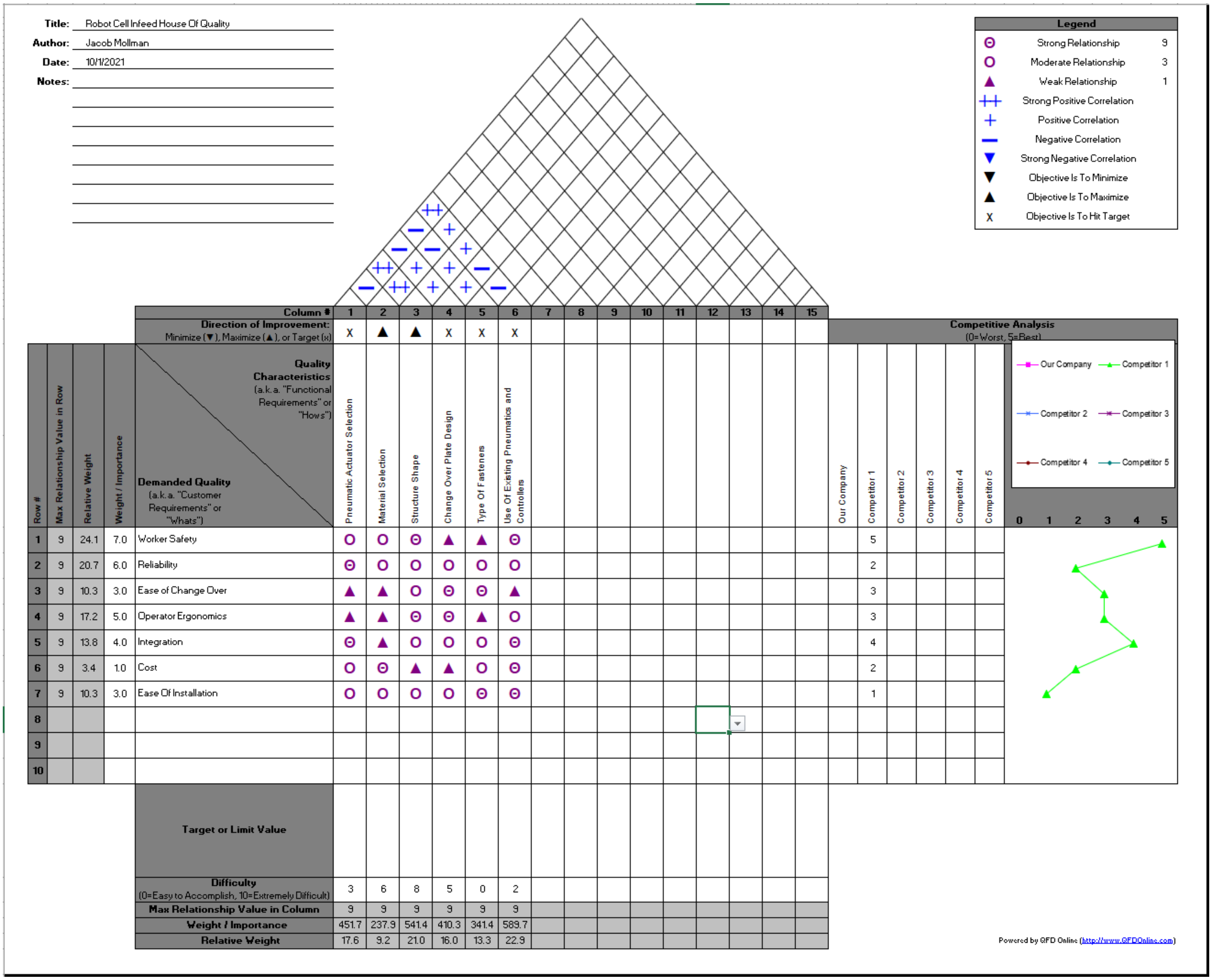

Figure 9 House Of Quality

Product Objectives

Use of Existing Pneumatics and Controllers (22.9%)

Using the existing pneumatic and control system, will be critical in my design. This can be achieved by integrating my design with the pneumatic actuating plate on the current system that pulls the part fixturing into the cell. My design must fit within the same area as the current infeed. I must also ensure that the pneumatic actuator that I use for the rotating mechanism works with the pneumatic system in place.

Structure Shape (21.0%)

The structural shape is the second most important part of the new infeed design. It will need to be designed safe, with all corners chamfered or rounded off. It will also continue to keep the same or better ergonomics for placing parts as the original system. Keeping the structure stiff will be important for ensuring that parts are put in the correct location for the robot to pick up the parts.

Pneumatic Actuator Selection (17.6%)

Selecting the pneumatic actuator for rotating the structure will be important for reliability as it is the main source of force being applied to the design. As such it will be important to select a pneumatic actuator that can be controlled using the existing system. The actuator should also provide enough force to rotate the infeed structure 180 degrees in the same amount of time it takes the existing system to move back into the robot cell such that the cycle time remains the same.

Change Over Plate Design (13.8%)

To make sure that the changeover of products on the line is easy to do for the maintenance team, and to make sure that operator ergonomics remain the same, the design of the changeover plates will be imperative. They will utilize a simple 4 dowel pin system, one for each of the datum holes, to locate the plates onto the main structure. Then they will use a simple thumb screw to tighten down the changeover plates onto the main structure to hold them in place.

Type Of Fasteners (10.3%)

The type of fasteners is useful for ease of installation and maintenance of the infeed. To make it simple, I will design the infeed to use standard M type bolts. The ADVICS' engineering standards call for M8 and higher type bolts for most fixturing on the floor to ensure safety and reliability of the machines.

Material Selection (9.2%)

For material selection, it will be imperative to make the infeed out of a material that is stiff enough to hold proper tolerances, and tough enough to endure being used in a production plant.

But due to the rotating caused by a pneumatic actuator, the material must also be light enough to rotate easily. Most of Advics' fixturing for machines is made from 4140 steel that is heat treated and finished in black. The Structure should be made from a steel similar to this but the weight and how much material is used will mainly be determined by the structure design. I will finalize what materials to use based on pneumatic actuator selection and structural shape.

Concepts Drawings

Concept 1:

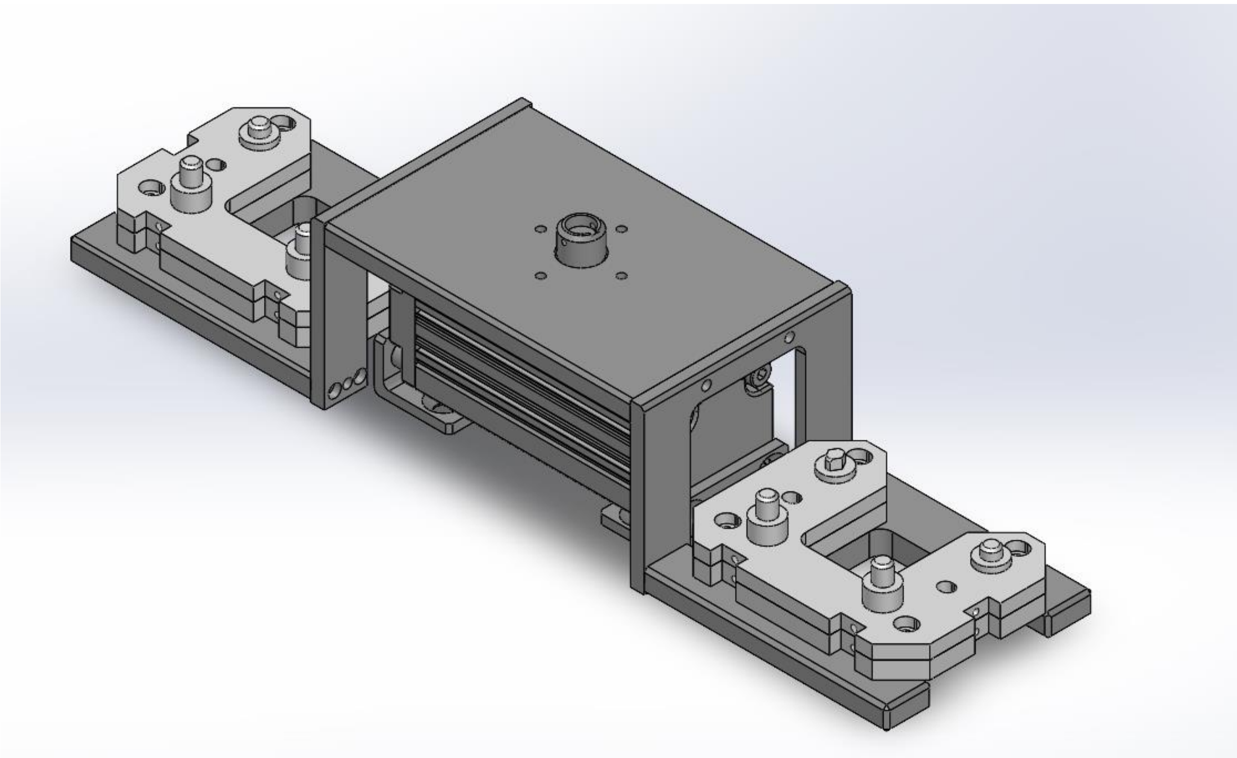

Figure 10 Concept 1

For the first concept, I kept built a structure around a pneumatic actuator such that the parts being placed on pins will retain a similar location vertically as the current design, with the distance between the two parts remaining constant as to make sure that the robot will be able to pick the parts up. The structure is made from simple machined plates bolted together using standard M type bolts, specifically M8 and M6 bolts, and also using some dowel pins to ensure proper location. To ensure safety the edges of all the corners have been chamfered off. For maintenance and ease of change over, I have designed the fixturing of the parts to be easy to remove using a simple two pin locating system with two thumb screws bolting in from the top for each side.

This design is good at utilizing the space available and keeping the ergonomics very similar to what is currently in place. The plate design should also be easy to create and assemble using standard bolts. Since this uses the existing pneumatic plate to move the infeed into the cell, it will also be simple to integrate in with the current systems in place. Safety should also be a simple thing to account for considering the rounded and chamfered corners, and simple integration with the existing PLC system.

The design does however suffer from having a more complex structure shape that may be difficult to keep from flexing under load. Since it is also a complicated shape made of multiple parts it needs to use many fasteners and dowel pins in order to ensure that the structure is sufficiently together and with all the parts in their precise locations. This also increases the amount of weight that the pneumatic actuator will need to rotate, making the rotation harder to control due to increased inertia. This design would be fairly costly due to the increased fastener count and machined parts.

Concept 2:

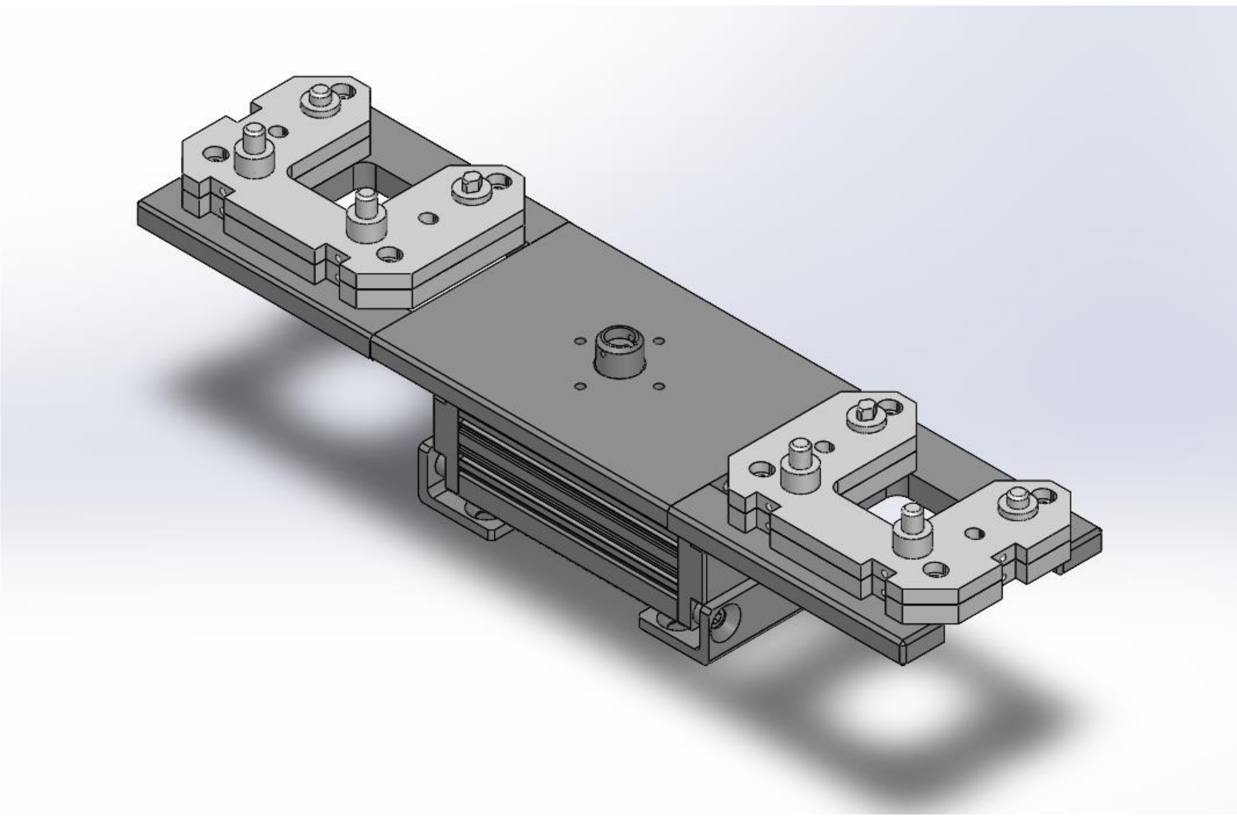

Figure 11 Concept 2

For concept 2, This utilizes a flat plate going straight across, similarly to the existing system. It will still utilize two separate change over plate fixturing as concept 1 so it will carry over the positives and negatives associated with that plate design. It will be made from one big solid plate, so there are no fasteners except for what is being used for the fixturing plates, and to attach the pneumatic actuator to the plate and the infeed linear actuation plate. This makes maintenance and installation much simpler as it is simply one piece. It also allows for more stiffness in the system since it only has one large plate instead of multiple pieces. The distance between the parts is the same, making integration with the robot system picking the parts off the infeed simple.

There are drawbacks to this design. The parts would have to be raised up higher than the current design making ergonomics more awkward for the operator. It also does not make a good use of the space available. In fact, the structuring above the infeed would need to be raised in order to accommodate this design. The entire infeed structure may also need to be lowered to keep the ergonomics the same as the current system. This would require much more time and effort to change the infeed in such a way and be very costly as this wouldn't use much of the existing infeed design and instead be a complete restructuring.

