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Development of a Heavy-Duty Aluminum Rail Hole Punch Manufacturing Fixture

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DEVELOPMENT OF A HEAVY-DUTY ALUMINUM RAIL HOLE PUNCH MANUFACTURING FIXTURE

By

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Abstract

This report details the development and testing of an improved replacement for a worn manufacturing fixture which was used to position the location of four drilled holes on the outside of a heavy-duty aluminum rail. Commissioned by JohnDow Industries, the new process improves upon the old one by implementing an electro-hydraulic punch and new locating fixture. The new design produced higher quality slots, decreased cycle time by 15%, and aimed to improve the ergonomics of the process for the employees. All these factors contributed to making the aluminum rails a high-quality end product for JohnDow's customers. Further iteration of the design will improve the accuracy of the slots and the ergonomics of using the punch.

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1. Introduction

The purpose of this project is to develop an improved replacement for a manufacturing fixture which is used to drill four holes in the outside of a heavy-duty aluminum rail which can reach up to thirteen feet long. Because the old fixture was no longer viable, three concepts were developed and evaluated to replace it, with the best of these concepts being further refined and prototyped. The new fixture and tool improved the quality of the holes, improved cycle time, and aimed to improve the ergonomics of the process for the employees. These improvements will result in a high-quality product that satisfies JohnDow's customers. This project report details the conceptual development, prototyping, validation, and costs of developing and testing a new fixture and the reasoning behind the steps taken.

1.1 Background

The project was sponsored by JohnDow Industries, a company located in Barberton, Ohio, who serves the aftermarket automotive industry. They provide two sizes of aluminum rail to their customers: a smaller, one-piece automotive rail and a larger, two-piece heavy-duty rail, each with a maximum manufactured length of 13 feet. This project is concerned only with the heavy-duty rail. The rail is fabricated by an external company and brought in-house so the holes can be created before being sent into the field for installation. Each hole is ninety degrees apart and located as shown in Figure 1. They are used to connect rails together using a coupler, as seen joined in Figure 2. In the field, they are installed on the ceiling of an automotive service centers, which means it is likely that any issue with the rails is not apparent until it is already 25 feet in the air.

Figure 1: Heavy-duty rail and hole positions.

Figure 2: Heavy-duty rail and coupler joined.

The old fixture, pictured in Figure 3, utilizes a drill to create the holes in the rail, with the full process listed in Appendix A. It is nearly 10 years old and does not perform as well as it once did. When a hole is placed incorrectly, it is usually not discovered until it is being installed in the field, which means the installation crew must then drill a new or oversized hole, costing them valuable time and money. The drill also has unsatisfactory hole quality, as seen in Figure 4, and produces shavings which get caught in crevices in the rails. Lastly, the employees who use the fixture are dissatisfied with the process because of its unergonomic setup for drilling and the worn and ineffective fixture. For these reasons, this project was started to replace the fixture and develop an improved process that would maintain the high quality of JohnDow's aluminum rails.

Figure 3: Old fixture and rail setup

Figure 4: Hole quality of old process

1.2 Objectives and Constraints

A variety of constraints for the project to meet were developed and are listed below. These provide guidance and goalposts to measure the success of the project. They center around the quality of the holes/slots, keeping the solution simple, remaining within budget, making the process ergonomic for the employees who will use it, and ultimately ending with a high-quality product that satisfies customers.

- Tool
  - Clean holes/slots
  - Weigh equal to or less than old tool (8.55 lbs)
  - Within budget ($5000)
- Fixture
  - Weigh equal to or less than old fixture (5 lbs)
  - Position holes/slots accurately
  - Easy to understand
  - Easy to manufacture
  - Within budget ($5000)
- Process
  - Equal to or faster than old process (270 s)
  - Ergonomic for employees

2 Design

The first step of the design was selecting the tool to be used for the process. Based on the recommendation of the project sponsor, an electro-hydraulic punch was chosen as the new tool, specifically a Hougen-Ogura 75002.5A, of which a model is shown in Figure 5. This method produces slots which give a better range of clearance for the bolts versus the oversized holes which had been drilled before. Rather than having to clean up shavings, the punch creates one-piece slugs which are easy to collect and do not get caught in the rail's crevices. Cycle time will also be improved as the punch is faster than the drilling process, which took 27 seconds per hole. This kind of punch was already used to create slots in the automotive rails and a backup punch was available to use, so it made sense to utilize this method. For clarity going forward, Figure 6 gives the terminology used for the rail components.

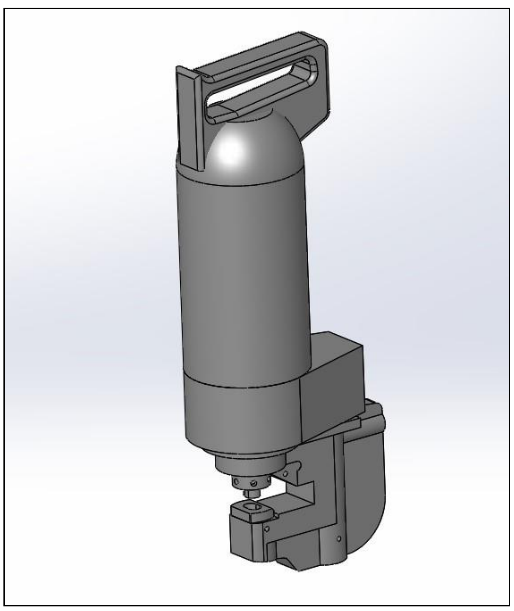

Figure 5: Hougen-Ogura electro-hydraulic punch

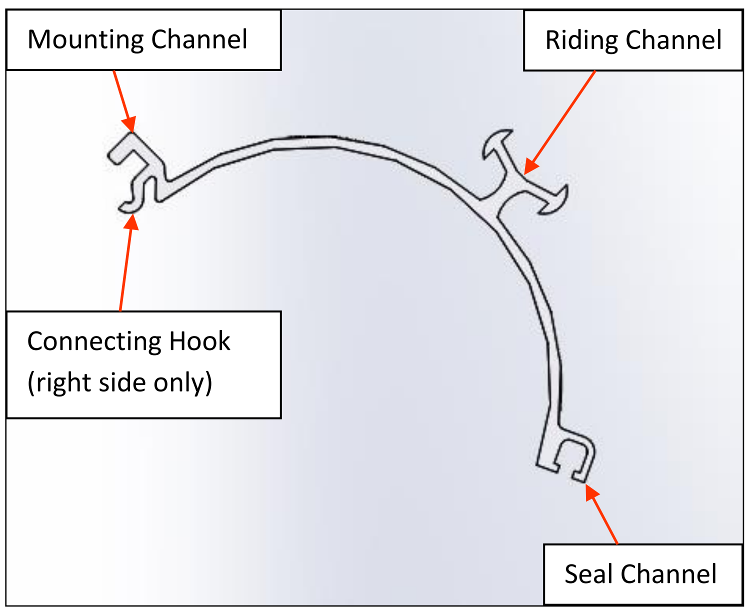

Figure 6: Rail terminology, right side

2.1 Design Strategy

This task was approached as an open-ended design project, so multiple concepts were created and weighed against one another to determine the best solution to the problem. The concepts created were presented to the sponsor and discussed to determine which was most preferable and able to meet the constraints, schedule, and budget of the project.

2.2 Conceptual Design

Three fixture concepts were developed as potential candidates to move forward into embodiment design. Each concept was roughly modeled in SolidWorks to get an idea of the scale and function of each.

2.2.1 Concept 1: Fixed table

The first concept was a workstation which had already been design and was on file at JohnDow but had never been fabricated, as seen in Figure 7. It would function by holding the tool fixed and moving the workpiece into position. First, a rail half is placed onto the two supports, then it is slid towards the punch on Teflon strips that allow it to slide easily. The angular position of the slots is set by locating off the channel on the side of the rail, while the depth is set by the back-plate, seen in Figure 8. Its design is very complex, so the time it would take to update, fabricate, and assemble would be extensive.

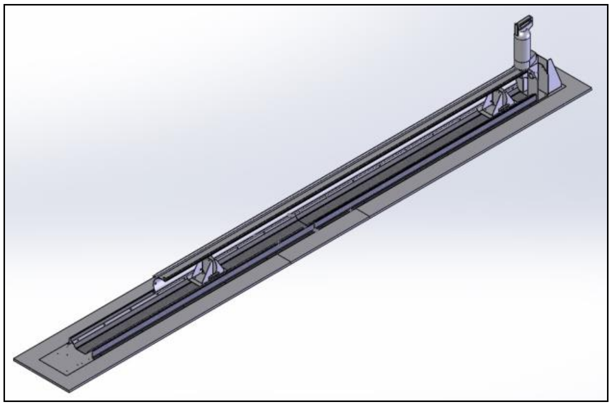

Figure 7: Concept 1 complete model

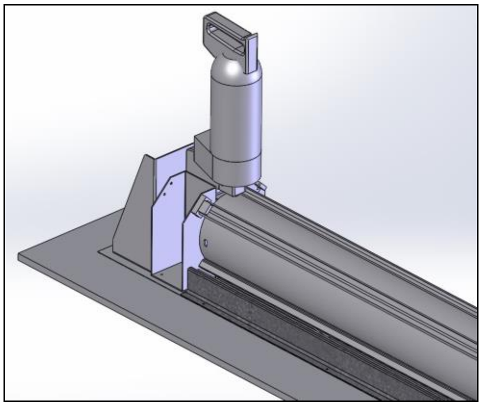

Figure 8: Close-up of concept 1 locator and punch fixture

2.2.2 Concept 2: End Locator Fixture

The second concept was designed based off the locator used to punch holes in the automotive rails, as seen in Figure 9. Rather than using an expensive machined part, however, the same function for use with the heavy-duty rail could be achieved using sheet metal, as shown in Figure 10. Here, the fixture was fixed while the tool was moved by the employee to punch holes. The 3 cutouts locate the angular position of the slots and the backplate provides the proper depth. HDPE blocks would then be used to locate the fixture to the channel on the rail. Instead of punching holes in joined heavy-duty rails, however, the rail halves would be punched first before sliding them together; this is done so that the rails can be placed flat onto sawhorses or a table during the process and so that the punch will not need to be held at an awkward angle. Its operation is very similar to the old process and would be simple to fabricate, assemble, and test within the schedule.

