SHLYM Designs

University of Alberta
Engineering Department
116 St and 85 Ave.
Edmonton, Alberta T6G 2R3

August 9, 2021

Connie Phillips
Executive Director
Alberta Beekeepers Commission
11434-168 Street, #102
Edmonton, AB T5M 3T9

Re: Design/Automate Removal of Frames from an Extraction Line – Project Phase III Deliverables.

Dear Ms. Phillips,

SHLYM Designs is pleased to present the Phase III report of the Automated Removal of Frames from an Extraction Line. The following are outlined in the report:

- Description of final design
- Design Analysis
- Cost and Manufacturing estimates
- Design Compliance Matrix
- Component and Assembly CAD drawings

The total number of engineering hours for the project was 481 for a total hour cost of $25,250. The estimated manufacturing cost for the designed device is $16,637.

If there are any concerns or questions regarding the Phase III report, please do not hesitate to contact our Team Leader by email: mlantz@ualberta.ca. It has been a pleasure working with you and we look forward to your review of our final design for the automated removal device and future partnerships.

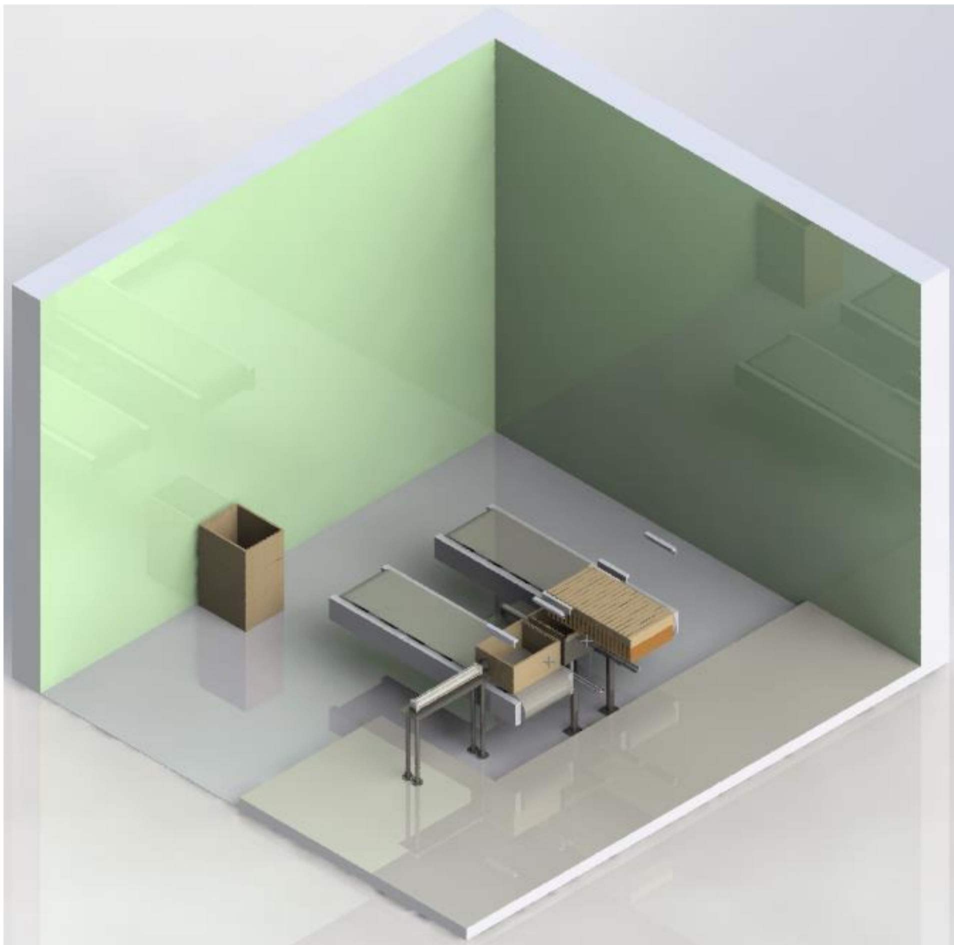
Best Regards,

SHLYM Designs

Cc: Dr. Kajsa Duke, University of Alberta
Dr. Martin Barczyk, University of Alberta
Mr. Mark Ackerman, University of Alberta

Mec E 460 Design Project

Design/Automated Removal of Frames from an Extraction Line



Phase III

August 9, 2021

SHLYM Designs

SHLYM Designs Team:
Aidan She
Carlos Moreno
Mason Lantz
Qiulin Yu
Zachary Hansen

Executive Summary

The objective of SHYLM Design is to design an automated device to remove frames from the end of the honey extraction line and return the frames to the hive box. The design must be able to continuously pack the 8 frames in a hive box at the end of the extraction line.

The designed automated frame removal device has three parts: the box removal system, the box packer, and the flat belt conveyor. The general dimensions of the device are: 2351 mm in width, 2541 mm in length, and 931 mm in height. The box removal system is used to push the empty hive box from the flat belt conveyor to the box carrier of the box packer with a speed of 0.61 m/s. The box packer moves with the empty hive box to reach the end of the extraction line and pack the frames into the empty hive box. The frames are evenly distributed through adjusting the motion in the z-direction of the pneumatic cylinder of the box packer. Then the full packed hive box is removed from the box carrier by another stroke of the pneumatic cylinder from the box removal system. This off loads the filled box to the output flat belt conveyor. The total time of "Pack and Go" frames is estimated to be 12s.

To complete the work required for the project to be successful the projected incurred a cost of hours worked by the members of the SHYLM Design team. In Phase I the team expended 63 hours doing market research, understanding the problem, and considering possible solutions. In Phase II the team utilized 171 hours to create three design concepts to be considered in more detail for potential solutions to the problem at hand. In Phase III the group completed the design of the automated frame removal device using 247 hours to finish the project. Overall the total hours amounted to 481 hours and used 8 advising hours which at a rate of $50/hr and $150/hr respectively lead to the expense of $25,250 in management costs.

Word Count: 343

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1 Introduction

In Alberta, most of the beekeeping industry relies on human labour at the end of the honey extraction line (Figure 1) to remove the frames (Figure 2) from the line and place them into the hive box (Figure 3). When human workers are involved, the beekeeper must pay salaries and other benefits, which can be a large proportion of a beekeeper's expenses.

SHLYM Designs has been contracted by Alberta Beekeepers Commission to design a device to remove frames from the end extraction line and return the frames to the hive box. The client requested the device to be semi-automated, able to pack 100 boxes/hour, and have a return on investment in 3 years. SHLYM Designs has developed a completed design – a pneumatic hive box packer to satisfy the project requirements. The dimensions of the workspace are shown in Figure 4.

Figure 1 Honey extraction line and its components [1].

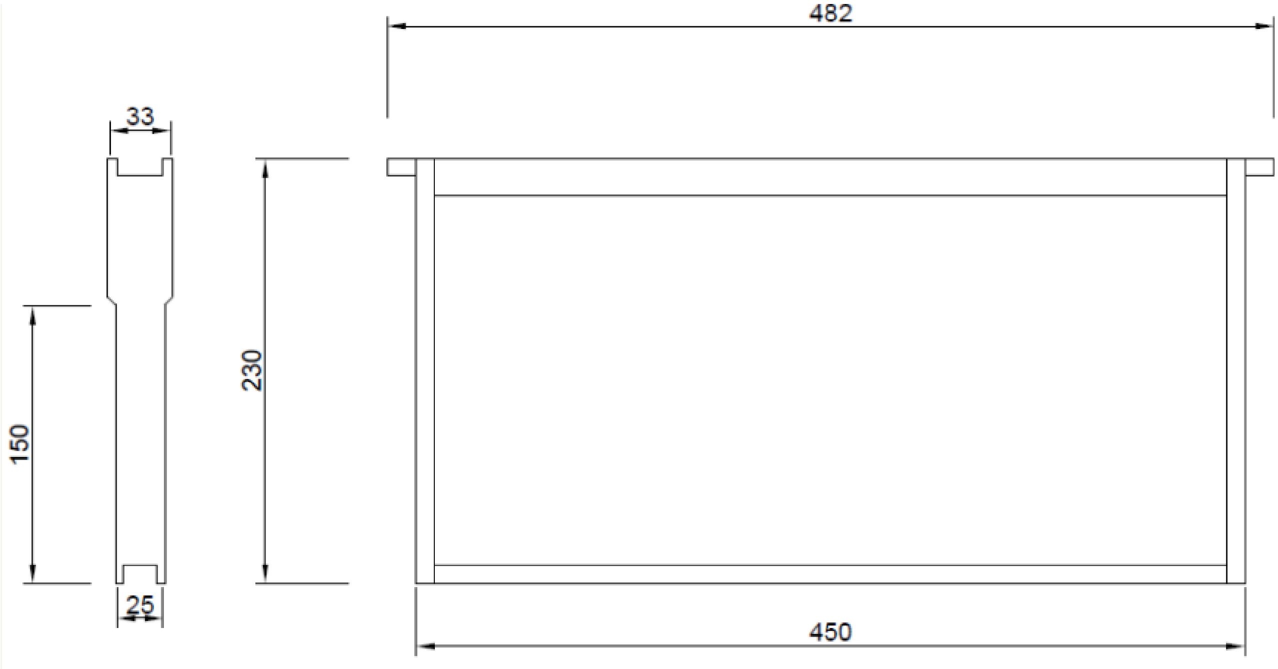
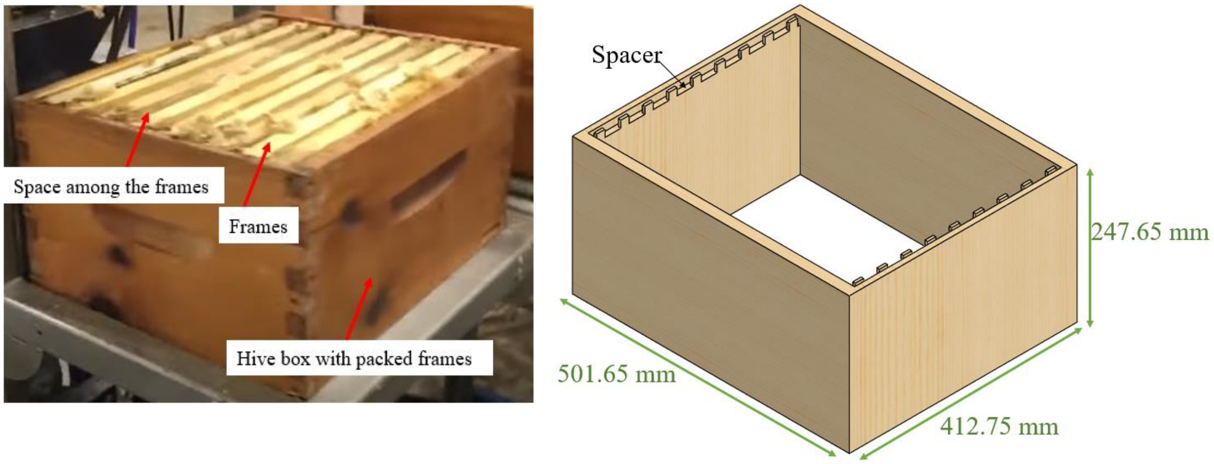


Figure 2 Scale of the frame in mm [2].



(a) (b)

Figure 3 Views of the hive box. (a) Hive box with frames [1]. (b) Standard empty hive box with view of spacer [3].

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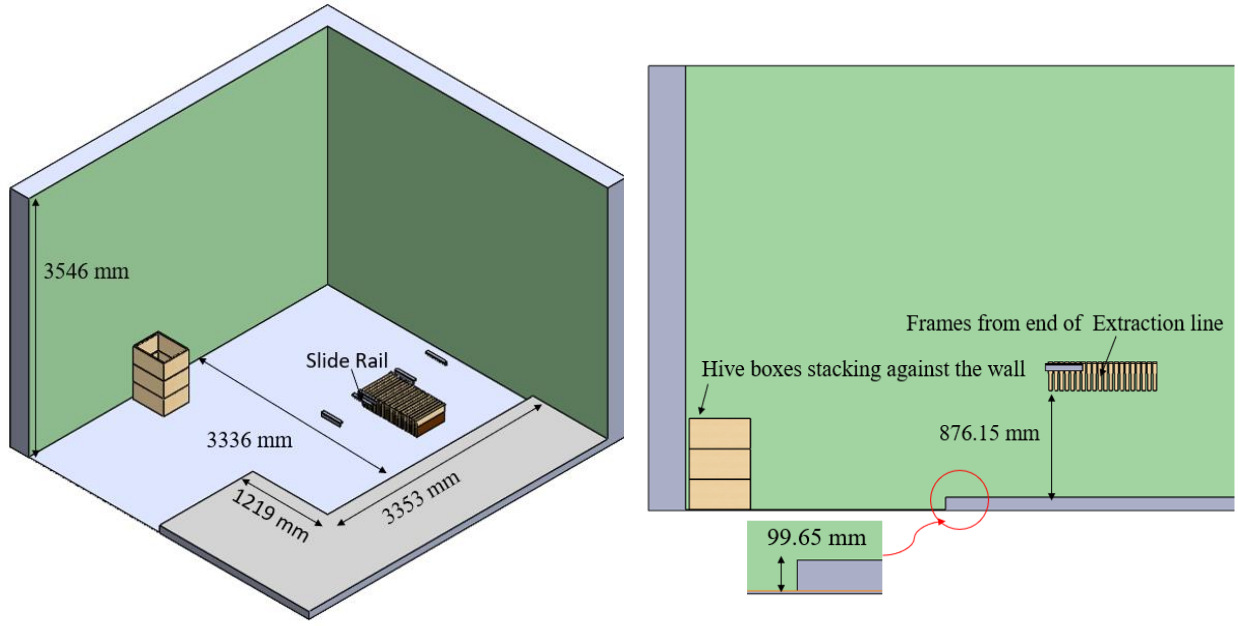


(a) (b)

Figure 4. Dimensions of the workspace. (a) Isometric view. (b) Front view.

2 Innovated Design Description

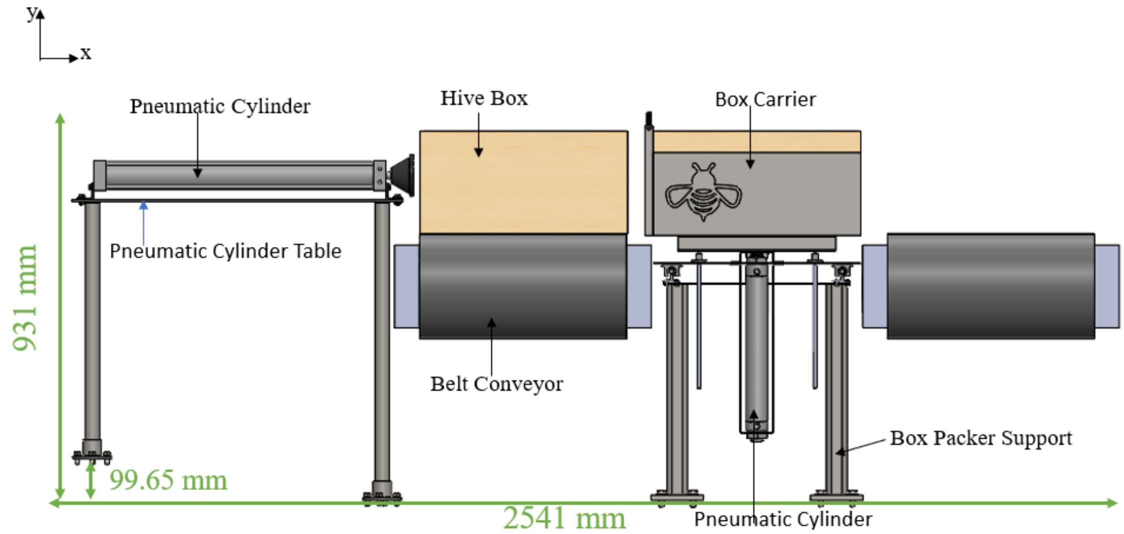
2.1 Design Overview

The device for the automated removal of frames from the extraction line designed by SHLYM Designs contains 3 parts: hive box removal system, box packer, and flat conveyors. The dimensions of the entire automated device (2351 mm x 2541 mm x 931 mm) fits the workspace (Figure 4). The complete device model can be viewed in Figure 5. Both the hive box removal system and box packer are driven by pneumatic cylinders. The flat belt conveyors are driven by the motor to assist in transporting the hive box. The entire device allows the hive box to move in the x, y, and z directions. In this report, the designed parts are discussed (Table 1).

