STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Development of Robotic Arm for the Purpose of Glovebox Automation to Enhance Nuclear Waste Processing and Worker Safety

DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

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EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Development Initiative, an innovative program developed by the U.S. Department of Energy's Office of Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2023, a DOE Fellow intern, Nicholas T. Espinal, spent 10 weeks doing a summer internship at Savannah River National Laboratory under the supervision and guidance of Senior Engineer, Patrick Folk. The intern's project was initiated on June 5, 2023, and continued through August 11, 2023, with the objective of improving the Surplus Plutonium Disposition (SPD) Program's material handling through the mechanical design of alternate robotic arm gripper designs.

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1. INTRODUCTION

Savannah River National Laboratory's (SRNL) Surplus Plutonium Disposition (SPD) Program leads the development and transition of automated unit operations for the processing of plutonium oxide. In K-Area, plutonium oxide is processed for disposal by hand in the glovebox shown above in Figure 1-A**.** The process is displayed with the modeled cans shown in Figure 1-C. A mixing can is opened, filled with material, mixed, set inside of a shield can, and finally punched into a Robust Outer Container. Replication of the process is constructed in A-Area, where the mixing can weigh 1.6 kg (3.5 lbs.) and the Robust Outer Container material weighs 4 kg (8.8 lbs.).

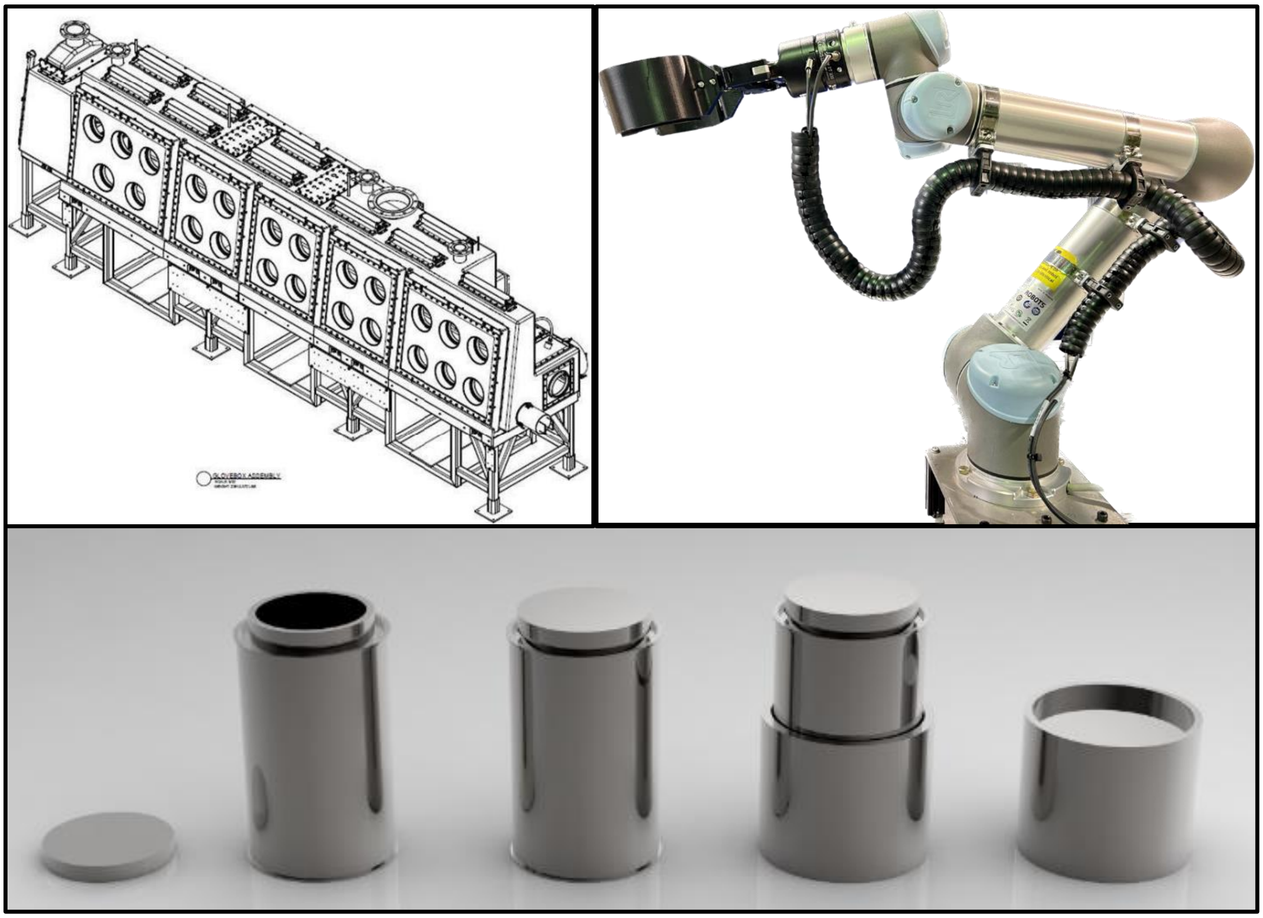


Figure 1. (A - Top Left) Surplus plutonium disposition glovebox; (B - Top Right) Robotic arm with fingers; (C - Bottom from Left to Right) Opened mixing can, closed mixing can, mixing can in shield can, and Robust Outer Container.

Due to the constant process of plutonium disposition, the fatigue on workers and worker dose accumulates quickly over time. SPD aims to automate this process by using a robotic arm (shown in Figure 1-B) to replace the hands-on worker. Automation will:

- Reduce worker radiation dose.
- Increase process throughput.
- Reduce costs for the disposition of plutonium oxide.