Figure 9: Automotive rail machined fixture inspiration

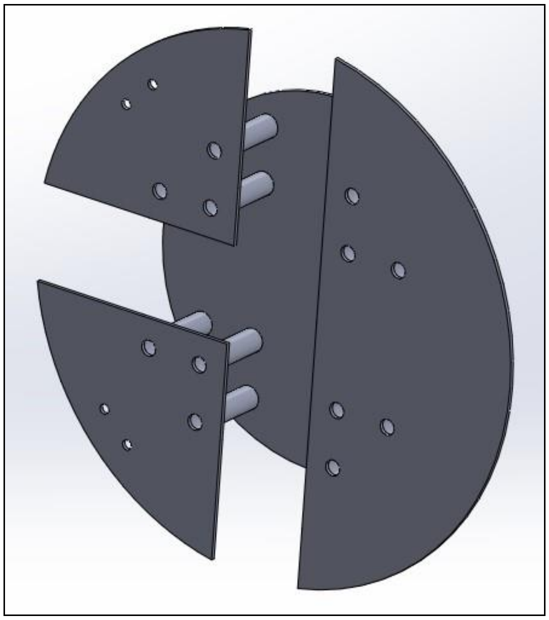

Figure 10: Concept 2 rough SolidWorks model

2.2.3 Concept 3: Expanding Table

The third concept was designed to be compactible so that it could be easily stored and would not take up much space. It was designed to use prefabricated plastics carts which are connected with metal tubing and custom brackets, as seen in Figure 11. During operation, the employees first open the cart to the desired length depending on the size of rail. Then, like concept 1, it is designed with a fixed tool with a moving workpiece which locates using the channel on the side of the rail half.

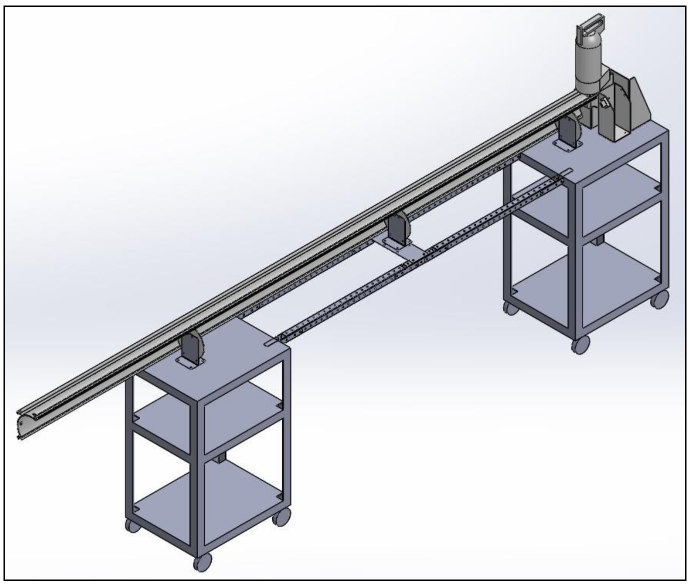

Figure 11: Concept 3 SolidWorks model

2.2.4 Concept Evaluation

Each of the concepts was evaluated by the project sponsor and the team based on the constraints, with concept 2 determined to be the best solution to move forward with. It is similar to the current process, so the transition should be easier for the employees than the other concepts discussed. The only point where concept 2 may need further work is with ergonomics and using the punch, which is very heavy at 24.9 lbs, but this concept best meets the other criteria of the project.

2.3 Embodiment Design

This stage involved fleshing out the design and creating a full model which was fabricated for validation of the fixture. Views of the fixture are seen in Figures 12 and 13, where the primary components are labelled for future reference in the paper.