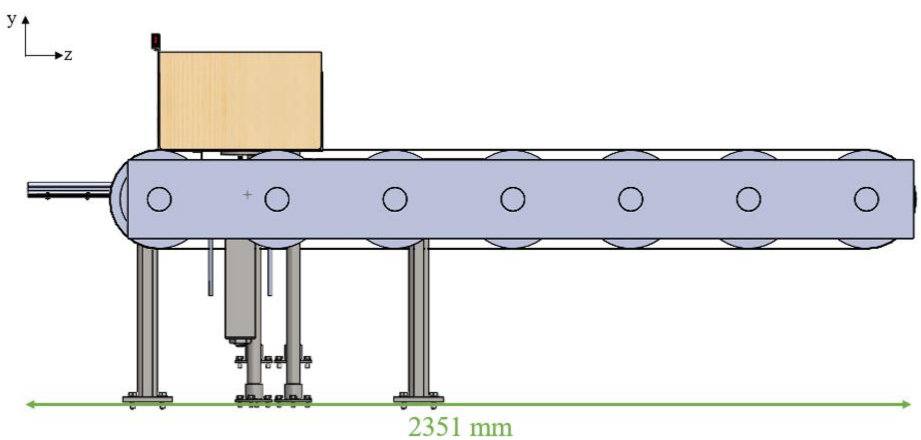
Table 1. The parts of the automated removal of frames from extraction line.

N.O.	Parts	Direction	Function
1	Hive box removal system	Moves box in x direction	Pushes the empty box from belt conveyor to box carrier of box packer. Also pushes packed box from box carrier to another belt conveyor.

2	Box packer	Moves box in y & z direction	Packs the frames from the slide rails and acts as a transfer station for the hive box. Adjust the speed in z direction of the pneumatic cylinder to evenly distribute the frames in the box by control system.
3	Flat belt conveyor	Moves box in x & z direction	Transfers the empty hive box to the hive box removal system area and removes the packed hive box from the hive box removal system area.



(a)



(b)

Figure 5. Overview of the design.

2.2 Hive Box Removal System

The Hive Box Removal System is an automatic, pneumatic based material removal system that allows for separation of the hive box placed on a flat conveyor belt using a pneumatic separator. The sensor in the flat conveyor belt can detect if empty hive box reaches the end of the flat conveyor belt based on its location (Figure 6). The control circuit is required to be able to detect the hive box and stop the conveyor belt from pushing the empty hive box aside. The pneumatic cylinder then pushes the empty hive box out of the conveyor belt to the box carrier.

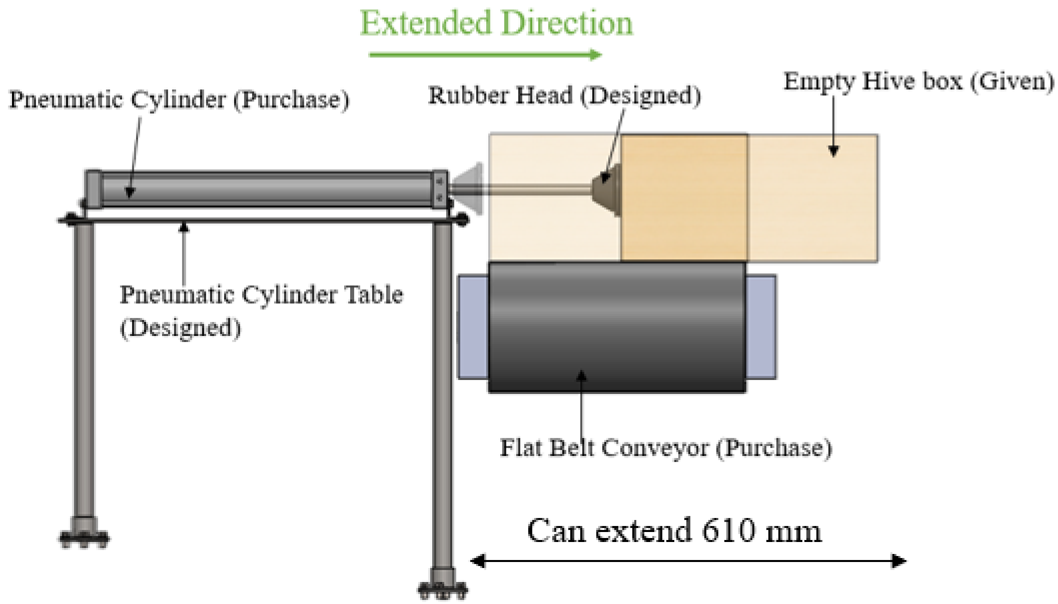
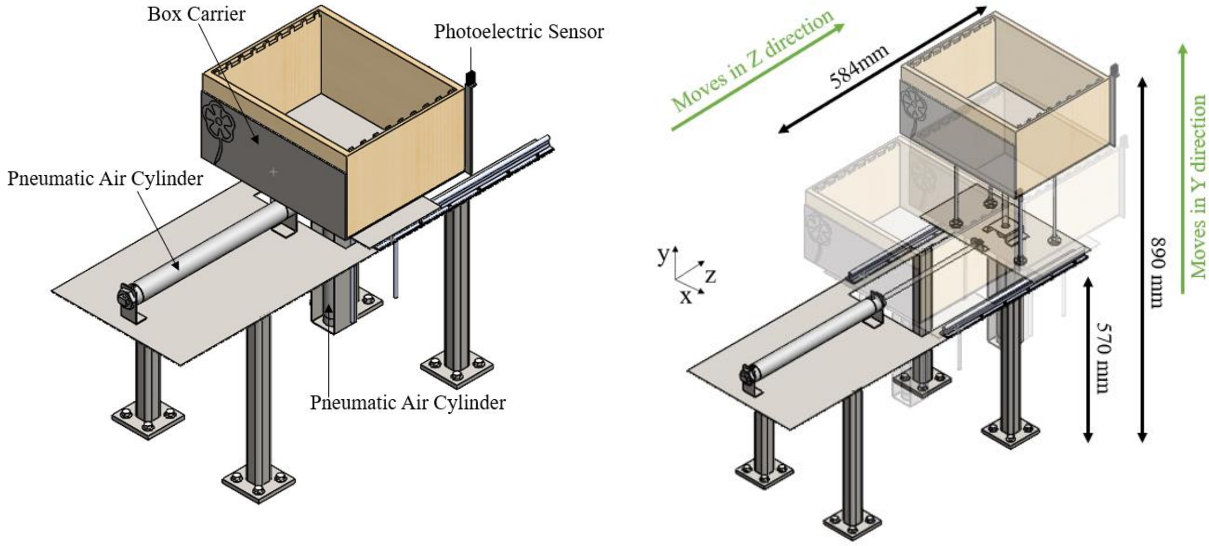


Figure 6. The overview of hive box removal system.

The pneumatic cylinder selected is the Sensor Ready Tie Rod Air Cylinder. It uses sensors to detect the linear position of the piston for application, which is critical in this system to make sure the stroke is long enough to push the empty box to the box carrier of box packer.

2.3 Box Packer

The box packer (Figure 7) consists of a box carrier and pneumatic cylinders. The box packer will replicate the motion of a human packing the box which is to scoop the frames from underneath using the box itself. Therefore, the box packer packs the frames by moving the box around using the box carrier, done by positioning the box directly under the frames, and then moving up and out to scoop the frames in.



(a) (b)

Figure 7. The overview of the box packer. (a) The isometric view. (b) The motion view.

2.3.1 Photoelectric Sensor

The diffuse-reflective sensor is used to detect and count 8 frames from at the end of extraction line. It consists of emitter and receiver in same housing. The emitter sends out a beam of pulsed infrared light, which is reflected directly by the frame. Then the output switches when the frame is detected within the reflective distance. Further Program Logic Control developing is required to integrate into the automated system.

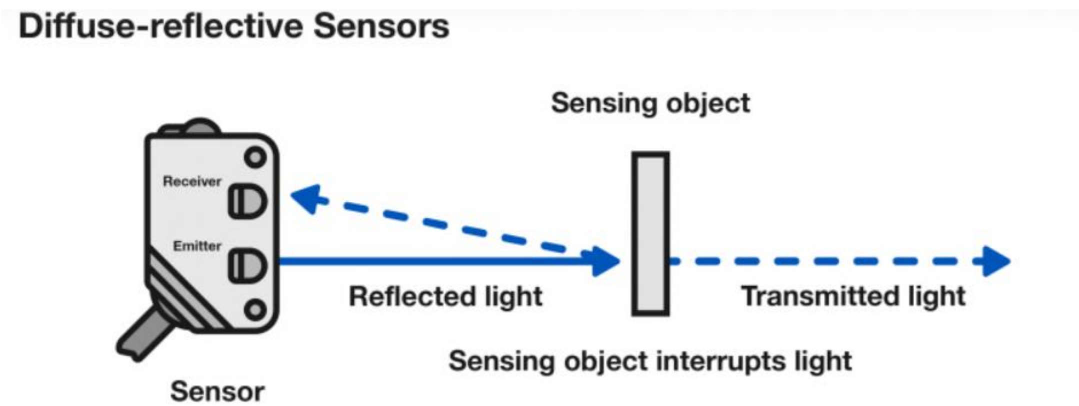


Figure 8. Performance of the Diffuse-Reflective Sensors [4].

2.3.2 Two Pneumatic Cylinders of Box Packer

The two pneumatic cylinders are used to control the movement of the box carrier of box packer in y and z directions (Figure 7 (b)). First, set the unstretched pneumatic cylinders as the starting point (Figure 7 (a)). The control system will control the box carrier as it moves up in the y-direction with a limit of 876.15mm from the ground (height of frames from extraction line) Figure 4 4(b)). The height will ensure the diffuse-reflective sensor can reach the side of the frames. Second, the control system will turn on the pneumatic cylinder to extend the rod to move the box carrier towards the frames from the slider rails in z-direction. Meanwhile, the diffuse-reflective sensor counts the number of frames. Third, once the output of the sensor is 8, the control system switches the pneumatic cylinder from the z-direction to the y-direction, with a limit of 890 mm from the ground. Then, the 8 frames reach the hive box by box carrier. Fourth, the pneumatic cylinder in the z-direction pulls the box carrier all the way back. Fifth, the pneumatic cylinder in the y-direction lowers the box carrier to the start point. Finally, the control system moves the pneumatic cylinder in the z-direction back and forth approximately 5 times (further testing is required) to make sure that each frame is located in the appropriate spacer (Figure 3 (b)).

2.3.3 Box Carrier

The box carrier is the compartment that actually holds the hive box while the packer is in motion. The box carrier consists of sheet metal in an angular U-shape, where two ends on either side are open. This is to facilitate the hive box receiving and removal. It also eliminates the need for the box packer to turn around. Per regulations, food-safe Steel 304 and Aluminum are the materials used for the box carrier.

3. Detailed Design Analysis

The final design was analyzed based on Concept III from Phase 2. In the new design, force analysis was completed based on the hive box and 8 frames. Pneumatic cylinder analysis and stress analysis were completed to evaluate the optimal materials and dimensions for the design's feasibility and safety. The design analysis process flow chart is shown in Figure 9 and the calculations are located in the Appendix.

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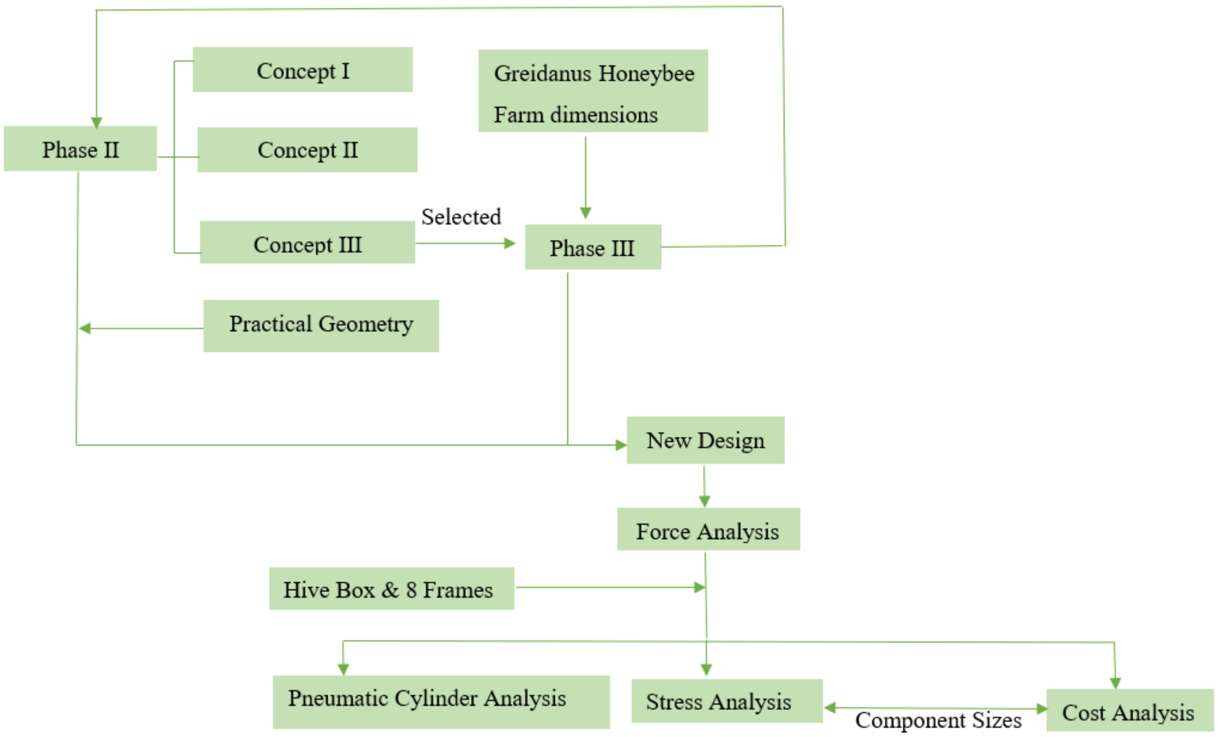

Figure 9. Design analysis process flow chart.

3.1 Cycle Calculations

To determine the cycle time for the system to operate a calculation was undertaken to find the time to pack a box, the velocity at which the box is packed, and the number of boxes and frames packed per hour. These calculations can be seen in Appendix G. The total time it takes to pack a single box was calculated to be between 6 and 12 seconds. The velocity at which the box is packed does not exceed 0.61m/s and the total number of boxes packed an hour is 300 which is three times the required amount, and 2400 frames packed per hour.

3.2 Box Carrier Stress Analysis

Stress analysis was used to ensure the box carrier will not break or be damaged during operation. The goal of the box carrier evaluation was to find the optimal material and thickness. The box carrier is required to be able to carry a full box containing 8 frames while being pushed from the bottom by a fixed pneumatic cylinder. Based on the completed detailed design analysis, Steel 304 was chosen as the material for its ability to withstand the stress, strain, and deflection required. A thickness of 4 mm was chosen because it resulted in a small mass and minimal stress for the box carrier. The design flow chart is shown in Figure 8. The analysis is in Appendix B.

