Final Report

Semi-Autonomous Twin Hoist System

EGR 402: Professional Design Project II

April 28, 2023

Team 24

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Increasing Changeover Capabilities

Isola

Jeremiah Adams

Executive Summary

Isola's current copper foil roll changeover solution is largely a manual process and takes 2 minutes, which is far longer than it should, decreasing their ability to fill out next-day laminate orders. Along with that, it currently can only hold 2 rolls, which is a bottleneck and results in longer production times and halts the processes that are before and after lamination. This directly affects the production capacity, and improving this would help the company to have shorter lead times, reach out to more customers, have faster production, and help in the economic growth of the company.

The success of this product would remove the bottleneck at the copper foil loading step. This allows Isola to manufacture laminate at a faster rate, allowing it to deliver the products to its customers faster. This allows them to take on more clients, fill more orders, and produce more value. The team managed to get the entire concept to change the roles in under 36 seconds (under the worst-case scenario) which means the team's design is 70% faster than Isola's current hoist. Adding to that the hoist is semi-autonomous and requires the workers to control the hoist at a distance making it safer to operate.

The scope of the solution is limited to the beginning at the copper foil pallet staged at the machine and the end at loading the copper foil rolls onto the existing chucks. The team noted the voice of the customer and derived the success criteria and project requirements.

Criterion (Requirement)	***Threshold (Halt & Review)***	***Team's Design***	**Stretch**	***POR Risk (H, M, L)***	***Comments***
Number of rolls staged on machine	4	5	>6	L	The dual hoist system adds extra roll space
Changeover Time	40 sec	36 sec (worst-case scenario)	20 sec	M	Even in the worst case scenario the team is able to keep the change over time under 40 sec.
Per roll weight capacity	500 lb	1000 lbs	1000 lb	L	Controllable by design
Clean room standard	Class 6	Class 6	Class 6	L	The components used in the design rated to maintain air cleanliness levels of a maximum of 1,000 particles per cubic meter

Table: Success Criteria

The final design utilized the twin-hoist concept that the team selected during the concept generation and selection phase. Starting with the base of the design: the design is meant to run on the existing linear rails at Isola, allowing them to keep their original structure and reduce installation time. The team only had to develop the CAD design in SolidWorks and was not required to develop any physical solution, so the prototyping process was purely done through a series of design reviews with the Industrial Partner (IP) to iteratively improve the CAD model.

The design was broken up into three separate subassemblies: the X-axis for moving each lifter, the Z-axis which allows for vertical movement, and the Y-axis/end effector, which allows the crane to pick up copper rolls.

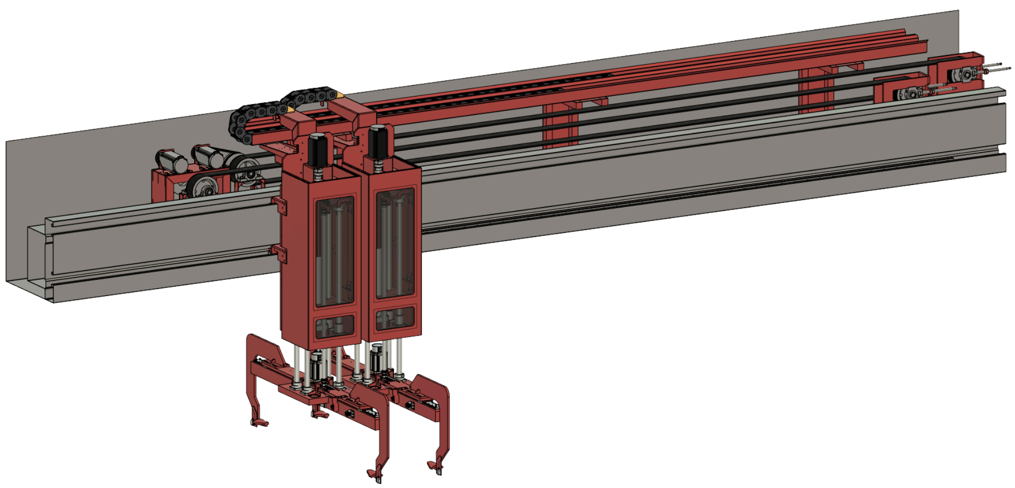

Figure: Overall view of the final solution

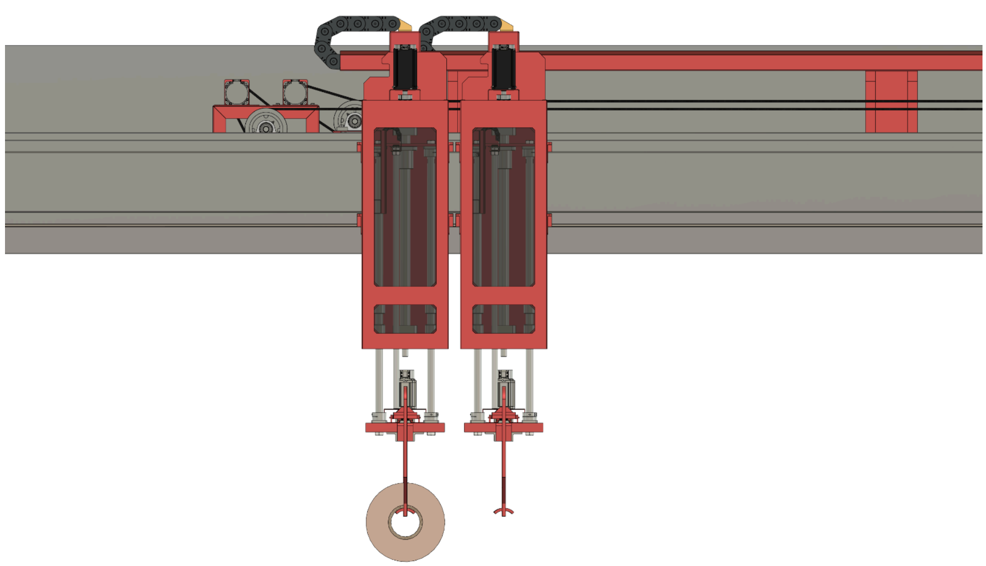

Figure: Front view of the final solution

The team designed a solution that meets all of their criteria and delivered a detailed mechanical and electrical design, and a bill of materials (BOM) of the solution. The solution comprises two hoists mounted to the existing X-axis gantry. Each hoist has its own servo drive system and uses ball screws for lifting the copper rolls. The end effector is driven by a rack and pinion and uses optical through-beam sensors to detect the presence of a roll. The team sourced US-based part suppliers and compiled a BOM. The team is not required to propose the actual cost of the manufacturing, since the goal was only to design everything in CAD and provide a list of major parts.

The team divided its high-level test plan into the following criteria: Changeover time, Weight capacity, Number of rolls staged on the machine, and Clean Room standards. The device was tested under these criteria and the team's solution met or exceeded all of the success criteria and found valuable info about how well the solution met them. Changeover time was tested using Simulink and found that the worst-case scenario changeover time was 36 seconds. Weight capacity was tested with a variety of FEA simulations in Solidworks, and it was found that the solution could carry at least 700lb copper rolls. The team designed a more efficient solution with better functionality that fits the needs of Isola. The team's success was due to working closely with the Industrial partner and instructor.

The project is actually and proposed scheduled during the Fall 2022 and Spring 2023 semesters. The major milestones in the process are shown in the following table:

Milestone	***Proposed Due Date***	***Actual Completion Date***
Design Review	Oct 31st	Oct 31st
Preliminary Prototype Plan	Nov 2nd	Nov 2nd
Sourcing Parts both electrical and mechanical	Nov 9th	Feb 5th
Prototype Complete (CAD model and Analysis) & Design Review	Jan 31st	Jan 23th
Second Design Review	Feb 28th	Mar 5th
Final project delivery date	Apr 15th	Apr 28th

The team was able to deliver the complete project within the time and was able to closely match the schedule that it initially proposed. Additionally, the team has successfully avoided encountering any of the risks.

Table of Contents

List of Figures

List of Tables

Introduction

The Isola Group is a global company that services the manufacturing industry by producing and supplying a range of products and raw materials. One of the products they offer is copper-fiberglass laminate, which is the base material for printed circuit boards. Their Chandler plant is designed specifically to meet this need, with a focus on high-speed turnaround and low-volume custom substrate. From their project description, “Changeover capacity and efficiency at Isola are key to meeting the customers' ever-evolving needs. Isola manufactures laminate supplies that can be used to further develop Printed Circuit Boards (PCBs). The new facility in Chandler was built to focus on high-mix, low-volume manufacturing to meet the needs of the quick turnaround program, offering the ability to receive custom-made materials within two days. Isola markets in wired telecommunications and computing, wireless telecommunications (RF/microwave), and automotive electrification” [1]. A major part of their process is the copper layup step, where individual layers of copper and fiberglass are stacked together before being sent to a heated press for curing. Copper foil is changed out on almost a job-to-job basis due to the amount of variation in their custom orders.

Isola's current copper foil roll changeover solution is a slow and largely manual process, decreasing its ability to fill out next-day laminate orders. Along with that, it currently can only hold 2 rolls, making changeovers and line halts more frequent. Isola has identified this part of the assembly line as a bottleneck, directly affecting their production capacity. The success of the solution would remove the bottleneck at the copper foil loading step. This allows Isola to manufacture laminate at a faster rate, allowing it to deliver the products to its customers faster. This allows them to take on more clients, fill more orders, and generate more value.

The team designed a twin hoist system that can decrease the copper foil change over time and remove the bottleneck in their line. The deliverables consist of a detailed mechanical and electrical design, a bill of materials (BOM) of the completed solution, and a budget for a completed solution. The solution’s scope is limited to the beginning of the process at the copper foil pallet staged at the machine and ending with loading the copper foil rolls onto the existing chucks.

The purpose of this paper is to document the team’s designs and testing for the solution Isola to meet their project requirements. It also covers the final designs and test results. And finally, the paper will end with the learning strategies used during the course of writing this paper.

Requirements

The team started out by interviewing the relevant customers and asking them a series of questions to better understand the problem that Isola is facing. Table 1 below summarizes the answers to these questions and converts them into measurable project requirements.