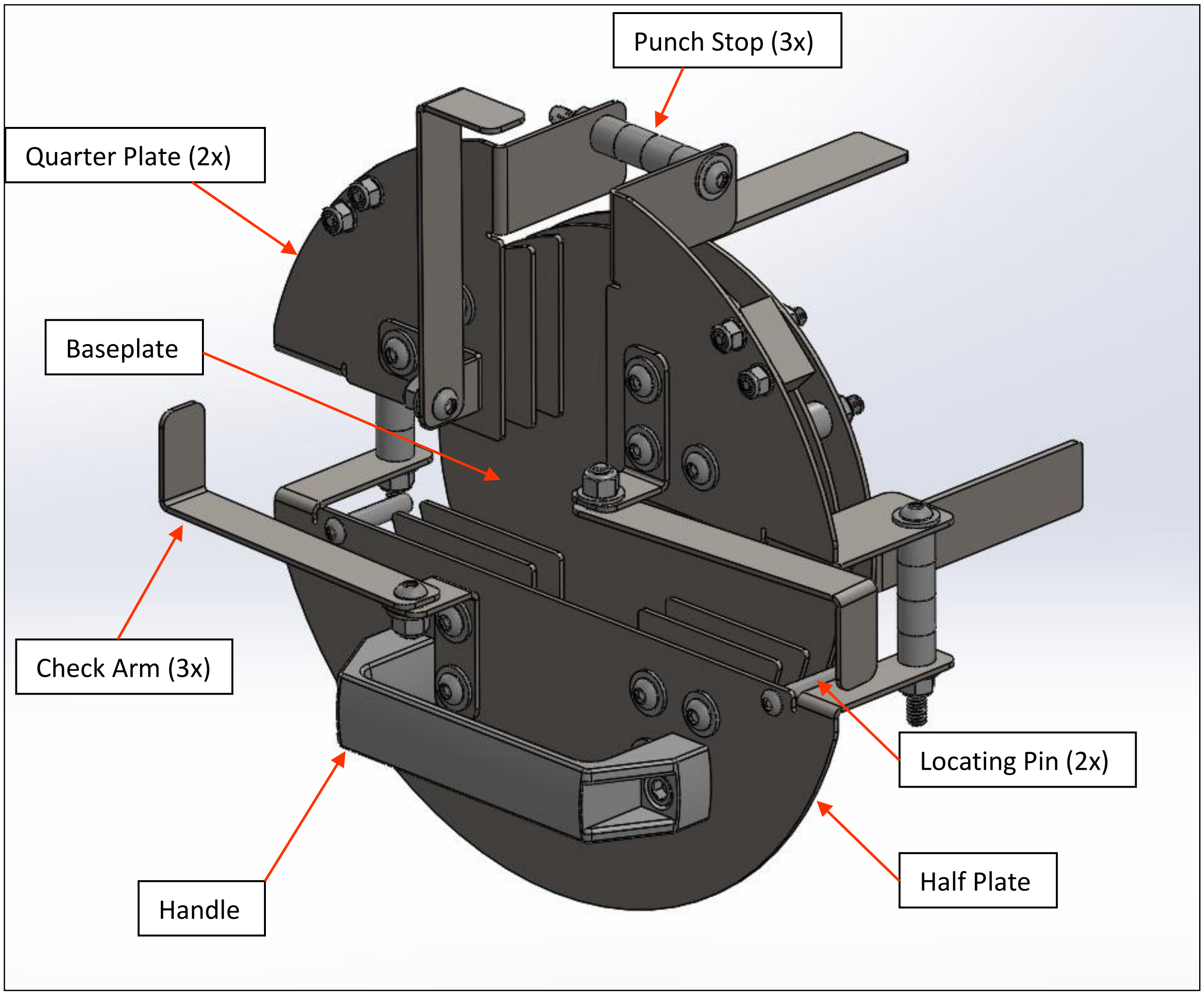

Figure 12: Prototype fixture design and terminology

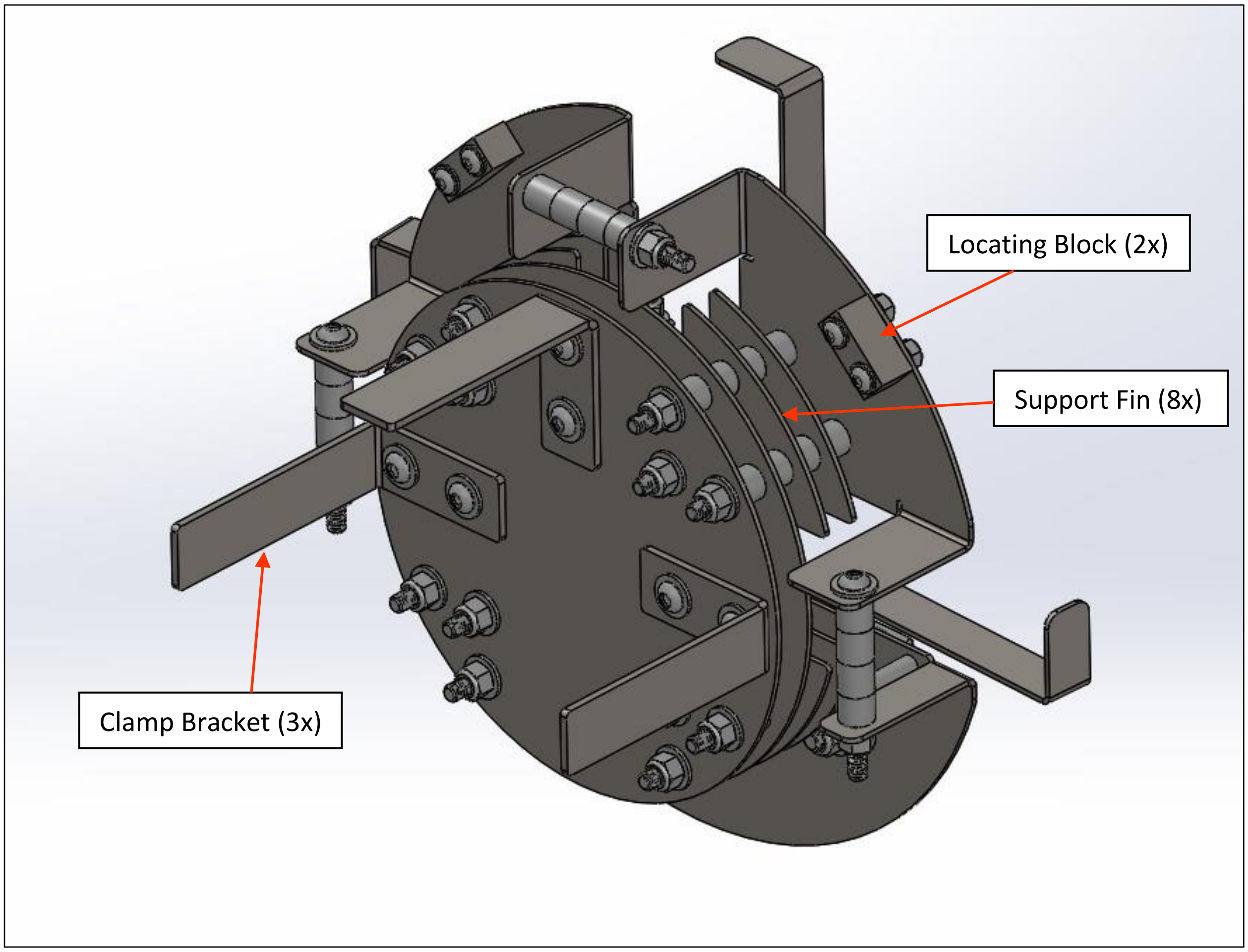

Figure 13: Alternate view of prototype fixture design and terminology

2.3.1 Engineering Standards

Relevant engineering standards for this project are those dealing with drawings, dimensioning, hole tolerances, and the safety of the workers using the fixture and punch. Holes were sized according to ASME standard B18.2.8 to have proper clearance. For example, for a ¼" diameter size bolt, the appropriate diameter of hole for normal clearance is a 9/32" drill size, with 0.281" diameter at minimum and 0.290" at maximum. ASME standard Y14.5 was applicable to properly dimensioning engineering drawings which can be interpreted by other engineers and the individual who ultimately fabricates the components. Employee safety while using the punch and new fixture is also important, as is the ergonomics of lifting both the tool and the fixture into place, with the National Institute for Occupational Safety and Health

(NIOSH) having recommended 51 lbs as the maximum load an employee should manually lift (p. 13).

2.3.2 Slot Position Calculations

The preliminary calculation which needed to be completed is the position of the slots relative to the coupler. Looking at the coupler, the center-to-center hole distance is 46.6mm, which means that the center of the slot in the rail will have to be set 23.3 mm into the end of the rail. The hydraulic punch will locate off the bottom piece which holds the die, measuring 8 mm between the edge of the slot and the edge of the punch, while the die itself measures 13 mm across as visualized in Figure 14. Adding up these measurements, the depth of the stopping plate is calculated in Equation 1, totaling to a depth of 37.8 mm.

$$(23.3 + 6.5 + 8)\text{ mm} = 37.8\text{ mm} \tag{1}$$

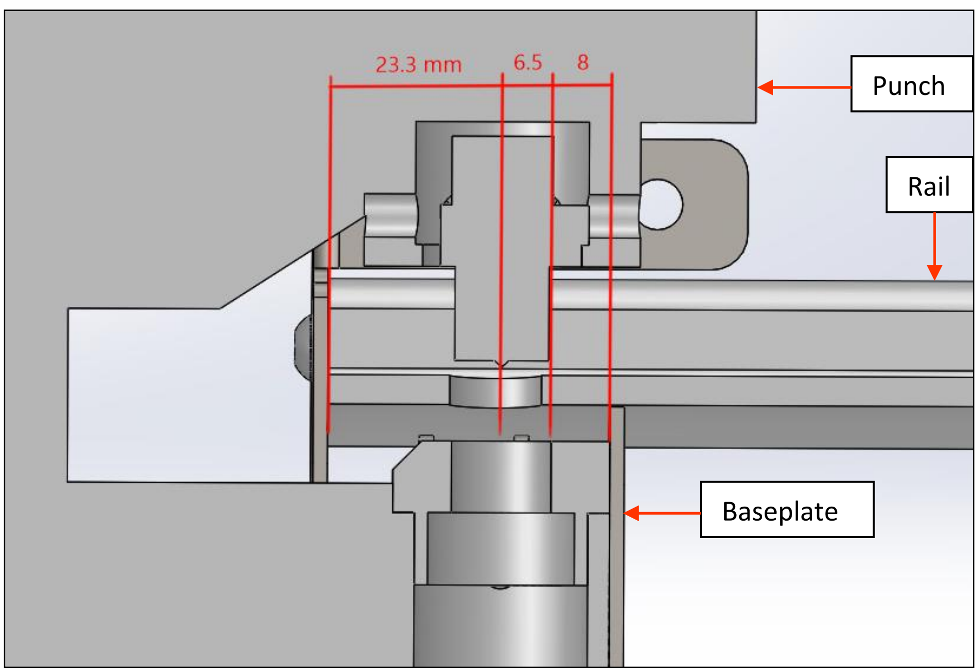

Figure 14: Section view of the dimensions of punch, die, and slot

Besides the depth of the holes, the angular placement of the holes and their relation to the edges of the rail must be established. This is aided by the fact that a model of the heavy-

duty rail was already on file, which was checked against the measurements of a current sample. There is a 90-degree angle between each hole, including those on the opposite half of the rail, with a 45-degree angle between the centerline of the mounting channel and the first slot position as seen in Figure 15. Between the second slot and the seal channel the angle is 20.2 degrees.

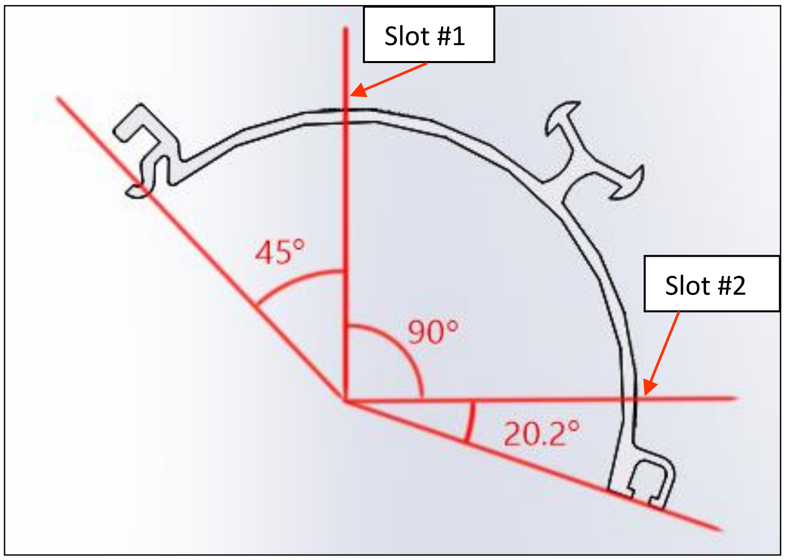

Figure 15: Slot angles for design

2.3.3 Detailed Design and Interfaces

The primary function of the fixture is to control the interface between the user, the rail, and the punch. First, user interface occurs between the handle, clamps, and check arms. The handle was added to provide a convenient method of handling the fixture during use, with the punch stops also serving as good points to help maneuver the fixture. After this, the clamps are applied on the clamping bracket and outside of the rail, which is protected from scratching by rubber on the jaws, setting the fixture into the proper location as seen in Figure 16. During operation, after the punch is inserted the check arms are raised to hold the punch in and confirm that it is inserted completely.