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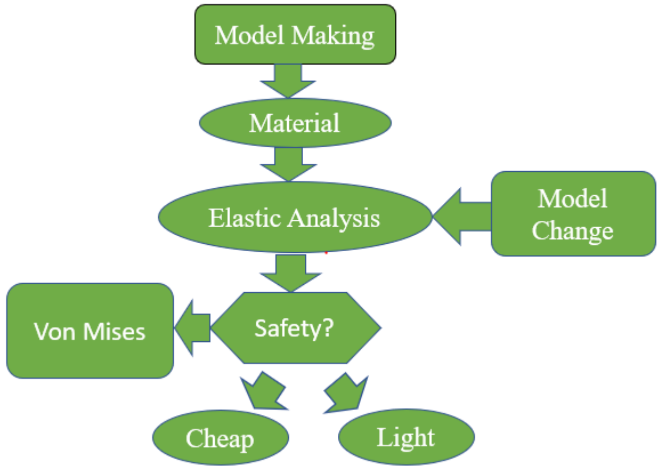

Figure 10. The design flow chart.

3.3 Sensor Support Stress Analysis

Stress analysis was completed on the sensor support to ensure it will not snap or yield during operation. The stress was evaluated to choose the optimal length for the sensor support using the material AISI 304. Simulations were completed based on the stress, displacement, and factor of safety when the force from the box was applied to the top plate. The completed detailed design analysis demonstrated that a length of 260 mm would be best as the stress would be minimized. The analysis refers Appendix B.

3.4 Pneumatic Calculations

The facility that this system is intended to be implemented in already has a high capacity compressed air system installed. Calculations were done to show what the required CFM of air in a compressed air system would be in order to determine what the load would be on the system. Also this calculation also has the added benefit of helping to determine the size of compressed air system that would be required if it was installed in a new honey extraction line. Honey extraction lines tend to use compressed air in other processes of the extraction line, so the assumption that compressed air should be available for our machine is a good assumption. The system is pressurized to 100psi at the facility, so the CFM require to achieve the speeds we expected was approximately 4 CFM. The calculations also allowed us to determine the minimum size of tubing required to transfer the compressed air to the piston, and the minimum size was found to be 1/8” tubing, however large tubing that is already installed on the extraction line will be used to add to the safety of the device

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4 Product/Manufacturing Cost Analysis

Table 2. Product Cost Analysis.

Part	Component	Component Description	Model	Unit Price (CAD)	Quantity	Total Cost (CAD)	Reference
Hive Box Removal System	Pneumatic Cylinder	Sensor Ready Tie Rod Air Cylinder, Double Acting, 2-1/2’’ Bore, 2-7/8’’ Wide, 24’’ Stroke Length	4917K408	$358.30	1	$358.30	https://www.mcmaster.com/4917K408/
	Pneumatic Cylinder table plate	Manufacturing Steel 304	-	$176.76	1	$176.76	Quote in Appendix C
	Pneumatic Cylinder Table Legs	304/304L Stainless Steel Unthreaded Pipe, 1 Pipe Size, 3 Feet Long	4804T152	$170.30	4	$681.2	https://www.mcmaster.com/4804t152/
	Pneumatic Cylinder mount	Manufacturing Steel 304	-	$35.98	2	$71.96	Quote in Appendix C

	Pneumatic Cylinder Table Fitting	Medium Flange 1'' Diameter	Global Industrial Pipe Fitting	$10.75	4	$43	https://www.globalindustrial.ca/
	Rubber Head	Manufacturing Polyurethane	-	$50	1	$50	-
	Bolts for Table Fitting	M12-1.75 X 70mm Class 8.8 Metric zinc Plated Steel Flange Bolts	Prime-Line	$50.09/package (10)	2	$100.18	Home Depot
	Bolts for Pneumatic Cylinder Mount	M8-1.25X 20 mm Class 8.8 Zinc Plated Hex Bolt	Everbilt	$0.96	4	$3.84	Home Depot
	Washers for Pneumatic Cylinder Mount	M8 Zinc-Plated Metric Flat Washer	Everbilt	$1.17/box (5-piece/Bag)	2	$2.34	Home Depot
	Nuts for Pneumatic Cylinder Mount	M8-10.9 Zinc Metric Hex Nut	Everbilt	$2.47/ box (5 per bag)	1	$2.47	Home Depot
	Bolts for Pneumatic Cylinder	5/16 in.-18X 2 in. Zinc Plated Hex Bolt	Everbilt	$0.27	4	$1.08	Home Depot

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	Fabrication & Assembly				1	$349.00	See Appendix C
Hive Box Removal System Subtotal:						$1,840.13	
Belt Conveyor	Flat Belt Conveyor	Belt Conveyor. 120V AC, 12 Feet Long, 20’’ Wide Belt, 25’’wide Frame	5816K531	$4764.90	2	$9,529.8	https://www.mcmaster.com/5816K531/
Belt Conveyor Subtotal:						$9,529.8	
Box Packer	Tapped Linear Motion Shaft	Tapped x Straight linear shaft, 52100 Alloy Steel, 3/8" Diameter, 18" Long	6649K128	$46.95	4	$187.79	https://www.mcmaster.com/6649K128/
	Round Body Air Cylinder for Washdown	Double Acting, 300 Series Stainless Steel, 2" Bore, 12" Str oke Length	6239K271	$320.56	1	$320.56	https://www.mcmaster.com/6239K271/
	One-Piece Support-Rail Shaft	Ceramic-Coated 6063 Aluminum, 1/2" Diameter, 18" Long Support shaft	1049K14	$155.23	2	$310.46	https://www.mcmaster.com/1049K14/

	NITRA Pneumatic Air Cylinder	all stainless steel non-repairable, 2in bore, 18in stroke, double acting, magnetic piston, double end mount	F32180DD-M	$217.98	1	$217.98	https://www.automationdirect.com/adc/shopping/catalog/pneumatic_components/pneumatic_air_cylinders/round_body_all_stainless_steel_air_cylinders_(f-series)/f32180dd-m
	Mounted Linear Sleeve Bearing	Mounted Linear Sleeve Bearing for Support Rail Shafts, 0.0015" Clearance, 1-1/2" Length	6374K313	$106.19	2	$212.39	https://www.mcmaster.com/6374K313/
	Flange-Mounted Linear Ball Bearing	Flange-Mounted Linear Ball Bearing with Round Housing, 3/8" Shaft Diameter, 7/8" x 1-1/2" x 1-1/2"	6483K52	$35.00	4	$140.01	https://www.mcmaster.com/6483K52/
	12 Ga 304 Stainless Steel Sheet Metal	30" x 52"		$352.13	1	$352.13	Quote in Appendix C
	½" 304 Stainless Steel Plate	12" x 12"		$208.34	1	$208.34	Quote in Appendix C

	2" x 2" x 0.25" Stainless Steel Tubing	For support legs, 80" total		$205.07	1	$205.07	Metal Supermarkets
	½"-13 SS Hex Bolt			$2.42	16	$38.72	Fastenal
	½"-13 SS Hex Nut			$0.73	2	$1.46	Fastenal
	½" SS Washer			$0.56	18	$10.08	Fastenal
	10-24 x ½" SS Socket Cap Screw			$0.18	16	$2.88	Fastenal
	10-24 SS Nut			$0.19	16	$3.04	Fastenal
	#10 SS Washer			$0.04	32	$1.28	Fastenal
	8-32 x ½" SS Bolt			$0.14	28	$3.92	Fastenal
	8-32 x 5/8" SS Bolt			$0.16	8	$1.28	Fastenal
	8-32 SS Nut			$0.16	32	$5.12	Fastenal
	#8 SS Washer			$0.04	68	$2.72	Fastenal
	Fabrication & Assembly			$500	1	$500	See Appendix C
					Box Packer Subtotal:	$4,114.42	
Control System	Arduino Uno Microcontroller		A000073	$34.99	1	$34.99	Amazon

	SainSmart 4-Channel Relay Module	Switched voltage: 250 V AC, 10 A Switching voltage: 5V DC	101-70-101	$9.99	2	$19.98	Amazon
	Air Directional Control Valve with Flow Control	5/3 (Closed Center) Flow, 3/8" Push-to-Connect	4666A3	$413.53	1	$413.53	https://www.mcmaster.com/4666A3/
	Air Directional Control Valve with Flow Control	5/2 Flow, Double Solenoid, 3/8" Push-to-Connect	4666A1	$278.84	2	$557.67	https://www.mcmaster.com/4666A1/
	Photoelectric Switch	1 ft sensing distance, 120 V AC input	65845K46	$125.80	1	$125.80	https://www.mcmaster.com/65845K46/
					Controls Subtotal:	$1,151.97	
				Design Subtotal:		$16,636.32	
				Markup (10%)		$1,663.63	
				Total selling cost:		$18,299.95	

5 Design Compliance Matrix

The Design Compliance Matrix in Table 3 was derived from the Design Specification Matrix previously generated in the Phase 1 Report and the Design Evaluation Matrix previously generated in the Phase 2 Report. The revised Design Specification Matrix is located in Appendix A.

Table 3. The Design Compliance Matrix.

Item	Specification (description)	Design Authority	Comments	Importance (1-5)	Achieved? (Yes/No)
Physical					
1.1	Fit the working place dimensions	SHLYM	The working size is 3353 mm x 3336 mm x 3546 mm	5	Y
1.2	Can hold full frame box	Client	Full frame box is ~15kg	5	Y
1.3	Operational at 1.5 m	Client	Height of frame removal	4	Y
Functional					
2.1	Automatic Spacing of Frames	Client	Boxes come with spacers that frames should slot into	3	Y
2.2	No Damage to Box Spacers	Client	Damage to spacers will cause difficulty in inserting frames into boxes	4	Y
2.3	Be able to consistently remove and replace the frames without damage	Client	Client requires throughput of 100 boxes/hour	4	Y
2.5	Ability to Replace Frame in Hive Box	Client	The purpose of this design	4	Y
2.7	Ease of Manipulation	SHLYM	Should be easy to start and stop by client	4	Y

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2.10	Resistance to Corrosion (from water, cleaning solutions, honey, etc.)	Client	Extraction line is sprayed down daily which increases chance of corrosion	5	Y
2.13	Intersperse	Client	The ability to add new frames to the 3 and 6 slots in the box is useful for removing old decayed frames	2	N
2.14	Food Safe	Client	All parts of the mechanism that touch the frame must be food safe and cannot be painted. Machine should be easy to clean/sanitize	5	Y
Others					
3.1	Cost of Product $20,000	Client	Maximum cost of product considered by client	5	Y
3.3	Manufacturability	Client	Design should be made with manufacturability in mind	3	Y
3.4	Reliability	Client	Important to not drop frames	4	Y
3.5	Life Span of 10yrs	Client	The mechanism should last for 10-15yrs to make the return on investment	4	
3.6	Documentation	Client	Drawing and documents of the device should be provided	5	Y
Maintenance					
4.1	Part Availability	SHLYM	Parts information should be provided and readily available	4	Y
4.2	Ease of Assembly/Disassembly	SHLYM	Limit the requirement for specialized tools	4	Y
4.3	Ease of Maintenance	SHLYM	The device should be easy to repair and maintain	3	Y
Environmental					

5.1	Material processing	SHLYM	The raw material extraction, processing, and manufacturing are not dangerous to the environment or to the employees	4	Y
5.2	Waste Producing	SHLYM	Minimizing waste and hazardous by-products, air pollution, energy expenditure and others	3	Y
5.3	Design for Disposal or Reuse	SHLYM	The disposal or reuse plan should be provided	2	Y
Client's Signature				Connie Phillips	

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6 Project Management

A total of 481 hours was spent on the project during Phase 3. This is higher than the expected total hours predicted during Phase 1 and 2.

6.1 Project Phases

This project was spit up into three phases for the purposes of spreading out the work required to accomplish the design of the product. The first phase was intended to gather information about the process, and research potential solutions on the market. We were successful in determining that there were not any commercially available devices on the market currently within the price range for the intended task, and we were committed to being able to create one. Unfortunately, during Phase 1, we missed some crucial facts about the process which led to a change in design after the completion of Phase 2. The second phase was mostly about the creation and exploration of concept designs that could reasonably meet the clients needs. We were successful in generating three concept designs at the time and chose a design that we felt had the strongest ability to accomplish the task at hand. Phase 3 was the third and final phase of our project. At the beginning of Phase 3 we took the time to visit the facility with the intentions of getting the measurements to scale our design to the location it would be implemented in. However, visiting the facility showed us that our design would not work. The assumptions made early in Phase 1 and 2 did not fit the reality of the task, but we learned from these mistakes and iterated upon our design, converging to a final design that we are confident solves the problem at hand. In the end, the Phase 2 design that we selected did not continue through Phase 3 and in reflection, the design shares more similarities to Concept 1 in Phase 2 with a significant more fleshed out mechanism.

6.2 Hours and Work Accomplished

The updated project schedule is provided in Appendix H. Comparing actual hours to baseline hours, an increase of 22 hours for Phase III from the estimate in Phase II is noted. It is clear that the baseline hours from Phase I was, in the end, an underestimate, as our initial expectations for the time the project would take was expecting a majority of the work for the design to be accomplished in Phase II. The major shakeup in redesigning our project after visiting the extraction facility led to an increase in the amount of time it took to complete Phase III. The new updated hours tell the actual hours it took to complete the project. Table 4 has been updated with the new revised hours and associated costs. Figure 11 shows the updated hours forecast in comparison with the previous forecast.

Table 4. Engineering Hours and Associated Costs.

	SHLYM Hours	Senior Advisor Hours	Subtotal (CAD)
Phase I	63	2	$3,450
Phase II	171	3	$9,000
Phase III	247	3	$12,800
Total	481	8	$25,250

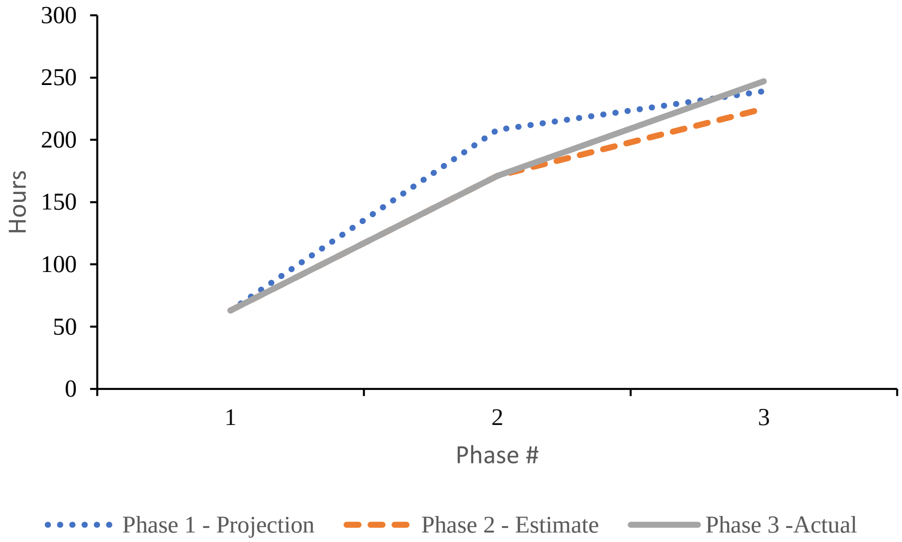

Figure 11. The hours for three phases.

7 Future Work

Some factors could be analyzed further to ensure the success of the design during operation on the assembly line. However, due to time constraints, these considerations were not investigated in depth during the design project. Future recommendations for the client to consider include:

- Adjustable operational heights - the height of the design could be adjustable for more convenient use in other beekeeping farms, where the operational height may be different.
- Method of placing certain frames in desired "3" and "6" slots - originally a "nice to have" from the client, could be useful in placing certain frames in selected slots in order to help protect older, weaker frames and cycle in new frames.