Concept 3:

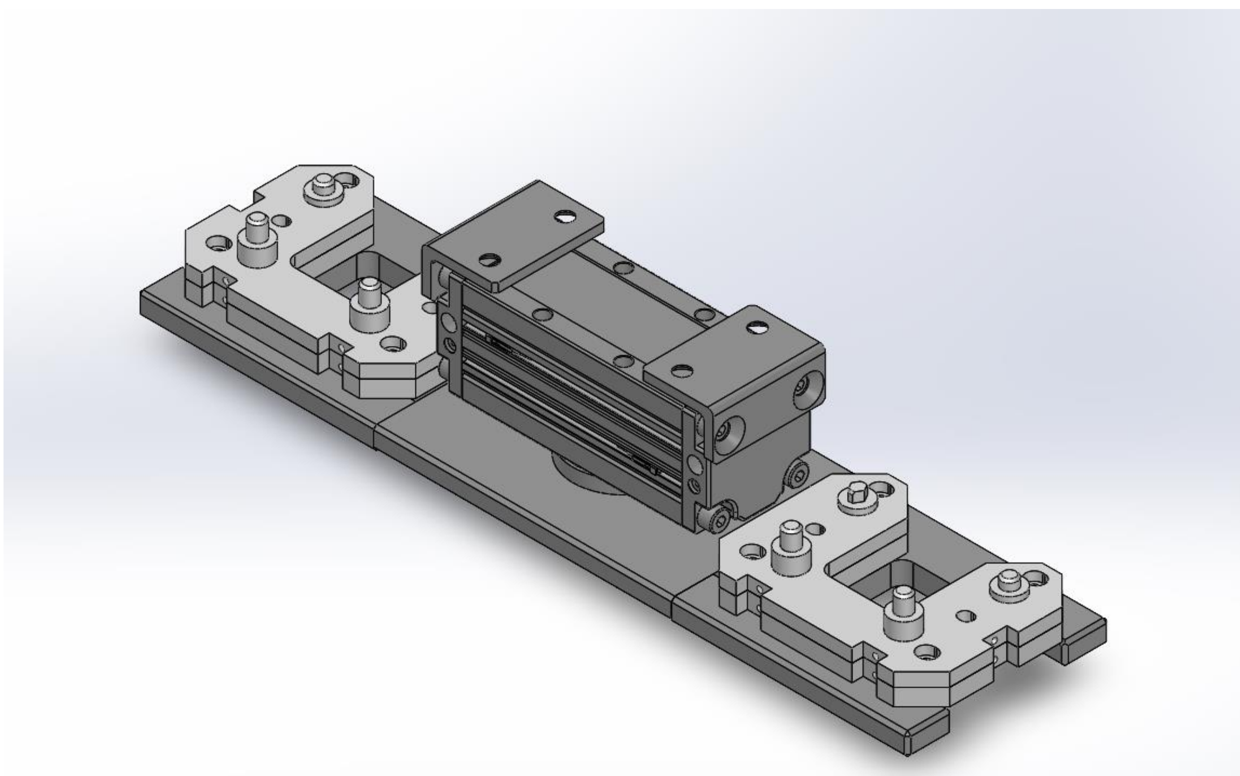

Figure 12 Concept 3

Concept 3 uses a similar flat solid plate to attach the change over plate/ part fixturing to. However, this design would utilize an upside-down pneumatic actuator that will be hanging from a new plate and track similar to the existing infeed design, but upside down. This would allow the parts to be placed at the same level as they are now, unlike concept 2. Since it would be a solid plate, it will also utilize concept 2's positive feature of using less fasteners and stiffer overall design. This design will also utilize the space given to it in a much more efficient way and it won't require an entire restructuring of the infeed like concept 2.

There are drawbacks to this design, however. This would require some restructuring of the robot cell infeed, mainly designing a new linear rail system positioned upside down relative to its current position. This will make the design more complex, and installation will be more complicated. Reliability may also be a challenge considering that making all that weight hang in the air instead of being supported may require more supports to be used and may make the structure not as stable as needed for our use case. This design could use much of the existing components for the infeed, just with a slightly modified structure to accommodate the upside down hanging components.

Overall, it uses the space available well, but it would require some restructuring of the infeed which would increase installation time. The hanging design may also not be as stiff as needed for the robot to pick up the parts and may create a wobble as the parts move into the robot cell.

Main Design Process

I chose concept 1 as the overall design I would use going forward. This is due to concept 1 being easier to install with the current structure in place with the current system, and it retains the ergonomics of the operator. I took this design and noticed that the weight of the structure was fairly heavy with a mass of the structure having over 16 Kg

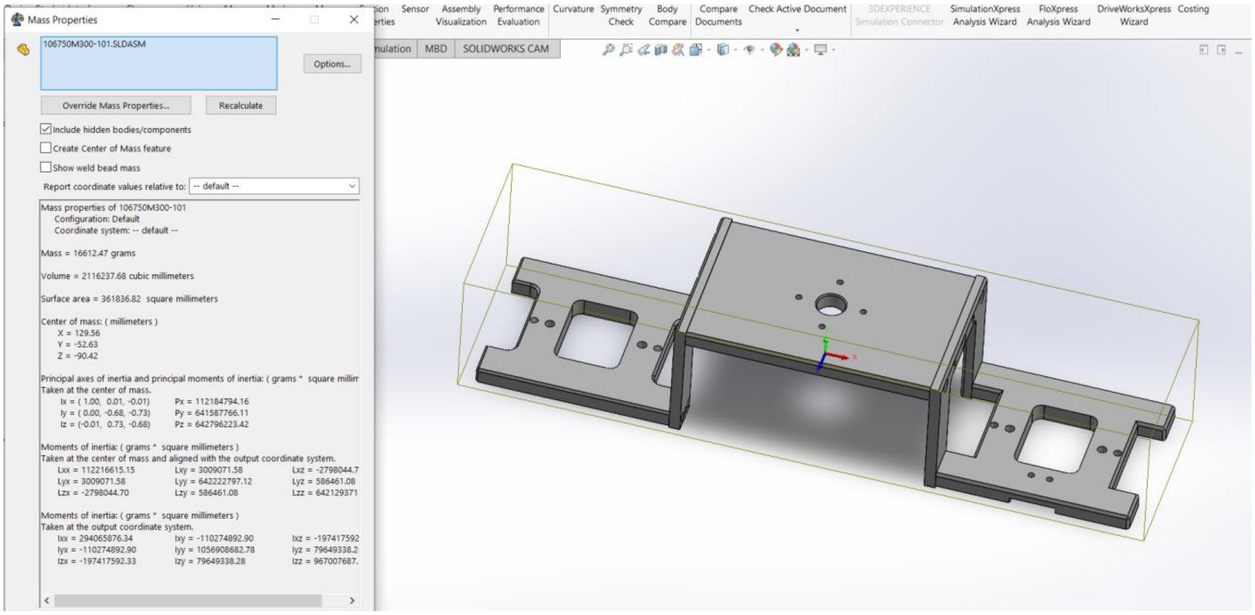

Figure 13 Original Rotating Structure

To improve on the weight while retaining the strength of the main structure, I added some windows through the center plate. I made sure that it retained support from the center mounting hole outward to the edges of the plate to retain strength. I kept the plate as thick as it is to allow the use of M8 bolts for the side support plates. I also added filets to all the corners to make sure that stresses along the edges of the windows were reduced to make the structure stronger.

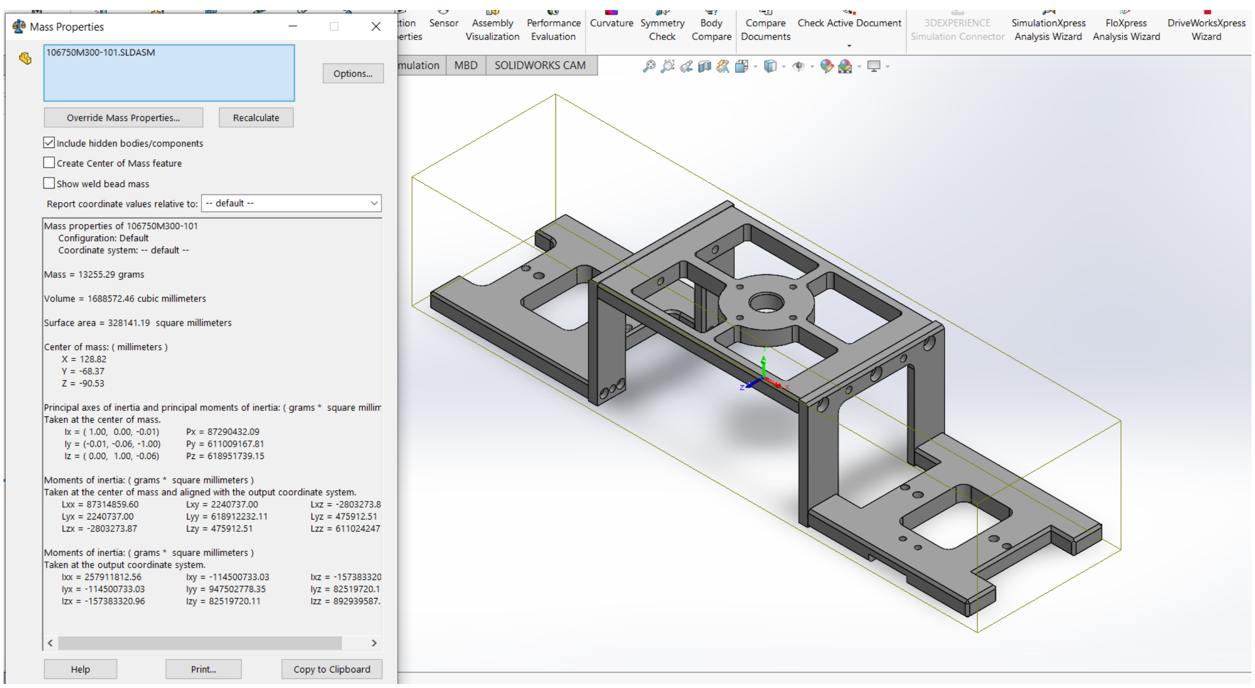

Figure 14 Lightened Rotating Structure

This weight reduction allowed for there to be an approximate 3 kg of weight reduction from the system. Strength analysis on the structure still needs to be performed to see if it will withstand the forces applied to it.

For the part fixture plates, my company requested that I add a way to manipulate the location of the parts relative to the main structure to ensure that the exact locations of both parts on the infeed are as precise as needed for the robot to pick up the parts. This is critical since the robot grippers will remain the same and since it picks up both parts at once from the infeed, both parts need to be relatively the same distance apart from each other. To accomplish this I went with a tiered plate design where there is a base fixture plate that is attached to the structure of the infeed, and the plate on top has the datum pins that allow the parts to be placed on top. This top plate can be moved using spacers with a maximum of 5.5 mm in the x and y axis if looking from the top down. This does however increase the size of the fixturing for changing over to a different product and adds weight to the infeed which can make it more difficult for the pneumatic actuator to rotate the structure. This design will be looked into as it may be possible to integrate the ability to shift the plate into the structure it is attached to.

The parts are designed to be placed on top of the fixture plates where datum pins will hold the part in place by being inserted into the 4 datum holes of the parts. To ensure the operator can place the parts on fully while making it simple to take on and off, I have dimensioned the pins to be a slightly smaller diameter than the datum holes on the part, and made one of the pins a diamond shape pin. The basic design for this fixturing is borrowed from the fixturing inside the first machine inside the robot cell that the robot places the parts onto. This should allow for the robot to pick parts off of the infeed as well as it can inside the machines.

This fixture plate assembly can be switched for a different fixture assembly during the change over of the line to a different product. This is done due to the bottom of the bottom plate having two datum holes that line up with two datum pins, one round and one diamond on the top of the structure they attach to. There are also two tapped holes for two M10 thumb screws to be attached at the top of the fixture plate assembly to secure the assembly to the main structure. The thumb screws will be useful for allowing the maintenance technicians to easily swap the assembly fixtures for changing products.

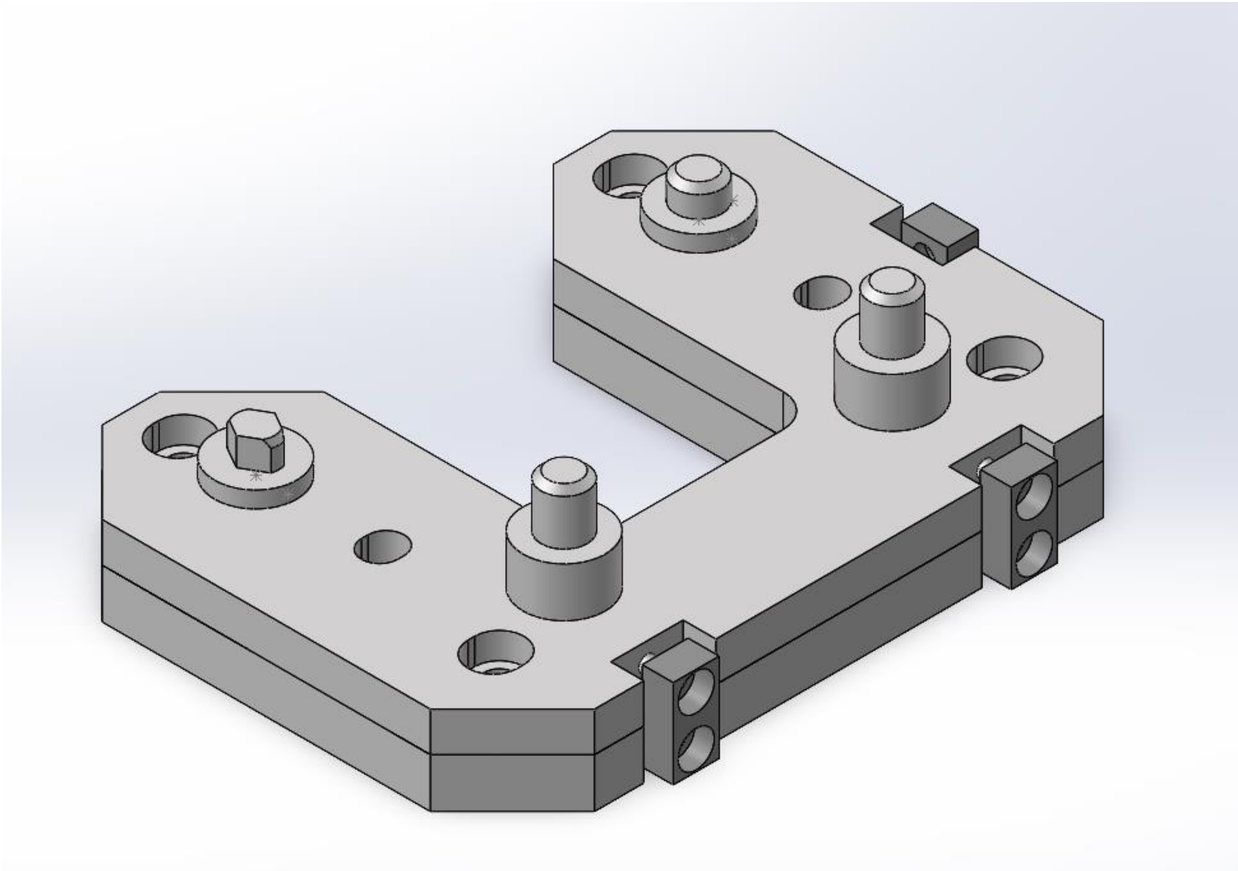

Figure 15 Original Fixturing Plate Design

For the pneumatic cylinder I had to find one that worked with the pneumatic and PLC systems in place on the line. It needed to also have the available torque to move the structure around in a controlled and expedient way to ensure that the cycle time of the infeed doesn't change too much from the current solution. Using Misumi, who is a parts company that works with Advics, I found a rack and pinion type rotary actuator that utilizes the switch type, and pneumatic pressures that Advics uses. It also is limited to 180 degree movement with cushioning inside to dampen the force of rotation when the structure turns to its maximum movement. It also has an adjustable torque range from 6 Nm to 63Nm of torque. This should be plenty of torque to turn this structure around fully loaded. The rotary actuator has a keyed shaft at the top which I have made a flange for to bolt the main structure onto it. It also can be mounted using some brackets. I have designed some L shaped brackets that utilize M12 flat bolts to bolt into the rotary actuator and the linear movement plate that will carry over from the current solution.