2. RESEARCH DESCRIPTION

The current gripper features a tool which is used to screw open and close the can body's lid, shown in Figure 2 – A. In Figure 2 – B, the inner contour of the fingers matches the outer contours of both the shield can and mixing can.

Figure 2. (A - Left) Current fingers with opening tool; (B - Right) Current finger contour.

Objective:

The objective of this research is to improve material handling through alternate robotic arm gripper designs and construct a grip strength sensor and other metrics to compare performance.

3. RESULTS AND ANALYSIS

The design metrics for alternate finger designs were made to compare the performance of new designs to the current design. Performance is divided by the fingers two separate tasks: handling or opening materials.

The gripper may use a separate tool to do either of these tasks. In the case it does not need a separate tool, the actions are combined. Combining tasks saves time during process and allows more material to be processed over long periods of time. This is considered an advantage.

The ROBOTIQ™ grippers of choice are either the 2F-85 or 2F-140 models (shown in Figure 3 - C). The 2F refers to the number of fingers (two) and the following number refers to the maximum space in between the fingers in millimeters. The 2F-85 model is shorter, lighter and stronger. The 2F-140 is longer, heavier and weaker [1]. However, the 2F – 140 model is the only Gripper capable of both Parallel and Encompassing Grasp, while the 2F – 85 model is only capable of Parallel Grasps with material at these sizes. The Encompassing Grasp is the ROBOTIQ ™ Gripper's ability to wrap fingers around circular contours (Figure 3 -B [3]). The zones of contact which activate either Parallel or Encompassing Grasp are divided by the

Table 1. Alternate Gripper Design Metrics

Task (Handling / Opening)
Encompass / Parallel
Combined Action (Y / N)
ROBOTIQ ™ Hand (85 / 140)
Approach (Axial / Perpend.)
Flexibility (low - High)
Assembly (Simple - Complex)
Material (ABS / TPU / SS)
Weight (kg)
Strength Average (kg)

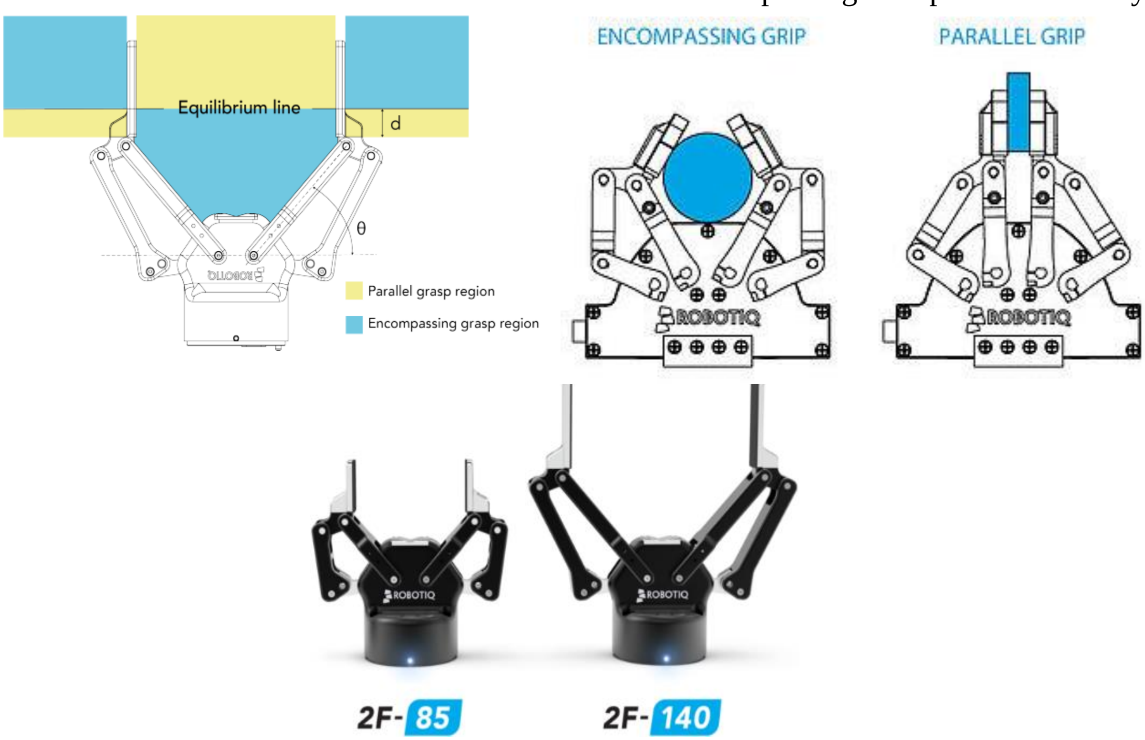


Figure 3. (A –Left), Equilibrium line for 2F models; (B – Right), Encompassing vs. Parallel Grip; (C – Bottom), ROBOTIQ ™ Gripper models.

Equilibrium Line, shown in Figure 3 - A [2]. Using the 2F-85 for the Parallel Grasp and the 2F-140 for Encompassing Grasp are considered advantages, while other design choices would be considered a disadvantage.

The approach which the gripper uses to either handle or open the materials can be improved. It is related to the axis of the cylindrical materials. If the approach for opening and handling materials are the same, the robotic arm will not need additional manipulation. This will additionally save time during the process and allow more material to be processed over a long period of time. A combined approach for handling and opening would be considered an advantage.

Flexibility advantages depend on the task. The opening task does not require flexibility, as the mixing can’s lid size will not change. Low flexibility in this task is considered an advantage. For handling, high flexibility is an advantage as materials inside of the glovebox do change. The diameter of the mixing can is 98.6 mm, and the diameter of the shell can is 115 mm. Additionally, any material which is sent into the glovebox with a diameter between 98.5 and 115 mm can be handled by flexible fingers.