8 Conclusion

SHYLM Design has designed an automated frame removal device for an extraction line. There are three steps of device action. First, the hive box removal system pushes an empty hive box to the box carrier of the box packer. Second, the box packer packs 8 frames together from an extraction line with the empty hive box. Third, the full packed hive box is transferred to the flat conveyor belt by another push by the hive box removal system. These three steps to achieve the objective "Pack and Go". A detailed cost analysis was performed, and calculations and FEA were done to ensure the automated frame removal design is working accurately to push the box, reach the frames and pack the frames. The new design meets most of the design compliance matrix. Additional work is necessary to make the design feasible and fully operational.

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References

[1] Mid Sized Commercial Honey Extracting Room., Aug 1, 2018. Accessed on: May 28, 2021. Available from: Mid sized Commercial Honey Extracting Room - YouTube

[2] Building bee boxes. Accessed on: July 11, 2021. Available from: https://www.kelpstrewn.com/docs/building_hiveware.html

[3] Fixed 9 Frame Spacer: 10PK. Betterbee. 2021. Accessed on: May 28, 2021. Available from: https://www.betterbee.com/wooden-hive-equipment-10-frame/spacer.asp

[4] Are Photoelectric sensors suitable for harsh environment use? 2020. Design Spark. Accessed on: August 05, 2021. Available from: https://www.rs-online.com/designspark/are-photoelectric-sensors-suitable-for-harsh-environment-use

SHLYM Designs

Appendix A: Design Matrix

In this appendix A, it is the revised Design Specification Matrix.

Table 5. Reversed Design Matrix.

Item	Specification (description)	Design Authority	Comments	Importance (1-5)	Changes	Achieved (Yes/No)	Notes
			Physical				
1.1	~~Mass of Single Frame is 1 kg~~	~~Client~~	~~Frames should not have honey in them after extraction~~	~~3~~			~~Parameter provided by client~~
1.2	Mass of Full Frame Box is 15 kg	Client	The boxes must be moved at both full and empty weights	3	Adjusted wording to move frame box	Y	
1.3	Height of Line is ~1.5 m	Client	Height of frame removal	4	Adjusted wording	Y	
1.4	~~Concrete Pad Support~~	~~Client~~	~~Mechanically fastened to concrete floor. Should be easy to disassemble/remove from extraction line~~	~~5~~			~~Unneeded in case of moving the assembly line~~
			Functional				
2.1	Automatic Spacing of Frames	Client	Boxes come with spacers that frames should slot into	5		Y	
2.2	No Damage to Box Spacers	Client	Damage to spacers will cause difficulty in inserting frames into boxes	4		Y	

2.3	Be able to consistently remove and replace the frames without damage	Client	Client requires throughput of 100 boxes/hour	4		Y	
~~2.4~~	~~Ability to Lift Frame~~	~~Client~~	~~Needs to be able to lift the frame off the extraction line and place into the box~~	~~5~~			~~New design does not lift frames~~
2.5	Ability to Replace Frame in Hive Box	Client	The purpose of this design	4		Y	
2.6	Ease of Maintenance	SHLYM	The device should be easy to repair and maintain	3	Moved to Maintenance section	Y	
2.7	Ease of Manipulation	SHLYM	Should be easy to start and stop by client	4		Y	
~~2.8~~	~~Emergency Stop Button~~	~~SHLYM~~	~~When an emergency occurs, operators can shut off machine immediately~~	~~5~~			~~Emergency will not be critical enough to need stop button~~
2.9	~~Operation Safety (safety guards, covers, etc.)~~	~~Client/ SHLYM~~	~~Worker's safety is paramount, the design should take this into consideration~~	~~5~~			~~Workers not present/minimal danger~~
2.10	Resistance to Corrosion (from water, cleaning solutions, honey, etc.)	Client	Extraction line is sprayed down daily which increases chance of corrosion	5		Y	
~~2.11~~	~~Adjustable Height~~	~~SHLYM~~	~~For different working environments~~	~~1~~			~~Not applicable with new design~~

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2.13	Intersperse New Frames	Client	The ability to add new frames to the 3 and 6 slots in the box is useful for removing old decayed frames	2		N	Could not be added due to time constraints
2.14	Food Safe	Client	All parts of the mechanism that touch the frame must be food safe and cannot be painted. Machine should be easy to clean/sanitize	5		Y	
Other							
3.1	Cost of Product $20,000	Client	Maximum cost of product considered by client	5			
~~3.2~~	~~Production Volume 100 Units~~	~~Client~~	~~If product is successful there are many honey extraction facilities that would be interested in product~~	~~1~~		~~Y~~	~~Focus on single production to accurately measure costs~~
3.3	Manufacturability	SHLYM	Design should be made with manufacturability in mind	3		Y	
3.4	Reliability	Client	Important to not drop frames	4		Y	
3.5	Life Span of 10yrs	Client	The mechanism should last for 10-	4		Y	

SHLYM Designs

			15yrs to make the return on investment				
3.6	Documentation	Client	Drawing and documents of the device should be provided	5	Added to matrix	Y	
Maintenance							
4.1	Part Availability	SHLYM	Parts information should be provided and readily-available	4	Added to matrix	Y	
4.2	Ease of Assembly/Disassembly	SHLYM	Limit the requirement for specialized tools	4	Added to matrix	Y	
4.3	Ease of Maintenance	SHLYM	The design should be easy to repair and maintain	3	Moved from Functional section	Y	
Environmental							
4.1	Material Processing	SHLYM	The raw material extraction, processing, and manufacturing are not dangerous to the environment or to the employees	4	Added to matrix	Y	
4.2	Waste Producing	SHLYM	Minimizing waste and hazardous by-products, air pollution, energy expenditure and others	3	Added to matrix	Y	

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4.3	Design for Disposal or Reuse	SHLYM	The disposal or Reuse plan should be provided	2	Added to matrix	N	Could not be added due to time constraints

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Appendix B: FEA

Box Carrier

Box Carrier is the component holding the hive box. Solidworks 3D finite element analysis was used to analysis the stress and strain of a specific component through changing the material.

In this box carrier design, the box carrier is fixed at the bottom by the pneumatic cylinder. On the top of the bee box, it carries a full box (a bee box with 8 frames). The mass of the full box is 7 kg; however, considering the residual honey after the extraction, the mass of the full box is 18 kg in this simulation.

There is gravity exerting on the bee box. Here g is the gravity with a value of 9.81 m/s^2.

Assumptions:

- Applied external load is downwards only
- Load is symmetric
- Material properties are constant- no work hardening occurs

Material

Based on Safe Food for Canadian Regulation subdivision C, there are 2 materials – Steel 304 and Aluminum are recommended to use with the frames. Therefore, Steel 304 and Aluminum are used to design the box carrier, and their basic properties are shown in Table 6.

Table 6. Properties of Steel 304 and Aluminum.

Material	Elastic Modulus (N/m^2)	Mass Density (kg/m^3)	Weight of carrier (kg)
Steel 304	$1.9 * 10^9$	8000	19.796
Aluminum	$6.9 * 10^{10}$	2700	6.681

Due to the limitation of CPU, the mesh is set to the global mesh 5. The mesh result is showed in Figure 12 for both Steel 304 and Aluminum.

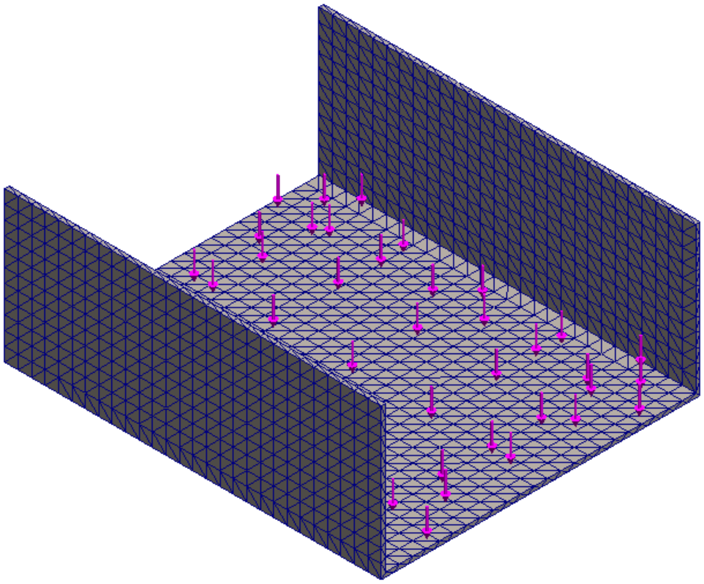
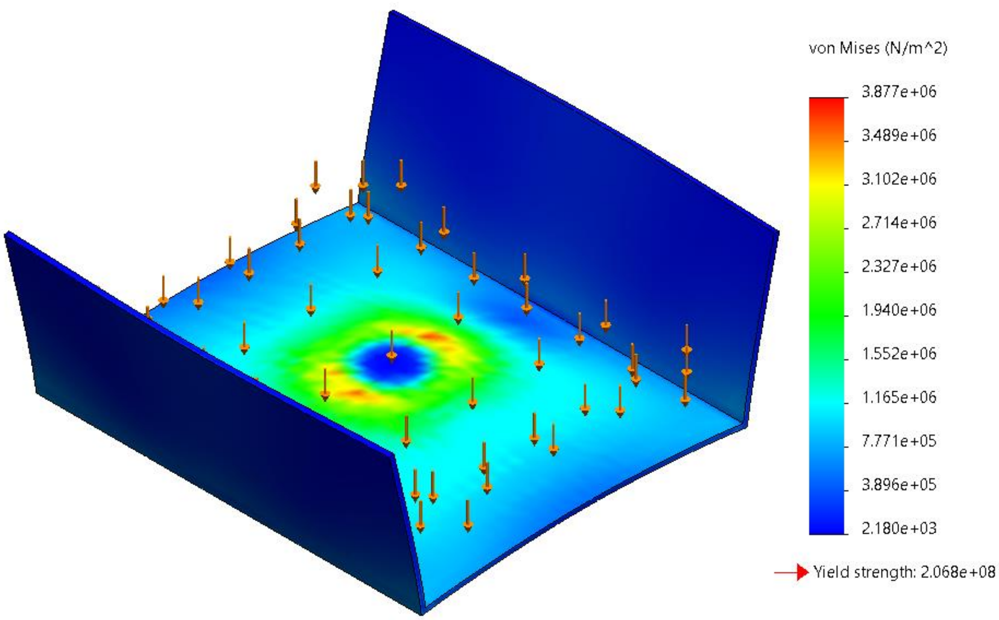
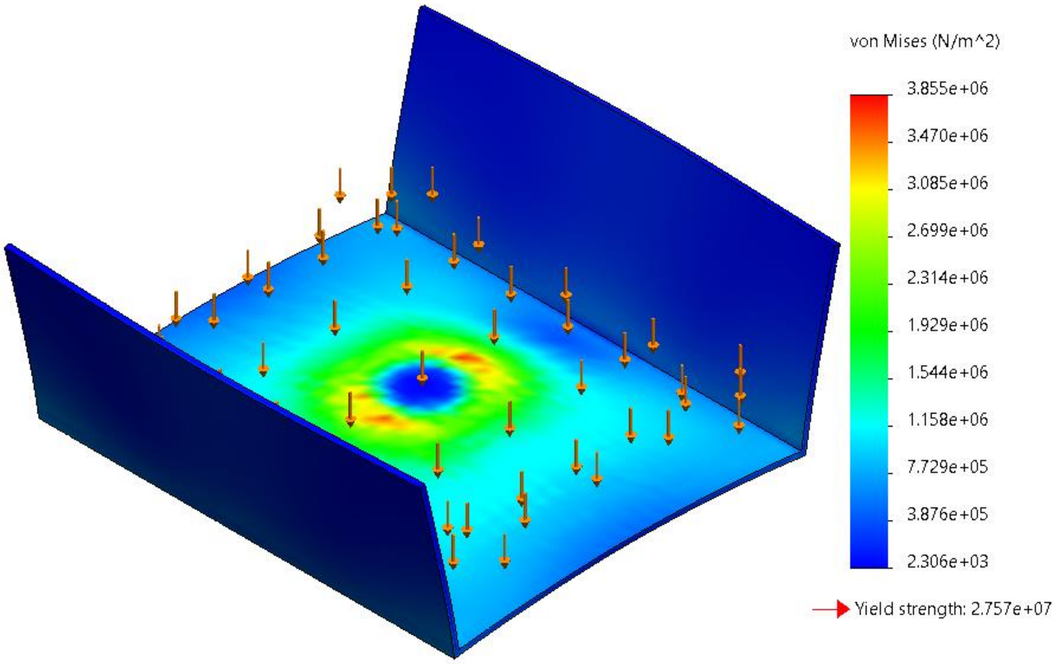


Figure 12. The view of generated mesh with even distributed load.



(a)

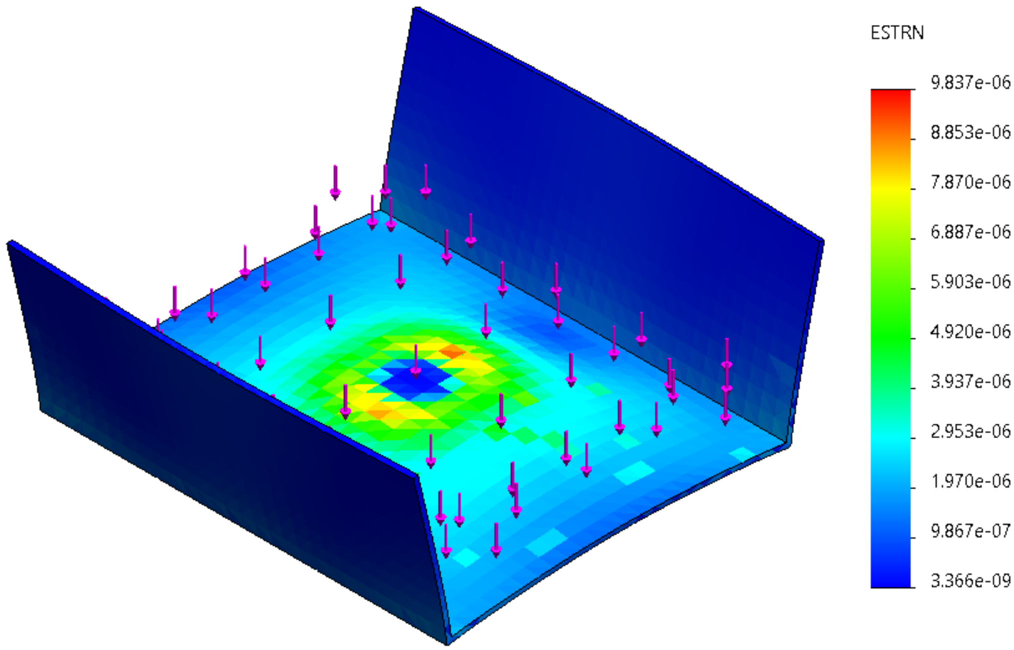


(b)

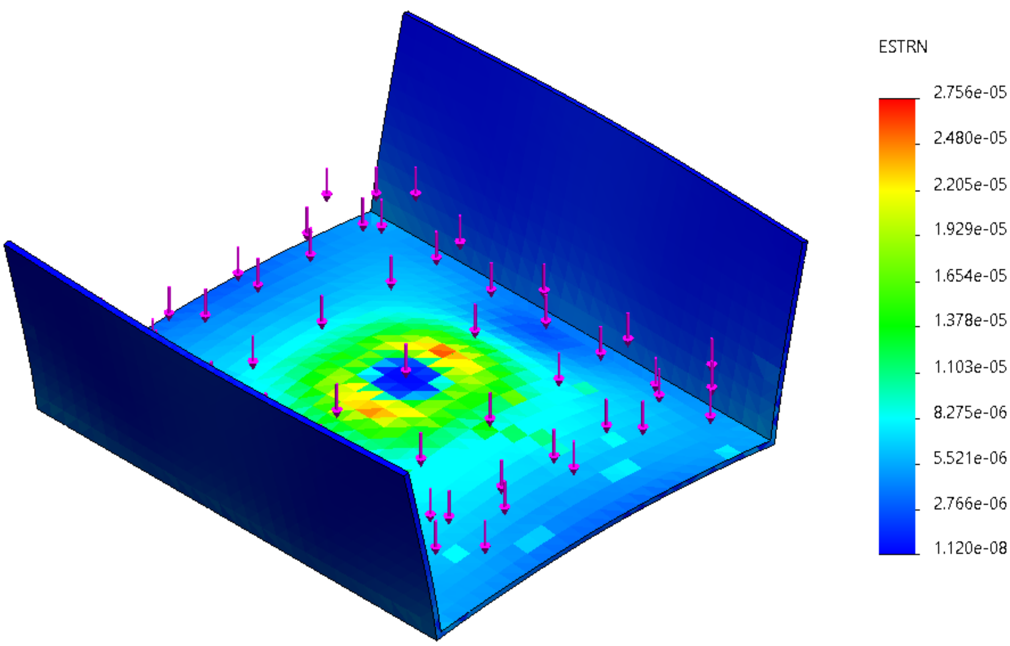
Figure 13. The simulation result of Von Mises. (a) Steel 304. (b) Aluminum.