Customer	VOC Statement	Requirement	Measure	Value
Jeremiah A (Plant Engineering Manager)	I want the machine to carry at least 4 rolls.	Number of rolls staged on the machine needs to be at least four.	# of rolls	>= 4
Jeremiah A (Plant Engineering Manager)	I want the changeover time to be less than 40 seconds.	Changeover time needs to be between 30-40 seconds.	time in seconds	< 40
Jeremiah A (Plant Engineering Manager)	I need the machine to carry 500-700 pound copper rolls easily.	Operating weight capacity of the machine	Weight in lbs	700
Jeremiah A (Plant Engineering Manager)	I need the machine to work with the existing 480V power system and 24V control system.	The machine needs to run on 480V power.	volts	24V control, 480V power
Jeremiah A (Plant Engineering Manager)	I want the machine to follow Class 6 clean room standards.	The machine needs to follow the Class 6 clean room standards.	Engineering standard	Class 6
Jeremiah A (Plant Engineering Manager)	I want the machine to not contaminate the copper layup.	Should not shed or contaminate copper lay up	% of rolls not contaminated	>99.99%
Jeremiah A (Plant Engineering Manager)	I want the machine to have a very long-term ROI without replacement.	The machine needs to have a very long usable period.	# years before total replacement	20
Eric Jimenez (Lay-up Operator 1)	I want the machine to reliably and easily hold on to rolls without dropping them.	The machine needs to have very high reliability for holding on to rolls.	% reliability of roll holding mechanism	> 99.99%

Ramses Zepeda (Lay-up Operator 2)	I want the machine to carry the rolls without damaging the copper or shredding the cardboard.	The machine needs to keep the rolls from being damaged.	% of rolls not damaged by the machine	> 99.99%
Jeremiah A (Plant Engineering Manager)	I want all parts of the machine that contact copper to be made of stainless steel.	All contact points to the copper need to be made with stainless steel	% of contact points that are made of stainless steel	100%

Table 1: Critical to Quality Requirements

Success Criteria

The table below describes the team's success criteria. These are the main requirements the team will test to determine if the team has successfully solved the industrial partner's problem. The first criterion was an explicit goal that was given to us by Isola. The second criterion is the ultimate goal that Isola gave to the team in the beginning, as well as a system-wide measurement of the speed of the solution. The third criterion was another requirement that was set by Isola based on the maximum weight of the roll that they use and is critical because the solution must be able to lift the typical copper rolls that Isola will use without failure. The last criterion was given by the Industrial Partner (IP) as a priority and is directly linked to a couple of the other requirements that have to do with the contamination of the copper rolls.

Criterion (Requirement)	***Threshold (Halt & Review)***	***Team's Design***	**Stretch**	***POR Risk (H, M, L)***	***Comments***
Number of rolls staged on machine	4	5	>6	L	The dual hoist system adds extra roll space
Changeover Time	40 sec	36 sec (worst-case scenario)	20 sec	M	Even in the worst case scenario the team is able to keep the change over time under 40 sec.
Per roll weight capacity	500 lb	1000 lbs	1000 lb	L	Controllable by design
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					a maximum of 1,000 particles per cubic meter

Table 2: Success Criteria

Conceptual Design

Solution 2 is an automatic hoist system that can hold 2 rolls (1 on each independent lifter) which allows for quicker changes. The machine can grab the old roll and deposit the old roll in the same place. The machine needs to grab the rolls from the sides to keep from damaging the copper. Making this an automatic or semi-automatic process increases operator safety and decreases changeover time.

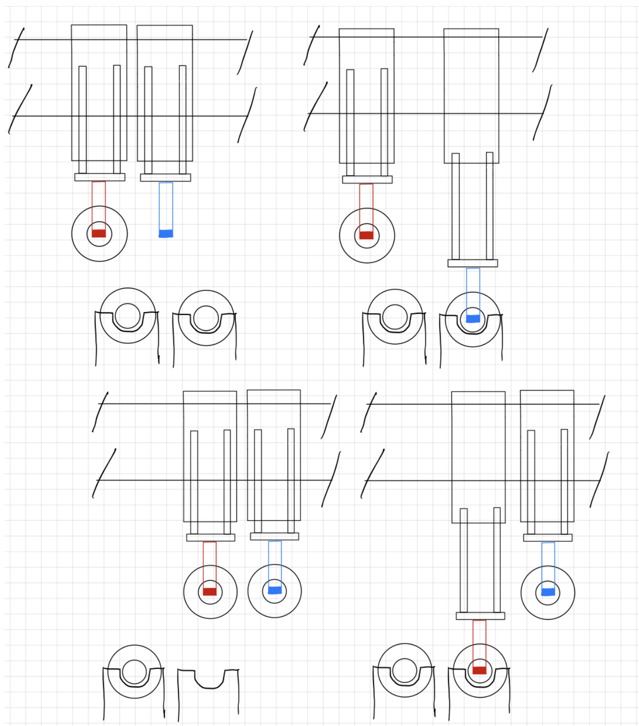

Figure 1: Solution 2 - Dual Head Lifter

Pros	Cons
• Holds 2 rolls • Can be attached to existing gantry • Allows rolls to be picked up and dropped simultaneously, speeding up changeover time • All loads are vertical	• May not fit on the existing gantry • Requires a second drive system • May be expensive

Table 3: Solution 2 Pros and Cons

The chosen solution was the Dual Head Lifter. This solution scored highest on the Pew Matrix. This solution has a proof of concept in the existing solution, as the individual crane carriage in the concept is essentially the same as the existing concept. This solution also did not have many cons: assuming that there is enough room for the solution (and there is) the only real con is that this solution's mechanical complexity. It also has the advantage of potentially being the fastest solution out of all of the proposed solutions: the two carriages can pick up a new roll and an old roll simultaneously, unlike the other solutions which have to pick up the old roll before dropping down the new roll with the same carriage. To implement this solution, the team has to design mechanical and software models like motor smoothing algorithms to avoid roll sway, motor jerks, and overloading while moving the roll as quickly as possible. However, when looking at the other solutions, this is one of the simplest designs. Overall Team 24 believes that this solution has the best potential to meet all of the success criteria and satisfy customer needs.

When talking about the problem with ISOLA a list of engineering standards was given. Below is a table that shows those standards.

Engineering Standards	Device should follow the following OSHA standards: 1910, 1926, 1809
	Devices should follow Class 6 clean room standards.
	Devices should be built using ISO 724 Metric threaded hardware.
	Device should interface with Mitsubishi PLC control systems by following IEC 61131-3

Table 4: Engineering Standards

The current solution that ISOLA uses meets all of these standards, and they want the new solution to continue to meet these standards. The new solution will not need to meet any new standards, as all of these are currently being met by the current solution. When Team 24 designs the solution they will need to make sure that it is OSHA-safe, this should not impose many hindrances on the project as designing a safe solution would be the goal even if this was not a standard that needed to be followed. The team will need to meet Class 6 clean room standards, this will mean that when parts are spaced each part will need to meet this requirement, which will limit the number of parts that the team can look for. Similarly, because all hardware needs to follow ISO 724 the pool of parts to choose from will shrink again. Assuming the solution needs to be programmed, it needs to be able to interface with Mitsubishi PLC control systems by following IEC 61131-3, this will, again, limit the number of parts that can be used on the project.

Final Detailed Design and Prototype Construction

Mechanical

Overall Assembly

The final design utilized the twin-hoist concept that the team selected during the concept generation and selection phase. Starting with the base of the design: the design is meant to run on the existing linear rails at Isola, allowing them to keep their original structure and reduce installation time. The team only had to develop the cad design in SolidWorks and was not required to develop any physical solution.

The design was broken up into three separate subassemblies: the X-axis for moving each lifter, the Z-axis which allows for vertical movement, and the Y-axis and end effector, which allows the crane to pick up copper rolls.

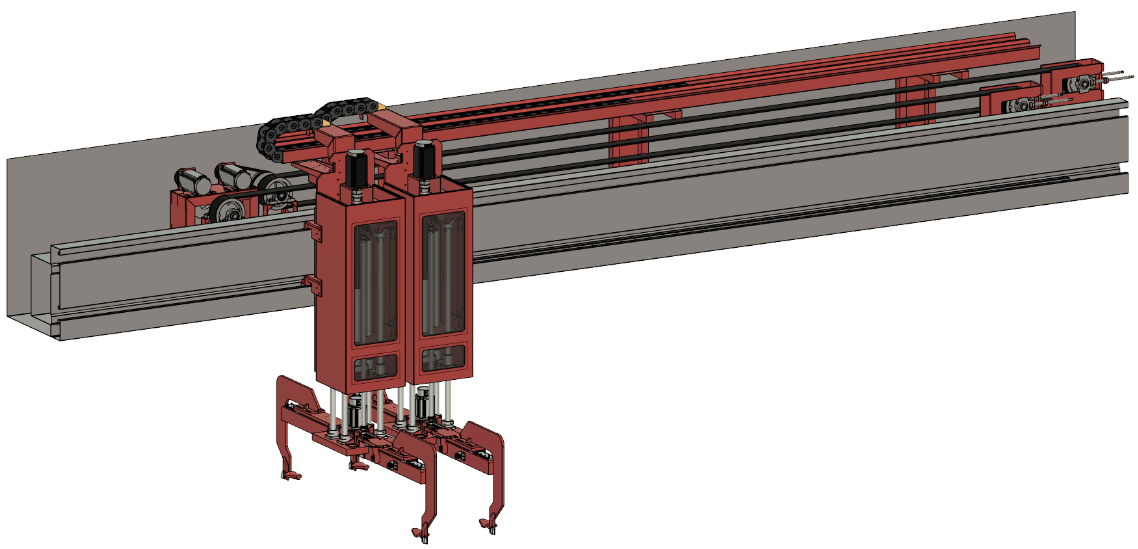

Figure 2: Overall view of the final solution

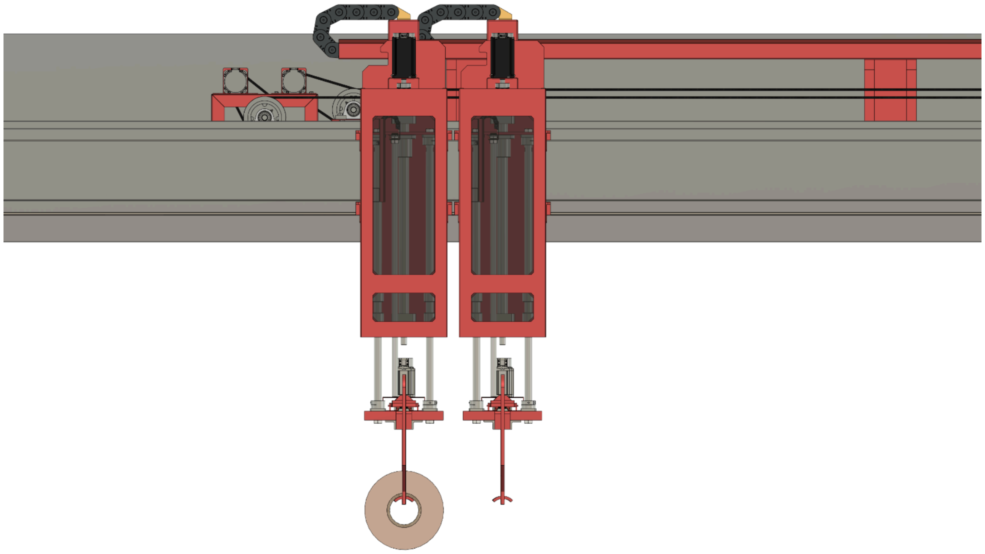

Figure 3: Front view of the final solution

Y-Axis

The Y-Axis' main function is to open and close the end effector in or out of the copper roll. In total it weighs 231 pounds and consists of 14 unique parts, 9 of those parts need to be custom made. Because of the Class 6 Cleanroom standards, every part is made out of stainless steel. Shown below is an overall view of the design.