Assembly should ideally be simple – meaning little to no assembly for maximum process output. If there are multiple components to be assembled, the design has an immediate disadvantage in comparison to the original design.

Different materials were used to produce the fingers. Acrylonitrile butadiene styrene (ABS) is the very strong and rigid material used for the main base of the fingers, shown in Figure 4 – A. Thermoplastic Polyurethane (TPU) is the flexible material used for different attachments on the fingers, shown in Figure 4 – C. Finally, stainless steel nuts and bolts were used to assemble the new fingers designs. Parts were modeled using PTC Creo Parametric 4.0 modeling software (Figure 5 – A). ABS and TPU were printed with a Stratasys™ f370 Fused Deposition Modeling (FDM) 3D printer (Figure 6– B). The material section tracks the change in materials, not the change in advantages in design.

Figure 4. (A – Left) Rigid 3D-printed ABS; (B – Middle) Stainless steel nuts & bolts; (C - Right) Flexible 3D-printed TPU.

Figure 5. (A – Top) PTC Creo Parametric.; (B - Bottom) Stratasys™ f370 3D printer

The weight of the fingers includes the entire addition of weight to the robotic arm at its wrist. This includes the ROBOTIQ™ gripper attached. Heavier fingers designs will be considered disadvantageous.

Finally, the grip strength average is used to measure output force from the finger design. The force is measured using an Omega LC321 – 500 load cell and is read using an input meter. Both are shown in **Error! Reference source not found.**. The current design requires better grip and friction. Thus, higher force outputs are considered an advantage.

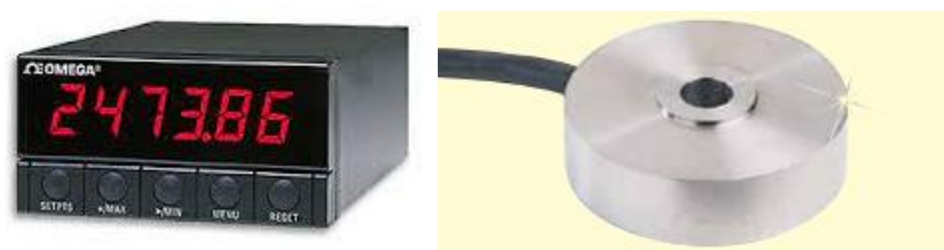


Figure 6. (Left) Omega DP41 - B universal input meter; (Right) Omega LC321-500 load cell.

The strength average is measured for either handling or opening. For handling, the force applied to a mixing can and shield can are measured. For opening, the force output on the lid is measured. For these three geometries, a specific grip strength sensor was designed, shown in Figure 7**.** The exploded view shows the inner adaptive core which will allow the load sensor to easily fit inside each of the three grip strength sensors.

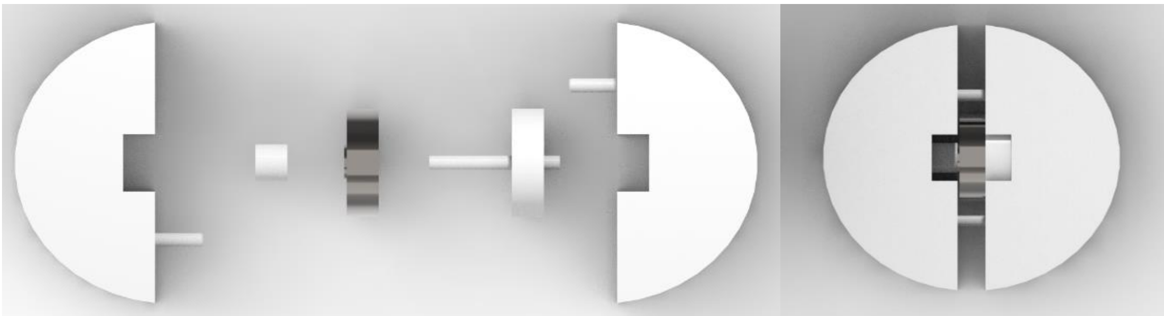


Figure 7. (A - Left) Grip strength sensor (exploded); (B - Right) Grip strength sensor assembled.

The shield can, mixing can, and lid will have its respective grip strength sensor. The sensors will be used to compare new finger designs.

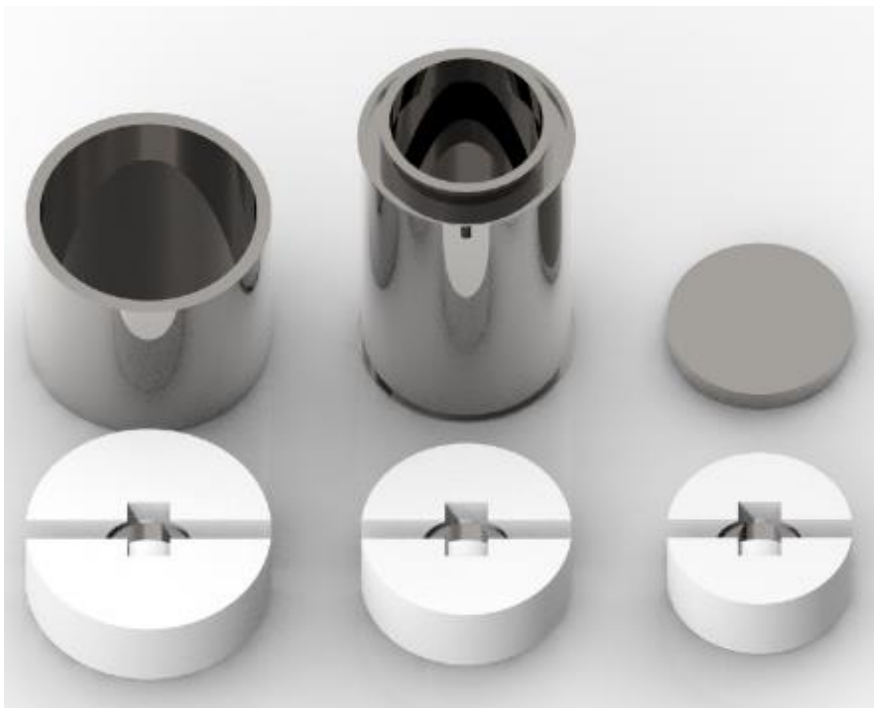


Figure 8. Grip strength sensors for shield can, mixing can and lid.