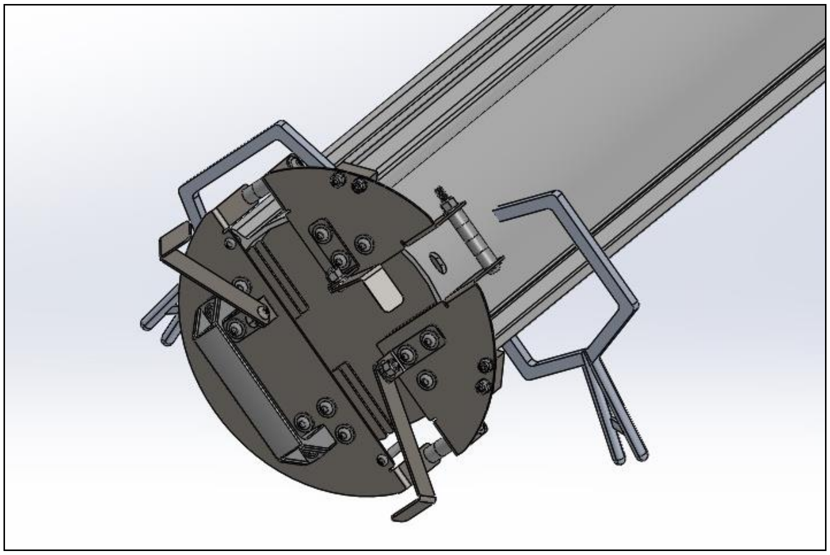
Figure 16: Fixture placed onto rail and clamped

Its interface with the rail is comprised of the locating blocks, locating pins, baseplate, support fins, and clamp brackets. HDPE locating blocks and stainless steel locating pins were used to align the fixture with the angular position of the slots. There are two of each locator, as seen in Figures 17 and 18, so that it can be used interchangeably between ends. The riding channel is located 45 degrees from both slots, making it a convenient place to locate the angular position of the fixture using the locating block. Additionally, the locating pins fit into the seal channel to provide a third point of contact. On the inside of the rail, the baseplate and support fins are used to create multiple points of contact which help to align the fixture concentric to the rail. The clamp brackets provide a clamping surface for the clamps which hold the rail firmly in place while the punch is operating and ensures that the fixture is appropriately held in place. While the rest of the sheet metal components are made from 14 gauge steel, approximately 2 mm thick, the clamping brackets are made of 11 gauge steel, approximately 3 mm, so that they are strong enough to hold the assembly to the rail.

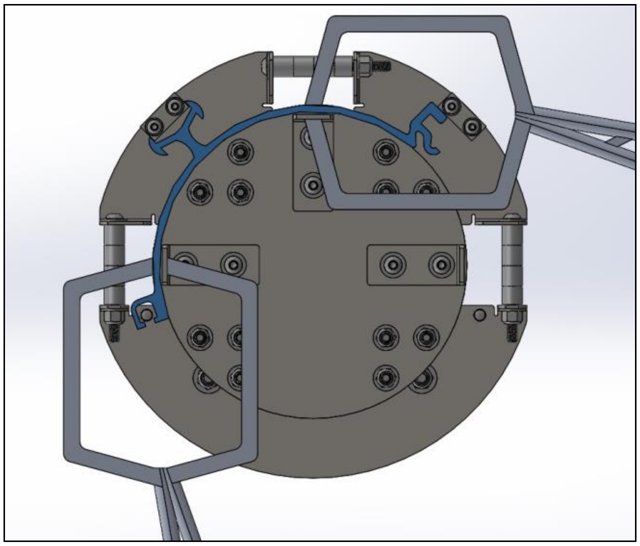

Figure 17: Left configuration of rail

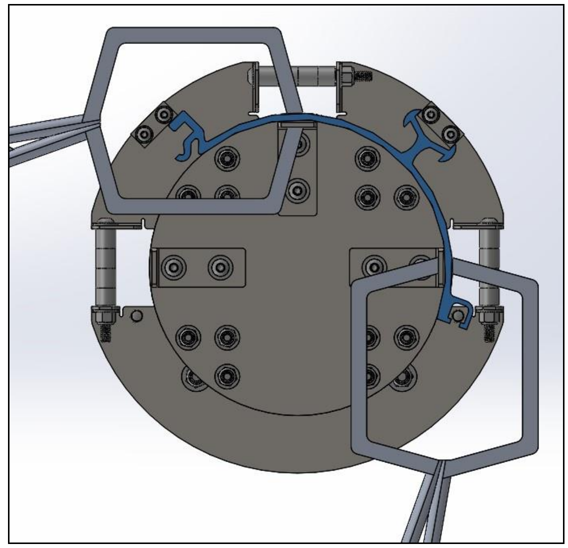

Figure 18: Right configuration of rail

Finally, the punch interface occurs between the baseplate, support fins, quarter plate, half plate, punch stop, and check arm. As discussed before, the baseplate provides the depth of the punch and slot position. However, more guides and points of contact are needed to constrain the potential angular rotation of the punch during use. Thus, the support fins and return on the quarter and half plates prevent the punch from being rocked left or right, while the punch stopper gives a second point of contact the prevent the punch from rocking up or down. Lastly, the check arms are rotated to touch the back of the punch and confirm that it is inserted fully. Figure 19 illustrates the insertion of the punch while Figure 20 highlights three points of contact for the punch.

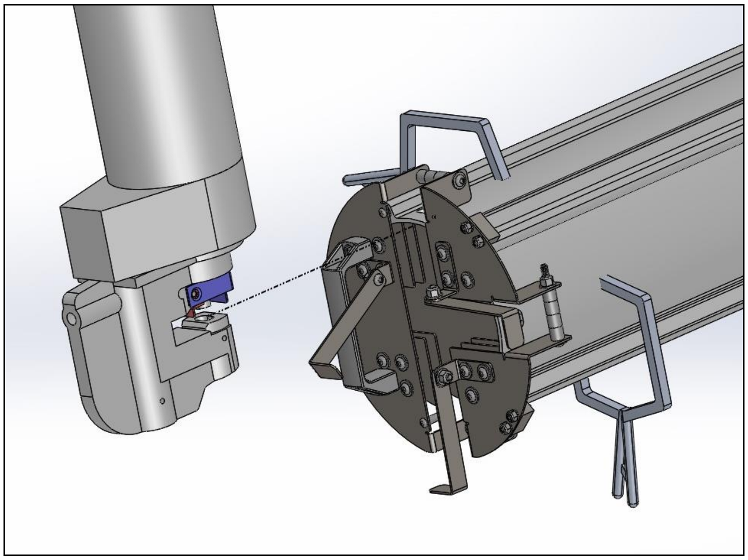

Figure 19: Inserting punch

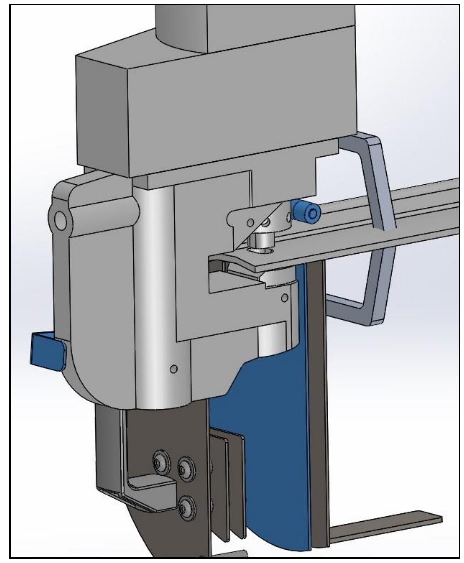

Figure 20: Punch interface with fixture

2.3.4 Punch Stripper Design

For the hydraulic punch to work effectively, strippers are attached besides the punch and serve to hold the workpiece down and prevent the punch from falling into the new slot. Because of the unique shape of the rail, the strippers which came with the punch were too wide and interfered with the seal channel, as shown in Figure 21, and was not discovered until testing began. A new, two-piece stripper, shown in Figure 22 and 23, was designed with cutouts for the channel which would mount onto the same holes as the previous one. It had to be two-pieces so that it could be assembled onto the punch, otherwise it would make it very difficult to turn the holding nut which holds the punch onto the tool. To fit within the fixture, the components had to be made of thin 19-gauge steel and countersunk so there was no interference.