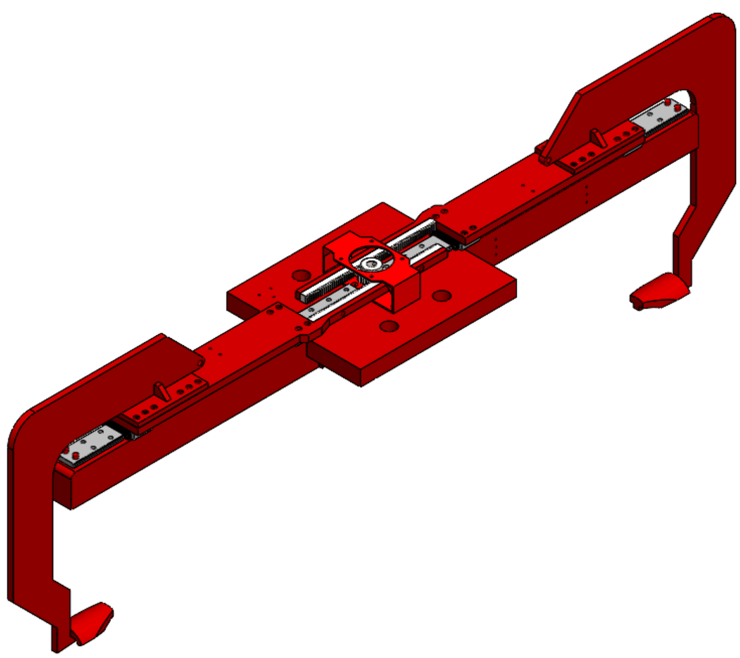

Figure 4: Y-Axis design

The Y-Axis uses a rack and pinion design, driven by a motor, to move the end effector.

The end effector sits on linear rails to allow near frictionless motion. One thing to note is that the linear rails use the clean room (Class 6) lubricant.

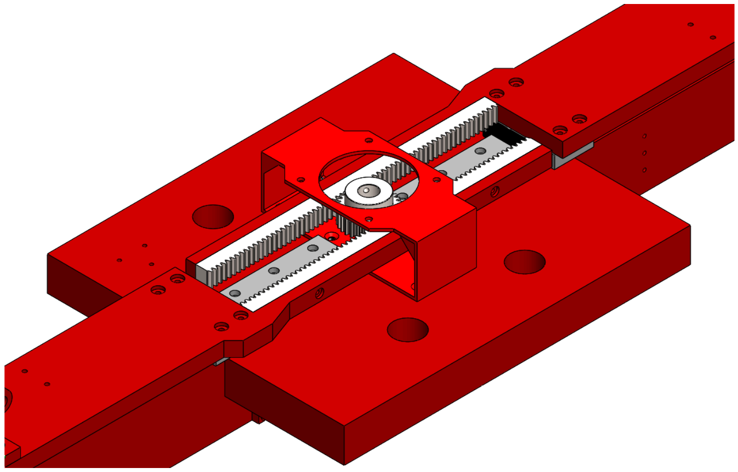

Figure 5: Y-Axis Baseplate Closed

Shown here is a close-up of the baseplate when the rails are in a closed position. The important thing to look at is the custom motor mount that holds our chosen motor. This photo also shows the holes that the Z-Axis attaches to.

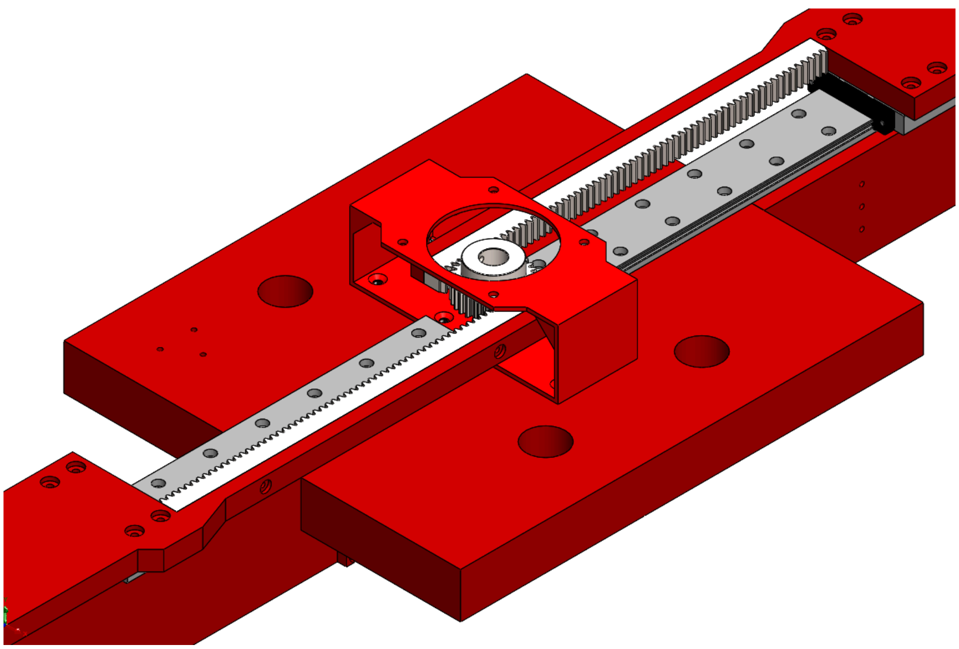

Figure 6: Y-Axis Baseplate Open

This photo shows the rack and pinion opened up. As one can see there are two lines that support the weight of the end effector. Each rail has two attachment points that act as extra support for the end effector.

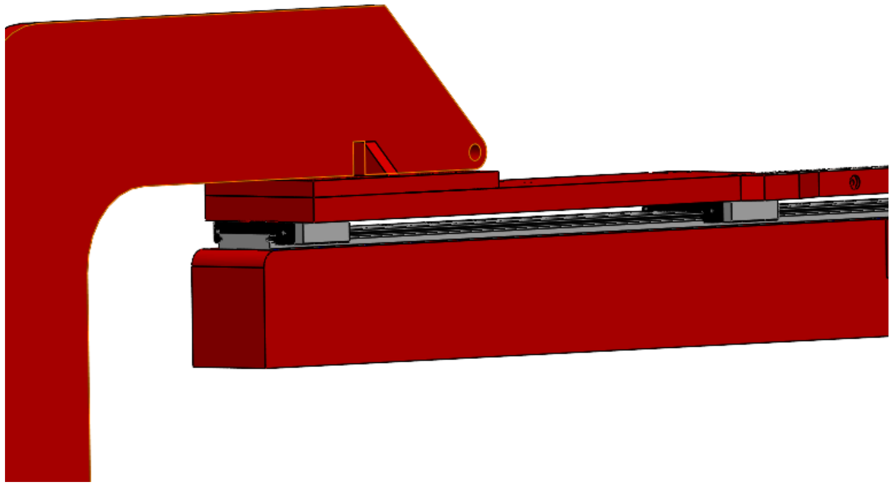

Figure 7: Y-Axis Linear rail close-up

This is a close-up showing the two rail attachments. This was also done as it was better to have a bigger linear rail than a bigger rack support-wise.

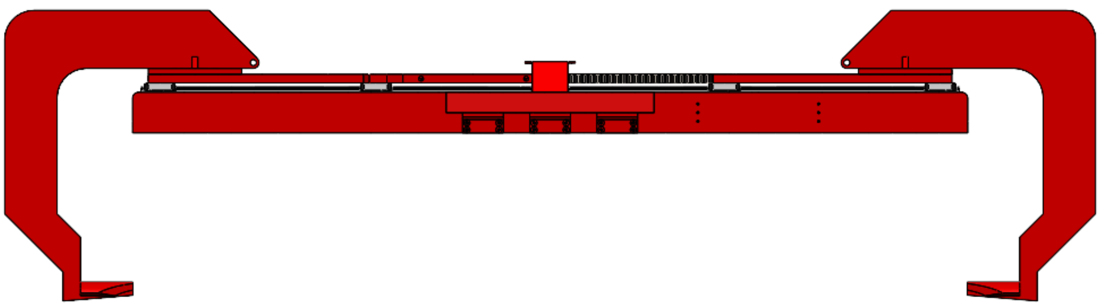

Figure 8: Y-Axis Linear rail close up

This view is so that one can see that under the base bar. This is the main support for the linear rail and end effector. The under-base bar attaches to the base with 6 L brackets, as seen in the photo. The one thing not mentioned is the motor used. A Mitsubishi HK-RT2034WBJ, a small stepper motor, was used.