Configured Specifications

Oscillation Angle A	[180°] 180°	**Torque [Range] (N・m)**	6 to Less Than 10 / 10 ~ Less than 20 / 20 to Less Than 50 / 50 to Less Than 100
Type	Rotary Actuator One Side Shaft Output	**Main Body Shape**	Block Shape
Operation Method	Single Rack	**Rigidity, Accuracy**	Standard
Environment, Applications	Standard	**Allowable Kinetic Energy [Range](J)**	1 ~ Less than 50
Tube Nominal Dia.	80	**Valves**	Provided
Allowable Kinetic Energy(J)	2.00	**Operating Pressure Range(MPa)**	0.1 ~ 1.0

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Figure 16 Pneumatic Actuator Spec Table

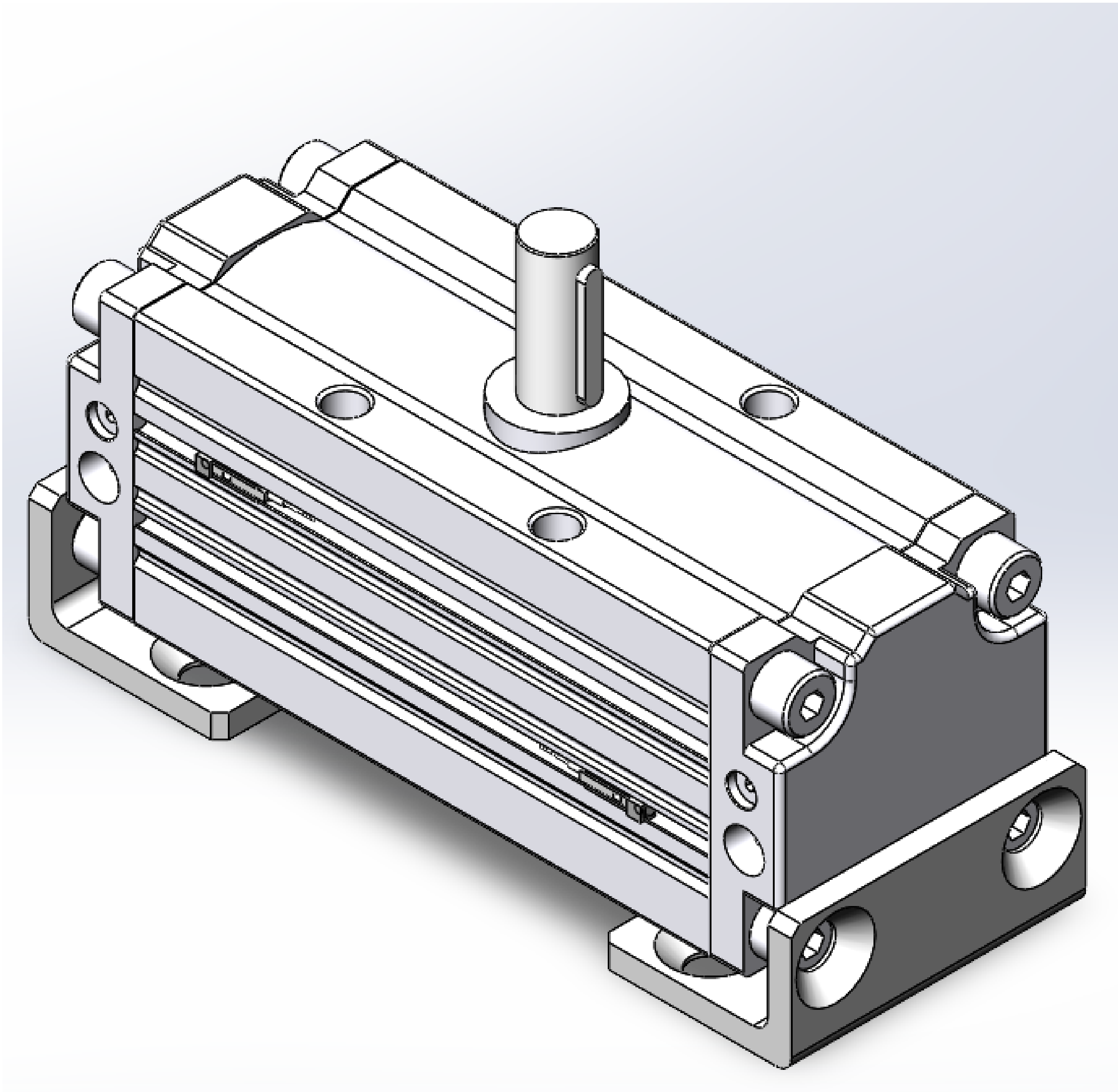


Figure 17 Pneumatic Actuator

I noticed that the datum holes for both bracket products have the same distance apart for the datums in the back of the bracket where they are to be fixed on the infeed. The main difference between them is the distance between the datum holes towards the front of the bracket. Knowing this I made the fixturing pins in the back fixed in place on the infeed structure and allowed only the datum pins in the front to be removable as a plate to change the products. This change should make the process of changing products for the infeed much simpler to do, and lightens the entire structure making it perform better.

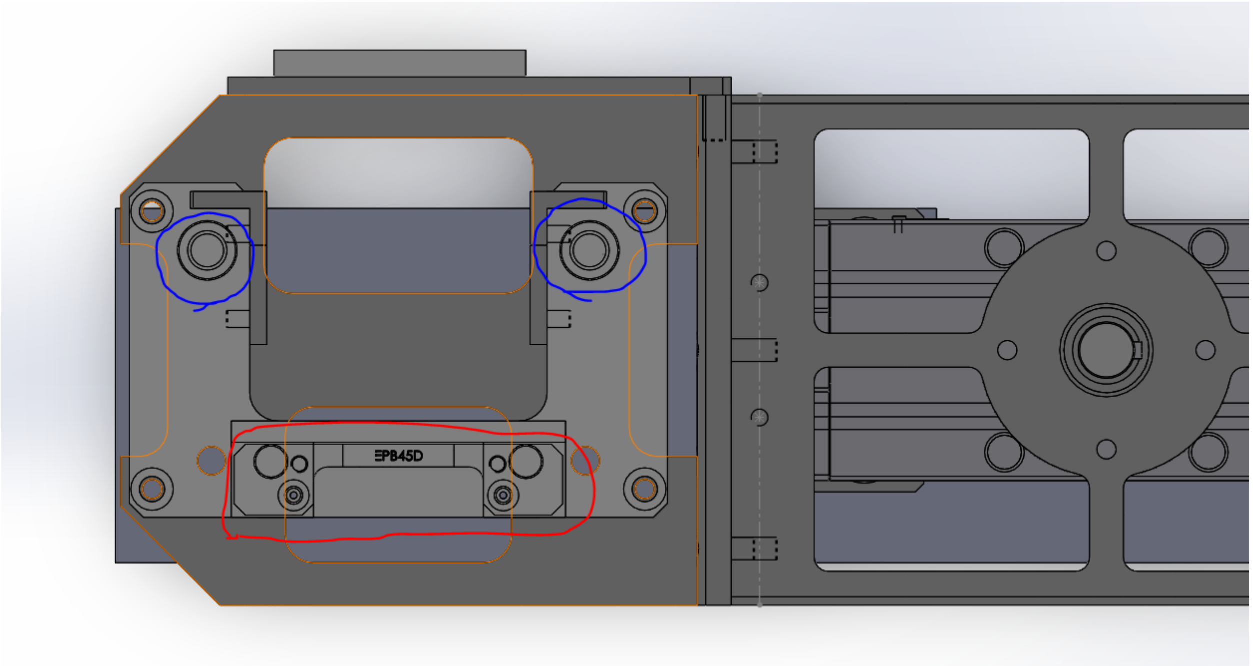


Figure 18 Top View of Left-Hand Side Of Fixturing, Fixed Datum Pins Are Circled In Blue, Change Over Fixturing Plate Circled In Red

In this change I also allowed for one of the sides to be adjustable by moving the adjustment blocks to work with the main structure and the fixturing plate as well as adding slots to the mounting holes between the fixture plate and the main structure. This two is an improvement in lowing the weight of the whole structure and simplifying the design such that only one side is adjustable. This should be enough adjustment to work with the robot since the pitch of the parts is already designed to be within the proper dimensions of the robot grippers but having that one side be adjustable will allow for fine adjustment to made in case of any changes over time to the system.

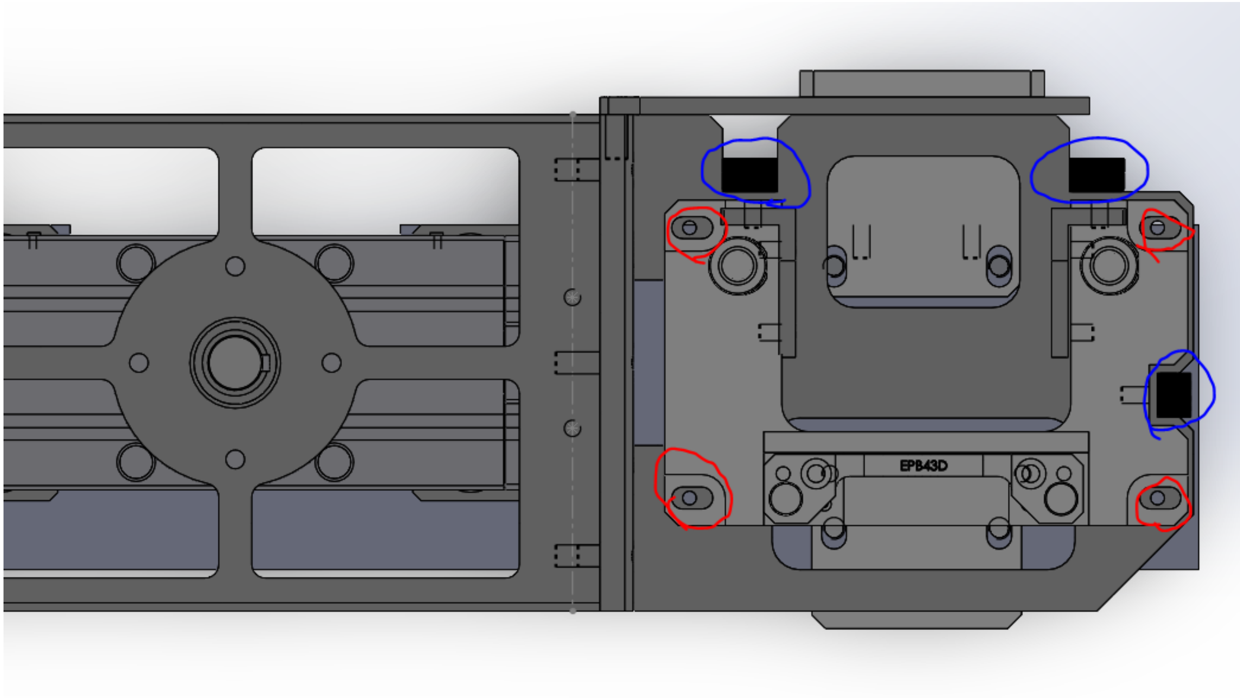


Figure 19 Top View Right Side, Adjustment Blocks Circled In Blue, Mounting Hole Slots Circled In Red

After communicating with ADVICS about this design, they requested adding some fixturing to the plates to allow the operators to line up the parts on the plate correctly and to protect the fixed datum pins from being damaged accidentally by operators misloading the parts or by the robot accidentally crashing into them. I added a wall around the back of the fixturing plate with a slanted edge towards the front on the inside of the plate to guard the back fixturing datum pins and to allow the operators to line up the brackets onto the pins. This should help the operators to load the parts as well as guard the datum pins while offering protection to the fixed datum pins. This will add more weight but considering the design changes so far to reduce weight, it shouldn't offset the weight savings gained so far.

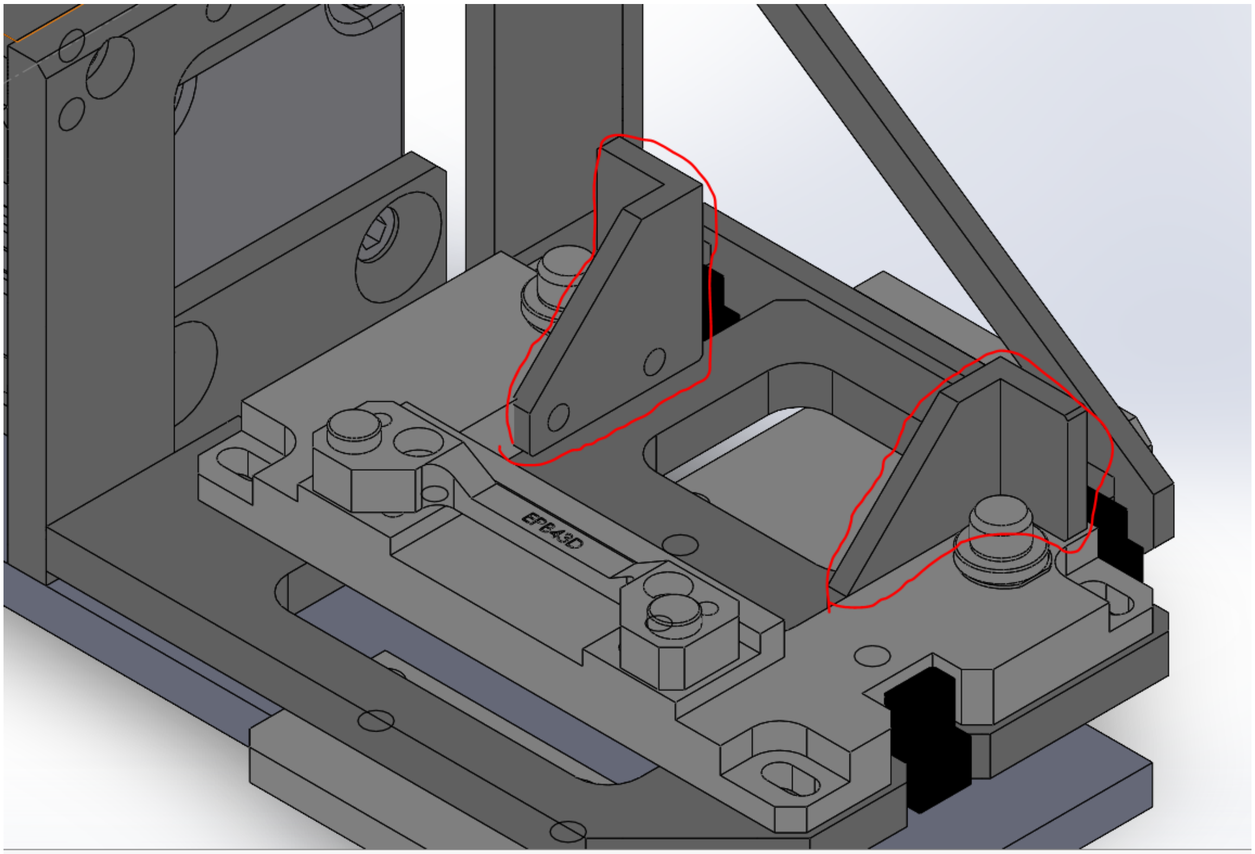


Figure 20 Right Side Fixturing Plate With New Protective Wall Circled In Red

Also after discussing my design with ADVICS, they were concerned of flexing occurring for the fixturing plates and requested I add supports to the vertical and horizontal plates to add support to the structure to be safe. To do this I added a gusset that attaches to both structural plates on each side to add support. Originally this plate was a solid triangular piece, but I lightened it by adding a hole in the middle that allows enough material to be left so that the gusset will support the structure. After running an analysis of the structure, I noticed that there was a significant amount of strain happening at where the top of the main structure plate meets the vertical structure plates. So I added an additional gusset to make sure that the structure would be stiff without adding too much material.