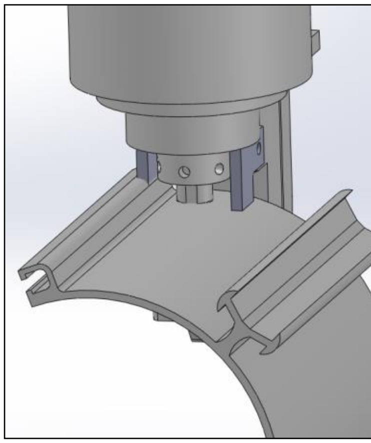
Figure 21: Old stripper interference

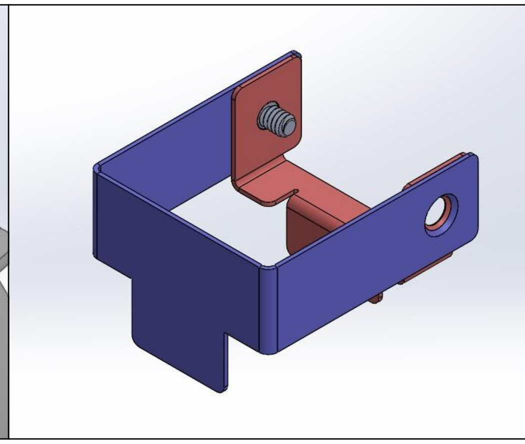
Figure 22: Stripper CAD model

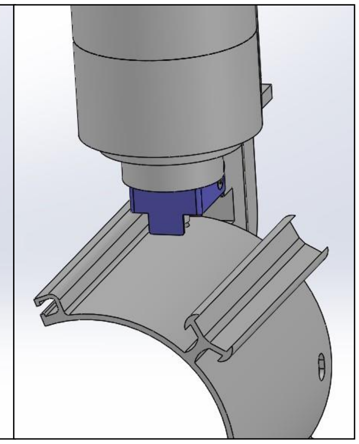
Figure 23: New stripper clearance

2.3.5 Hardware

Where possible, hardware was specified as ¼”-20 thread size to maintain consistency. Smaller 10-24 hardware was used for the locator blocks and pins and 5/16”-18 for the handle according to the required size. Initially, all hardware was specified as 18-8 stainless steel to resist wear during use, but this was later replaced with regular steel hardware. During operation, the punch generates vibrations which travel into the fixture, so nylon insert locknuts were used to prevent the fixture from coming loose over time. Two sizes of pre-machined spacers were utilized to achieve the desired spacing between the quarter and half plates, support fins, and baseplate, giving a true depth of 38.9 mm compared to the ideal 37.8 mm. This error, 1.1 mm, is very small but may still influence the accuracy of the slots. In the verification stage the hole depth will be further tested and examined.

2.3.6 Detailed Drawings, Exploded View, and Bill of Materials

Detailed drawings of all components have not been added to this document for reasons of confidentiality. An exploded view is shown in Figure 24 which gives a view of the construction of the fixture. A bill of materials for the prototype fixture is listed in Appendix B.

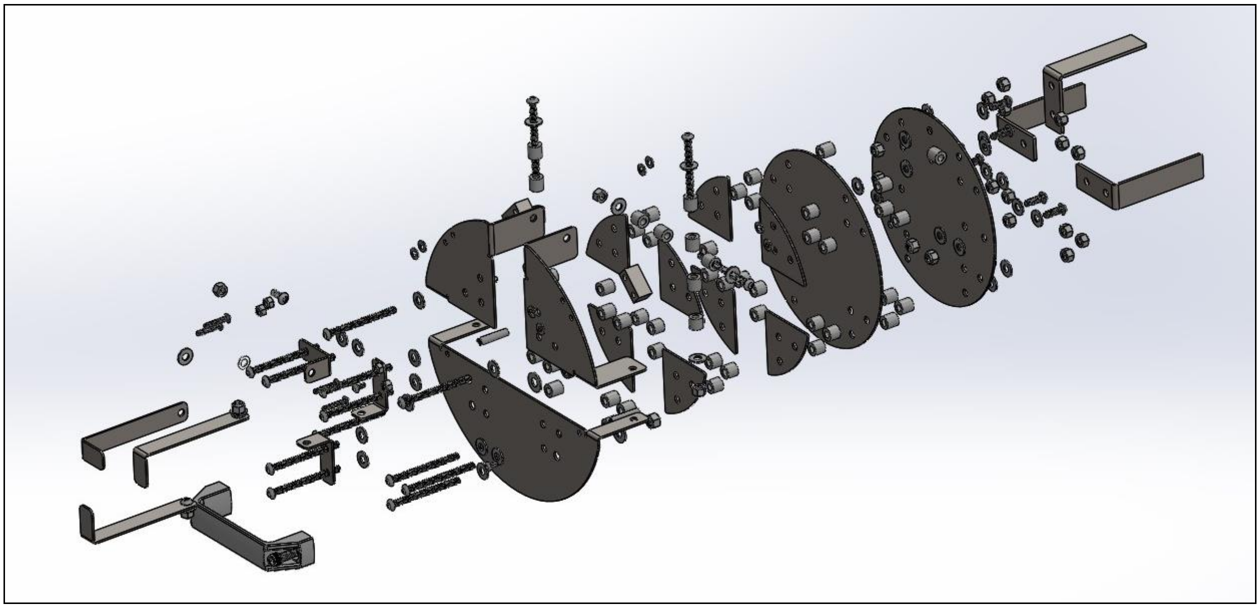

Figure 24: Exploded view of fixture

2.3.7 Final Process

The final process that was developed for the fixture and punch follows similar steps to the original process and is found in Appendix C. Ideally, the new process includes sawhorses and a cart which eases the transport of the punch and fixture between the ends of the rail, as pictured in Figure 25.

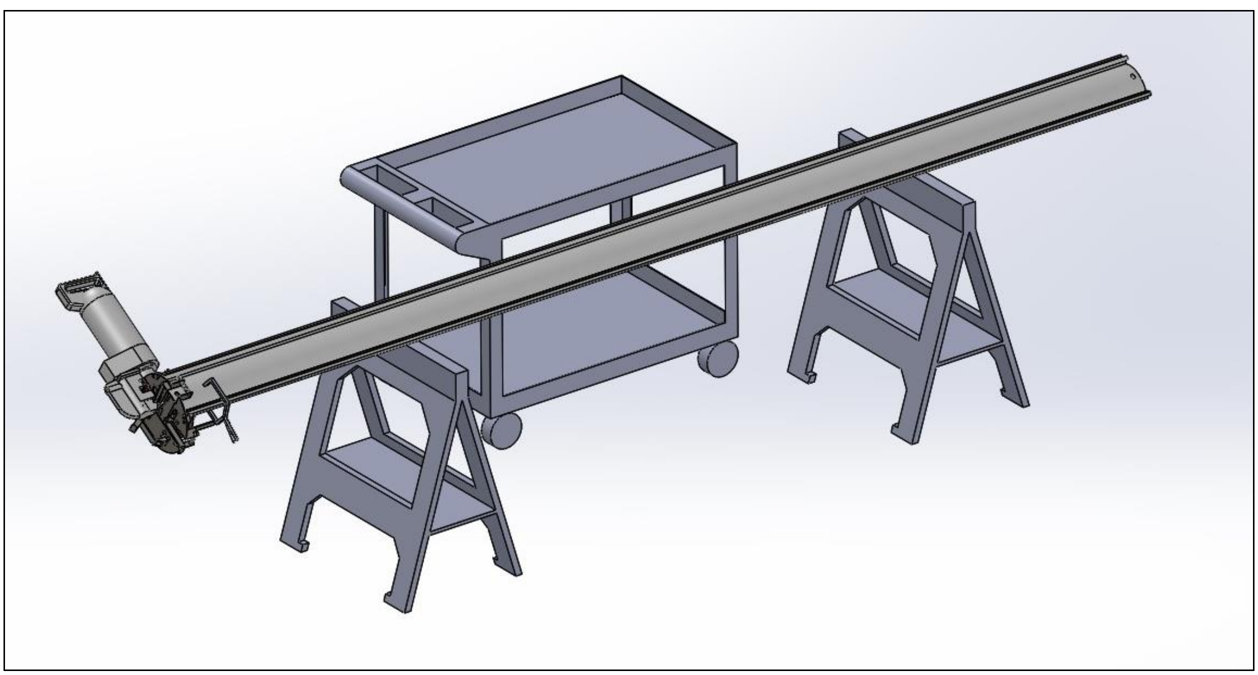

Figure 25: Complete process setup

3. Design Verification

After prototype design was completed, the verification stage involved testing to see if the prototype met the requirements of the project and looked for ways to improve the process. The fixture properly fit onto a heavy-duty rail after some adjustments were made in assembly. Cycle time was determined to be 15% faster than the old process and the punch produced clean slots. Based on six samples, slot depth accuracy was found to be 1.56 mm off center on average. If further testing confirms this, the fixture can easily be adjusted to correct this problem. Overall, the fixture meets the requirements for the project, but further design iteration and improvement can be made.

3.1 Fixture Assembly

Before receiving the fixture, a breakdown of the punch was created in SolidWorks using explode functions and compiled into a drawing file for printing. During assembly, it was found that the direction of the 12 primary bolts made it difficult to assemble with the many washers and spacers, so their direction was reversed on the actual assembly. This has not yet been updated in the SolidWorks model or instruction manual.

An issue was found with the 18-8 stainless steel hardware during assembly when the nylon insert locknuts were locking up on the threads. Force was applied to the nut with a vise and pliers to the point where the metal yielded rather than coming free. Researching this issue online, it was found that stainless steel is susceptible to galling because of friction, especially when the hardware is the same grade (Greenslade, para. 1-2). The nylon-insert locknuts had created increased friction between the two parts and led to galling and jamming of the nuts and bolts. This issue was resolved by ordering all new carbon steel hardware which did not

suffer from galling. Because the fixture is not being used in a highly corrosive environment, it was determined that stainless steel was unnecessary in extending the life of the fixture.