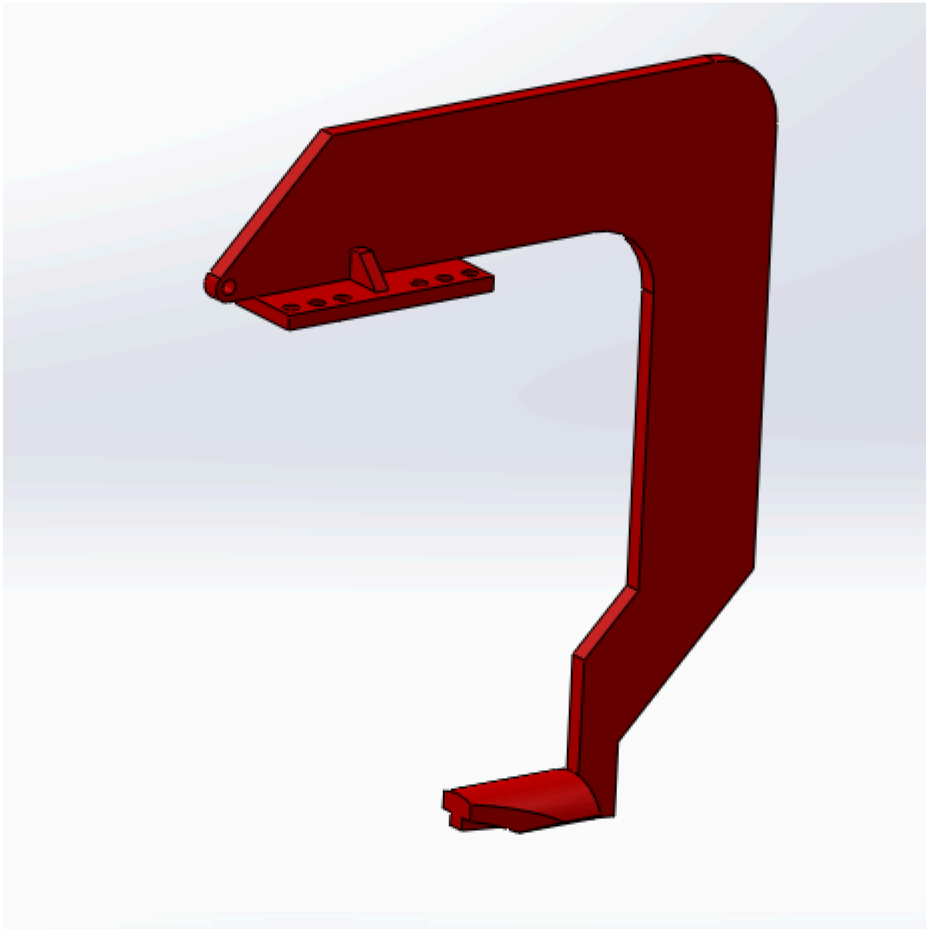

Figure 9: End Effector

The End effector is responsible for ensuring that the copper rolls are lifted and placed back down without damaging the copper. To ensure the end effector may not rip through the cardboard inner tub, the part where it makes contact with the cardboard tub was made with the same curve space as the tube to make sure that they were making contact with the most surface area as possible and not specifically on one point making it less likely to ripe. Since the opening to the cardboard tube is a circle, the lower part of the end effector was made into a cone shape so if not centered correctly. As the y-axis closes, the cone shape end effector will realign to ensure that the roll is secured properly.

For actuation, there are two inductive limit switches from AutomationDirect mounted to the side of the Y-axis, with a sheet steel trigger flag. These allow the Y-axis motor to home, as well as easily be controlled with triggers instead of positional control. Additionally, there is a Keyence through-beam laser sensor mounted to the tip of the end effector. This creates a beam through the tube of the copper roll, allowing the machine to detect when the end effector has successfully aligned with the tube of the copper roll. This helps to ensure that the system can stay autonomous and detect when there are errors to notify the operators.

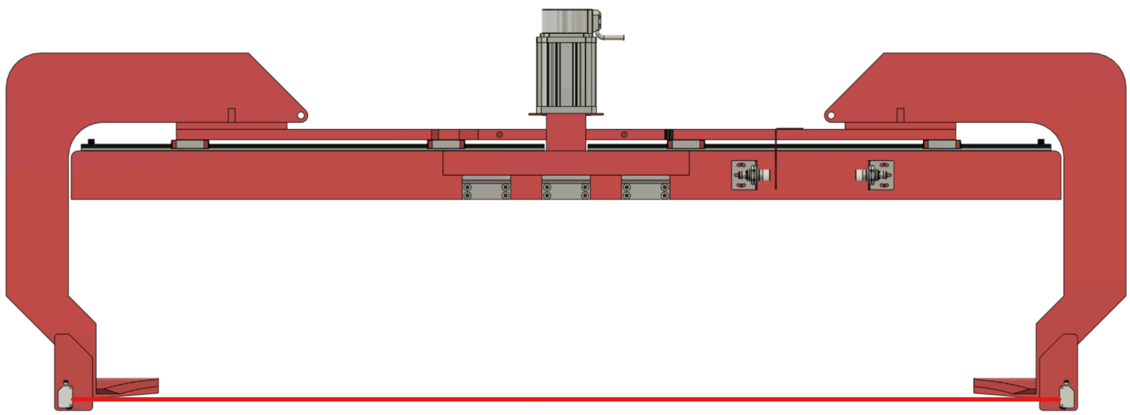

Figure 10: Laser through beam detector on the end effector.

Z-Axis

The Z-axis serves a variety of functions for the entire system. Mainly, it allows for vertical movement of each roll, letting them be lifted and carried from the copper roll palette to the roll staging chucks. Additionally, it provides structure and support for the Y-axis and end effector, as well as connecting to the drive belt of the X-axis.

At the core of the Z-axis lies the motion components. This uses a Hiwin RBS series rolled ball screw that is the main actuating component of the Z-axis. It is 40mm, with a lead of 10mm per revolution, making it ideal for the high loads that are placed directly on-axis with it. The ball screw is driven by a 2kW Mitsubishi HK-RT series servo motor through a simple disc coupling. This drives a plate with four 30mm stainless steel linear rods that are attached with M20 bolts for vertical load bearing and flanged shaft clamps for alignment. These linear rods are what connect to the Y-axis, and are the sliding components so that the entire Z-axis has a telescoping feature. Additionally, they keep lateral loads off of the ball screw because they are constrained by the eight-flanged linear bearings near the bottom of the Z-axis. These eight linear bearings are what take up the side loads encountered during acceleration and braking, and they are what provide the precise, smooth motion needed for the y-axis lift. Lastly, all of the linear motion components are mounted to 10mm stainless steel plates.

Figure 11: Core motion stage of the Z-axis

The linear motion components are housed within a welded 10mm sheet steel frame. Specifically, the back and two sides are welded together at the corners. This ensures rigidity of the Z-axis, but it isn't enough: welding can cause warping during manufacturing, and the Z-axis needs to be absolutely parallel and square to ensure long component life. To remedy this, 10mm square stainless steel keys are bolted into the three plates into CNC machined grooves. Since these grooves are made from one datum, they ensure that the keys and plates are also completely parallel. Additionally, there is extra load-bearing capacity with the keys since instead of relying on a set of dimensionally loose holes and screws, the surfaces cleanly mate against each other, evenly distributing the load through the entire face. Keys were also used instead of grooves for assembly: with grooves that the horizontal plates slide in, there's no way to assemble the linear motion axis, inside or outside the frame. To eliminate even more twisting of the Z-axis frame, a front plate is bolted on, directly into the edge of the 10mm SS wall. Lastly, the entire frame is mounted to the X-axis rails with four 10 mm welded stainless steel brackets, which mount to the frame using three M8 bolts each.

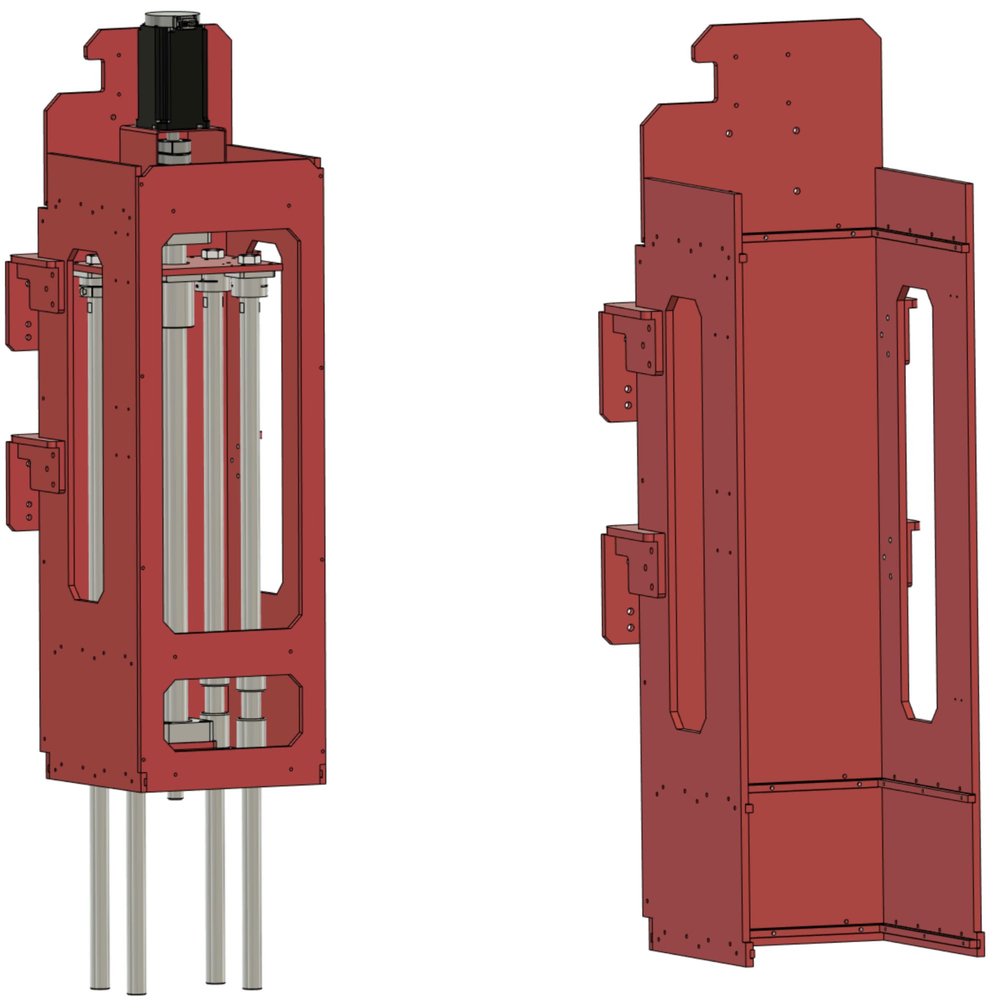

Figure 12: Structure of the Z-axis

For the wiring of the Z-axis, a few things had to be considered: first, the Z-axis will have to act as a bridge between the stationary X-axis and the moving Y-axis down at the base, and second that the Z-axis itself is moving. For the former requirement, a variety of design features were introduced. First, a miniature cable chain from Dynatect was mounted vertically on the interior of the Z-axis. This connects to a moving conduit tube, which is attached to the top plate of the moving stage. The conduit runs down through the plates and mounts to the Y-axis with a sheet steel bracket. This facilitates a connection between the Z and Y axes. One advantage of having the cable chain inside of the Z-axis is that any plastic particulate from gradual wear of the chain will not escape the Z-axis frame, keeping the copper from being contaminated.