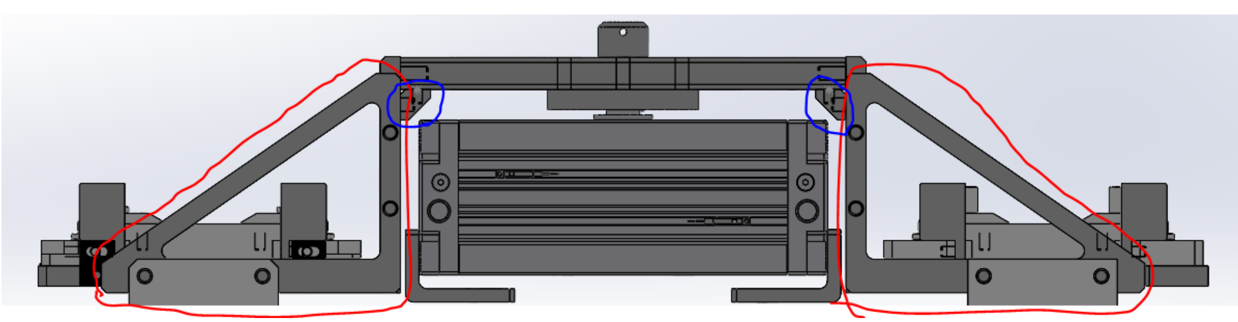


Figure 21 Back Side View, Outer Horizontal Structure Plate to Vertical Structure Plate Gusset Circled In Red, Center Structure Plate to Vertical Structure Plate Gusset Circled In Blue

Lastly, I have been working on a kind of hard stop for the infeed, so that when the structure reaches its beginning and ending positions it will be able to keep the same position each time it rotates. This is to ensure that the robot will be able to pick up the parts in the same position every time parts are fed into the cell. The pneumatic actuator does have buffers inside of it to provide a way for the structure to come to a stop, but these are soft stops that don't hold position so their needs to be a hard stop to keep the position every time. Initially I thought that a simple two plate stop would be sufficient. Basically, one plate is mounted to the main plate bellow the rotating structure, and another plate is mounted on one side of the rotating structure so that when the structure gets to its final position the two plates will be in contact with each other, constraining the structure from moving. After discussing with ADVICS, they brought up the idea of creep, where since the bottom hard stop plate is mounted using bolts with slotted holes for adjustment, the pressure applied by the bolts won't be enough to keep the hard stop plate from moving back over time since the plates will come into contact each rotation. This would bring the parts out of position and create failures. So, I decided to modify my hard stop plate such that it has another constraining face on the outer edge of the plate, with spacers to ensure that the hard stop is adjustable, but the spacers and this new face constraint will keep the plate from moving back.

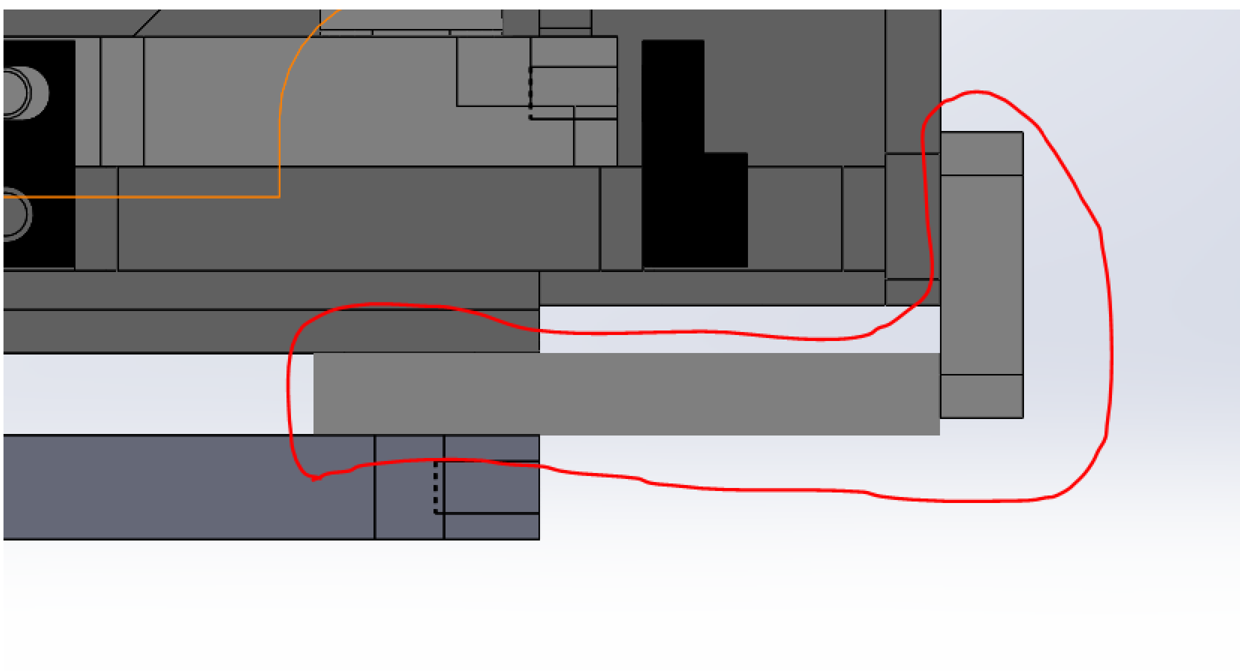


Figure 22 Side View, Original Hard Stop Design Circled In Red

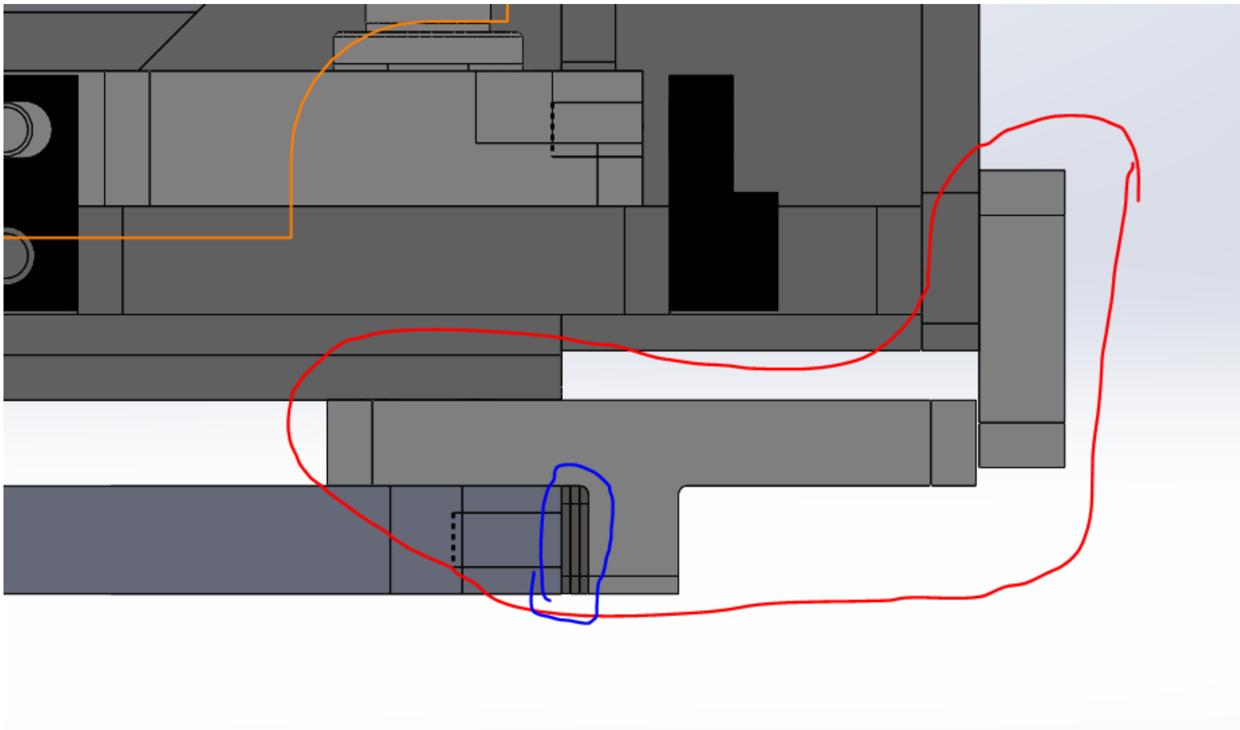
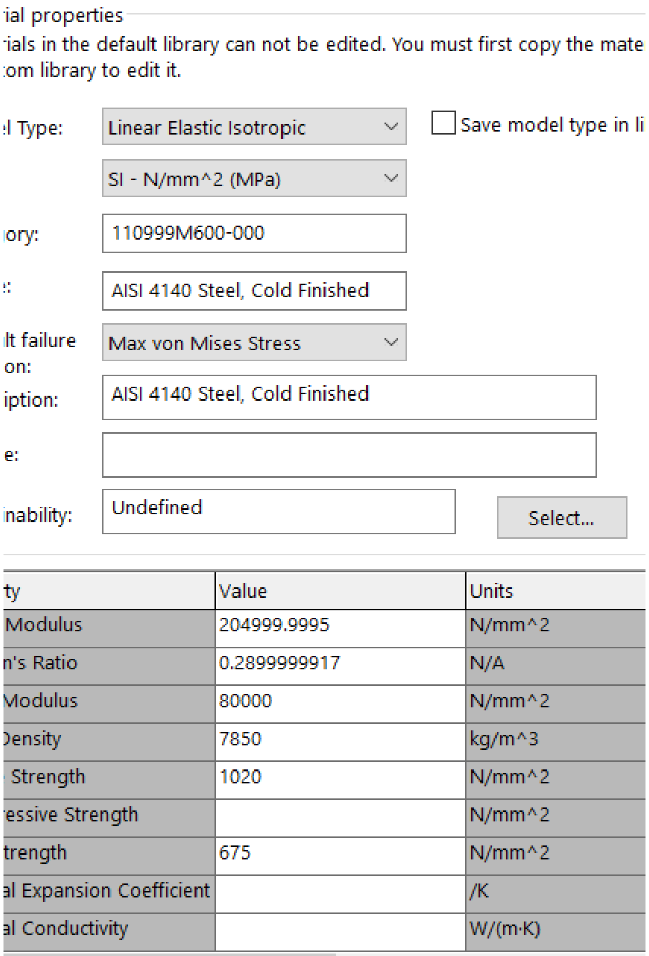


Figure 23 New Hard Stop Design Circled In Red, With Spacers Circled In Blue

Material Selection

For material selection I used ADVICS standards for fixturing on the factory floor. They recommended that I use 4140 Hardened Steel as the main material for the structural components. This is mainly due to the performance characteristics of 4140, which are having a high tensile strength and fatigue strength. These characteristics means that the structure will be sturdy and able to handle the abuses of being in a production environment where potential crashes may occur. The high fatigue strength also allows it to retain its shape over time, which will prove great for reliability.

For the datum fixturing pins and change over plate, I will be using A2 Tool Steel. This steel has great toughness, and dimensional stability over time. The toughness is needed since this will be interfacing with products being loaded and unloaded constantly which would cause wear over time. The dimensional stability is great since the datum fixturing pins are what determine how well the parts are loaded onto the infeed and the fine precision of how they are located.



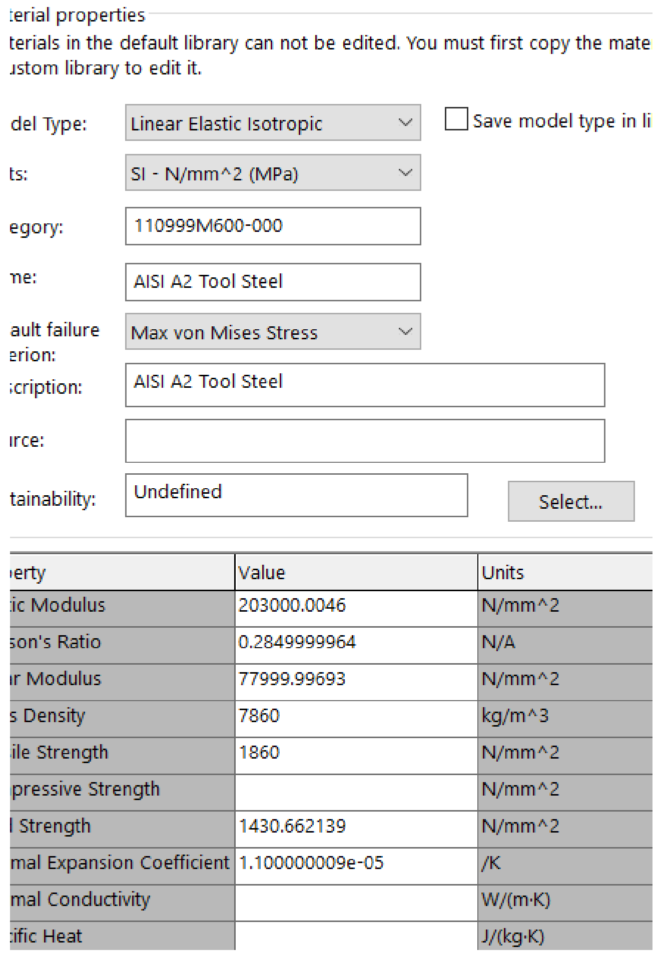


Figure 24 Material Properties for 4140 (Left) and A2 Tool Steel (Right)

Rotation Calculations:

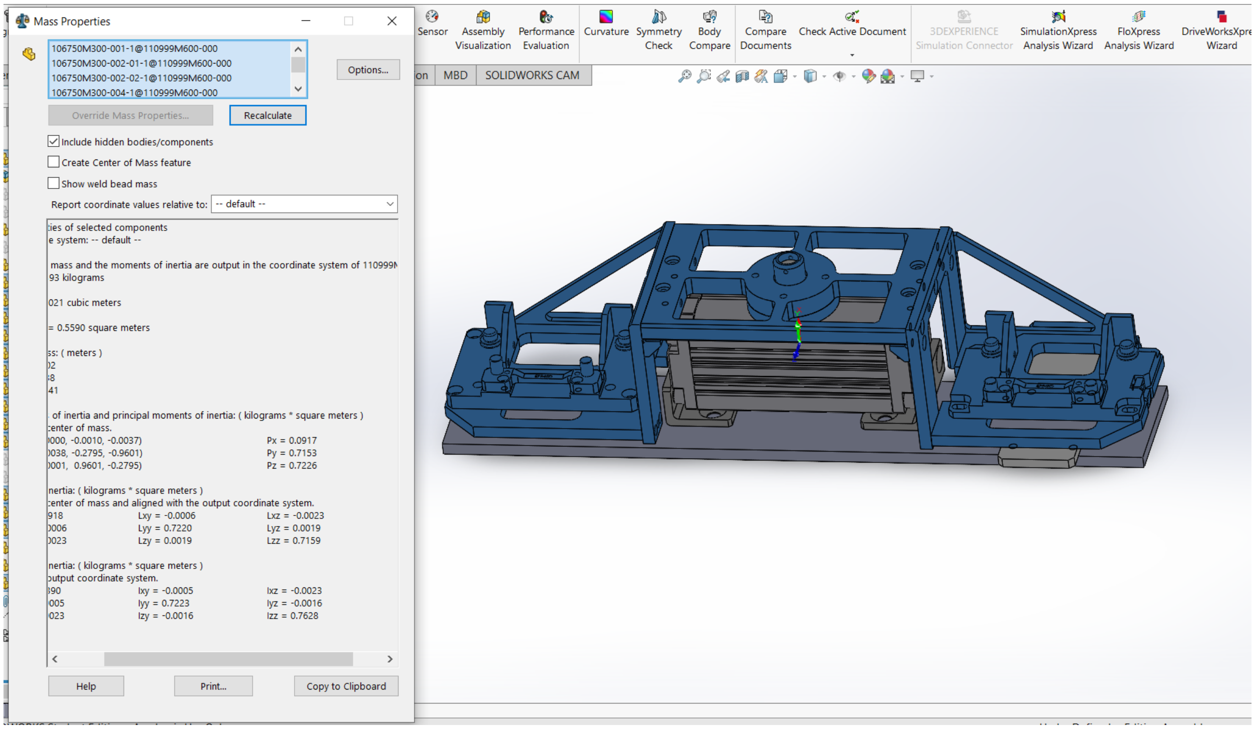


Figure 25 Mass Properties Of Rotating Structure

Moment of inertia for y axis: 0.7153 kg*m^2

Angle of Rotation: 180 degrees = pi radians

Max torque of pneumatic actuator: 63 Nm

$$\alpha = \frac{\tau}{i}$$

$$\alpha = \frac{63}{0.7153} = 88.08 \frac{radians}{s^2}$$

$$\theta f = \theta o + \omega o t + \frac{1}{2}\alpha t^2$$

$$\pi = 0 + (0)t + \frac{1}{2}(88.08)t^2$$

$$t = \sqrt{\frac{2\pi}{88.08}} = 0.267 \; seconds$$

According to the calculations, the pneumatic actuator will be able to rotate the structure the full 180 degrees in 0.267 seconds, which is plenty fast enough for the infeed to get into position. This torque is adjustable with air pressure, so the time to move the structure around can be increased by lowering the torque. In fact, this may be changed so that it rotates within a second or two. This will be fine-tuned when it comes to installation, but this proves that the pneumatic actuator has plenty of torque for this application.