3.2 Fitment Testing

After assembly was complete, the fitment of the fixture was tested to ensure that everything fit together properly. Fitting a short test piece of rail onto the fixture, as seen in Figure 26, the baseplate radius fit snugly into the rail. However, after adding the clamping brackets it was found that they had been fabricated incorrectly and stuck out 3mm over the baseplate. This caused a gap between the fixture and the rail, as seen in Figure 27, and would lead to inaccuracy during slot punching. To rectify this, 10-24 hardware that was on-hand was used to move the clamping brackets inward for further testing. No further action has yet been taken to get new brackets made.

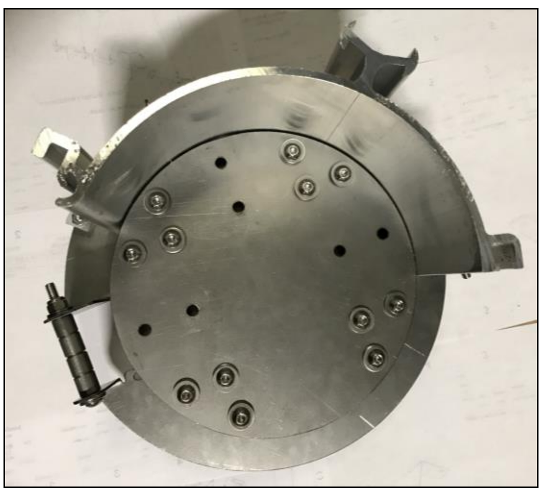

Figure 26: Baseplate fit

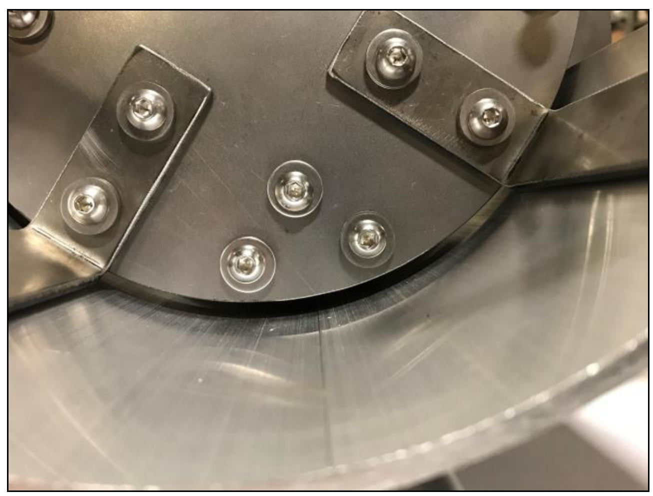

Figure 27: Gap from incorrect clamping bracket

Two other issues were found regarding the locating blocks, half- and quarter plates. For the plates, their guide returns were very tight to the outside of the rail and during insertion of the fixture the outside of the rail was scratched by the metal edge. To remedy this, PTFE tape was applied to the returns as seen in Figure 28. Alongside this issue, the locator block for the

alternate configuration interfered with the edge of the rail. This was addressed by moving the mounting holes for the locator block closer to the edge so it could be spaced out further from the mounting channel of the rail, allowing it to fit as seen in Figure 29. It was also determined that the locating pins were not necessary for locating the angular position of the fixture because the locating blocks already had two points of contact with the riding channel.

Figure 28: PTFE applied to returns, before and after

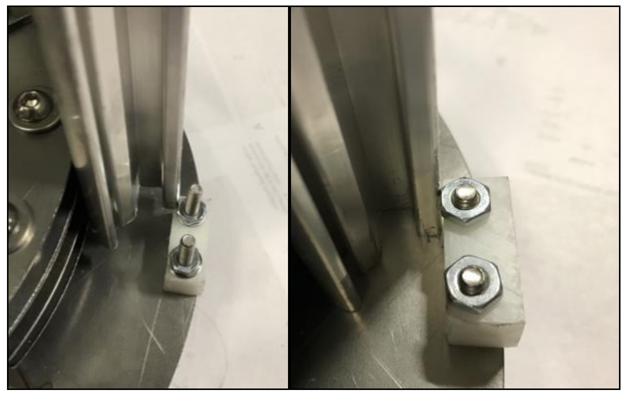

Figure 29: Locating block clearance issue, before and after

3.3 Process Testing

Next, the punch was tested to determine fitment and cycle time, as illustrated in Figure 30. It was measured to take six seconds per slot to extend and return the punch, which is significantly faster than the 29 seconds it took to drill and widen the holes in the original process. During testing it was found that the punch was falling into the slot it had made and was difficult to remove from the rail and fixture. This is because there was no rail stripper on the punch to hold the workpiece down when the punch was returning. As discussed in chapter 2, a new stripper was designed with cutouts to fit the unique shape of the rail. It was also found that the rails were being widened by 3-4 mm because of the forces exerted by the punch and die. This can be amended by machining a curve onto the die. The quality of the slots, shown in Figure 31, was greater than the quality of the holes drilled using the old process.

Figure 30: Punch testing

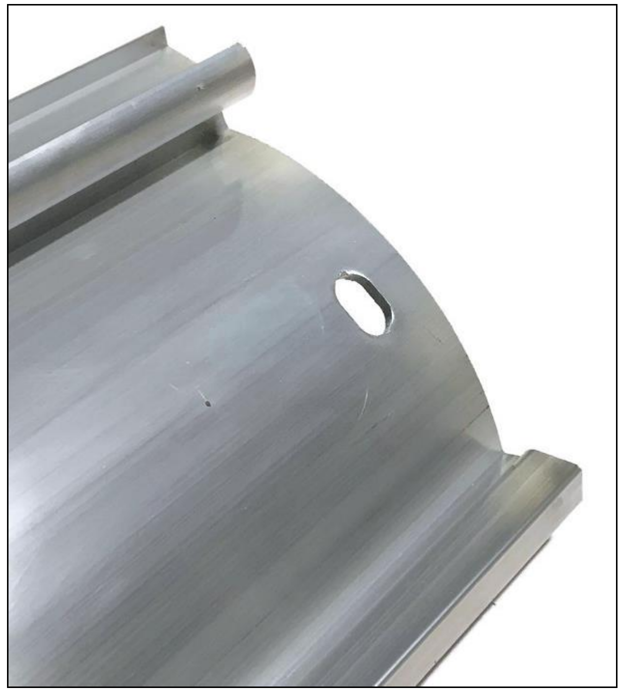

Figure 31: Improved slot quality

To calculate the approximate cycle time of the fixture, the process was acted out using the fixture, clamps, punch, and a six-foot piece of rail used for testing. The new process shown in Appendix B was followed, with the exclusion of the cart and a table used instead of sawhorses. To simulate putting the fixture on two rail halves, the fixture was inserted and removed on the same rail twice. Instead of running the punch, a six-second count was used, with the entire process time being recorded using the stopwatch app on a cellphone. After six runs, the best time achieved was 200 seconds, excluding the time taken to slide the rails together which takes approximately 30 seconds. This is 40 seconds better than the previous process, a 15% increase in speed, with time being gained because of the speed of the punch and some time being lost because only two slots can be punched before the fixture needs moved, unlike the original process which could drill four holes before moving the fixture. This time could be improved by further practice with the process and the addition of another employee.

3.4 Slot Accuracy

Six measurements were recorded from testing the punch and are listed in Table 1 below. The distance measured was between the end of the rail and the edge of the slot, shown in Figure 32, which ideally should measure 16.8 mm. These samples, whose average is 15.26 mm with a range of 2.82 mm, is 1.56 mm difference from the ideal. This can be compared to the 1.1 mm difference between the calculated and actual spacing of the backplate, so it makes sense that there is a small amount of error present. Further measurements are needed to form a more conclusive analysis, and if the distance needs to be adjusted the combination of washers and unthreaded spacers can be altered to change the backplate distance can be modified.

Table 1: Slot measurements, D

Measurements (mm)	Calculations (mm)	
14.05	Average	15.26
16.32	Range	2.82
16.38		
15.87		
13.56		
15.40		

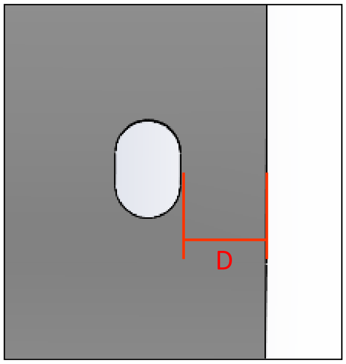

Figure 32: Distance measured

The punched rail samples were then fitted with a coupler to see if the holes lined up properly. In Figure 33, the end-to-end fitment of the slots and coupler is proven out, in the future the position of the slots could be improved based on the measurements taken above. Figure 34 shows that the angular location of the slots is correct, though they do not all align with the center of the slot as seen in Figure 36.