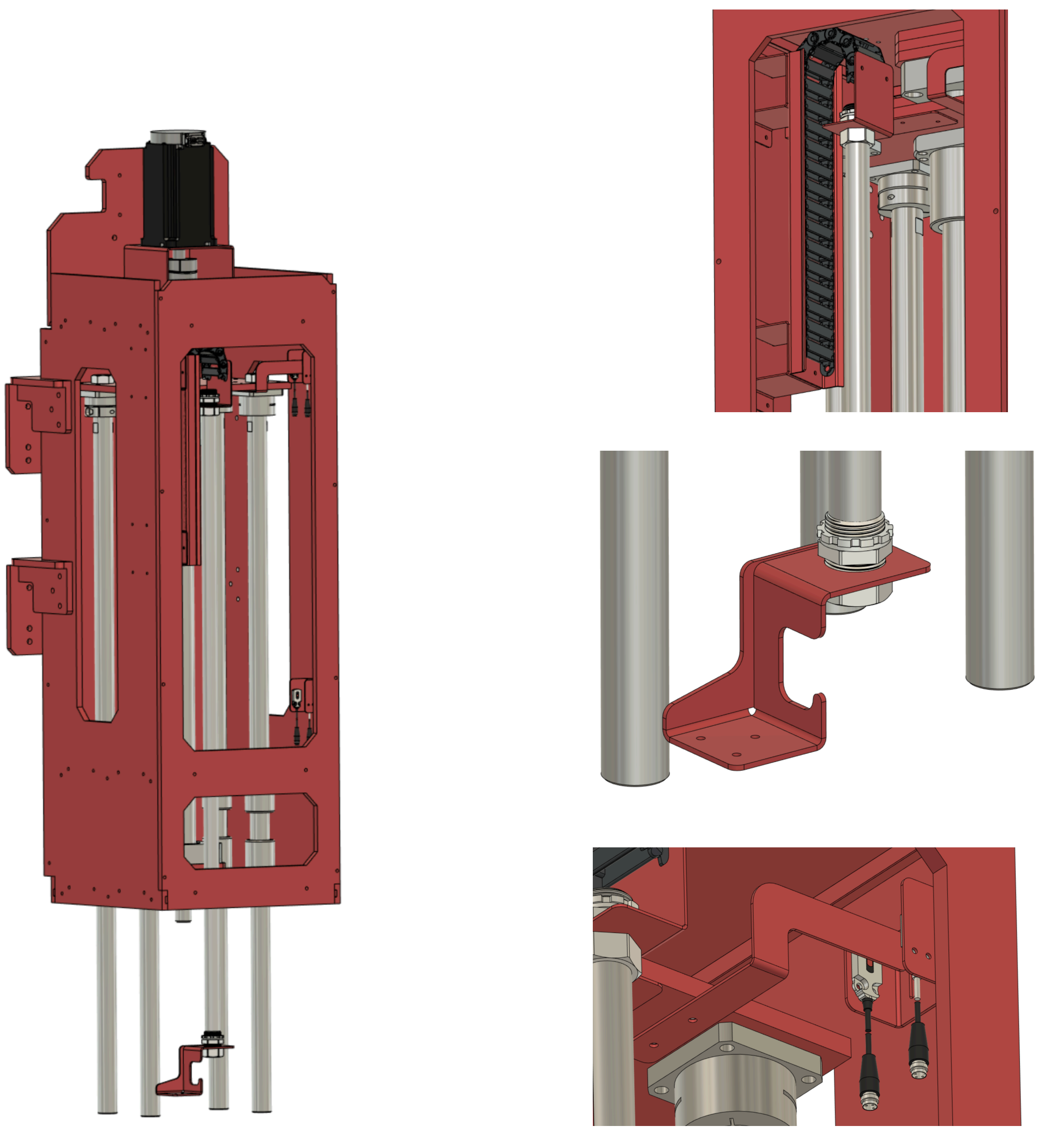

Figure 13: Internal wiring design features of the Z-axis

Additionally, two sets of Keyence through beam optical sensors were added to act as limit switches. These are mounted to adjustable sheet steel brackets, and activated with a simple sheet steel flag.

For the connection between the Z-axis and the X-axis, another sheet steel bracket was mounted to the back of the Z-axis. This has allowances for cable routing, and rounded corners to ensure that there is no significant wear. The cable chain used is from Dynatect as well and spans an overall length of ~12ft. It is guided by a bent 16 GA sheet steel guide which is suspended above the X-axis belts using welded 1 ½” steel tubing.

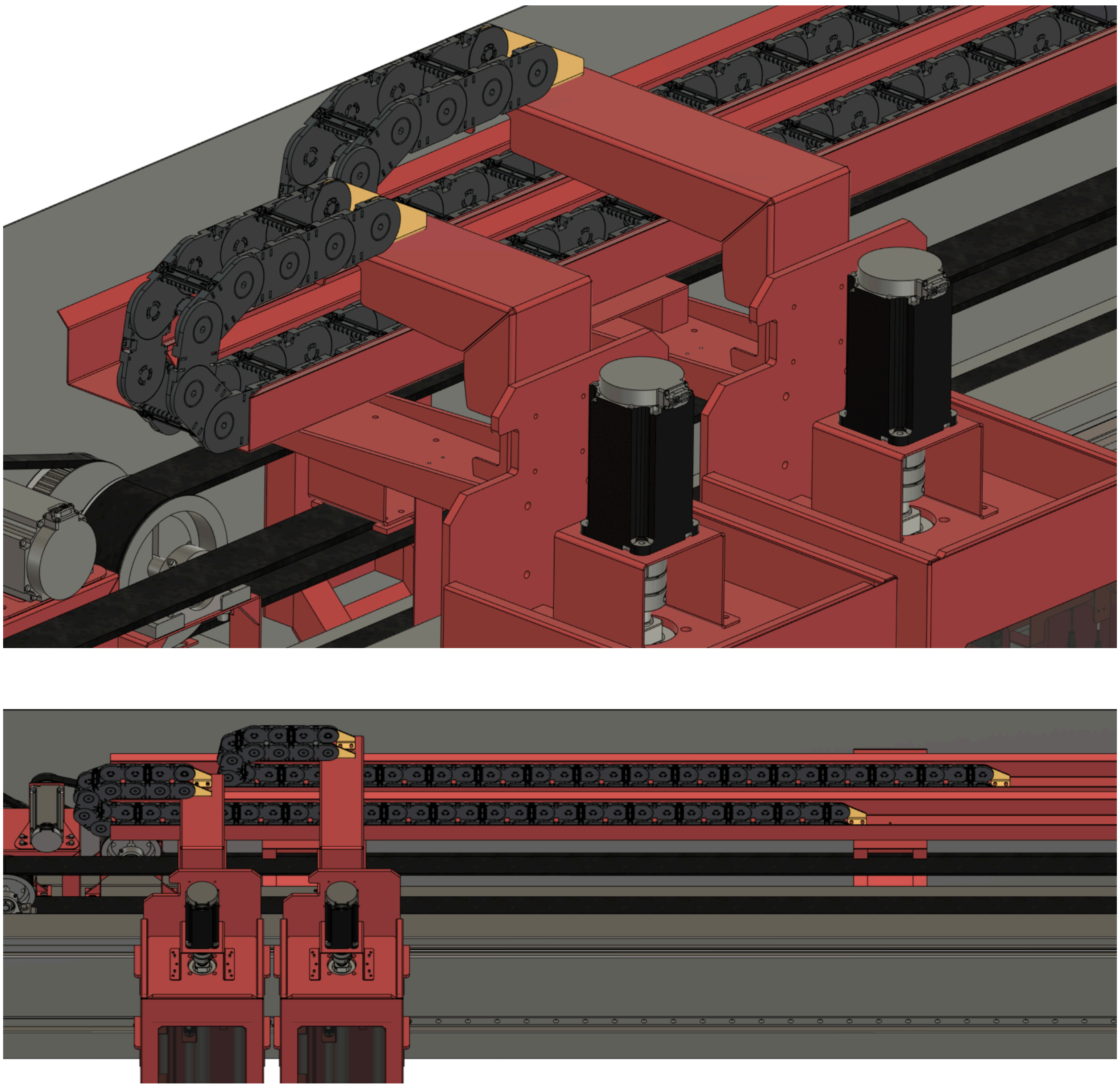

Figure 14: Cable chain between X-axis and Z-axes

X-Axis

The images below illustrate a Computer Aided Design (CAD) rendering of the current X-Axis hoist carrier configuration at Isola. The primary responsibility of the X-Axis assembly is to facilitate the movement of two hoists via linear rails. To enable the hoist's motion, two Gates Corp's LL8MGT-036 belt systems are employed, which are connected to Gates 8MX-60S-62 sprockets having 62 teeth. For this purpose, the team has opted to utilize Mitsubishi's HK-RT2034WBJ as it is compatible with the Mitsubishi Programmable Logic Controller (PLC) installed at the manufacturing plant, which employs an iQ-F processor. Additionally, a set of sprockets is connected to the two motors, while another set is linked to the belt tensioner. The two belts are positioned parallel to each other, slightly offset to conserve space. The X-Axis design incorporates Keyence optical through-beam sensors to track the position of the hoist, they are mounted to adjustable sheet steel mounts and are triggered by a sheet steel flag.

Please refer to Appendix… for more detailed designs.