Using the Alternate Finger Design Metrics (Table 1), the initial data for the Current Finger was listed (

Table 2).

Table 2. Current Gripper Design Metrics

	Current	
Task (Handling / Opening)	Handling	Opening
Encompass / Parallel	Parallel	
Combined Action (Y / N)	No	
ROBOTIQ ™ Hand (85 / 140)	85	
Approach (Axial / Perpend.)	Perpendicular	Axial
Flexibility (low - High)	Low	Low
Assembly (Simple - Complex)	Simple	Simple
Material (ABS / TPU / SS)	ABS / Foam	TPU / SS
Weight (kg)	1.14	
Strength Average (kg)	Can: 6.3	Lid: 2.1
	Die: 5.8	

As shown, the current finger applied a parallel grasp with a 2F-85 gripper. The gripper approaches perpendicularly to the materials' axis for handling and approaches axially for opening. There is low flexibility in both handling and opening, as the fingers themselves is made of ABS and a small layer of foam. The additional tool needed for opening uses very thick TPU and a small spring, which also provides little flexibility. The weight of the fingers and 2F-85 together were 1.14 kg (2.5 lbs.). Using the grip strength sensors, the strength average for the mixing can, shield can, and lid are 6.3 kg (13.9 lbs.), 5.8 kg (12.8 lbs.), and 2.1 kg (4.6 lbs.) respectively.

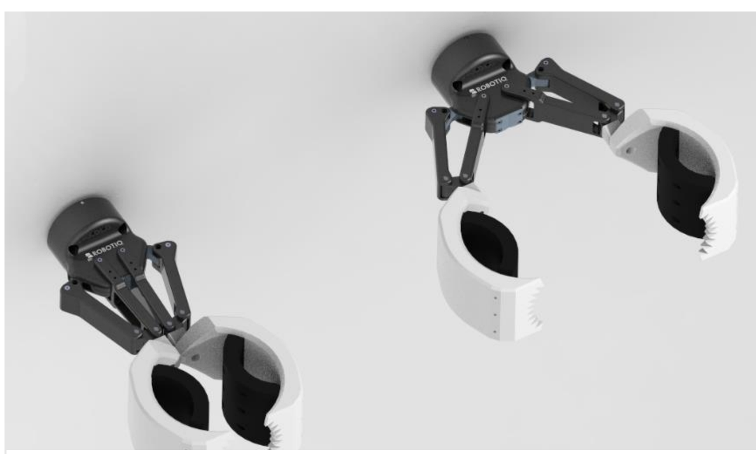


Figure 9. Gripper Design - Mark I open (Right) and closed (Left).

The first gripper design uses the 2F – 140 gripper with a parallel grasp (shown in Figure 9). The approach for handling and opening was the same. The finger is composed of two different materials, an outer base of ABS and inner grip of TPU. The inner TPU is designed for high flexibility, while the outer ABS is rigid. Attaching the two separate parts creates a more complicated assembly.

This finger design features a serrated edge which applies pressure points around the mixing can lid. This addition of an opening tool onto the finger adds a combined action of handling and opening, and thus no longer needs an additional tool. The edge is flat, shown in Figure 9, and has a curvature of the mixing can lid’s diameter, shown in Figure 10.

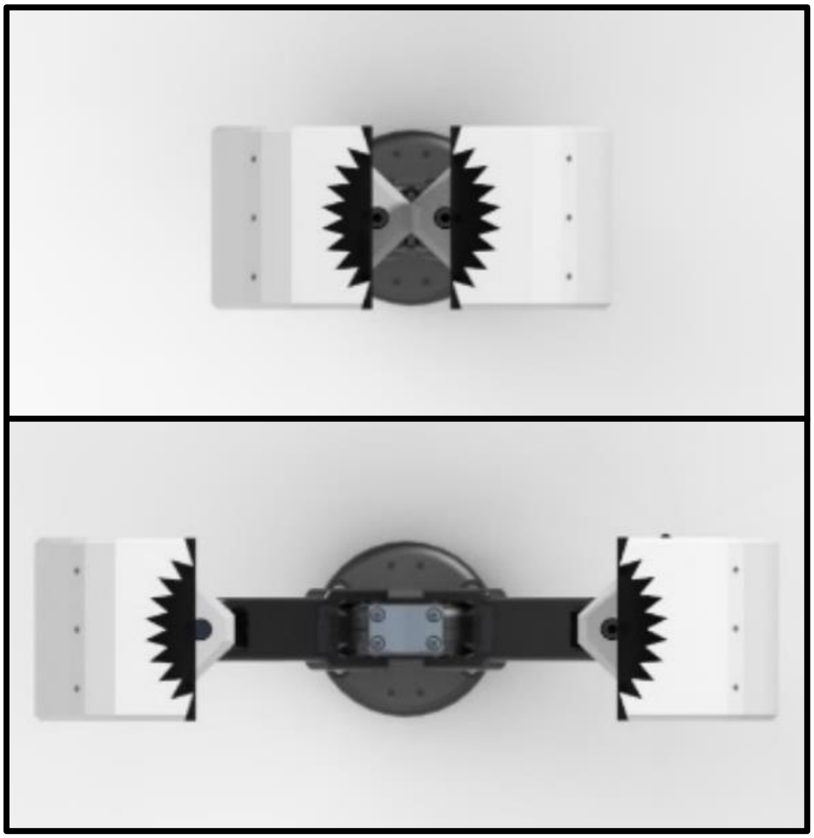


Figure 10. Gripper Mark I serrated edge closed (Top) and open (Bottom).