Figure 33: Coupler and rail end-to-end fitment


Figure 34: Coupler and rail angular fitment

Looking closer at the hole position by removing some bolts, the holes do not seem to have a clear pattern showing which way they tend to vary towards as seen in Figures 35 and 36. Thanks to the larger size of the slot, there is greater allowance for variance where the bolt can still fit even if the slot is not punched perfectly. In Figure 36, a mark is also seen on the left where the punch scraped the seal channel. Further testing will need to be done to determine if it occurs frequently or not.


Figure 35: Hole location offset


Figure 36: End-to-end hole location offset, worst example

3.5 Constraint Evaluation

Returning to the constraints established for this project, the tool, fixture, and process can be evaluated based on the testing performed with the results summarized in Table 2. Both the tool and fixture weigh more than their counterparts from the old process. The fixture should not be a problem, but the weight of the punch is significantly heavier than the drill. This could be addressed by creating a fixture for the punch which removes the need for the employee to lift it and can pivot 90 degrees to reach both slot positions. By addressing this issue, the process will be more ergonomic for the employees using it. For the fixture, the accuracy of the hole location will need to be further tested to ensure that it is satisfactory, with the fixture able to easily adjust by the addition of a washer to the 12 bolts that go through the baseplate.

Table 2: Tool, Fixture, and Process Evaluation

Section	Constraint	Evaluation
Tool	Hole Quality, Clean Holes/Slots	Yes
	Weigh less than or equal to old (8.55 lbs)	No, 24.9 lbs
	Within Budget ($5000)	Yes
Fixture	Weigh less than or equal to old (5 lbs)	No, 7.20 lbs
	Accurate Holes	Needs Improvement
	Easy to Understand	Yes, like old process
	Easy to Manufacture	Yes, made of sheet metal and basic hardware

	Within Budget ($5000)	Yes, $2552.78
Process	Cycle Time, faster than or equal to old (270 s)	Yes, 230 s
	Ergonomic for Employees	Needs Improvement

4. Costs

A budget of $5000 was funded by JohnDow to complete the project. The project was completed under budget, primarily because a backup punch was available to use rather than purchasing a new tool, which otherwise would have added a cost of about $2500. Sawhorses and a cart which were discussed in design have not been purchased, so once the fixture is fully implemented it would be useful to purchase those items. The expense of the project totaled to $2552.78, just over half of the allotted budget.

4.1 Parts

As the project progressed, a costed bill of materials was created with Microsoft Excel to track the cost of the project. McMaster Carr was the primary supplier because of the fast shipping and availability of hardware and parts. The general categories of cost are listed in Table 3, and a full costed bill of materials can be found in Appendix D.

Table 3: Part Category Costs

Part	Supplier	Actual Cost ($)
Hardware	McMaster Carr	$400.22
Sheet Metal Components	Beacon Metal Fabricators	$197.00
Tools	McMaster Carr	$47.56
	Total	**$644.78**

4.2 Labor

Because this was an industry sponsored project, labor compensation was provided at a rate of $18 an hour. The total amount was tracked on the company’s online payroll software, so

the exact amount of labor, shown in Table 4, was calculated over the 9 months of work on the project.

Table 4: Labor Costs

	Hours Worked	**Compensation**
Semester 1 (August – December)	42.75	$769.50
Semester 2 (January – April)	63.25	$1138.50
	Total	**$1908.00**

5. Conclusion

The outcome of the project was a working prototype fixture which uses a punch to create clean holes in JohnDow Industries' heavy-duty aluminum rails. Along the way, mistakes brought about valuable lessons about the importance of understanding the old process and getting feedback from the employees before beginning design, as well as learning about material properties before purchasing special hardware. The new process still has room for improvement, both with improving the consistency of the slot depth and in creating another fixture to improve the ergonomics of the heavy punch, but the project overall has been successful at meeting its objectives. Customers will be more satisfied with the quality of the rails and the installation process with go smoothly.

5.1 Accomplishments

The project accomplished its goal of creating a working prototype fixture which can be implemented in place of the old process. Using a punch produced higher quality slots and reduced the extensive cleanup which the shavings required before. The fixture properly aligns the position and depth of the slots and the new process is 15% faster than the old process. All these factors contribute to a high-quality end product for JohnDow's customers.

5.2 Challenges and Lessons Learned

At the start of the project, too much time was spent on concept development before fully understanding the old process, which led to the loss of valuable time. By speaking to the employees who worked with the old process the criteria for improvement were better understood and aided in guiding the project objectives. The importance of understanding

material properties was also made clear when the stainless steel hardware and nylon insert locknuts created galling that fused the two together during assembly.

5.3 Uncertainties

The biggest uncertainty is the consistency of the fixture in setting slot depth. Six measurements were taken between the end of the rail and the inside surface of the slot, with 2 mm of variation between maximum and minimum value measured. One possible cause could be variation of the straightness of the cut at the end of the rails, or the punch is not held at a proper 90-degree angle. This will need to be further explored before fully implementing the process.

5.4 Ethical considerations

Employee safety while using the punch and fixture is important, as is the ergonomics of lifting both the tool and the fixture into place. The fixture is designed with minimal pinch points, and it is very difficult to accidentally insert a finger into the operating area once the punch is inserted into the fixture. Additionally, the punch is operated with a trigger by one hand while the other hand is typically supporting the punch, so it is very unlikely that a person will be injured by the punch or fixture. The 24.9 lb punch being used for the new process is within the 51 lb recommended manual lifting weight limit put forward by NIOSH, so it is not an excessive load for the employees who are performing the operation. However, repeated lifting of the punch during operation proves to be tiresome, so a method of improving the setup should be explored.

5.5 Future work

To continue the work of this project, the following items should be addressed:

- Because of the weight of the punch fixture, in the future a punch table should be designed which would support the punch during the operation, allowing for a 90-degree rotation to meet both required angles of the fixture and rail.
- Further iteration of the current fixture could also be performed to improve its function, especially improving the reliability of the depth as noted in the uncertainties section. One way to do this could be by improving the check arm design to better hold the punch in place.
- To complete the implementation of the fixture, a cart and sawhorses should be purchased to provide a work surface to set rails on and to aid in the transport of the fixture and punch between rail ends.
- The clamp brackets which were bent incorrectly should be re-ordered to properly align with the outside of the base circle.
- During testing it was found that the die needs to be rounded so that the rails are not bent during the operation.

References

[1] B18.2.8 (1999). *Clearance holes for bolts, screws, and studs.* ASME.

[2] Y14.5 (2018). *Dimensioning and Tolerancing.* ASME.

[3] Waters, T.R., Putz-Anderson, V. & Garg, A. (1994). *Applications Manual for the Revised NIOSH Lifting Equation*. U.S. Department of Health and Human Services.

[4] Greenslade, J. *How To Stop Thread Galling On Stainless Fasteners.* http://www.estainlesssteel.com/gallingofstainless.html. Accessed on April 29, 2021.

Appendix A Old Process Flow Chart

Table 5: Steps for Old Process of Hole Fabrication

Step	Procedure	Duration
0	Setup - get tables, large drill with bit, locator tool, hand clamp, hand-held drill, widening bit. 2 employees needed.	N/A
1	Get rail halves and slide them together on the table. One employee on each end, 1st employee slides while the 2nd keeps the stationary rail from moving. May have to use lubrication, makes process messy.	30 s
2	Place fixture in end of rail, clamp to rail. Use hand clamp on outside to hold together halves, place 1/5th of the way away from the end being drilled.	30 s
3	1st employee drills first set of holes. After 2nd hole, remove hand clamp, it gets in the way of rotating the rail. Both employees must push on end of rail to prevent movement.	70 s
4	Move large drill, locator tool, and hand clamp to the other end of rail. 2nd employee places locator tool into rail and uses hand clamp to hold halves together. 1st employee helps support rail.	30 s
5	Repeat step D for opposite end of rail. While 2nd employee is drilling, 1st employee pushes on finished end and uses hand drill and widening bit to widen holes to desired size.	70 s
6	2nd employee removes locator tool and uses hand drill and widening bit to widen holes to 9/16" diameter.	40 s
7	For 13 foot rails, TL-230A is installed on one end to aid in installation at location.	N/A
8	Place joined rail on pallet for shipping, proceed to next rail section.	N/A
	Total Operation Time (excluding setup)	270 s

Appendix B Bill of Materials

Table 6: Bill of Materials of Fixture

Part #	Description	Quantity
1182018	Baseplate	1
1182051	Baseplate w/ mounting holes	1
1182037	Support fins	8
1182016	Quarter plate	2
1182017	Half plate	1
1182057	Arm bracket	3
1182055	Check arm	3
1182054	Clamping bracket	3
1182066	Punch stripper outer piece	1
1182067	Punch stripper inner piece	1
1182023	HDPE rail locator block (cut and drilled from 6" x 6" x 1/2" HDPE to 30mm x 15mm x 1/2")	2
92320A665	18-8 Stainless Steel Unthreaded Spacer, 1/2" OD, 1/2" Long, for 1/4" Screw Size	33
92320A878	18-8 Stainless Steel Unthreaded Spacer, 1/2" OD, 7/16" Long, for 1/4" Screw Size	27
95630A470	Chemical-Resistant PTFE Plastic Washer, for 1/4" Screw Size, 0.281" ID, 0.5" OD	3
1078A331	Plastic Unthreaded-Hole Rectangular Pull Handle, with 5-3/16" Center-to-Center, Black	1
90351A101	Tapped Taper Pins, Pin Number 5, 0.289" Large End Diameter, 1-1/4" Long	2
5105A23	Locking Plier Clamp, Pivoting Jaw, 0" to 4-1/2" Opening	2
91306A717	Button Head Hex Drive Screws, 1/4"-20 x 3" long	15