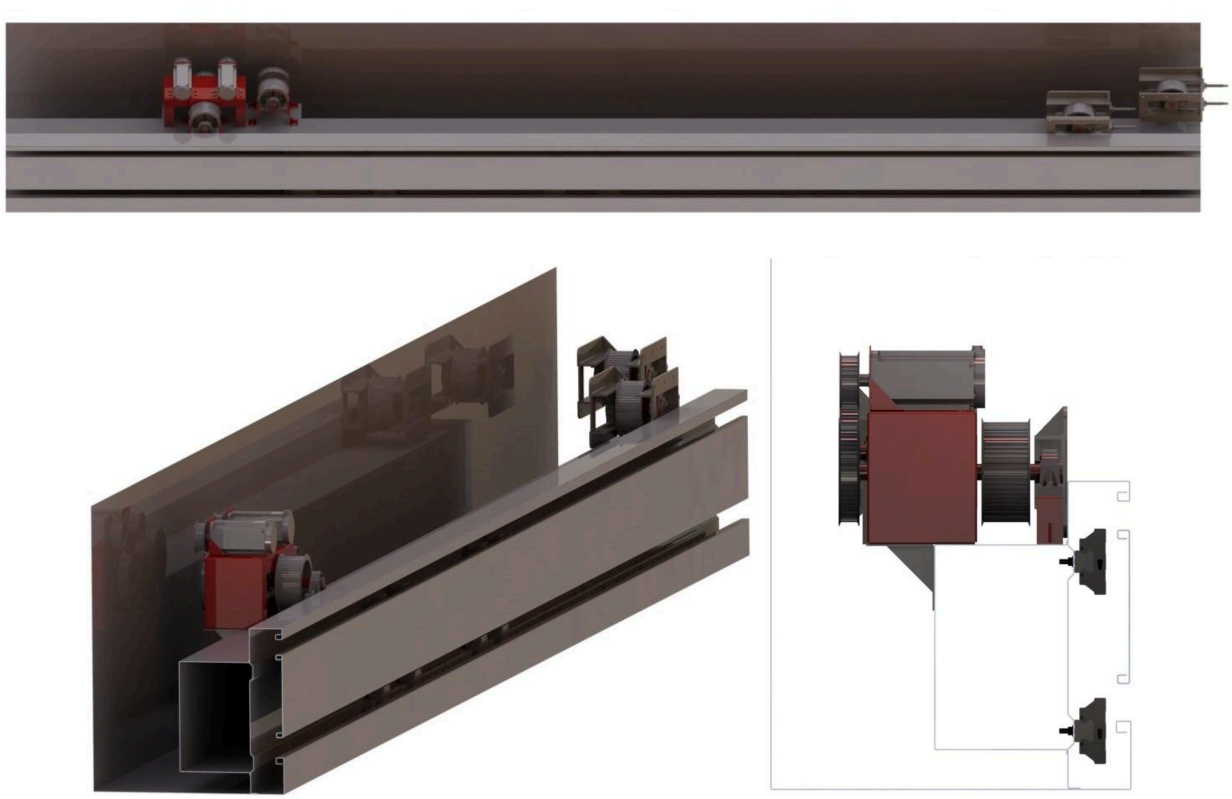

Figure 15: X-Axis hoist carrier configuration at Isola

The attached image provides an exploded view of the X-Axis Computer-Aided Design (CAD) model. This better explains the assembly of the X-Axis gantry. The X-Axis primarily comprises two motor mounts, a tailor-made tensioner, Gates' sprocket, along with their corresponding bushings, mounting for pillow blocks, and an electrical cable carrier.

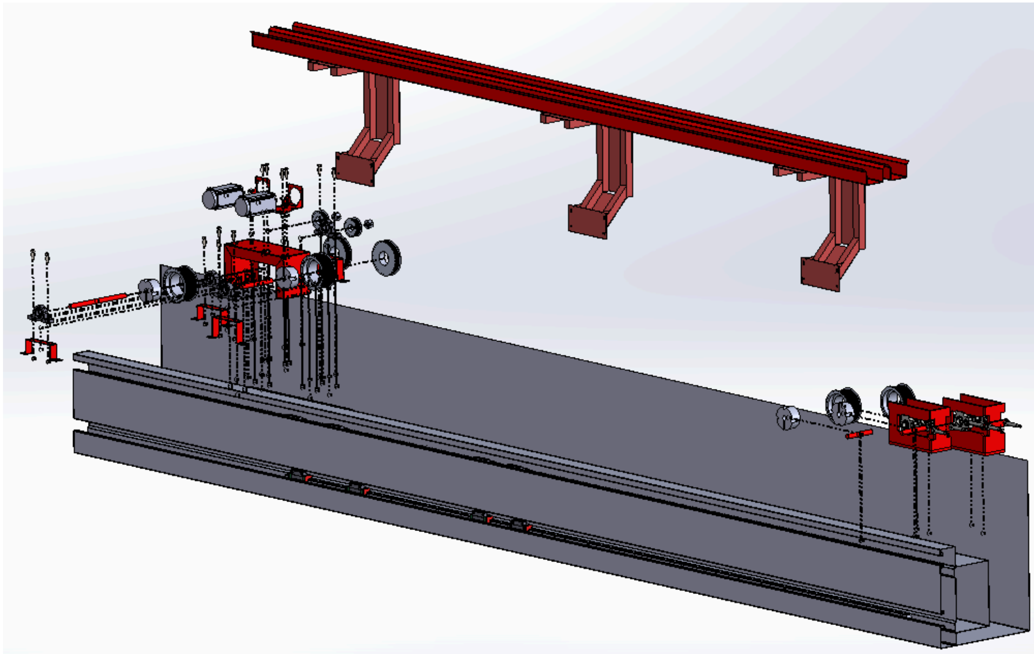

Figure 16:X-Axis Computer-Aided Design

X-Axis Casing

The team has designed the casing based on the existing gantry already available at Isola's facility. Figure 15 represents the model developed by the team, which closely resembles the X-Axis unit available at Isola, shown in Figure . .

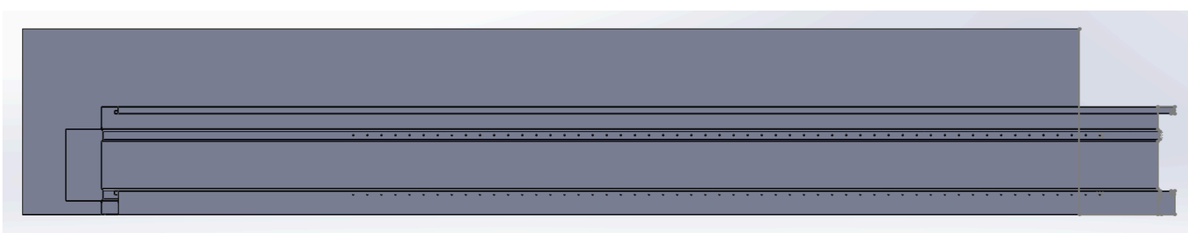

Figure 17: Casing Based on Isola

Figure 18: Isola X-Axis mount

During the factory's pause, the team obtained the exterior dimensions of the current X-Axis mount at Isola, which currently supports only one hoist via two HIWIN linear rails. As the team was unaware of the inner structure of the rails, they made the assumption that the X-axis rails could handle the weight of the hoists. The attached figure outlines the dimensions of the X-Axis unit at Isola.

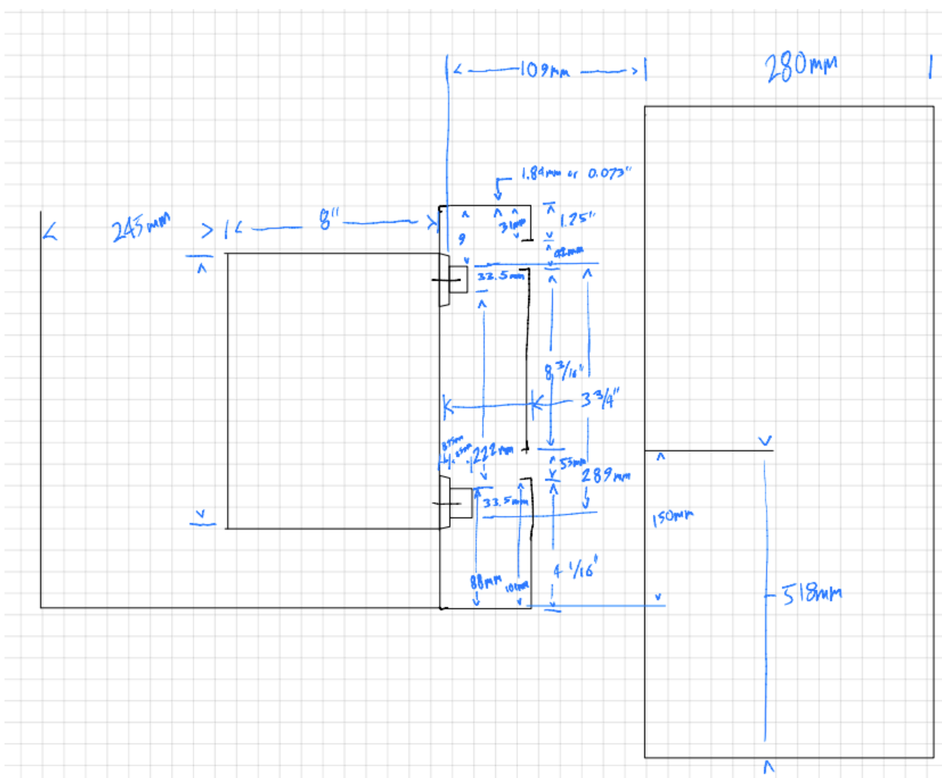

Figure19: X-Axis mount at Isola measurements

Motor Mounts

To support the motors, the motor mount is fabricated using 2.5mm thick sheet metal. The team has opted to use sheet metal due to its ease of sourcing and manufacturing. The motor mount is secured using M8 hex bolts.