Table 3. Gripper Design I Metrics (No Strength Averages)

	Gripper Mk. 1	
Task (Handling / Opening)	Handling	Opening
Encompass / Parallel	Parallel	
Combined Action (Y / N)	Yes	
ROBOTIQ ™ Hand (85 / 140)	140	
Approach (Axial / Perpend.)	Perpendicular	Axial
Flexibility (low - High)	High	Rigid
Assembly (Simple - Complex)	Moderate	None
Material (ABS / TPU / SS)	ABS / TPU / SS	ABS
Weight (kg)	1.53	

Improvement
Disadvantage
No Change

Table 3 shows the design metrics of the first Gripper design, with a summary of its improvements and disadvantages, up until the strength averages.

In the beginning of the design stage, it was made clear that the current convex TPU model was too thick to use its flexible properties. Data was collected which shows the weakness and poor design of the first few models, shown in Figure 11.

The serrated edge applied on the mixing can lid had proven to apply more force (3.3 kg compared to the current design's applied force of 2.1 kg).

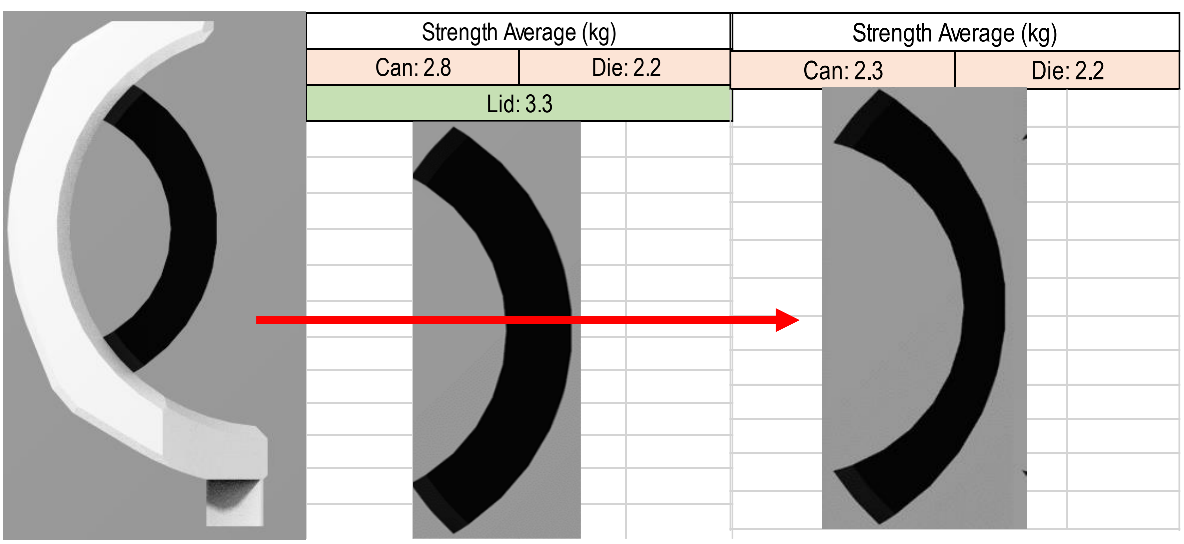


Figure 11. First convex TPU grip models.

Opposed to the convex TPU model, concave TPU models were designed. Their shape already adheres to the shape of the contour of the handled materials and uses the TPU material to flex into shape. The "W" shaped model had to be tested with and without a supported backing. A dovetail assembly was designed to add the backing, shown in Figure 12.

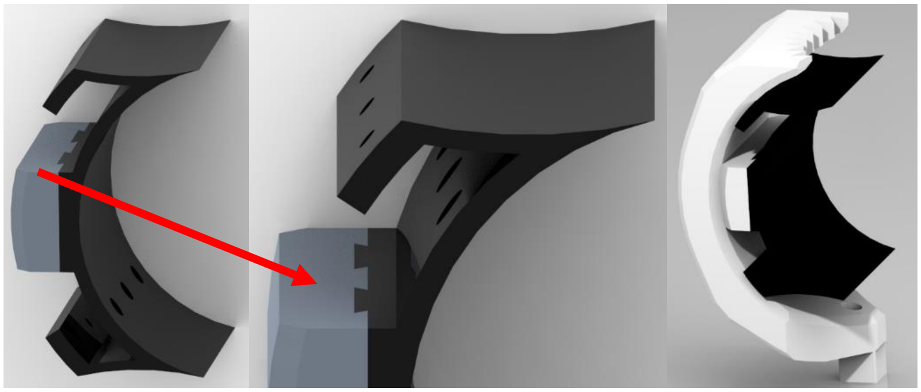


Figure 12. First concave TPU grip model with dovetail.

The support was proven to be unnecessary. The support, combined with the geometry of the TPU model, did not allow the TPU to mold about the contour of the grip sensor. Without the support, the TPU model molded much better. Additionally, the force applied increased. The concave grip without support attached is shown in Figure 13.