Finite Element Analysis:

For the loading conditions for my analysis, I isolated the main rotating structure and fixed it in space on the collar component, which is what locates on the pneumatic actuator. I then applied a gravitational force across the entire structure. To simulate the weight of the bracket parts being fixed onto the datum pins, I had to calculate the heaviest bracket which would be placed onto the structure. I found the mass of the corolla bracket to be 1.5 kg, and the highlander bracket to be 1.81 kg. I selected the highlander bracket and applied an uniform force across the tops of the datum pins on each side of the structure.

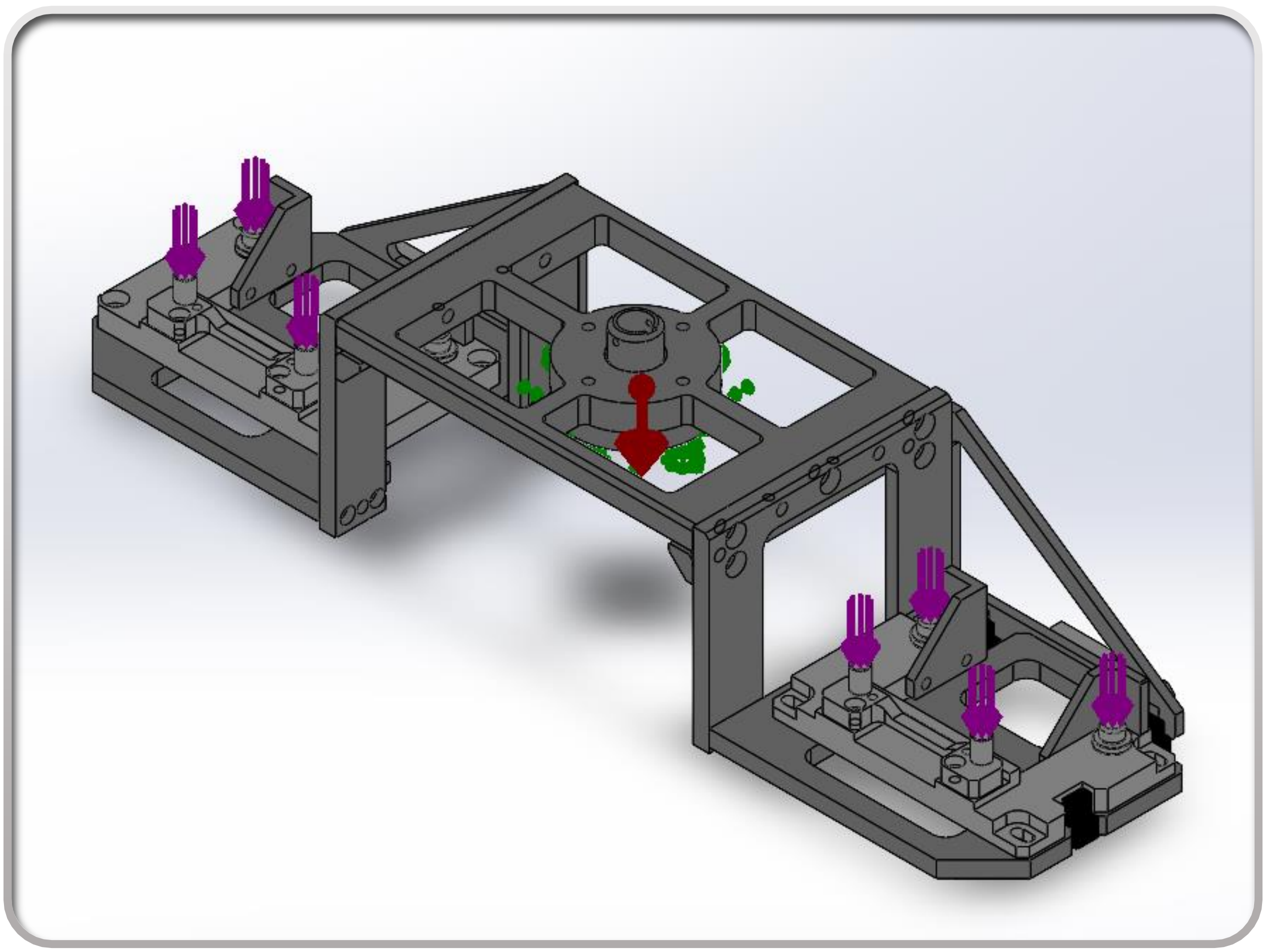


Figure 26 Loading Conditions

After applying these loading conditions, I ran an analysis on the stress, strain, displacement and factor of safety for the structure.

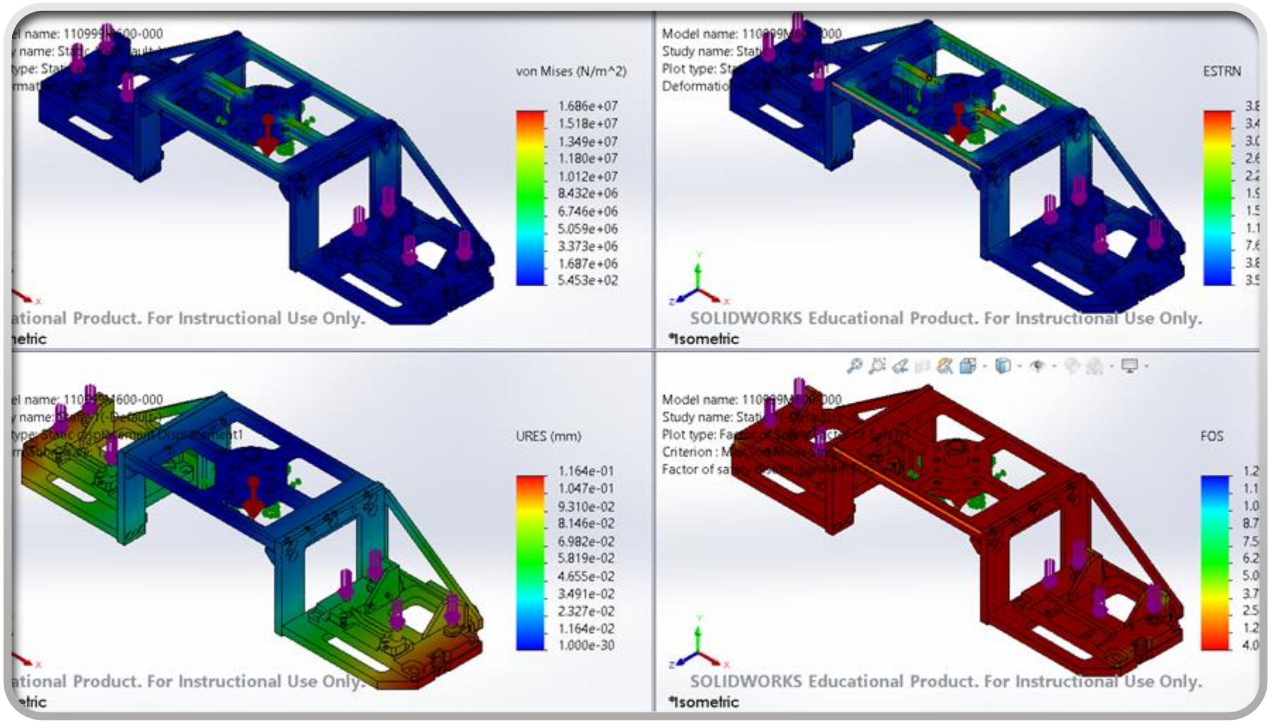


Figure 27 Overall Results For Stress, Strain, Displacement, and Factor Of Safety

Starting with the stress analysis, I had a maximum stress result of 1.686 *10^7 Pa or 16.86 MPa. This stress was mainly located at the center of the center structural plate around the collar component that attaches the structure to the pneumatic actuator. Otherwise, the stress around the structure was minimal, with only stress appearing where the plate had been lightened previously.

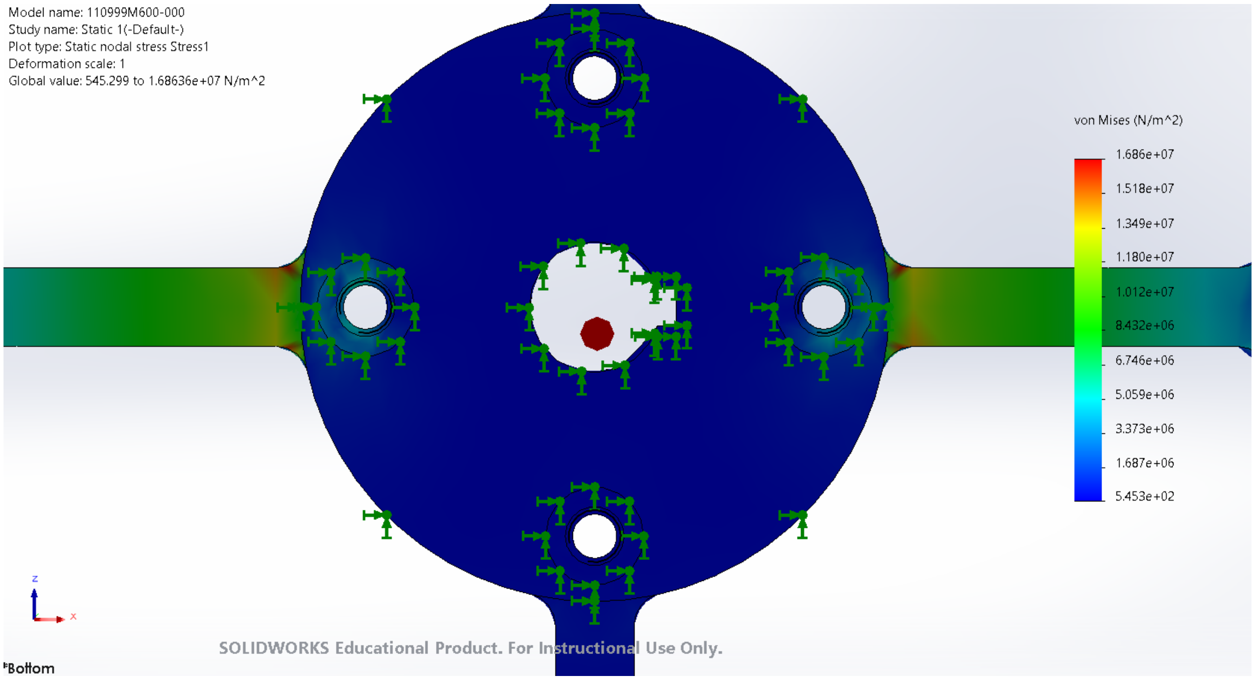


Figure 28 Stress Analysis Focus On Area Of Maximum Stress

For the strain analysis, the areas of strain reflect the areas of stress. This is shown with the areas of maximum strain being located in the same areas as the areas of maximum stress, at the center of the center structural plate around where it meets the collar component.

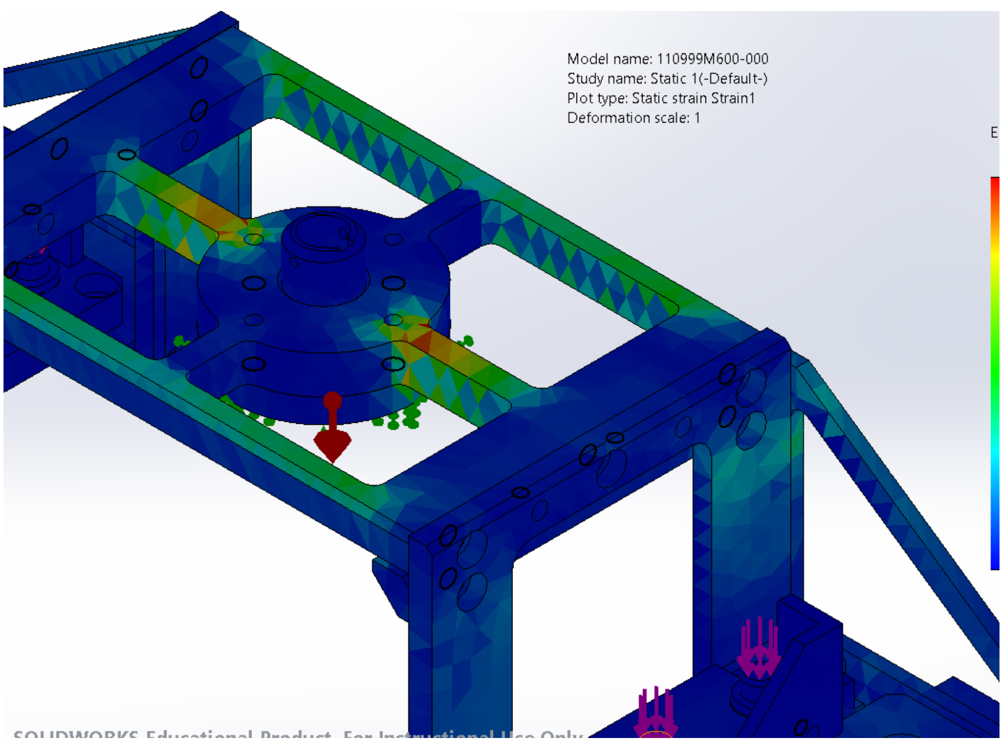


Figure 29 Stress Analysis Results

For displacement, the results show displacement increasing the further from the center of the structure a component is. The maximum displacement of the very outer edge of the structure is 0.12 mm off from normal position. To see how this will effect the fixturing pins, I took the difference in displacement between the outermost datum pin and innermost datum pin. I found this to be 0.06 mm. This displacement shouldn't effect the part placement, mainly because this displacement is a top to bottom displacement instead of side to side displacement. Also, the displacement itself is quite minimal, and due to the adjustment built into the structure, this can be alleviated.