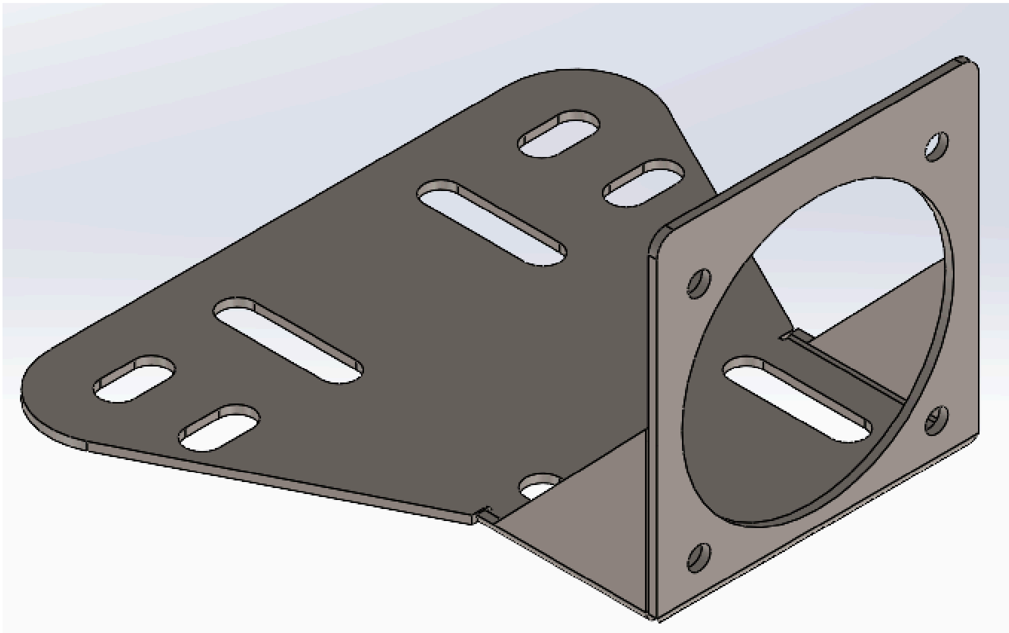

Figure 20: Motor mount

The accompanying image depicts a mount that is responsible for holding both the motors, as well as their respective mounts. The mount is also constructed using sheet metal and features welded gussets to support each corner.

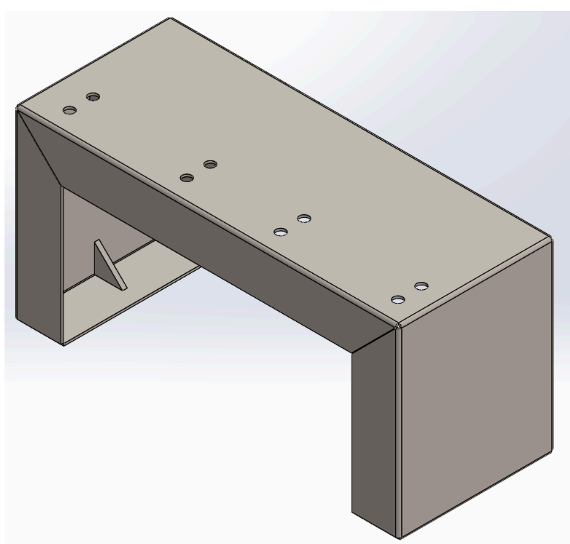

Figure 21: Mount

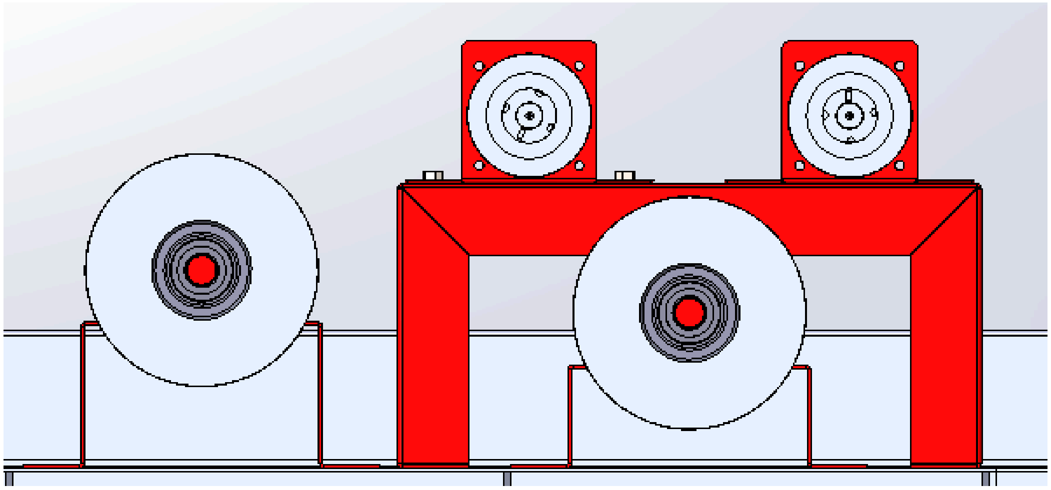

Figure 22 (a): Detailed view of the Motor mounts and X-Axis assembly

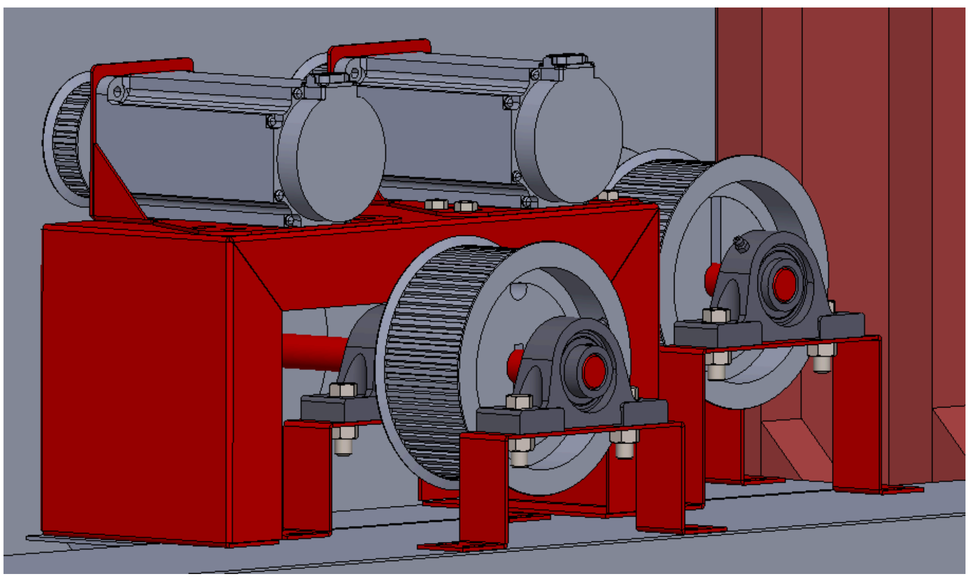

Figure 23 (b): Detailed view of the Motor mounts and X-Axis assembly

Belt Tensioners

The team had to design custom-made tensioners as off-the-shelf alternatives were not suitable due to size constraints. The tensioners needed to be around 200 cm to accommodate both units. Both tensioners feature Gates 8MX-60S-62 sprockets and are equipped with FYH's Take-up unit that can be adjusted via a lead screw. Although both tensioners are relatively similar in size, the rear tensioner (right in the image) is 30mm taller to reach the belt, which has a thickness of 20mm. The assembly comprises a back plate, back support of 12mm thickness, and a base with slightly thinner walls of 10mm thickness.

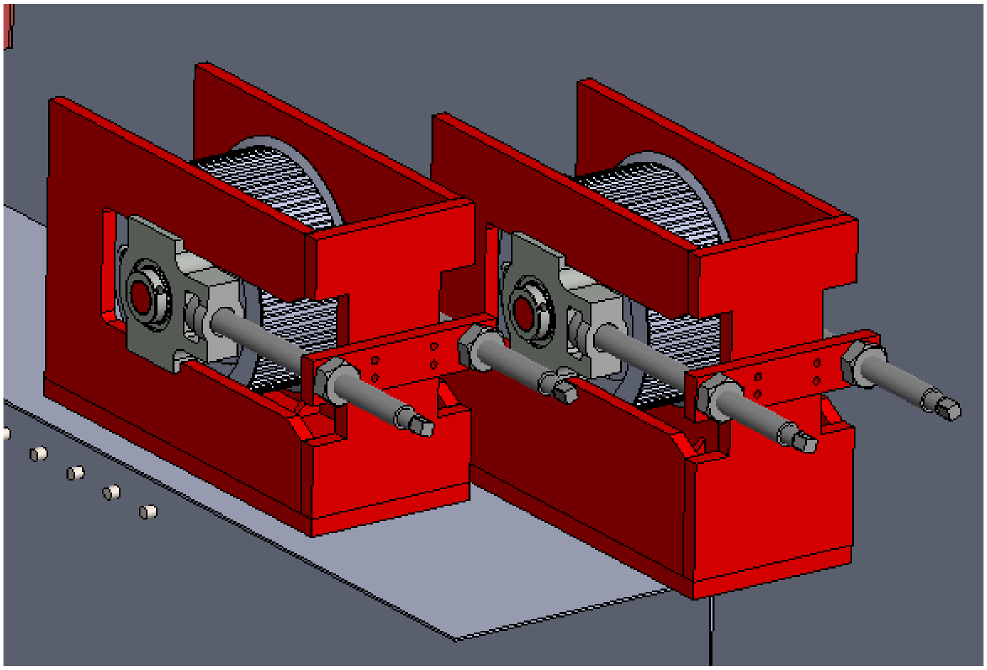

Figure 24:Belt Tensioners

The image below is the exploded view of the tensioner.