In Figure 13, the highest of Von Mises stress are presented around the fixed and symmetric for both Steel 304 and Aluminum, $3.877*10^6$ N/m^2 and $3.855*10^6$ N/m^2, respectively. There is 0.022 $*10^6$ N/m^2 difference.

In Figure 14, the strain of the box carrier of Steel 304 is $1.77 * 10^{-5}$ lower than Aluminum.



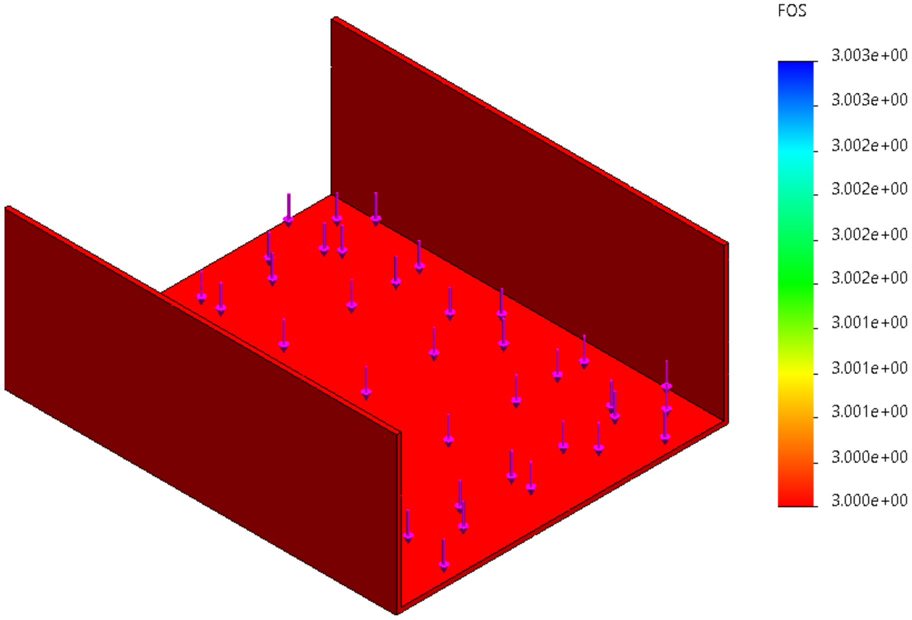
(a)



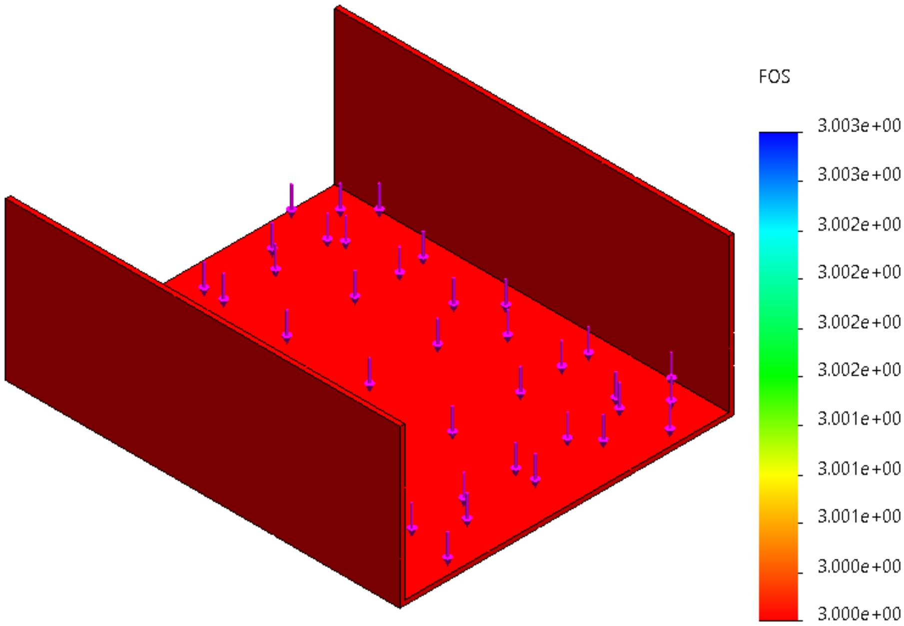
(b)

Figure 14. The simulation result of strain. (a) Steel 304. (b) Aluminum.

In Figure 15, both the safety factor of Steel 304 and Aluminum is about 3. Therefore, both materials achieve the design goal.



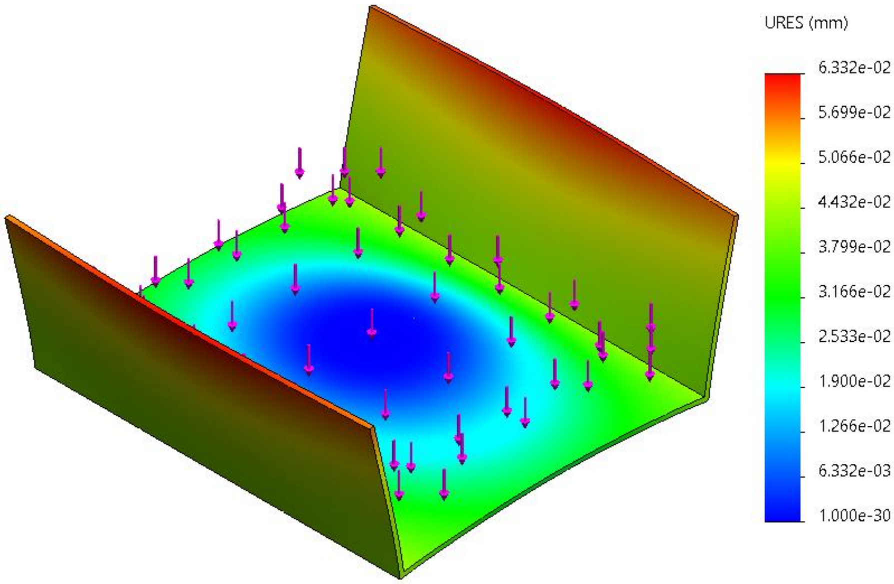
(a)



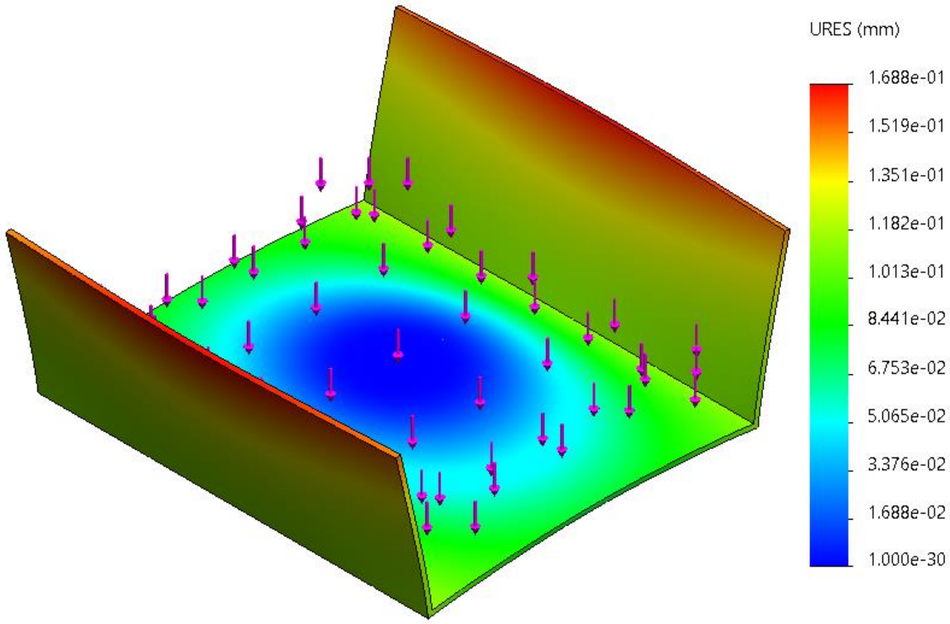
(b)

Figure 15. The simulation result of the safety factor. (a) Steel 304. (b) Aluminum.

Figure 16 shows the displacement of each material. The displacement of the Steel 304 is less than Aluminum by 0.105 mm.



(a)



(b)

Figure 16. The simulation result of the displacement. (a) Steel 304. (b) Aluminum.

Therefore, Steel 304 is selected in this design.

Dimension

To find the minimum stress and mass in the designed box carrier, the thickness was monitored in the design study. The result (Table *7*) shows when thickness is 4 mm, the box carrier has a minimum stress 3.866 * 10^6 N/m^2 and a relatively small mass of 18.191 kg. In Figure 17, it presents the changing steps of the thickness.

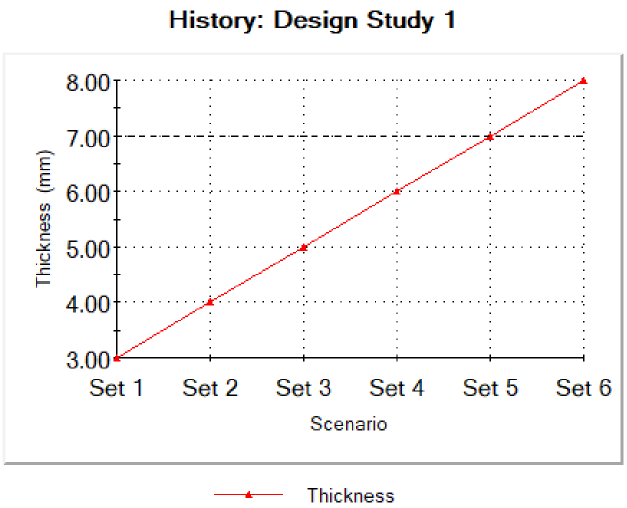


Figure 17. The thickness changing for each scenario.

Table 7.The design study results.

Scenario No.	1	2	3	4	5	6
Thickness (mm)	3	4	5	6	7	8
Stress x10^6 (N/m^2)	3.926	3.866	3.945	3.877	4.028	3.868
Displacement x10^{-5}(mm)	7.387	6.554	6.936	5.455	5.331	5.237
Factor of Safety	52.67	53.50	52.56	53.34	51.337	53.47
Mass (kg)	17.388	18.191	18.993	19.796	20.599	21.401

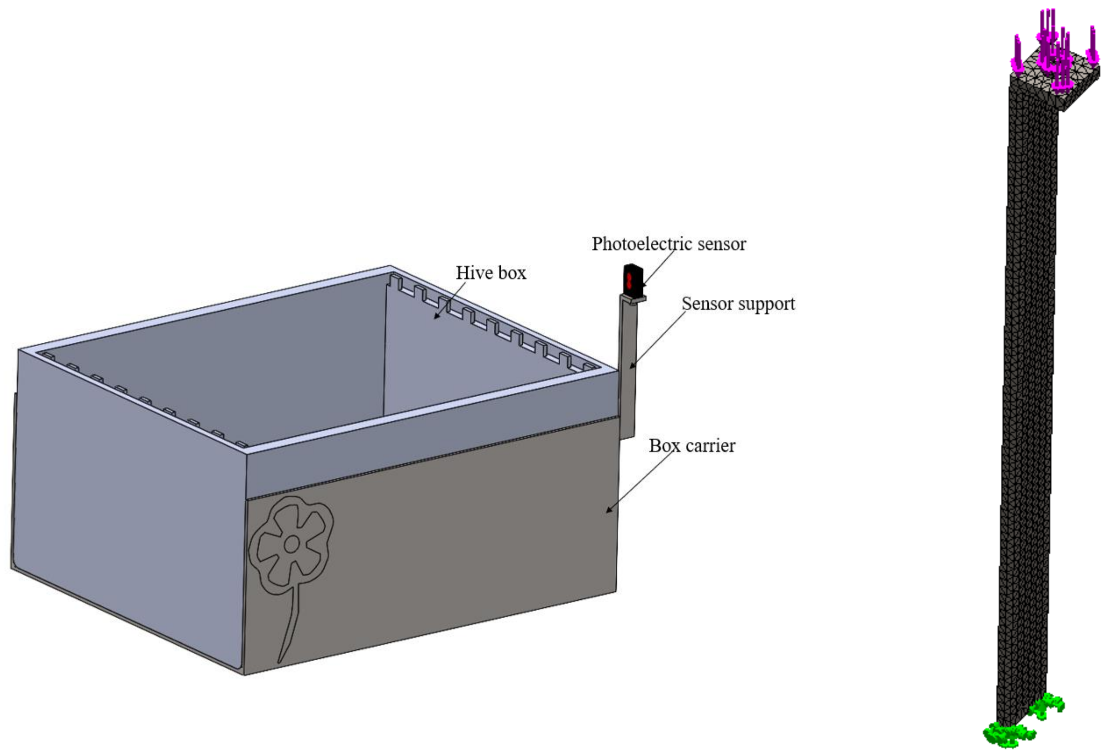
Sensor support

The sensor support (Figure *18* (a)) holds a 30 g Diffuse-reflective Sensor which senses the number of frames from the extraction line. The material of the sensor support is selected to be AISI 304, and length of the sensor support is 260 mm.

Assumptions:

- Applied external load is downwards only
- Load is symmetric
- Material properties are constant- no work hardening occurs

Due to the limitation of the CPU and time constraints, the mesh was set to global meshing as shown in Figure 18 (b). To find the maximum displacement of the sensor support, the load was applied to the top and the fixture was applied to the bottom, even though part of the sensor support would be welded to the box carrier as shown in Figure 18 (a).



(a) (b)

Figure 18. View of the sensor support. (a) General view. (b) Mesh of sensor support.

Using Von Mises simulation, the results demonstrated that the highest stress of 3.103 * 10^4 N/m^2, which occurred at the concave side, was lower than the yield strength of 2.068 * 10^4 N/m^2, shown in Figure 19.

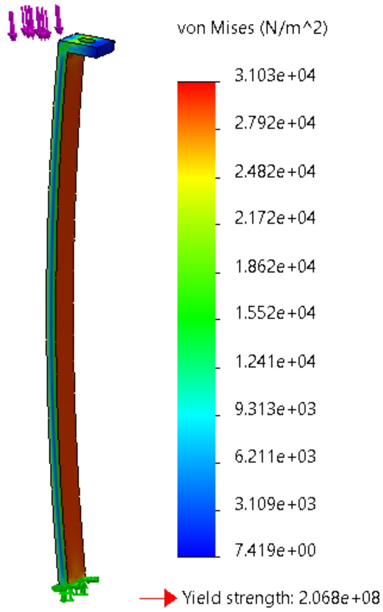


Figure 19. Simulation result of stress.