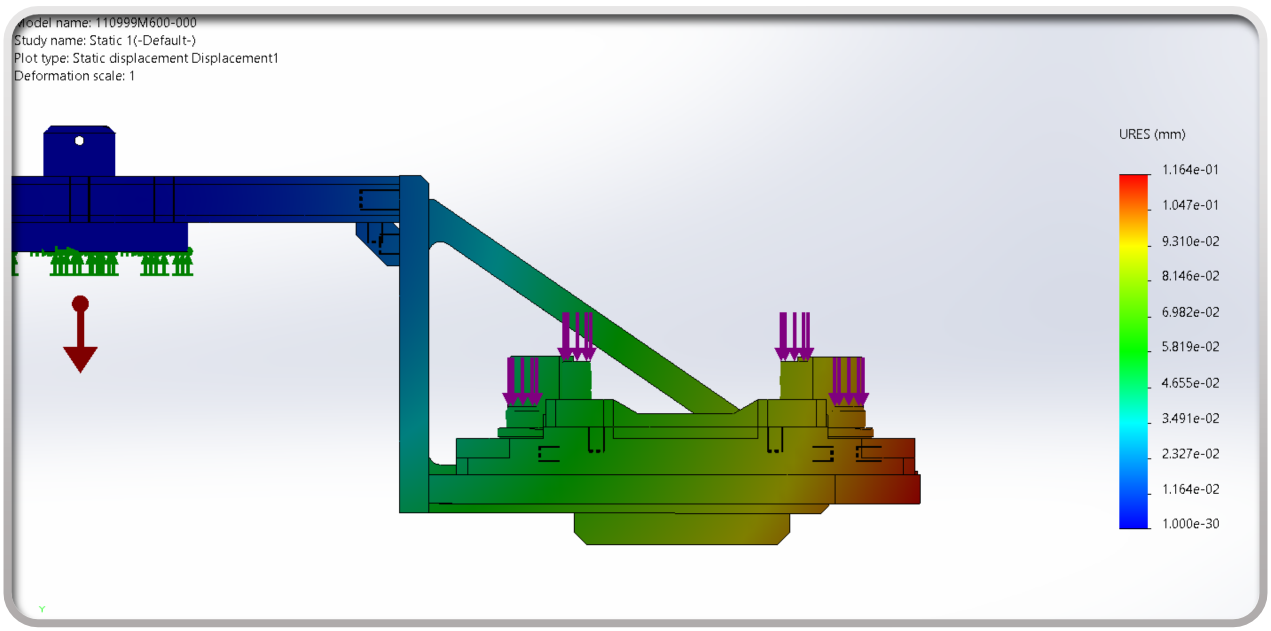


Figure 30 Displacement Results

After analyzing the stress and strain results, the simulation gave me the results for the factor of safety, considering the yield strengths of all parts. The areas which have the least factor of safety are those areas of max stress and strain. However, this is only given a factor of safety of 40. Considering ADVICS has a factor of safety for their structures of 10, this is well and above minimum, and will work well

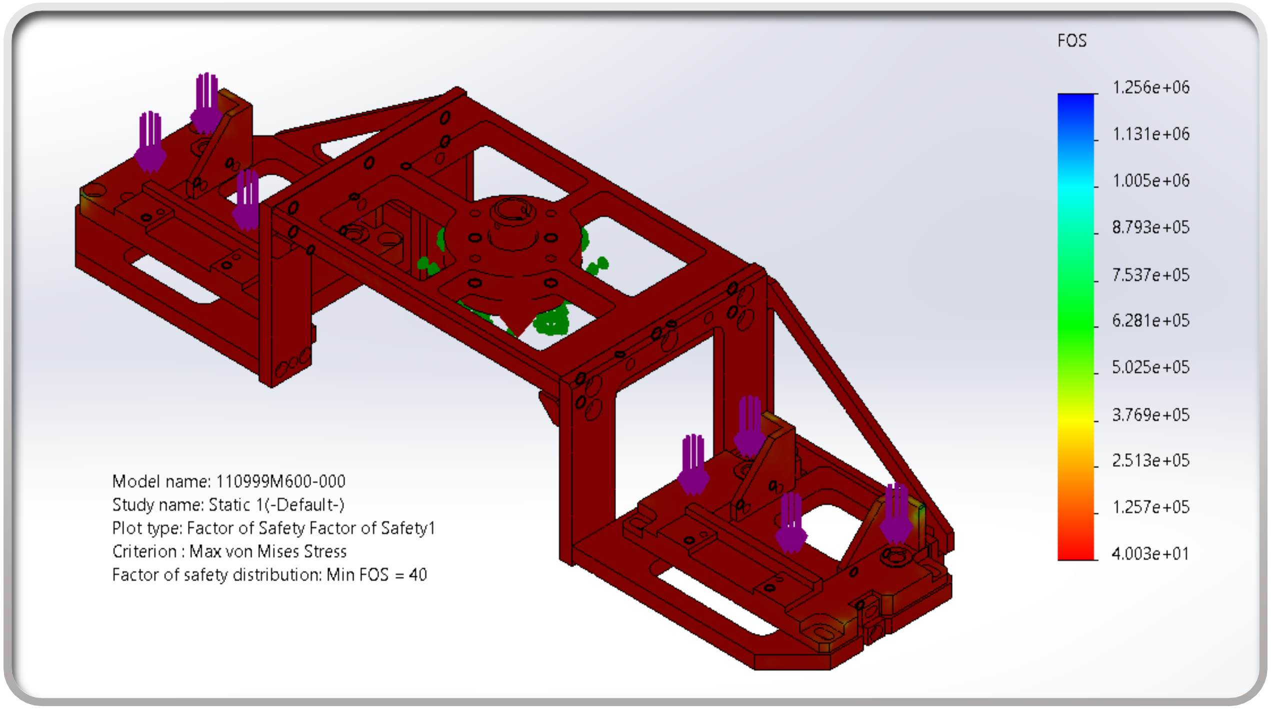


Figure 31 Factor Of Safety Analysis Results

Fabrication Plan

For the Fabrication plan, all drawings have been made of the individual components and have been approved by ADVICS engineering. These drawings are now being sent out to their main fabrication shop to machine the parts and have them shipped to ADVICS in time for the Christmas plant shut down. The pneumatic actuator has also been ordered from Misumi, and should arrive at the same time as the parts. All the necessary bolts are readily available on the factory floor, ready for installation.

Assembly Plan

For assembly, this will be done mainly by the ADVICS maintenance group, with oversight by ADVICS engineering and myself. All programming of the robot cell PLC, as well as the installation of the pneumatic cylinder with the existing pneumatic controllers will be done by the maintenance group. The pitch of the parts, and the hard stop location will be adjusted to work with the robot grippers and ensure that the robot will be grabbing the parts consistently. The force of the pneumatic actuator will also be adjusted to ensure proper cycle time with the rest of the line.

Testing Plan

The Design will be tested initially, by running 15 pairs of parts through to the cell. This is the standard testing done by ADVICS to ensure that everything is working well. If all 15 go through without fail, then a shift will be run on the line. Then the parts run through the line will be counted, and all errors made by the robot cell and the infeed will be recorded to see if there need to be any adjustments to the infeed. If not, then the infeed will be ready for use.

Project Management

Project Budget Limit

Based on the current purchase orders made by ADVICS to the fabrication shop, the total cost of parts will be approximately $17,500. This cost is higher than usual since this will need to be ready to install for the Christmas plant shutdown, the week of December 20th.

Key Milestones

Original Schedule:

Date:	Milestone Completed:
12/3/2021	Design completed
12/17/2021	Drawings made and approved by ADVICS
1/21/2021	Parts Arrival and beginning of Installation
1/30/2022	Assembly is complete beginning testing
2/4/2022	Testing is complete

New Schedule For Christmas Shutdown Installation:

Date:	Milestone Completed:
11/12/2021	Design completed
11/19/2021	Drawings made and approved by ADVICS
11/19/2021 – 12/20/2021	Parts Fabricated
12/20/2021 – 12/23/2021	Assembly / Fabrication
12/29/2021	Testing / Adjusting If Needed

Installation

Pre-Installation

Before installation, we had a machining shop called K&K do the machining of all the parts for the infeed, including all the main structural components, fixturing and all other pieces. They were made to the specifications outlined with the drawings. The pneumatic actuator was also ordered from Misumi and arrived at ADVICS in time for installation.

Day 1:

Once the parts arrived, we began installation starting on Monday December 27th 2021. The crew for installation was Drew an ADVICS manufacturing engineer, Brian an ADVICS improvement technician, and myself. Firstly, Drew and I assembled the rotating structure together and ensured that the parts we sent out to be made were made to the specifications we had outlined. We started assembling from the top plate outward, where we pressed the datum pins and bolted the plates from the inside of the structure out. This is due to the way the components were tolerance to prevent tolerance creep. Essentially the base of the rotating structure, the top plate, was held to tighter tolerances than the other structure components and that the component tolerances get looser the further out from this main structure. Once the main infeed structure was assembled, we began working on disassembling the existing infeed and changing it to work with the new infeed design.

Brian began removing the electrical connections to the existing infeed and removing the pneumatics for use in the new system. We then began to disassemble the current infeed structure. The pneumatic cylinder that moves the base plate into the cell was unbolted. We took it off its mount and decided to mount the actuating side directly to underneath the base plate rather than on top as it was before to make room for the rotating structure mounted on top to rotate freely. The base plate had all of its fixturing removed to make room for the new fixturing. The base plate was also taken back to have new holes drilled and tapped into it to allow for mounting the pneumatic rotary actuator, and the hard stops.

We also realized that a pokeyoke, or a failsafe, needed to be added to ensure that corolla brackets could be mounted on the correct side. Unlike the highlander bracket part, the corolla bracket part is handed when entering the robot cell, since it has a protrusion called an ice breaker, poking out from the casting. We used this protrusion to ensure that the correct handed parts are placed. We bolted on a simple plate that attaches to the fixturing plate such that if the ice breaker is pointed out, which is incorrect, then it cannot be placed onto the pins since the failsafe plate will hold up the outside edge of the bracket. We sent the fixturing plates to the machine shop on site to have holes drilled and tapped for this plate to bolt onto

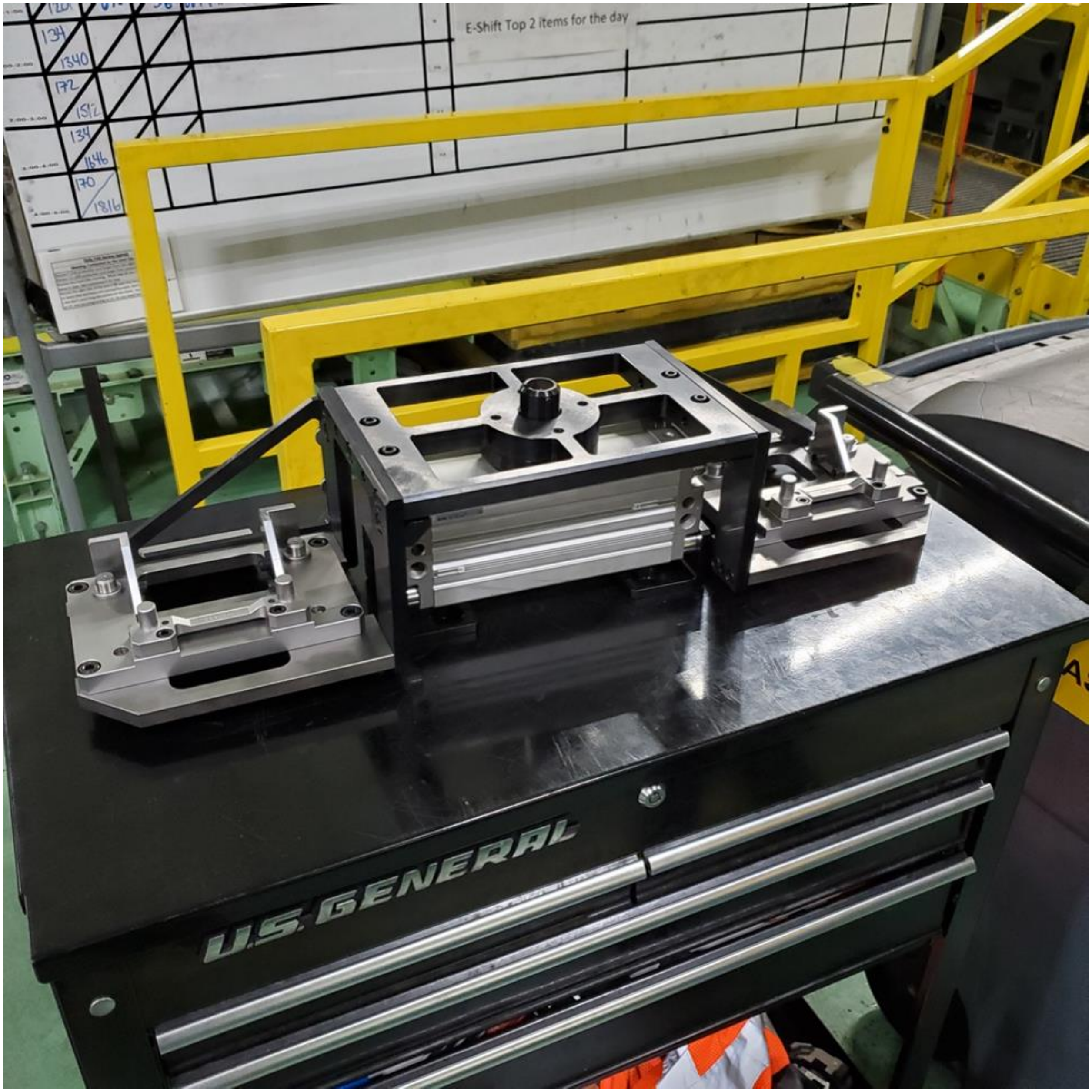


Figure 32 Rotating Structure Assembled

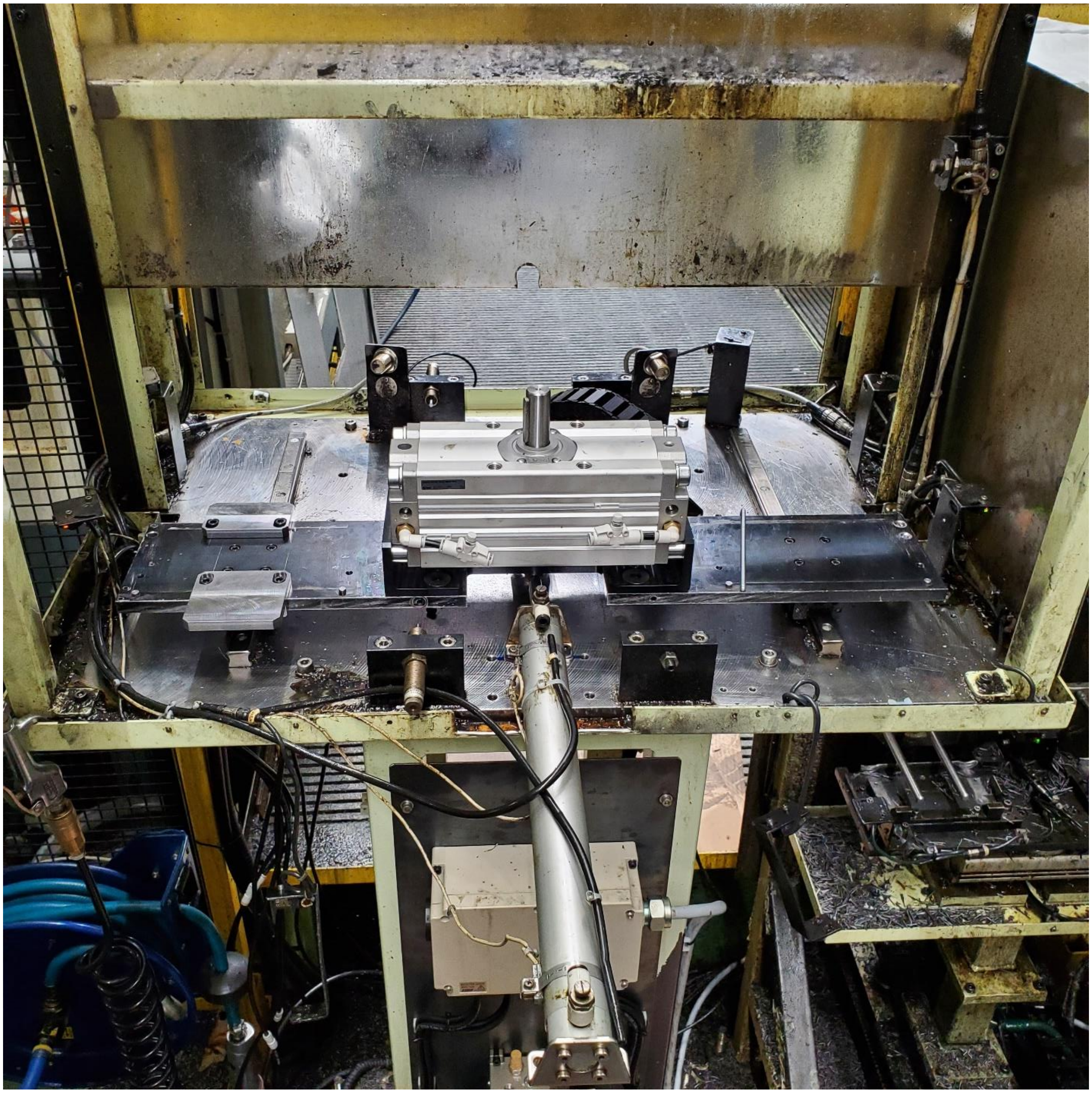


Figure 33 Hard Stops And Actuator Mounted

Day 2:

After receiving the new failsafe installed on the fixturing plate, we assembled the rotating main structure again. However, we noticed that on the corolla bracket parts, the ice breaker piece is pointed towards the inside of the structure, which would mean that when the robot picks the parts up from the infeed, the ice breaker will collide with the outer edge of the main structure side plates. To stop this from occurring, we took off the side plates and sent them to the machine shop to have a 8mm deep slot be milled in the area that the ice breaker would have collided with.