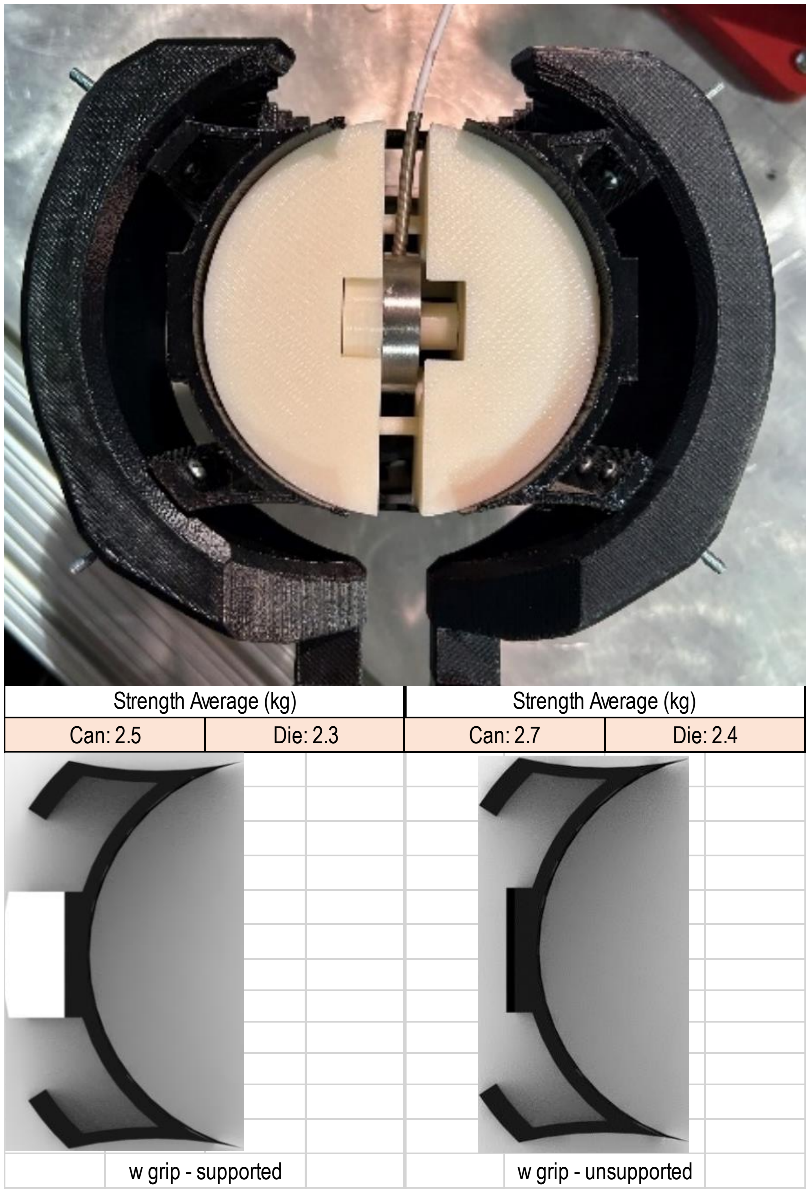


Figure 13. (Top) Concave TPU grips attached; (Bottom Left) supported concave grip; (Bottom Right) unsupported concave grip.

To avoid the weakness of the 2F-140 gripper, the ABS finger base was converted to attach to the stronger 2F-85. The attaching end was modified with a slot versus a screw hole, shown in Figure 14**.** A circular clearance was made for securing bolts with a rachet.

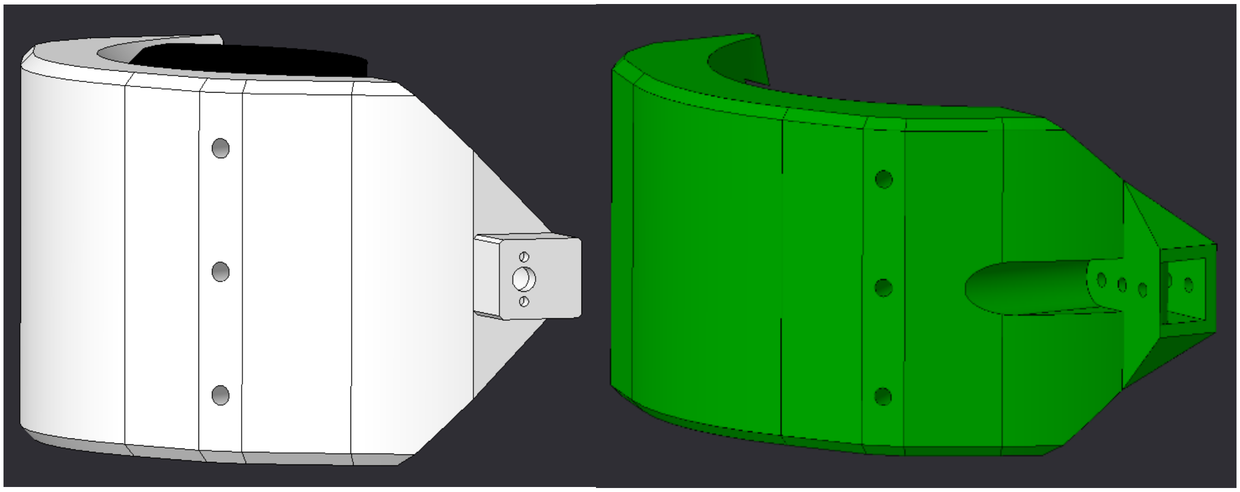


Figure 14. 2F - 140 Finger attachment (Left); 2F - 85 Finger attachment (Right).

After switching the finger to the stronger 2F – 85, the grip strength applied to the lid significantly increased from 3.3 kg (7.3 lbs.) to 5.8 kg (12.8 lbs.). The convex model was continued to be made thinner and was tested once more. The concave model's geometry was edited to test more beneficial changes. If the flexible edge which molded about the contour of the handling material was made sharper, the performance on strength improved as it can make better contact with material. Figure 15 shows how the concave model outperformed the convex model, and how the concave model with the sharpest edge did best.