91255A539	Black-Oxide Button Head Hex Drive Screws, 1/4"-20 x 5/8" long	3
91255A540	Black-Oxide Button Head Hex Drive Screws, 1/4"-20 x 3/4" long	6
91306A341	Zinc-Plated Alloy Steel 10-24 x 3/8" long	2
91306A350	Zinc-Plated Alloy Steel 10-24 x 1" long	4
98023A029	Zinc Yellow Chromate Grade 8 Steel Washer for 1/4" screw size	51
91251A582	Black Oxide Alloy Steel Socket Head Screw, 5/16"-18 x 7/8" long	2
98023A030	Zinc Yellow-Chromate Plated Grade 8 Steel washer for 5/16" screw size	2
95615A120	Medium Strength Steel Nylon Insert Locknut, 1/4"-20	24
95615A160	Medium Strength Steel Nylon Insert Locknut, 5/16"-18	2
90729A465	Passivated 316 Stainless Steel Hex Drive Flat Head Screw	2
91210A310	Alloy Steel Cone-Point Set Screw	2

Appendix C New Process Flow Chart

Table 7: Proposed Steps for New Process of Slot Punching

Step	Procedure	Duration
0	Setup – get sawhorses, cart, fixture, two welders clamps, and punch. 2 employees ideal, but possible with 1.	N/A
1	Place both rail halves onto sawhorses	20 s
2	Place fixture in end of first rail, then fix to rail with welder's clamps.	15 s
3	Punch slots in the end of the first rail half.	20 s
4	Remove fixture and move to second rail half on the same end.	20 s
5	Punch slots in the end of the second rail half.	20 s
6	Remove fixture and place fixture and punch on cart, move to the other end of the rail halves.	40 s
7	Insert fixture into the end of the first rail half, then fix in place with welder's clamps.	15 s
8	Punch slots in the end of the first rail half.	20 s
9	Remove fixture and move to second rail half on the same end.	20 s
10	Punch slots in the end of the second rail half.	20 s
11	Slide together rail halves. May have to use lubrication, makes process messy.	20 s
12	For 13 foot rails, TL-230A is installed on one end to aid in installation at location.	N/A
13	Place joined rail on pallet for shipping, proceed to next rail section.	N/A
	Total Operation Time (excluding setup)	230 s

Appendix D Full Costed Bill of Materials

Table 8: Full Cost of Fixture

Part #	Description	Supplier	Quantity	Minimum Order Quantity	Cost per Item	Actual Cost
1182018	Base Disk 1	1182018	1	-	-	$24.66
1182051	Base Disk 2	1182051	1	-	-	$24.62
1182037	Support fins	1182037	8	-	-	$24.62
1182016	Guide bracket 1	1182016	2	-	-	$24.62
1182017	Guide bracket 2	1182017	1	-	-	$24.62
1182057	Arm bracket	1182057	3	-	-	$24.62
1182055	Check arm	1182055	3	-	-	$24.62
1182054	Clamping bracket	118254	3	-	-	$24.62
1182023	HDPE rail locator (cut and drilled from 6" x 6" x 1/2" HDPE to 30mm x 15mm x 1/2")	1182023	2	-	-	$7.57
92320A665	18-8 Stainless Steel Unthreaded Spacer, 1/2" OD, 1/2" Long, for 1/4" Screw Size	92320A665	33	1	$2.86	$94.38
92320A878	18-8 Stainless Steel Unthreaded Spacer, 1/2" OD, 7/16" Long, for 1/4" Screw Size	92320A878	27	1	$2.86	$77.22
92949A554	18-8 Stainless Steel Button Head Hex Drive Screw, 1/4"-20 Thread Size, 3" Long	92949A554	15	10	$0.63	$12.66
92949A540	18-8 Stainless Steel Button Head Hex Drive Screw, 1/4"-20 Thread Size, 3/4" Long	92949A540	6	50	$0.14	$6.95
91831A029	18-8 Stainless Steel Nylon-Insert Locknut, 1/4"-20 Thread Size	91831A029	24	50	$0.09	$4.51
92141A029	18-8 Stainless Steel Washer, for 1/4" Screw Size, 0.281" ID, 0.625" OD	92141A029	45	100	$0.03	$3.47
91831A011	18-8 Stainless Steel Nylon-Insert Locknut, 10-24 Thread Size	91831A011	4	100	$0.06	$5.70

92141A011	18-8 Stainless Steel Washer, for Number 10 Screw Size, 0.203" ID, 0.438" OD	92141A011	8	100	$0.02	$2.40
92949A247	18-8 Stainless Steel Button Head Hex Drive Screw, 10-24 Thread Size, 1" Long	92949A247	4	50	$0.11	$5.30
92949A539	18-8 Stainless Steel Button Head Hex Drive Screw, 1/4"-20 Thread Size, 5/8" Long	92949A539	3	50	$0.13	$6.39
95630A470	Chemical-Resistant PTFE Plastic Washer, for 1/4" Screw Size, 0.281" ID, 0.5" OD	95630A470	3	10	$0.38	$3.81
1078A331	Plastic Unthreaded-Hole Rectangular Pull Handle, with 5-3/16" Center-to-Center, Black	1078A331	1	1	$6.20	$6.20
92141A030	18-8 Stainless Steel Washer, for 5/16" Screw Size, 0.344" ID, 0.75" OD	92141A030	2	100	$0.05	$5.27
92196A582	18-8 Stainless Steel Socket Head Screw, 5/16"-18 Thread Size, 7/8" Long	92196A582	2	25	$0.38	$9.50
91831A030	18-8 Stainless Steel Nylon-Insert Locknut, 5/16"-18 Thread Size	91831A030	2	50	$0.15	$7.66
92949A240	18-8 Stainless Steel Button Head Hex Drive Screw, 10-24 Thread Size, 3/8" Long	92949A240	2	100	$0.06	$5.93
90351A101	Tapped Taper Pins, Pin Number 5, 0.289" Large End Diameter, 1-1/4" Long	90351A101	2	1	$6.73	$13.46
5105A23	Locking Plier Clamp, Pivoting Jaw, 0" to 4-1/2" Opening	5105A23	2	1	$23.78	$47.56
91306A717	Button Head Hex Drive Screws, 1/4"-20 x 3" long	91306A717	15	10	$13.12	$26.24
91255A539	Black-Oxide Button Head Hex Drive Screws, 1/4"-20 x 5/8" long	91255A539	3	50	$0.18	$8.87
91255A540	Black-Oxide Button Head Hex Drive Screws, 1/4"-20 x 3/4" long	91255A540	6	50	$0.19	$9.46
91306A341	Zinc-Plated Alloy Steel 10-24 x 3/8" long	91306A341	2	50	$0.22	$11.23
91306A350	Zinc-Plated Alloy Steel 10-24 x 1" long	91306A350	4	25	$0.32	$8.06
98023A029	Zinc Yellow Chromate Grade 8 Steel Washer for 1/4" screw size	98023A029	51	100	$0.07	$7.16
91251A582	Black Oxide Alloy Steel Socket Head Screw, 5/16"-18 x 7/8" long	91251A582	2	50	$0.22	$10.87
98023A030	Zinc Yellow-Chromate Plated Grad 8 Steel washer for 5/16" screw size	98023A030	2	50	$0.11	$5.43

95615A120	Medium Strength Steel Nylon Insert Locknut, 1/4"-20	95615A120	24	100	$0.04	$4.39
95615A160	Medium Strength Steel Nylon Insert Locknut, 5/16"-18	95615A160	2	100	$0.06	$6.43
76475A32	Low-Friction PTFE tape 0.004" Thick, 1/2" Wide, 15 feet long	76475A32	2	1	$10.44	$10.44
1830T259	Black Delrin® Acetal Resin Oversized Tube 1-3/4" OD x 1-1/2" ID, 1 Foot Long	1830T259	2	1	$13.26	$13.26
90729A465	Passivated 316 Stainless Steel Hex Drive Flat Head Screw	90729A465	2	1	$4.92	$9.84
3013A64	Uncoated High-Speed Steel Countersink, 100-degree angle	3013A64	1	1	$18.14	$18.14
91210A310	Alloy Steel Cone-Point Set Screw	91210A310	2	50	$0.15	$7.66
					Total	**$644.78**

Appendix E Table of Terms

Table 9: Abbreviations and Meanings

Abbreviation	Meaning
ASME	The American Society of Mechanical Engineers
BOM	Bill of Materials
HDPE	High Density Polyethylene
mm	Millimeters
NIOSH	National Institute of Occupational Safety and Health
PTFE	Polytetrafluoroethylene

Appendix F Detailed Drawings Attached for Sponsor (omitted from University Report)