This should give us a few millimeters all around the ice breaker for clearance and ensure that there won't be any crashes from the robot picking the parts off the infeed.

In the meantime, Brian has been setting up the pneumatics and electrical connections for the pneumatic cylinders and the new laser sensors. The infeed currently uses optical sensors to detect part presence on the infeed, but their location interferes with the rotation of the structure, so we moved the sensors onto the side of the infeed and replaced them with longer distance laser sensors to detect the part presence instead.

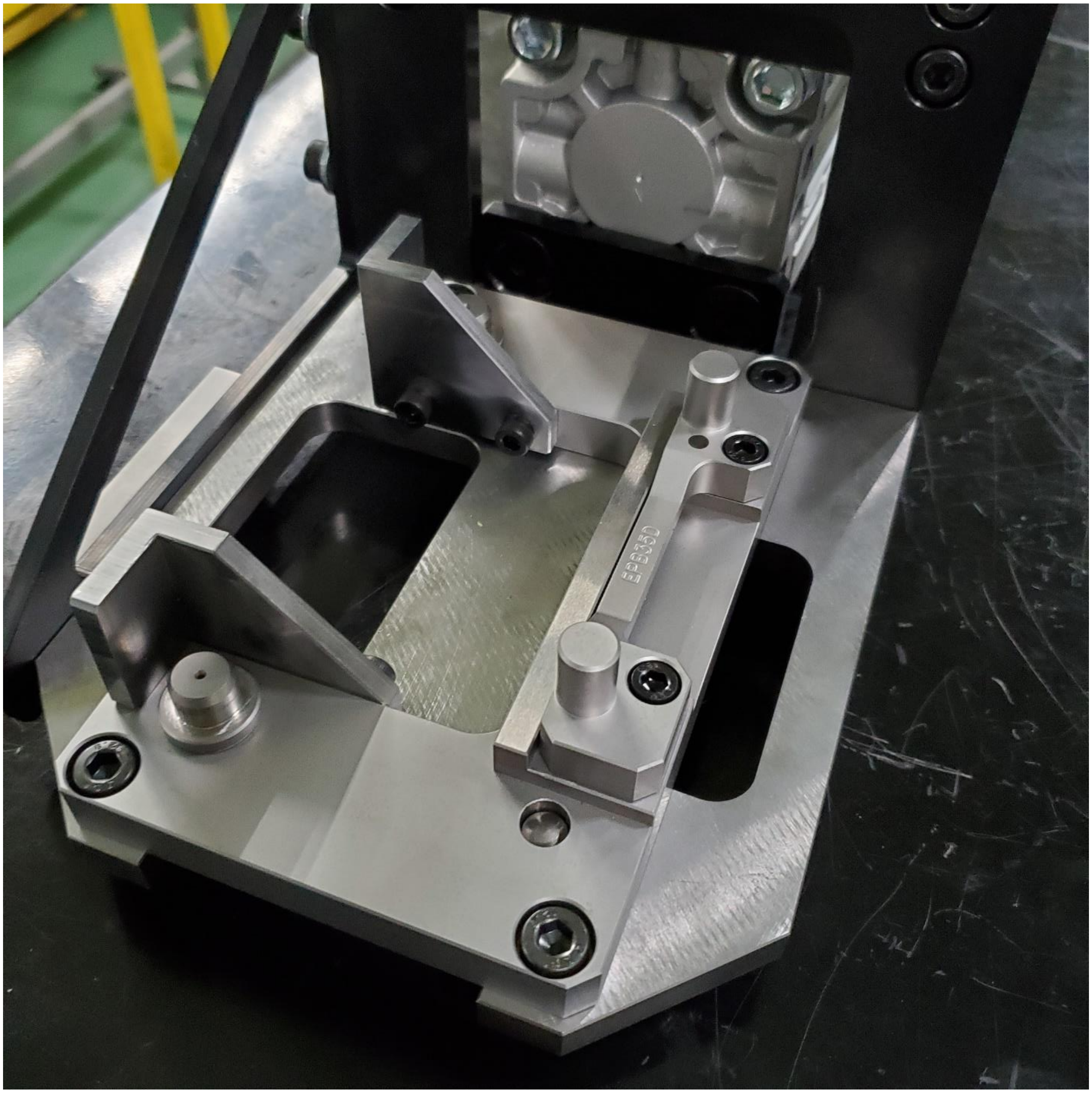


Figure 34 Up Close Of New Fixturing

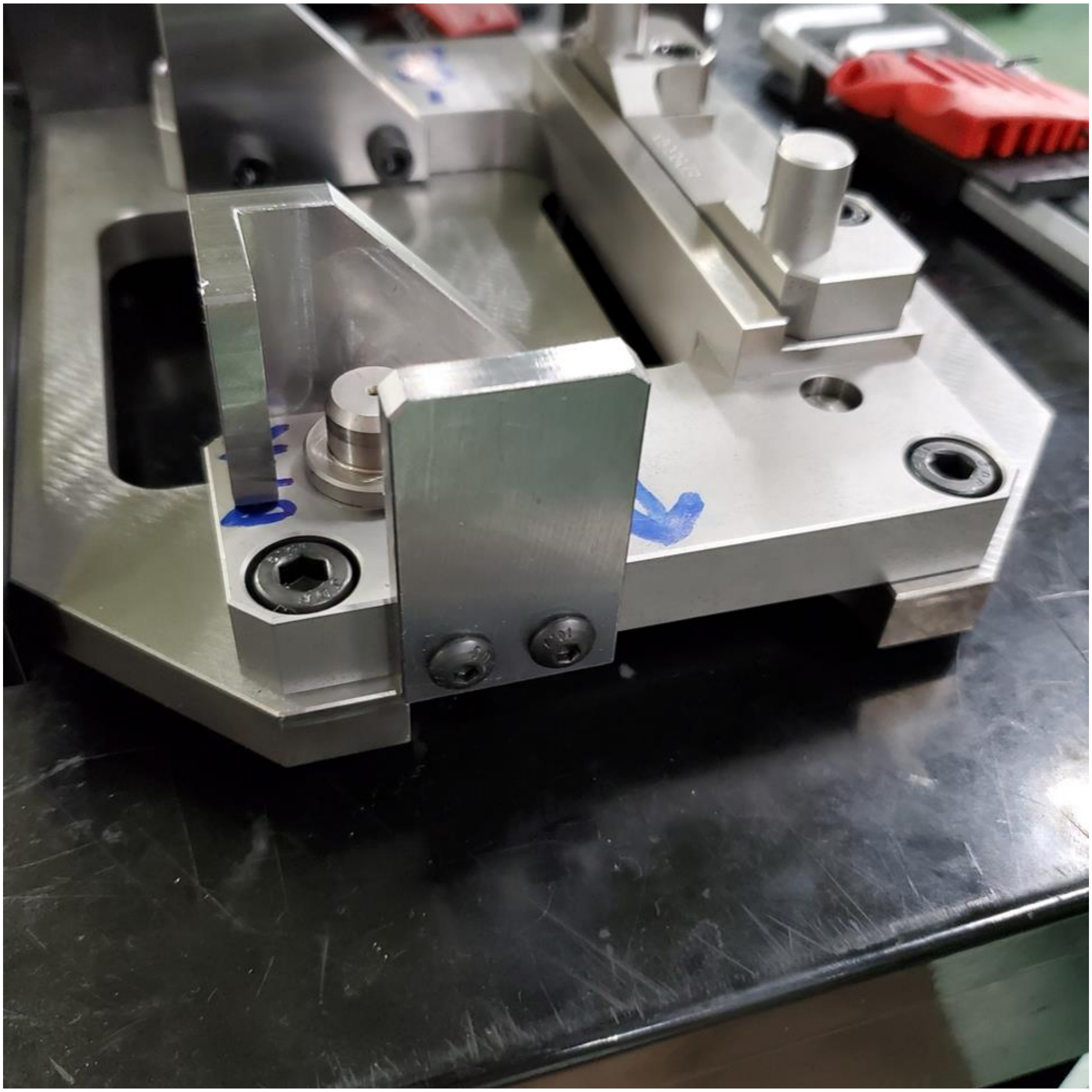


Figure 35 New Failsafe For Corolla

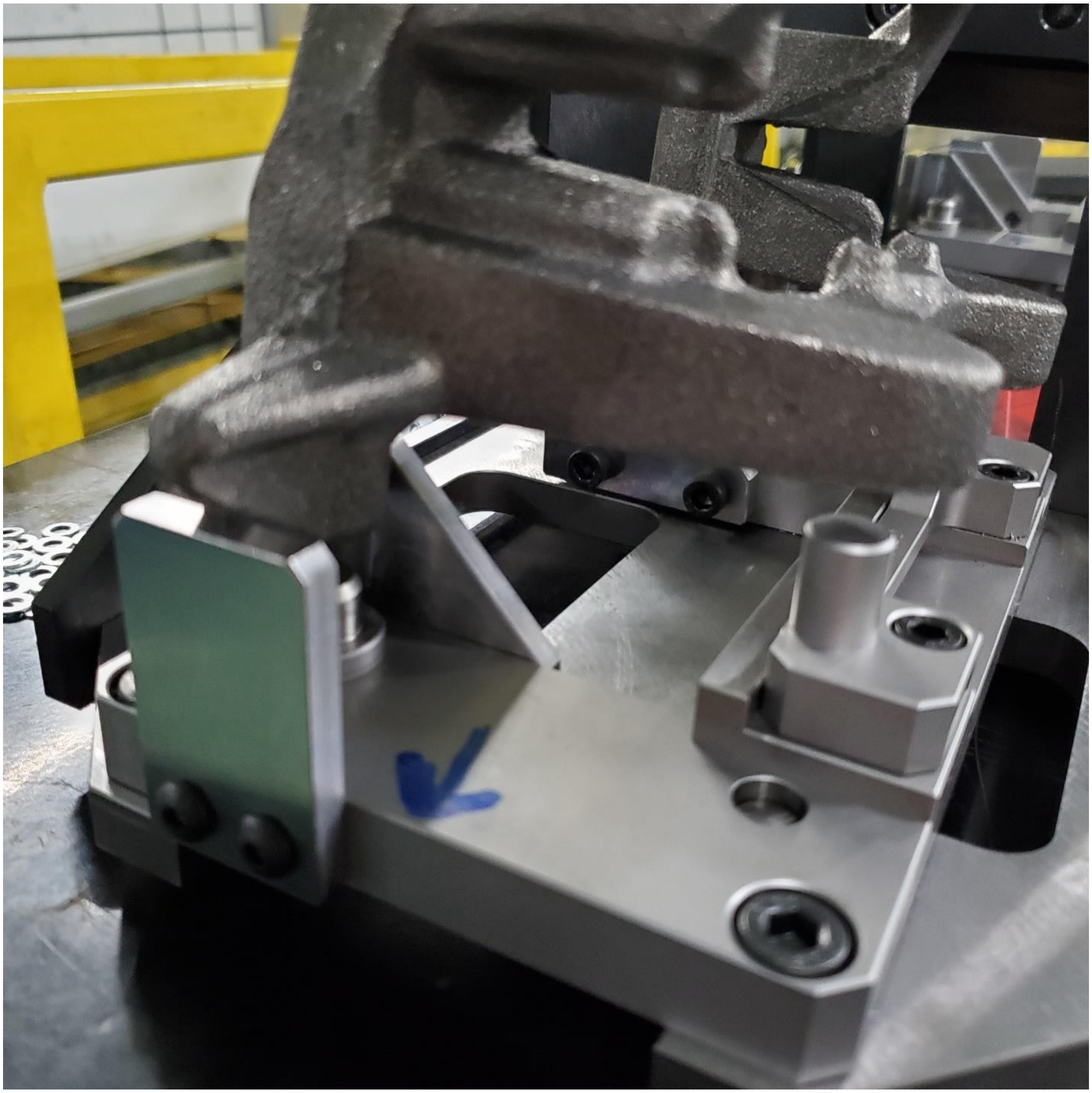


Figure 36 Improperly Placed Corolla Part

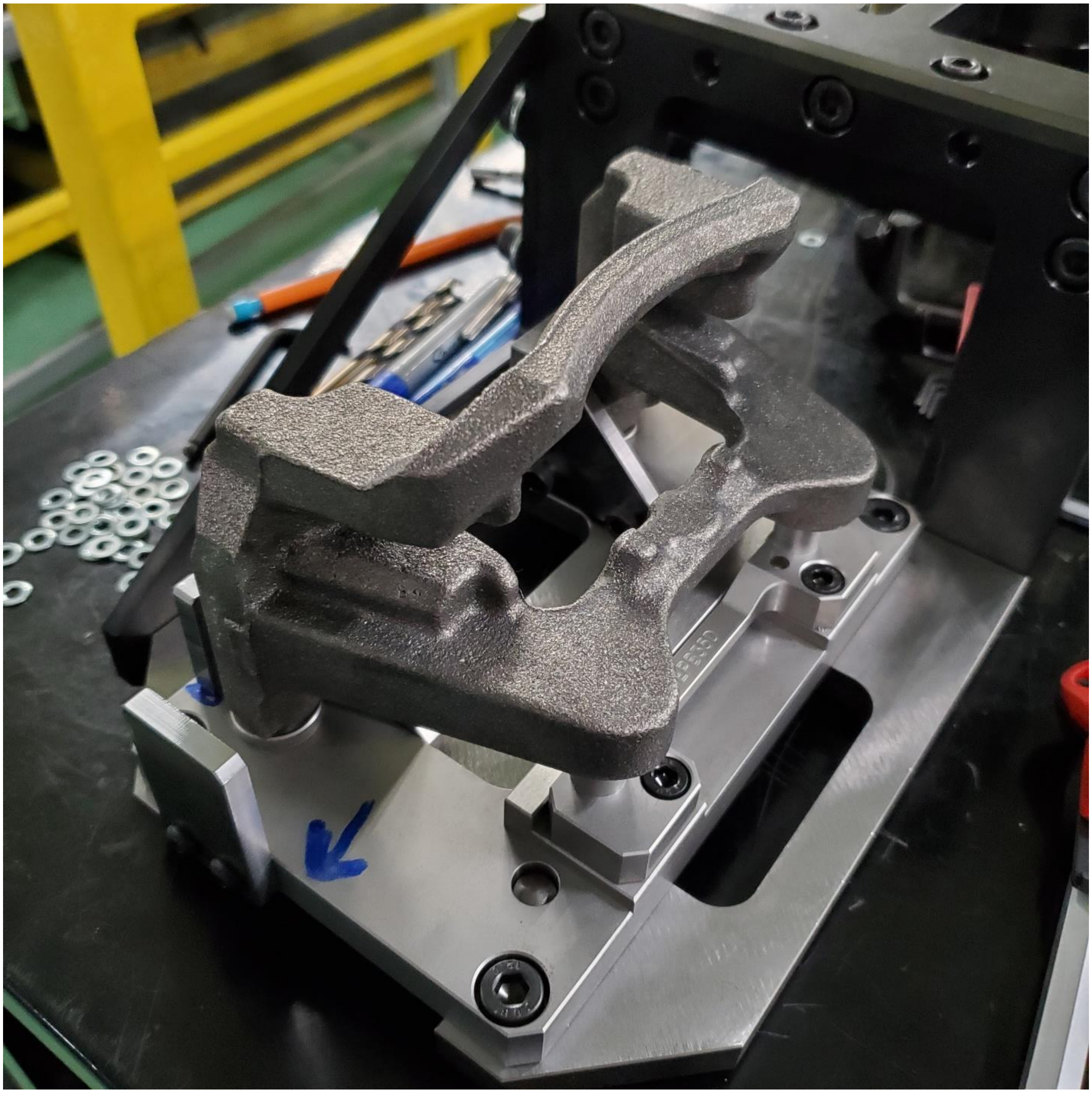


Figure 37 Properly Placed Corolla Part

Day 3

We received the side structure plates back from the machine shop with the appropriate cut and re assembled the rotating structure again. Brian was able to install the pneumatic rotary actuator on the linear plate and we placed the rotating structure on top to test the infeed. We adjusted the cylinder until it was moving in the smoothest way possible while retaining some speed to keep up with cycle time. Once the structure was on and the sensors were working correctly, we sent the infeed into the cell, and taught the robot the new picking points. While Drew and I do this, Brian worked on programming the PLC to send the infeed into and out of the cell, and made sure the sensors worked with the PLC

Drew and I managed to re program the robot to pick up the pieces from the new position and make sure the robot would not collide with anything on its path in and out of the infeed area and placing into the first machine. After we programmed the new robot path, we exited the cell and ran the line to make sure that everything worked as we intended. Everything worked great after programming and the line was able to run parts.

Figure 38 New Infeed Installed

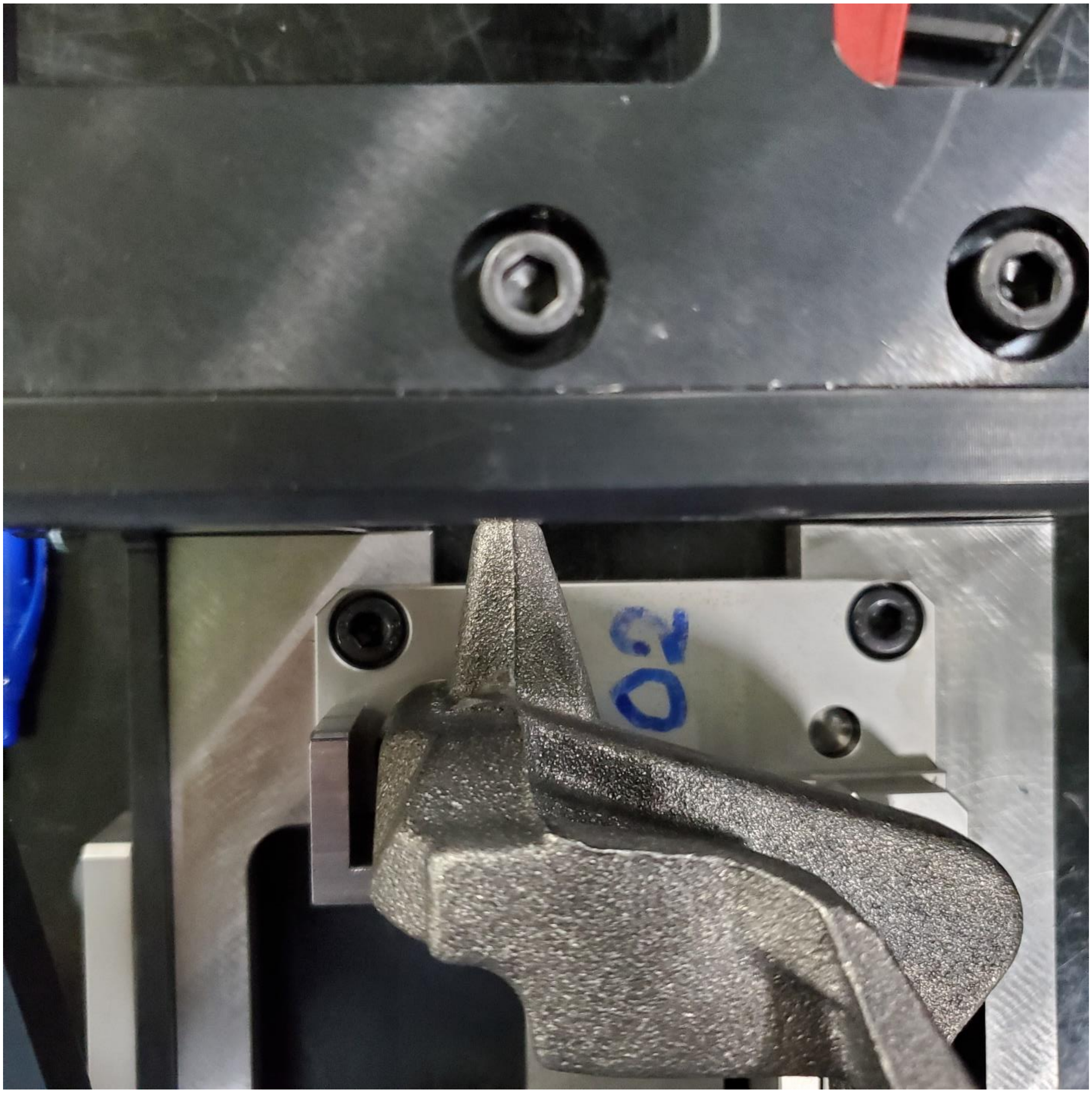


Figure 39 Side Plate Pre Cut

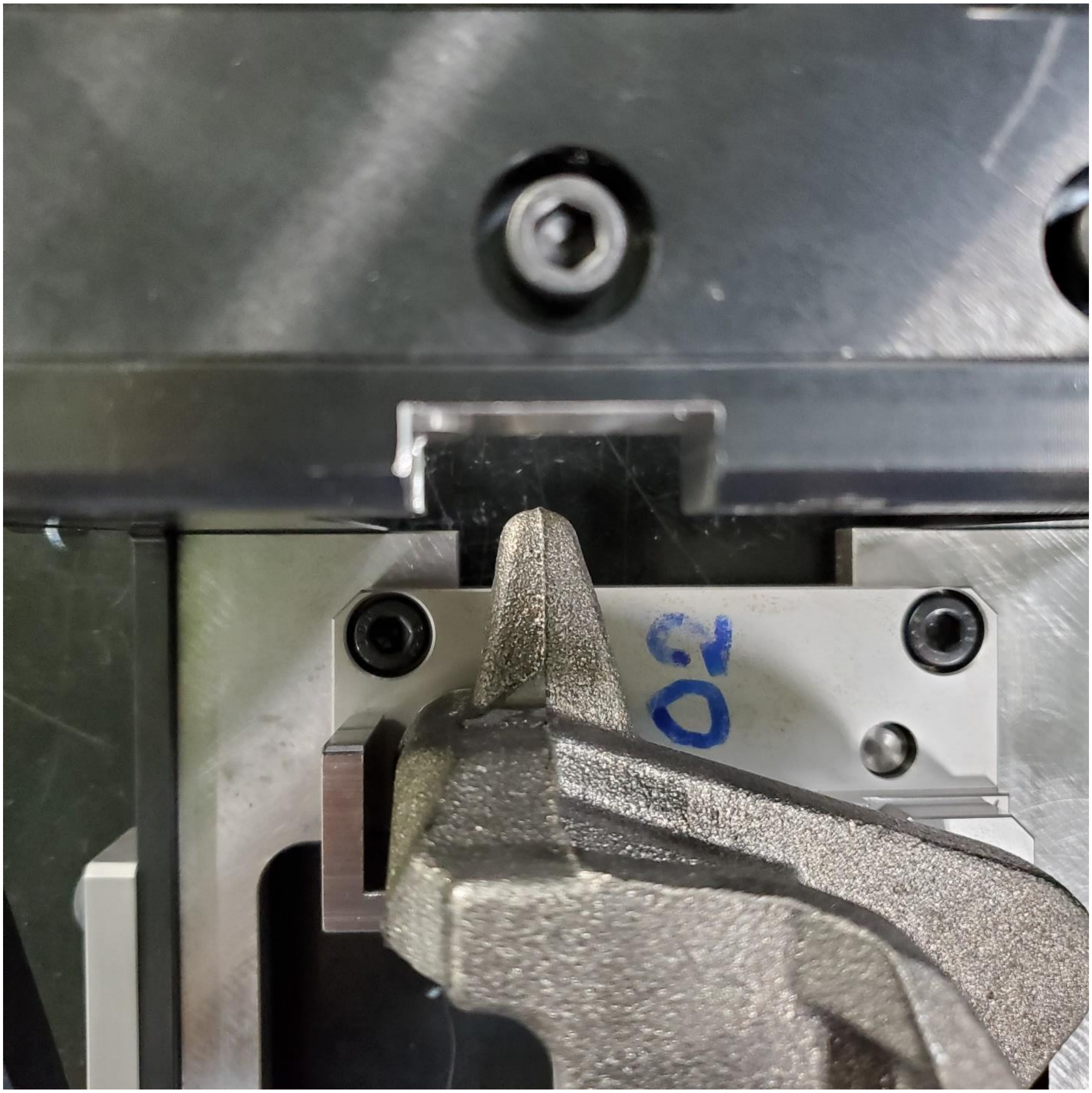


Figure 40 Side Plate Post Cut

Figure 41 Testing Sliding The New Infeed

Figure 42 Robot Moving To Infeed

Figure 43 Gripper Positioning To Pick Part

Figure 44 Gripper Picking Up Part

Results

After running the line for a month or so, Drew was able to send me data showing the lost time for the robot cell before installation and after installation. The main stoppage that this new infeed is attempting to alleviate is the loading of parts into the first machine in the cell. This machine is known as OP 30, or operation 3, since the first 2 operations are done on the operator side of the cell, and then the parts are passed into the cell. Looking at the data, there does appear to be an improvement in the amount of stops that occur at OP 30. Pre installation, OP 30 was responsible for 2.37% of the down time of the line, where as post installation OP 30 was only responsible for 1.18% of the down time of the line.