The highest displacement of 1.968 * 10^{-3} mm occurred at the top plate where the sensor was mounted. This displacement was less than the goal displacement of 0.01 mm by 5 times. The results are shown in Figure 20.

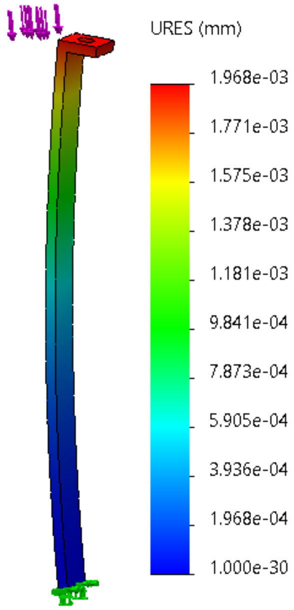


Figure 20. Simulation result of displacement.

The minimum factor of safety distribution is 3 or above. The results are shown in Figure 21.

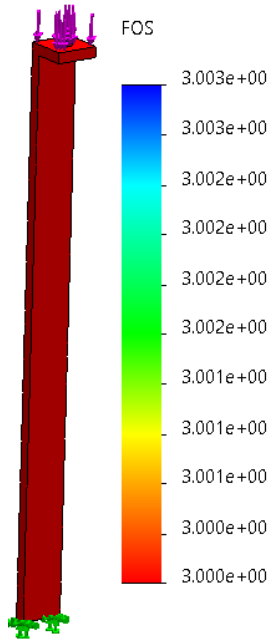


Figure 21. Simulation result of factor of safety.

To obtain the minimum mass, stress and displacement, the completed design study is shown in the Table *8* based on modifying the height of the support. The optimal height size was found to be 260 mm.

Table 8. The design study of sensor support.

Scenario	1	2	3	4	5	6	7	8	9	10	11
Height (mm)	100	120	140	160	180	200	220	240	260	280	300
Stress (N/m^2)	33059	33012	31127	31287	31800	32527	32348	32813	31025	31188	31941
Mass (kg)	94	110	126	142	158	174	190	206	222	238	254
Displacement x 10^{-8} (mm)	5	5	5	4	4	4	5	5	5	5	4

Pneumatic Cylinder Table

The pneumatic cylinder table supports the Pneumatic air cylinder. The material of the sensor support is selected to be AISI 304.

Assumptions:

- The mass of the pneumatic cylinder table is 10 kg
- Applied external load is downwards only

- Load is evenly distributed
- Material properties are constant- no work hardening occurs

Due to the limitation of the CPU and time consuming, the global mesh is used in this study. The mesh is in Figure 22.

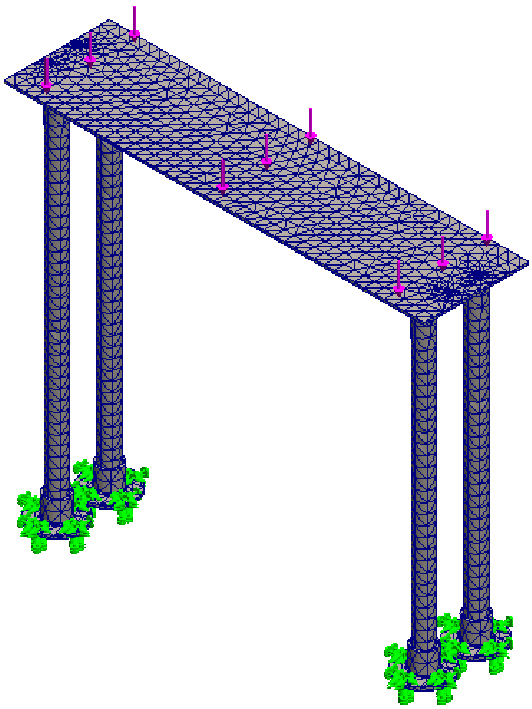


Figure 22. The mesh of the pneumatic table.

Through the Von Mises analysis, the largest of the Von Mises stress is 7.403 x 10^5 N/m^2 which is 280 times less than the yield strength 2.068 x 10^8 N/m^2. The result shows in Figure 23.

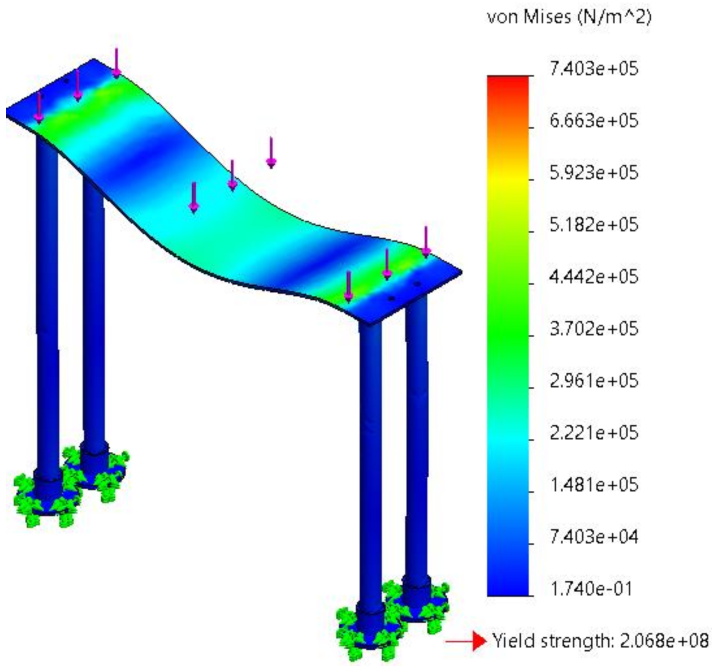


Figure 23. The Von Mises analysis result of the pneumatic cylinder table.

With set upper limit for factor of safety as 3, the simulations result shows the pneumatic cylinder table is meets the requirement. The result shows in Figure 24.

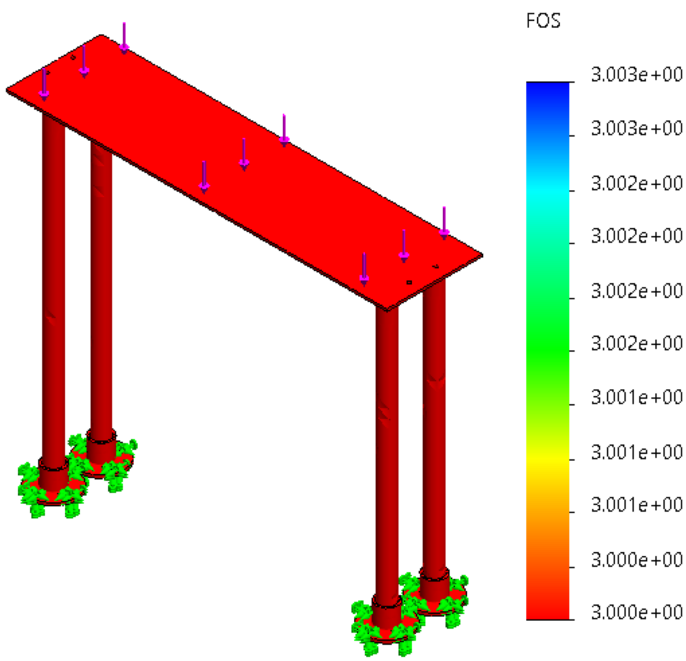


Figure 24. The FOS simulation result of pneumatic cylinder table.

Appendix C: Cost Analysis

For the box packer machine, the required fabrication processes are:

- Waterjet cut sheet metal
- Bend sheet metal
- Cut plate steel and drill holes into plate steel
- Assemble cylinders into supports
- TIG weld sheet metal and Stick/MIG weld tubing to plate
- Form bolted connections

The estimated fabrication time is five hours including waterjet cutting time. Using a shop rate of $100 per hour, the total manufacturing costs of the box packer are $500.

For the box removal system, the required fabrication processes are:

- Cut plate steel and drill holes into plate steel
- Assembly cylinders into supports
- Form bolted connection
- 3D printing the rubber head

The estimated fabrication time is 24 hours including 3D printing. By the Solidworks manufacturing cost analysis, and a shop rate $ 100 per hour, the total manufacturing cost of the box removal is $ 349.

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Products you are buying: 1

Item Description	Dimensions	Quantity	Price
STAINLESS SHEET 304 (0.109 (12Ga) ST 304 - 2B SHEET) **Sku:** SSH304/105/2	30.00 x 52.00 Inches	1	CDN$352.13

Weight: 53 LBS Per piece price: CDN$352.13 Update Price Delete

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Comments:

Material Cost: CDN$352.13

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Item Description	Dimensions	Quantity
STAINLESS PLATE 304 (0.250 ST 304 PLATE) **Sku:** SP304/250	10 x 10 Inches	1

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Comments:

Online Prices may vary from in-store prices. This may not be used as an in-store order or quotation. Product availability varies from store to store.

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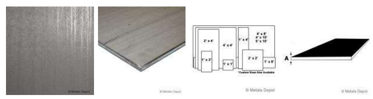
Other Metals with similar Profile

- ALUMINUM SHEET
- BRASS SHEET
- COPPER SHEET
- GALVANIZED SHEET
- STAINLESS SHEET
- STEEL-COLD ROLLED SHEET
- STEEL-HOT ROLLED SHEET

Other Like Profiles with similar Grade

- 304 STAINLESS ANGLE
- 304 STAINLESS FLAT BAR
- 304 STAINLESS ROUND
- 304 STAINLESS SHEET
- 304 STAINLESS SQUARE
- 304 STAINLESS TUBE SQUARE

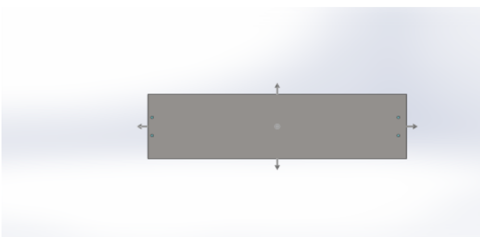
304 Stainless Plate



⚠California Residents Warning!

Product / Size / Weight / Stock
Select Size & Quantity to Add to Cart

3/16" (.1875) thick 304/304L Stainless Steel Plate - Mill Finish	Select Size	Qty	0.00	Add To Cart
1/4" (.250) thick 304/304L Stainless Steel Plate - Mill Finish	Select Size	Qty	0.00	Add To Cart
3/8" (.375) thick 304/304L Stainless Steel Plate - Mill Finish	Select Size	Qty	0.00	Add To Cart
1/2" (.500) thick 304/304L Stainless Steel Plate - Mill Finish	Select Size	1	USD **$165.35** ea. ✔ **In Stock**	Add To Cart
3/4" (.750) thick T304 Stainless Steel Plate - Dull Mill Finish	Select Size	Qty	0.00	Add To Cart
1" (1.00) thick 304/304L Stainless Steel Plate - Mill Finish	Select Size	Qty	0.00	Add To Cart



Model Name: pneumatic table

Date and time of report:	2021-08-02 1:36:53 PM

Manufacturing Method: Machining

Material:	AISI 304
Stock weight:	14.11 lb
Stock Type	Block
Block Size:	31.50x0.20x7.87 in
Material cost/weight:	9.80 USD/lb
Shop Rate:	N/A

Quantity to Produce

Total number of parts:	100
Lot size:	100

Estimated cost per part: **141.29 USD**

Costing template used:	machiningtemplate_default(englishstandard).sldctm
Costing mode used:	Manufacturing Process Recognition
Comparison:	0% Current 141.29 USD Previous 141.29 USD

Cost Breakdown

Material:	138.27 USD	98%
Manufacturing:	3.01 USD	2%
Markup:	0.00 USD	0%
Mold:	0.00 USD	0%

Estimated time per part: **00:06:01**

Setups:	00:05:35
Operations:	00:00:25

Model Name:	pneumatic table	Material:	AISI 304	Material cost:	138.27 USD	Total cost /part:	141.29 USD
				Manufacturing cost:	3.01 USD	Total time /part:	00:06:01
				Markup:	0.00 USD		

Manufacturing Cost Breakdown

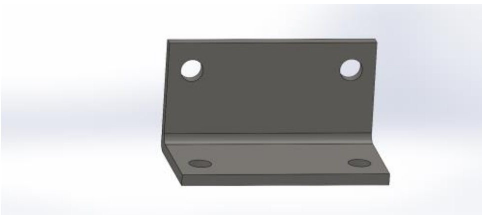
Operation Setups	Time (hh:mm:ss)	Cost (USD / Part)
Setup Operation 1	00:00:36	0.30
Total	**00:00:36**	**0.30**

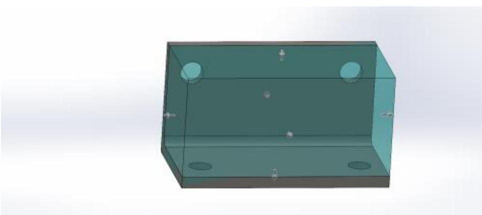
Load and Unload Setups	Time (hh:mm:ss)	Cost (USD / Part)
Setup Operation 1	00:05:00	2.50
Total	**00:05:00**	**2.50**

Hole Operation	Surface Finish	Volume Removed (in^3)	Time (hh:mm:ss)	Cost (USD / Part)	Tooling	Cost-per-Volume (USD/in^3)
Hole 1	Drill	0.02	00:00:06	0.05	HSS Drill	N/A
Hole 2	Drill	0.02	00:00:06	0.05	HSS Drill	N/A
Hole 3	Drill	0.02	00:00:06	0.05	HSS Drill	N/A
Hole 4	Drill	0.02	00:00:06	0.05	HSS Drill	N/A
Total		**0.06**	**00:00:25**	**0.21**		

Setup Operations

1. Setup Operation 1
   a. Hole 3
   b. Hole 1
   c. Hole 2
   d. Hole 4





Model Name: pneumatic cylinder mount

Date and time of report:	2021-08-02 2:55:33 PM

Manufacturing Method: Machining

Material:	AISI 304
Stock weight:	2.06 lb
Stock Type	Block
Block Size:	2.88x1.57x1.57 in
Material cost/weight:	9.80 USD/lb
Shop Rate:	N/A

Quantity to Produce

Total number of parts:	100
Lot size:	100

Estimated cost per part: 28.77 USD

Costing template used:	machiningtemplate_default(englishstandard).sldctm
Costing mode used:	Manufacturing Process Recognition
Comparison:	100 Current 28.77 USD

Cost Breakdown

Material:	20.20 USD	70%
Manufacturing:	8.57 USD	30%
Markup:	0.00 USD	0%
Mold:	0.00 USD	0%

Estimated time per part: 00:17:08

Setups:	00:16:48
Operations:	00:00:20

Model Name:	pneumatic cylinder mount	Material:	AISI 304	Material cost: Manufacturing cost: Markup:	20.20 USD 8.57 USD 0.00 USD	Total cost /part: Total time /part:	**28.77 USD** **00:17:08**

Manufacturing Cost Breakdown

Operation Setups	Time (hh:mm:ss)	Cost (USD / Part)
Setup Operation 1	00:00:36	0.30
Setup Operation 2	00:00:36	0.30
Setup Operation 3	00:00:36	0.30
Total	**00:01:47**	**0.90**

Load and Unload Setups	Time (hh:mm:ss)	Cost (USD / Part)
Setup Operation 1	00:05:00	2.50
Setup Operation 2	00:05:00	2.50
Setup Operation 3	00:05:00	2.50
Total	**00:15:00**	**7.50**

Operation	Surface Finish	Volume Removed (in^3)	Time (hh:mm:ss)	Cost (USD / Part)	Tooling	Cost-per-Volume (USD/in^3)
Volume 1	Roughing	0.01	00:00:00	0.00	Flat End Mill	N/A
Total		**0.01**	**00:00:00**	**0.00**		

Hole Operation	Surface Finish	Volume Removed (in^3)	Time (hh:mm:ss)	Cost (USD / Part)	Tooling	Cost-per-Volume (USD/in^3)
Hole 1	Drill	0.01	00:00:05	0.04	HSS Drill	N/A
Hole 2	Drill	0.01	00:00:05	0.04	HSS Drill	N/A
Hole 3	Drill	0.01	00:00:05	0.04	HSS Drill	N/A
Hole 4	Drill	0.01	00:00:05	0.04	HSS Drill	N/A
Total		**0.05**	**00:00:20**	**0.17**		

No Cost Features
Slot 1
Fillet 1

Setup Operations

1. Setup Operation 1
    a. Hole 1
    b. Hole 2
2. Setup Operation 2
    a. Hole 3
    b. Hole 4
3. Setup Operation 3
    a. Volume 1

Appendix D: Sustainability & Material Recycling Information

Sustainability was kept in mind during the design of the box packer. As well as being key to the economic feasibility of the machine, it is also good for the environment. Specifically, it is straightforward to repair/replace broken or defective components without needing to throw the existing unit out. Once the machine has outlived its productive usefulness, there is little in the ways of disposable garbage. Most of the material used in the design is recyclable. The contact information of some local recyclers who can safely dispose of the machine is offered in Table 9 below.