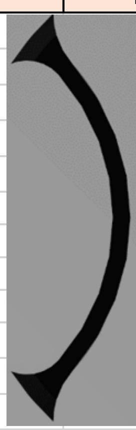
2f-85:					
Strength Average (kg)		Strength Average (kg)		Strength Average (kg)	
Lid: 5.8		Can: 4.7	Die: 3.6	Can: 5.1	Die: 4.8
Can: 4.2	Die: 4.2				
					
gripper grip design #1 (thinnest)		w mid angle		w highest angle	

Figure 15. Convex and concave TPU model strength performances.

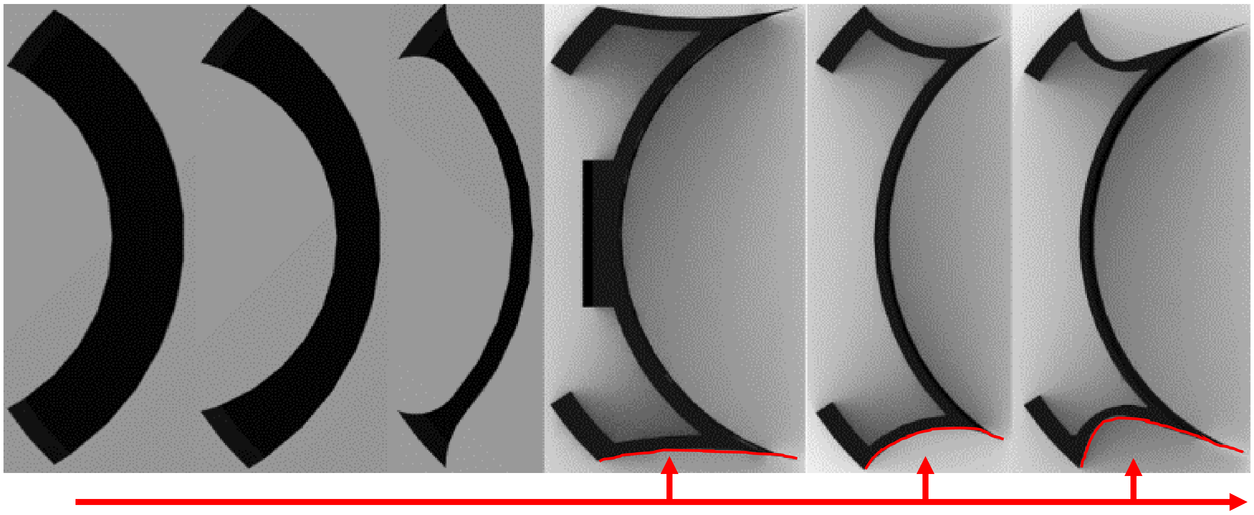


Figure 16. Evolution of TPU models.

Figure 16 above shows the evolution of the TPU models for grasping material. Notice the increase in angle in the edge of the model which further sharpens the grip. This new data for the strength average provided a complete design metric for the first official Gripper design, shown in Table 4.

Table 4. Complete Gripper Design I Metrics

	Gripper Mk. 1	
Task (Handling / Opening)	Handling	Opening
Encompass / Parallel	Parallel	
Combined Action (Y / N)	Yes	
ROBOTIQ ™ Hand (85 / 140)	85	
Approach (Axial / Perpend.)	Perpendicular	Axial
Flexibility (low - High)	High	Rigid
Assembly (Simple - Complex)	Moderate	None
Material (ABS / TPU / SS)	ABS / TPU / SS	ABS
Weight (kg)	1.53	
Strength Average (kg)	Can: 5.1	Lid: 5.8
	Shield: 4.8	

Improvement
Disadvantage
No Change

Switching to the 2F-85 greatly improved Gripper Design I, bringing outputted strength averages much closer to the current gripper. The weight change was negligible. Despite the shortcomings in the strength averages, the forces are still high and can potentially still perform well in material handling. Figure 17 shows the clearances made in one TPU model which allows for rubber chords to be inserted. Attaching with adhesive, the rubber chords can provide additional friction to the fingers which will improve its performance in grasping material. Tests for actual handling and opening performance have yet to be constructed and measured.

Figure 17. (Top Left) Clearances in TPU model; (Top Right) Rubber chord attached to TPU model; (Bottom) Rubber chords.

Gripper Design – Mark II

Gripper Design I incorporated a parallel grasp, but a design using the encompassing grasp was yet to be made. Gripper Design II features an encompassing grasp, utilizing the 2F – 140. The gripper is composed of two ABS fingers which attach to a TPU belt that flexes about the contour of the handled material. Notice, there are also clearances for rubber chords to increase friction. The edge of the finger also features a serrated end as an opening tool. The fingers are shown in Figure 18.

Figure 18. Gripper Design - Mark II.

Figure 19. Modeled fingers (Left) vs. Printed fingers (Right).

Flexible material like TPU is particularly harder to model and predict using 3D software. Figure 19 shows a side-by-side comparison of the modeled fingers vs the printed fingers. Gripper Design II worked well with the shield can, however the mixing can was not properly grasped. This can be due to the geometry of the belt and where it attaches to the fingers. Additionally, the amount of material between the actual fingers prevented the fingers to join for the opening task. Gripper Design II does not contain data for the opening task in terms of performance for this reason. However, despite failing the opening task, this design outputted the greatest average strength of both new designs with 5.9 kg (13 lbs.) for the mixing can and 5.4 kg (11.9 lbs.) for the die. Gripper Design II is also lighter by 0.13 kg (0.3 lbs.). The design metric for Gripper Design II, excluding Opening Task Data, is shown below in Table 5.