This is a 50% reduction in percent down time for that operation. This is a significant improvement over the original infeed considering over a period of 6 months, 45.6 hours of down time before were OP 30, and now that down time will be reduced to 30.4 hours.

ADVICS is very impressed with the design and function of the new infeed and is going to implement this design on other machining lines similar to this one in the near future.

Area	Down Time Type	MC	Failure Type Desc	DT Mins	DT Hrs	Prod Mins	Pcs	DT %	Down Time Date	Shift Name	Down Time Desc
MC#28 Bracket				**29014.0**	**483.6**	**314006**	**578530**	**9.24 %**			
	Cycle/Short Stops			29014.0	483.6			**9.24 %**			
		BR21 Op30 Pad Gap	A/S	7439	124.0			**2.37 %**			
		BR22 Op40 Finished Notch	A/S	5748	95.8			**1.83 %**			
		MC28B Robot 1	ROBOT SIC BR21	292	4.9			**0.09 %**			
		MC28B Robot 2	ROBOT SIC NC209	152	2.5			**0.05 %**			
		MC28B Shuttle	OUT SHUTTLE LOST HOME	175	2.9			**0.06 %**			
		ML62 Op20 Disc Radius	A/S	519	8.7			**0.17 %**			
		NC206 Op10 Datum Holes, MTG Rough Face	A/S	1755	29.3			**0.56 %**			
		NC207 Op50 Finish MTG Face, Hole/Threads, SP Holes	A/S	2263	37.7			**0.72 %**			
		NC208 Op50 Finish MTG Face, Hole/Threads, SP Holes	A/S	1109	18.5			**0.35 %**			
		NC209 Op50 Finish MTG Face, Hole/Threads, SP Holes	A/S	1715	28.6			**0.55 %**			
		NC210 Op50 Finish MTG Face, Hole/Threads, SP Holes	A/S	1516	25.3			**0.48 %**			
		PL7 Op70 Plugger	PLUG JAM	5426	90.4			**1.73 %**			
		Robot 1	OUT SHUTTLE CYCLE TIME OVER	65	1.1			**0.02 %**			
		Robot 2	sic	52	0.9			**0.02 %**			
		Shuttle	not home	38	0.6			**0.01 %**			
		WS44 Op60 Washer	SIC	750	12.5			**0.24 %**			

Figure 45 Pre Installation Down Time

Area	Down Time Type	MC	Failure Type Desc	DT Mins	DT Hrs	Prod Mins	Pcs	DT %	Down Time Date	Shift Name	Down Time Desc
MC#28 Bracket				19971.0	332.9	154522	265935	12.92 %			
	Cycle/Short Stops			19971.0	332.9			12.93 %			
		BR21 Op30 Pad Gap	A/S	1826	30.4			1.18 %			
		BR22 Op40 Finished Notch	A/S	1774	29.6			1.15 %			
		MC28B Robot 1	ROBOT 1 DOWN	672	11.2			0.44 %			
		MC28B Robot 2	SIC NC209 GRIPPER #1	1265	21.1			0.82 %			
		MC28B Shuttle	SIC	15	0.3			0.01 %			
		ML62 Op20 Disc Radius	A/S	353	5.9			0.23 %			
		NC206 Op10 Datum Holes, MTG Rough Face	A/S	331	5.5			0.21 %			
		NC207 Op50 Finish MTG Face, Hole/Threads, SP Holes	A/S	3085	51.4			2.00 %			
		NC208 Op50 Finish MTG Face, Hole/Threads, SP Holes	A/S	2176	36.3			1.41 %			
		NC209 Op50 Finish MTG Face, Hole/Threads, SP Holes	A/S	3243	54.1			2.10 %			
		NC210 Op50 Finish MTG Face, Hole/Threads, SP Holes	A/S	2810	46.8			1.82 %			
		PL7 Op70 Plugger	JAMS	2274	37.9			1.47 %			
		WS44 Op60 Washer	SIC	147	2.5			0.10 %			

Figure 46 Post Installation Down Time

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