Table 9. Area recyclers accepting machine scrap.

Material	Company	Contact Information
Metals (Steel 304, Aluminum)	General Recycling Industries LTD.	4120-84 Avenue, Edmonton, AB, T6B, 3H3 Local : 780-452-5865 Toll Free : 1-866-983-9999 Fax : 780-468-6111 Email : Sales@generalcecycling.com
	Evraz Recycling	5857 12 St SE, Calgary, Alberta, T2H 2G7 Phone : 403-252-1229
Wires	Bare Wire Recycling Inc.	1512 Hastings Crescent SE, Calgary, AB T2G 3S1 Phone: 403-998-9209

General Recycling Industries LTD.: This company handles all the scrap metal recycling needs. They accept both ferrous materials (scrap metal) and non-ferrous material (such as copper, aluminum, and brass).

Evraz Recycling: The largest scrap metal recycler in Western Canada, and they buy, sell and process ferrous and non-ferrous materials and offer a wide variety of metal recycling option.

Bare Wire Recycling Inc.: This company recycles the wire in Alberta.

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Appendix E: Controls & Automation

The automation of the design detailed within this report is dependent on being able to operate reliably and predictably without the involvement of human operators. This means that once boxes are unloaded onto the conveyer, the automation process should be able to move the box off the in-conveyor onto the box packer machine and then off onto the out-conveyer. To provide this process autonomy, the electrical system is coupled with the pneumatic system through a microcontroller. Each of these systems is described in detail below.

Electrical

It is assumed that a standard 120 V 15 A circuit can be provided and a receptacle/drop installed where the machine is to be located. The power requirements of this machine are minimal due to the primary use of pneumatics as the source of energy for movement. The electrical system senses the current state of the machine and controls the pneumatic process according to a program stored in read-write memory.

The required components are:

- A microcontroller (with power adapter) having the ability to read and write external electrical signals and execute modifiable programs. Although a sample script (or 'sketch' in Arduino parlance) is provided for an Arduino later in this section, numerous other low-cost microcontrollers are available.
- (7) sets of relay contacts, 6 for powering the pneumatic control valve solenoids and one for the conveyor drive motor. In this system, the directional air control valve solenoids operate on 120 V AC and so 120 V AC relays switched by 5 V DC are specified.
- A normally-closed emergency stop button placed in series with the power source for the air solenoids.
- An optical sensor to detect when a box is positioned in front of the 'hive box removal system' pneumatic cylinder.

Pneumatics

It is assumed that the owner can provide dry, filtered air at a regulated pressure of 100 PSI to the location where the machine is to be installed. The components are as follows:

- (3) Pneumatic cylinders as specified in the bill of materials.
- (3) Directional air control valves to control pneumatic cylinder extension and retraction. These valves are double solenoid-controlled 5-port 3-position valves with either a closed or exhaust center. A closed center is used for the vertical cylinder only to ensure the cylinder remains extended when airflow is switched off. (1) Four-port manifold to let one inlet hose supply the three control valves.
- (6) Adjustable mufflers. These thread into the exhaust ports of the control valves and allow adjustment of the exhaust flow rate, in turn speeding up or slowing down how fast a cylinder can either extend or retract. Speeds can be set to be the same for extension/retraction or to be different.

Control & Sequence of Operation

1. Empty boxes are placed on the motorized feeder conveyer belt. The motor for this conveyor belt is switched on either by a manual pushbutton accessible by the labourer who empties the frames out of the boxes at the start of the extraction line or by a high signal sent by the microcontroller acting through a relay. An optical sensor positioned in line with the pneumatic cylinder detects when a box is in front of the pneumatic cylinder and sends a signal to the microcontroller to turn off the relay powering the motor.
2. The microcontroller tracks the position of the cylinders in a set of variables.
3. When the box packer is in the home position and a box is situated in line with the box carrier/the pneumatic cylinder, the pneumatic cylinder extends through a partial stroke of 12” to push the box onto the box carrier. The cylinder remains extended at this point.
4. The microcontroller begins to command the box carrier through its horizontal and vertical translations. The horizontal cylinder first extends through its 18” stroke travel and stops. The vertical cylinder extends up 12” and stops. The round tube support legs are to be cut to such a length that he honey frames will be between ½ to ¾ in the box at the end of this travel. The horizontal cylinder then retracts, pulling the frames off the extraction line chain. The vertical cylinder then retracts, returning the box carrier and box to the home position.

5. The conveyer pneumatic continues extending to its maximum stroke of 24” to finish pushing the box off the box carrier and onto the conveyer which leads to pallet stacking.
6. The conveyor pneumatic cylinder retracts and the process cycles again as in 1).

Recommended future investments

Should the owner wish to invest more into the machine, we recommend the following improvements to increase reliability and function:

1. Programmable flow valves on the exhaust ports of the directional air control valves allows for the speed of extension and retraction of the cylinder to be modified programmatically by adjusting the flow of exhaust through the flow valve. Specifically, this permits tuning of the motion that settles the frames into the box using quick back and forth motions of the horizontal cylinder to jostle the frames into the spacers. The use of programmable flow valves allows a gentler extension of the cylinder when moving the empty box under the frames, and for more rapid oscillations once loaded.
2. Sensor-ready cylinders and magnetic (reed) switches to sense cylinder position. Piston speed is intended to be kept low (on the order of 0.9144 m/s or 3.6 in/s) in order to keep dynamic loads low and reduce premature cylinder and support rail wear. The use of sensor-ready cylinders in conjunction with a reed sensor allows the position of the piston to be sensed and relayed to the microcontroller. With the higher speeds the recommendation in 1) entails, adding the ability to sense the piston location can be used to throttle the controlling flow valve, slowing the piston down to reduce the force acting on the cylinder endcaps.

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Sample Arduino Program

The following Arduino program or 'sketch' contains starter code with variables that will need to be fine-tuned during the commissioning process (namely, the length of time solenoids should be energized based on the speed of extension or retraction). The program also contains sections of commented-out code where the above future suggestions would go if implemented.

```
//digital pins 2-13 are available to use for digital read/write
//optical sensor which detects for a box on the conveyor in line with the conveyor pneumatic cylinder
int box_proximity_sensor = 2;

//conveyer pneumatic cylinder
int conveyer_pneumatic_extend = 3; //extend the cylinder by setting this pin high
int conveyer_pneumatic_retract = 4; //retract the cylinder by setting this pin low

//horizontal pneumatic cylinder
int horizontal_pneumatic_extend = 5;
int horizontal_pneumatic_retract = 6;

//vertical pneumatic cylinder
int vertical_pneumatic_extend = 7;
int vertical_pneumatic_retract = 8;

int conveyor_motor_relay = 9;


/*IMPORTANT! The time that solenoids are energized to move pistons must be adjusted in commissioning along with the exhaust
valves in order to ensure
piston extension/retraction is kept close to 0.9144 m/s or 3.6 in/s.
Adjust the below values as required. */

float conveyer_pneumatic_extend_partial_runtime = 0; //partial extension to push the box onto the box carrier
float conveyer_pneumatic_extend_full_runtime = 0; //additional time required to reach full stroke to push box off box carrier
float conveyer_pneumatic_retract_runtime = 0;
float horizontal_pneumatic_extend__runtime = 0;
float horizontal_pneumatic_retract_runtime = 0;
float vertical_pneumatic_extend__runtime = 0;
```

```
float vertical_pneumatic_retract_runtime = 0;


//set up pins to be in read or write mode
void setup()
{
 pinMode(box_proximity_sensor, INPUT);
 pinMode(conveyer_pneumatic_extend, OUTPUT);
 pinMode(conveyer_pneumatic_retract, OUTPUT);
 pinMode(horizontal_pneumatic_extend, OUTPUT);
 pinMode(horizontal_pneumatic_retract, OUTPUT);
 pinMode(vertical_pneumatic_extend, OUTPUT);
 pinMode(vertical_pneumatic_retract, OUTPUT);

 //home the cylinders

 if (digitalRead(box_proximity_sensor) == false)
 {
  digitalWrite(conveyer_pneumatic_retract, HIGH);
  delay(conveyer_pneumatic_retract_runtime);
  digitalWrite(conveyer_pneumatic_retract, LOW);
 }

 digitalWrite(vertical_pneumatic_retract, HIGH);
 delay(vertical_pneumatic_retract_runtime);
 digitalWrite(vertical_pneumatic_retract, LOW;

 digitalWrite(horizontal_pneumatic_retract, HIGH);
 delay(horizontal_pneumatic_retract_runtime);
 digitalWrite(horizontal_pneumatic_retract, LOW);


}

void loop()
{
 //if no box in front of conveyor cylinder, run the conveyor until a box is line with the cylinder
 if (digitalRead(box_proximity_sensor) == false)
 {
```

```
  do {
    digitalWrite(conveyor_motor_relay, HIGH)
  } while (digitalRead(box_proximity_sensor) == false)
}
digitalWrite(conveyor_motor_relay, LOW)

//begin by pushing the box onto the box carrier
digitalWrite(conveyer_pneumatic_extend, HIGH);
delay(conveyer_pneumatic_extend_partial_runtime);
digitalWrite(conveyer_pneumatic_extend, LOW);

//extend the horizontal cylinder
digitalWrite(horizontal_pneumatic_extend, HIGH);
delay(horizontal_pneumatic_extend__runtime);
digitalWrite(horizontal_pneumatic_extend, LOW);



//go up with the box
digitalWrite(vertical_pneumatic_extend, HIGH);
delay(vertical_pneumatic_extend__runtime);
digitalWrite(vertical_pneumatic_extend, LOW);

//retract to pull frames off the chains
digitalWrite(horizontal_pneumatic_retract, HIGH);
delay(horizontal_pneumatic_retract_runtime);
digitalWrite(horizontal_pneumatic_extend, LOW);

//go back down with the filled box
digitalWrite(vertical_pneumatic_retract, HIGH);
delay(vertical_pneumatic_retract_runtime);
digitalWrite(vertical_pneumatic_extend, LOW);

//push box off the box carrier
digitalWrite(conveyer_pneumatic_extend, HIGH);
delay(conveyer_pneumatic_extend_full_runtime);
digitalWrite(conveyer_pneumatic_extend, LOW);

//retract the conveyor cylinder to its fully retracted position
digitalWrite(conveyer_pneumatic_retract, HIGH);
```

```
  delay(conveyer_pneumatic_retract_runtime);
  digitalWrite(conveyer_pneumatic_retract, LOW);

  //give a one second delay and then repeat the program loop
  delay(1000);
}
```

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Appendix F: Pneumatics Calculations

UNIVERSITY OF ALBERTA

Rev.: 1.0
Author: M. Lantz

ENGINEERING CALCULATIONS WORKSHEET

Page: 1 of 3

TITLE:

PNEUMATIC CALCULATION TEMPLATE

PURPOSE:

THIS CALCULATION IS USED TO DETERMINE THE SIZE OF TUBING REQUIRED TO SUPPLY AIR TO THE PISTON AND FLOW RATE REQUIRED TO OPERATE AT THE PREDETERMINED SPEED FOR A CHOSEN PISTON

INITIAL CONDITIONS AND ASSUMPTIONS:

THIS IS A LIST OF ALL ASSUMPTIONS WITH A COLUMN OF LETTERS FOR REFERENCING.

- LOSSES ARE AT 10% OF THE INLET PSIG	(a)
- THE PIPING IS BETWEEN 1/8" AND 1/2"	(b)
- PRESSURE LOSSES ARE FOR 100'	(c)

LIST OF VARIABLES:

F	- FORCE	[lpf]
P	- GAUGE PRESSURE	[psig]
A	- CROSS-SECTIONAL AREA	[mm²]
L	- LENGTH	[ft]
t	- TIME	[sec]
D	- DIAMETER	[mm]
Q	- VOLUMETRIC FLOW RATE	[cfm]
V	- VELOCITY	[m/s]

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1) SYSTEM PARAMETERS

PISTON FORCE:

$F_{Piston} := 15\ kg\ g_e$

SYSTEM PRESSURE:

$P_{System} := 100\ psi$

PISTON STROKE:

$L_{Piston} := 2\ ft$

PISTON ACTUATION TIME:

$t_{Piston} := 1\ sec$

PISTON VELOCITY:

$$V_{req} := \frac{L_{Piston}}{t_{Piston}} = 0.6096\ \frac{m}{s}$$

---

2) CALCULATION OF MINIMUM BORE SIZE

$$A_{bore} := \frac{F_{Piston}}{P_{System}} = 213.3501\ mm^2$$

$$D_{bore} := \sqrt{\frac{4}{\pi} \cdot A_{bore}} = 16.4817\ mm$$

Actual BORE SIZE

$D_{bore2} := 2.5\ in$

$$A_{bore2} := D_{bore2}^{\ 2} \cdot \frac{\pi}{4} = 3166.9217\ mm^2$$

---

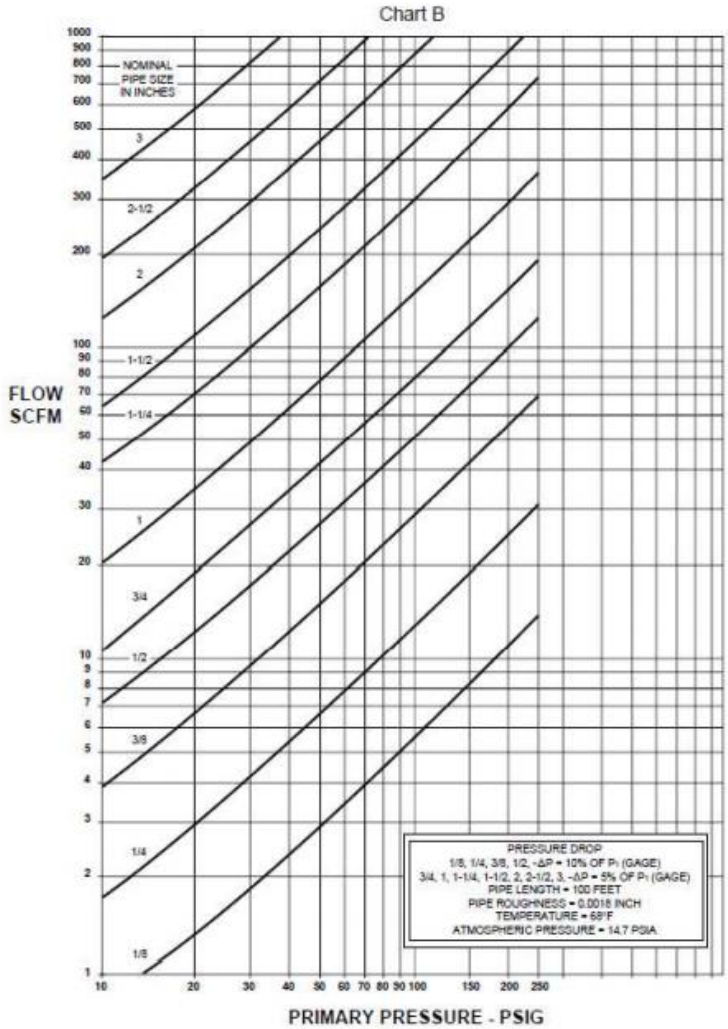
3) CALCULATION OF VOLUMETRIC FLOW RATE

$$Q_{Piston} := A_{bore2} \cdot V_{req} = 4.0906\ \frac{ft^3}{min}$$

Pipe Air Flow TEC-15

Flow of Air Through a Pipe

ASSUMPTIONS: (a), (b), & (c)