Table 5. Gripper Design II Metric (Excluding Opening Task Data)

	Gripper Mk. 2	
Task (Handling / Opening)	Handling	Opening
Encompass / Parallel	Encompassing	
Combined Action (Y / N)	-	
ROBOTIQ ™ Hand (85 / 140)	140	
Approach (Axial / Perpend.)	Perpendicular	-
Flexibility (low - High)	High	Rigid
Assembly (Simple - Complex)	Moderate	None
Material (ABS / TPU / SS)	ABS / TPU / SS	ABS
Weight (kg)	1.01	
Strength Average (kg)	Can: 5.9	-
	Die: 5.4	

Improvement
Disadvantage
No Change
Data Needed

Gripper Design III

Due to the length of the internship and frequent use of additive manufacturing by SRNL Engineers, the parts in the latest design could not be printed or tested. They have been modeled and will be handed over to the development team for further testing. The latest design incorporates the concave TPU models of Design I and still uses an Encompassing Grasp from Design II with ABS Fingers. There are 4 concave TPU models which grasp the handled material and can flex to the correct diameter while still applying a large force.

Gripper Design III can be seen in Figure 20 – A, while Figure 20 – B shows the circular contour made by the encompassed ABS fingers and concave TPU models.

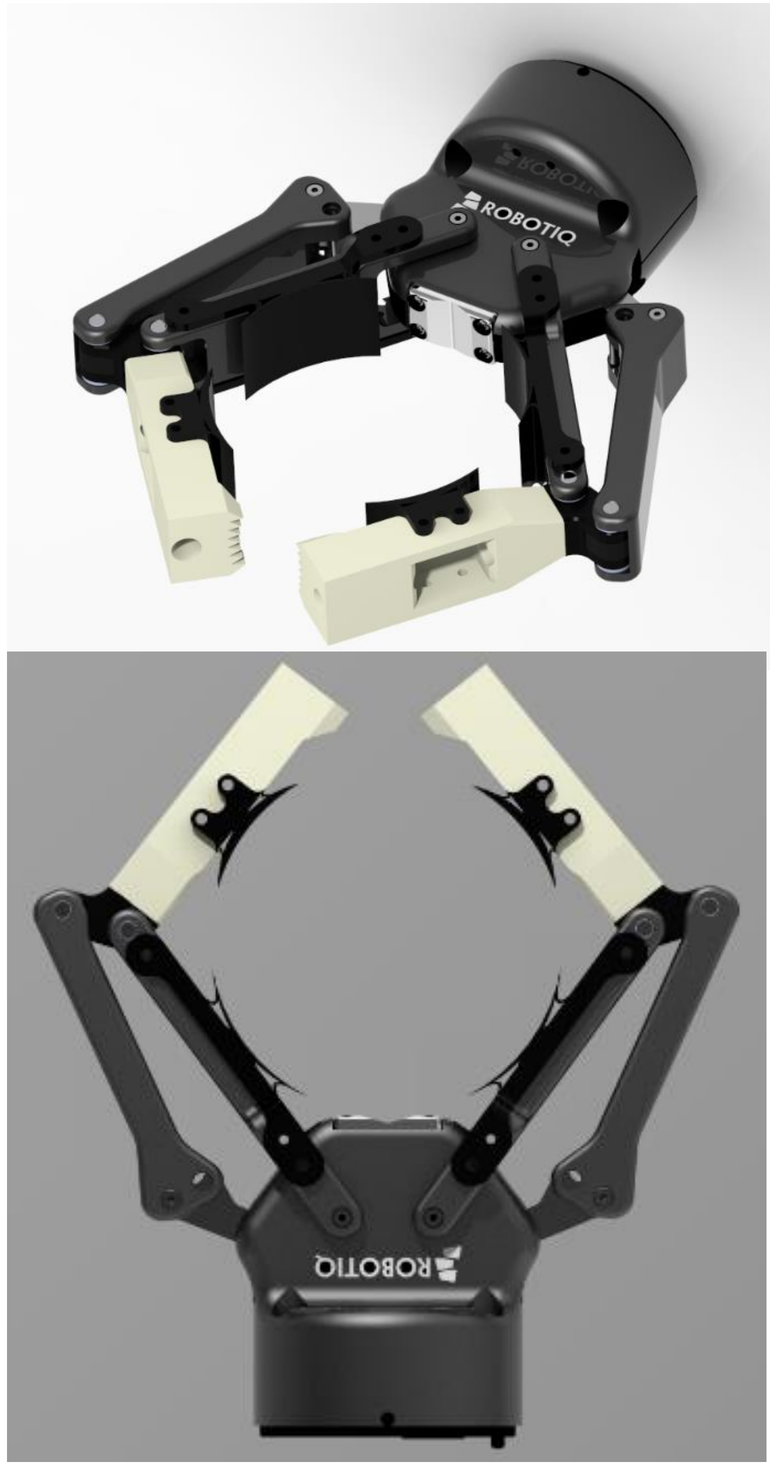


Figure 20. (A - Top) Gripper Design III;

(B - Bottom) Gripper Design III (Side View).

4. CONCLUSION

Intern Nicholas T. Espinal's participation in SRNL's development of SPD's Automated Material Handling System resulted in the possible addition of a serration feature on the current end-effector used for automated handling of hazardous material for the purpose of reducing worker dose, cost, and increase in production. Nicholas used qualitative and quantitative data to verify the improvements of his designs. Additionally, three new finger designs were developed and have been documented for further development and improvement. In his 10 weeks, Nicholas gained industry experience in terms of engineering, manufacturing, mechanical design, and methods for efficient development with the use of software, hands-on work, and insight through mentors.

5. REFERENCES

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