4) RECOMMENDED MINIMUM PIPING DIAMETER

THE RECOMMENDED MINIMUM PIPING DIAMETER HAS BEEN FOUND TO BE: 0.125 in

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Appendix G: Cycle Calculations

Cycle Time Calculations

UNIVERSITY OF ALBERTA

Rev.: 1.0
Author: M. Lantz

ENGINEERING CALCULATIONS WORKSHEET

Page: 1 of 2

TITLE:

CYCLE TIME CALCULATION

PURPOSE:

THIS CALCULATION IS USED TO DETERMINE THE CYCLE TIME FOR THE PROCESS

LIST OF VARIABLES:

L	- LENGTH	[ft]
t	- TIME	[sec]
V	- VELOCITY	[m/s]
N	- COUNT	[]

---

1) SYSTEM PARAMETERS

PISTON Length:

$L_{Piston} := 2\ ft$

PISTON ACTUATION TIME:

$t_{Piston} := 1\ sec$

PISTON VELOCITY:

$$V_{req} := \frac{L_{Piston}}{t_{Piston}} = 0.6096\ \frac{m}{s}$$

NUMBER OF PISTONS EXTENSIONS/RETRACTIONS:

$N_{Pistons} := 6$

SAFTEY FACTOR:

$S := 2$

NUMBER OF FRAMES PER BOX:

$N_{Frames} := 8$

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2) CALCULATION OF THEORETICAL CYCLE TIME

$T_{process} := N_{Pistons} \cdot t_{Piston} = 6\ s$

INCLUDING SAFTEY FACTOR FOR PAUSES:

$T_{process} := N_{Pistons} \cdot t_{Piston} \cdot S = 12\ s$

NUMBER OF BOXES PER HOUR:

$N_{Boxes} := \frac{1\ hr}{T_{process}} = 300$

NUMBER OF FRAMES PER HOUR:

$N := N_{Boxes} \cdot N_{Frames} = 2400$

Force Required to Move Box Carrier x-direction

$F_{appy} - N_{carr+box}g = ma_y \rightarrow \sigma_{pneu-y}\pi(r_{pneu})^2 - (m_{carr}+m_{box})g = (m_{carr}+m_{box})a_y$

Force Required to Move Box Carrier y-direction

$F_{appx} - \mu_k N_{carr+box} = ma_x \rightarrow \sigma_{pneu-x}\pi(r_{pneu})^2 - \mu k(m_{carr}+m_{box})g = (m_{carr}+m_{box})a_x$

Stress one pneumatic piston endures moving full Box Carrier y-direction

$$\sigma_{pneu-y} = \frac{N_{carr+box}}{4A_{pnu}} = \frac{(m_{carr} + m_{box})g}{4\pi {r_{pnu}}^2}$$

Stress pneumatic piston endures moving full Box Carrier x-direction

$$\sigma_{pneu-x} = \frac{\mu_{krail} N_{carr+box}}{A_{pnu}} = \frac{\mu_{krail}(m_{carr} + m_{box})g}{\pi {r_{pnu}}^2}$$

Stress pneumatic piston endures pushing Box

$$\sigma_{pneu} = \frac{\mu_{kbelt} N_{box}}{A_{pnu}} = \frac{\mu_{krail} m_{box} g}{\pi {r_{pnu}}^2}$$

SHLYM Designs

Name: Qiulin Yu

Date: 2021 – 07 – 26

Objective: with force 100 N , Find the acceleration and force exerting on each box

Known:

$m_1 := 5\ \text{kg}$ the empty hive box

$m_2 := 7\ \text{kg}$ the hive box with 8 frame

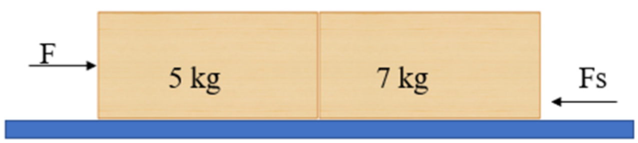
$\mu_k := 0.12$ The coefficient of kinetic friction between the box and the conveyor belt

$g := 9.81\ \frac{\text{N}}{\text{kg}}$ Gravity

Assumption:

The firction coefficient is uniform
No gap between two boxes

Sketch:



Analysis:

5 kg weight: $w_1 := m_1 \cdot g = 49.05\ \text{N}$

5 kg friction force: $F_{f1} := \mu_k \cdot w_1 = 5.886\ \text{N}$

7 kg weight: $w_2 := m_2 \cdot g = 68.67\ \text{N}$

7 kg friction force: $F_{f2} := \mu_k \cdot w_2 = 8.2404\ \text{N}$

The total mass of the system is $m_t := m_1 + m_2 = 12\ \text{kg}$

Assume a 100 N force is exterted on the 5 kg box $F := 100\ \text{N}$

Based on Newtons second law

$$F_t := F - F_{f1} - F_{f2} = 85.8736\ \text{N}$$

$$a := \frac{F_t}{m_t} = 7.1561\ \frac{\text{m}}{\text{s}^2}$$

Conclusion: The force exerting one each other is 85.87 N

SHLYM Designs

Appendix H: Gantt Chart

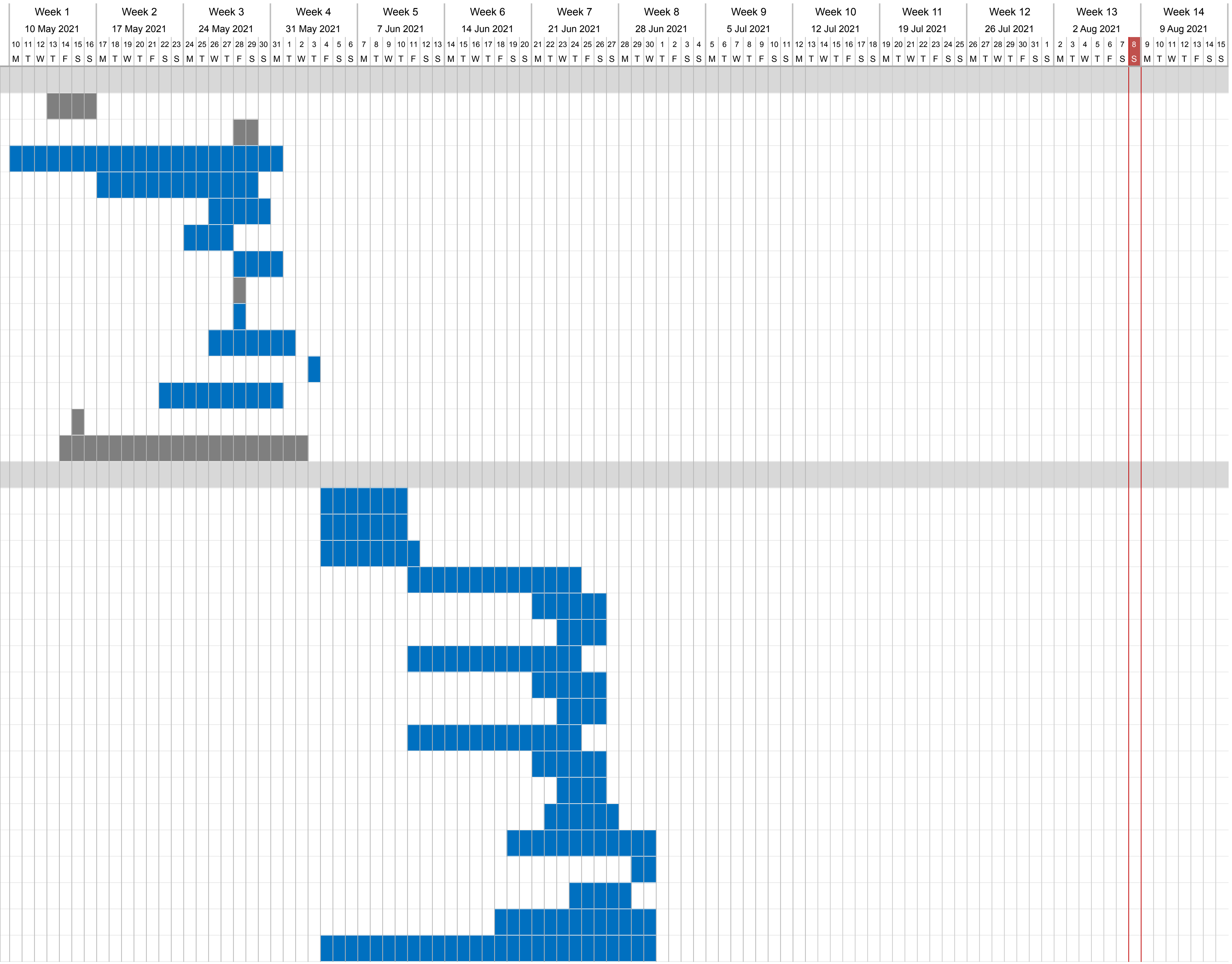
Design/Automate Removal of Frames from an Extraction Line and Return the Frames to the Hive Box

Team 2-SHLYM Design

Project Start Date: 5/14/2021

Project Lead: Mason Lantz

TASK	START	END	OWNER	HOURS
Phase I				63
Letter of Intent(LOI)	Thu 5/13/21	Sun 5/16/21	Carlos/All	2
Cover Letter	Fri 5/28/21	Sat 5/29/21	Carlos/Quilin	1
Preliminary Research	Mon 5/10/21	Mon 5/31/21	All	20
Gantt Chart	Mon 5/17/21	Sat 5/29/21	All	2
Preliminary Design Constraints	Wed 5/26/21	Sun 5/30/21	All	2
Assumptions	Mon 5/24/21	Thu 5/27/21	All	4
Specifications Summary	Fri 5/28/21	Mon 5/31/21	Mason	1
Client Meetings	Fri 5/28/21	Fri 5/28/21	All	1
Advisor Meetings	Fri 5/28/21	Fri 5/28/21	All	2
Costs and Economics	Wed 5/26/21	Tue 6/01/21	Mason	2
Check Against Marking Scheme	Thu 6/03/21	Thu 6/03/21	Aidan	2
Project Management	Sat 5/22/21	Mon 5/31/21	Mason	3
Finish Team Charter	Sat 5/15/21	Sat 5/15/21	Aidan/Carlos	1
Phase 1: Concept Report	Fri 5/14/21	Wed 6/02/21	All	20
Phase II				171
Brainstorming	Fri 6/04/21	Thu 6/10/21	All	5
Mind Mapping	Fri 6/04/21	Thu 6/10/21	Carlos	6
Feasibility Study	Fri 6/04/21	Fri 6/11/21	Quilin	10
Concept 1 CAD	Fri 6/11/21	Thu 6/24/21	Mason	8
Concept 1 Calculations	Mon 6/21/21	Sat 6/26/21	Aidan	7
Concept 1 Cost Estimate	Wed 6/23/21	Sat 6/26/21	Mason	3
Concept 2 CAD	Fri 6/11/21	Thu 6/24/21	Quilin	12
Concept 2 Calculations	Mon 6/21/21	Sat 6/26/21	Aidan	7
Concept 2 Cost Estimate	Wed 6/23/21	Sat 6/26/21	Zachary	3
Concept 3 CAD	Fri 6/11/21	Thu 6/24/21	Carlos	12
Concept 3 Calculations	Mon 6/21/21	Sat 6/26/21	Aidan	7
Concept 3 Cost Estimate	Wed 6/23/21	Sat 6/26/21	Carlos/Zachary	3
Decision Matrix	Tue 6/22/21	Sun 6/27/21	Quilin	6
Report Writing	Wed 6/23/21	Wed 6/30/21	All	60
Summary of Design	Tue 6/29/21	Wed 6/30/21	Carlos	10
Schedule Update	Thu 6/24/21	Mon 6/28/21	Quilin	5
Project Management	Fri 6/18/21	Wed 6/30/21	Mason	4
Advisor Meetings	Fri 6/04/21	Wed 6/30/21	All	3



Design/Automate Removal of Frames from an Extraction Line and Return the Frames to the Hive Box

Team 2-SHLYM Design

Project Start Date: 5/14/2021

Project Lead: Mason Lantz

TASK	START	END	OWNER	HOURS
Phase III				247
Concept review preparation	Fri 7/02/21	Sun 7/04/21	All	5
Concept review meeting	Mon 7/05/21	Mon 7/05/21	All	1
Facility Visit	Tue 7/06/21	Tue 7/06/21	Mason	6
Detailed Calculations	Tue 7/06/21	Fri 7/16/21	Mason/Qiulin	40
i) Hand/computer-aided numerical solutions	Tue 7/06/21	Thu 7/15/21	Mason/Qiulin	37
ii) FEA Verification of Design	Fri 7/16/21	Fri 7/16/21	Zachary/Qiulin	3
CAD	Tue 7/06/21	Fri 7/30/21	Zachary/Qiulin	30
i) Component/part-level modelling	Tue 7/06/21	Tue 7/13/21		
ii) Subassembly and final assembly	Tue 7/13/21	Fri 7/16/21		
iii) Part and assembly drawings	Fri 7/16/21	Sun 7/25/21		
iv) Compile drawing package and solid models	Mon 7/26/21	Wed 7/28/21		
v) Final product renders	Thu 7/29/21	Fri 7/30/21		
Electronics Analysis	Sat 7/31/21	Mon 8/02/21	Zachary	6
Cost Analysis	Mon 7/19/21	Fri 7/23/21	Zachary	10
i) Material and off-the-shelf component quotes	Mon 7/19/21	Wed 7/21/21	Zachary	6
ii) Assembly fabrication & integration quotes by vendors	Mon 7/19/21	Fri 7/23/21	Zachary	4
Design Compliance Matrix	Mon 7/12/21	Fri 7/16/21	Carlos/Aidan	10
Client sign-off Design Compliance Matrix	Sat 7/31/21	Tue 8/03/21	Mason	6
Project Management	Fri 7/02/21	Fri 8/06/21	Mason	4
Report Writing	Mon 7/12/21	Sun 8/01/21	All	50
Report Editing	Sun 8/01/21	Tue 8/03/21	All	5
Cover Letter	Mon 8/02/21	Mon 8/02/21	Carlos	2
Summary	Mon 8/02/21	Mon 8/02/21	Mason	2
Poster	Mon 7/19/21	Mon 8/02/21	All	24
Presentation	Mon 7/19/21	Mon 8/02/21	All	36
Client Meetings	Fri 7/02/21	Fri 8/06/21	All	6
Advisor Meetings	Fri 7/02/21	Fri 8/06/21	All	3
Phase III report submission	Wed 8/04/21	Wed 8/04/21	All	-
Peer evaluation	Wed 8/11/21	44419	All	0.5