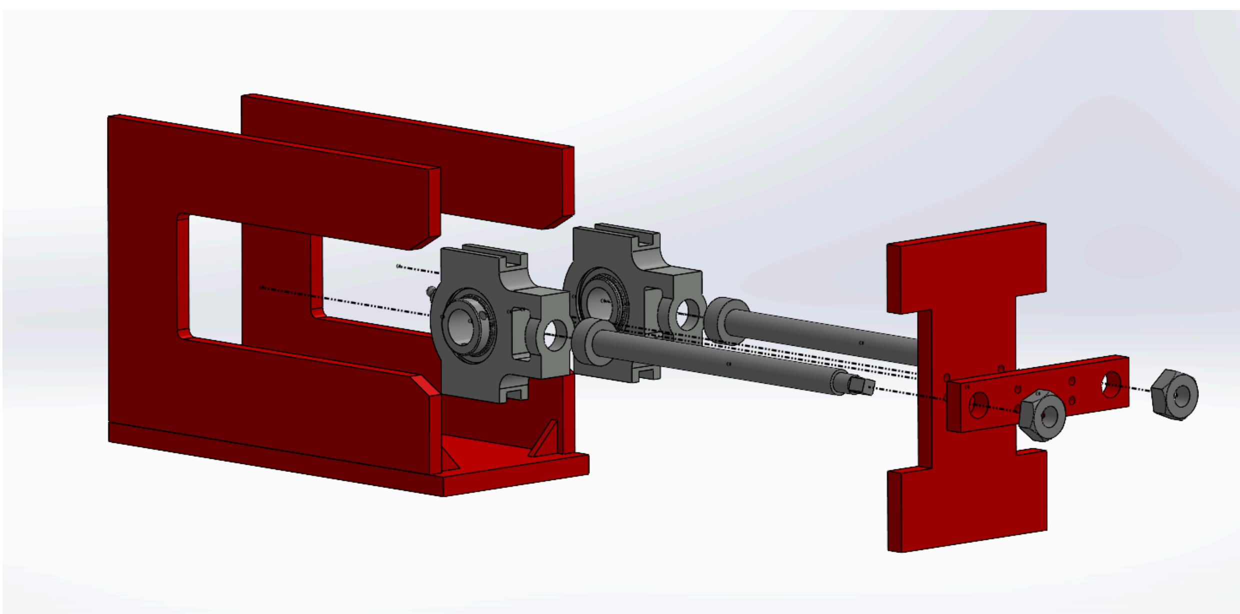

Figure 25:exploded view of the tensioner

The side plates of the base are attached using Gas Metal Welding and are supported by six gussets that are welded towards the interior.

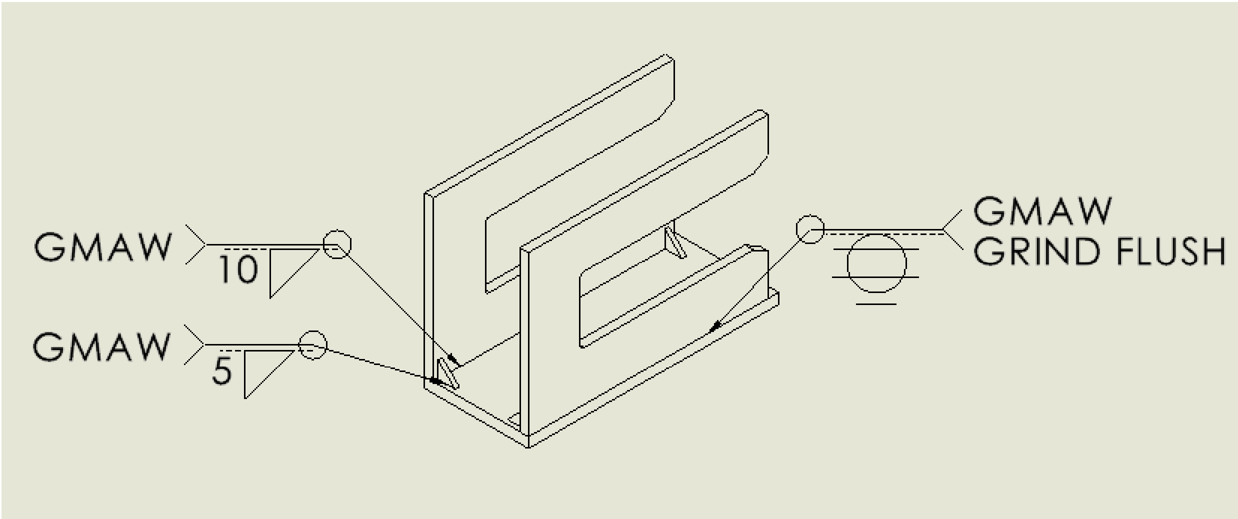

Figure 26: Weldment instruction for Idlers

Beating Mounts

The bearing mounts are also constructed using sheet metal for ease of manufacturing. These mounts are designed to hold UCP-78 22.225 pillow block bearings. Similar to the belt tensioner, the rear (right in the image) bearing mounts are designed to be 30mm taller.

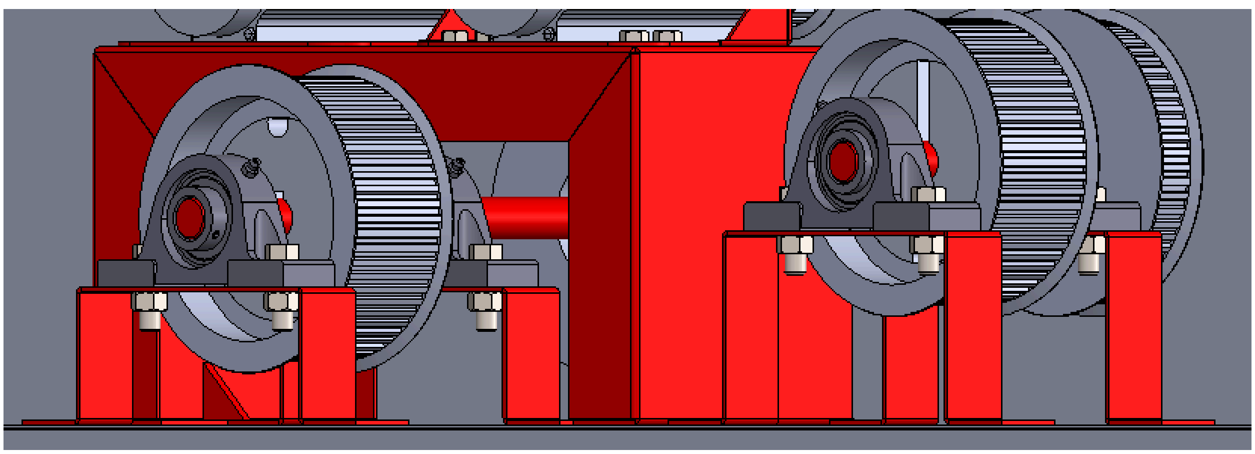

Figure 27:Beating Mounts

Electrical Schematic

Shown below is the electrical schematic. The IP will be using their own electricians, and also did not provide the intricate details of the wiring of the factory and the PLC controller, so the schematic became an operational map of all the components, their power supplies, and controls.

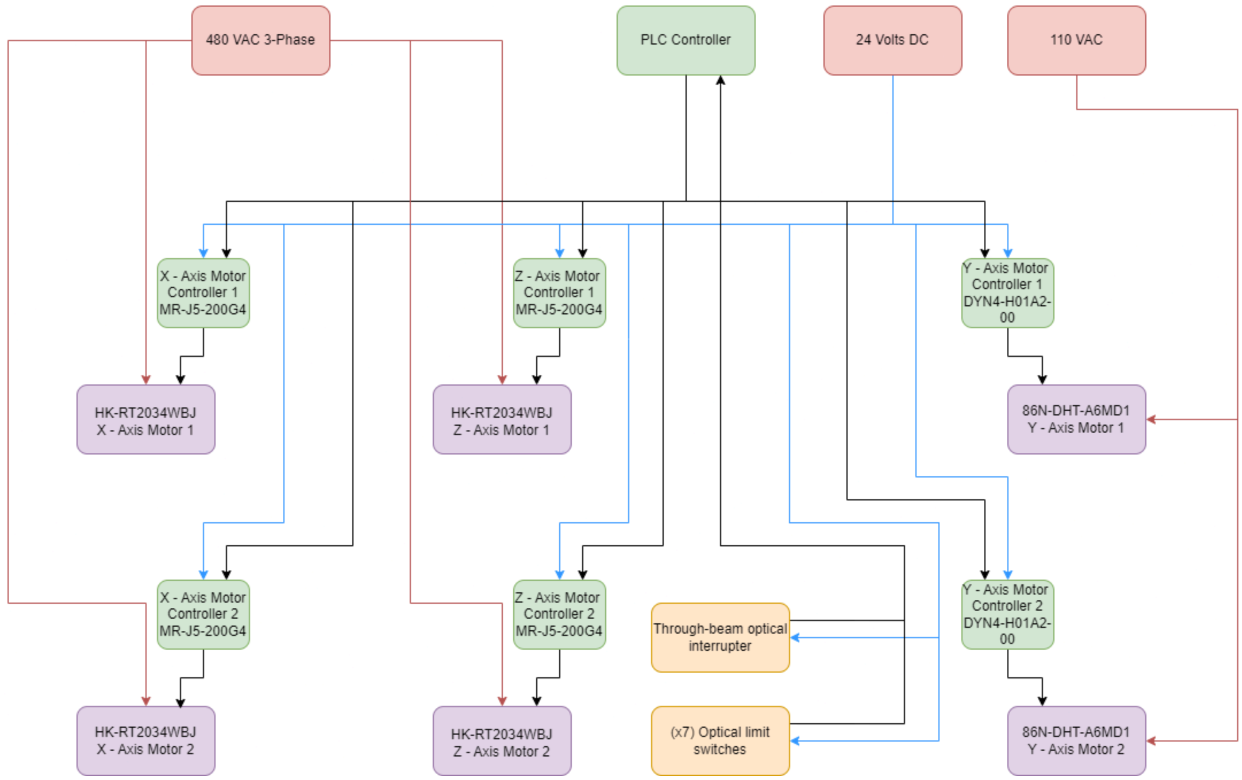

Figure 28:Electrical Schematic

For the high power servo motors for the X and Z axes, MELSERVO-J5 controllers were used to power them with 480VAC 3-phase. The motors themselves were selected to be 2.0kW HK-RT servo motors. The Y-axis had much less demands on torque and speed, so some stepper motors from Dynamic Motor Motion were used instead. These were controlled with their DYN4 controllers, and powered with 110VAC. Lastly the logic line levels were all 24VDC, as standard with Mitsubishi PLCs, and the limit switches similarly run off the same voltage.

Software

Control Flow

For the software portion of the project, all that was required was a conceptual expression of how the machine would operate. Using the design concept and testing the idea on a simulated scenario, a simple table was constructed that would show the steps and timing of the steps for a typical roll swap.

Scenario 1: Both positions occupied, swap pallet roll 1 with staged position 2

	Crane 1	**Crane 2**
1	Move from home to pallet position 1	Move from home to staged position 2
2	Open crane 1 jaws	Open crane 2 jaws
3	Lower crane 1 over pallet roll 1	Lower crane 2 over staged roll 2
4	Confirm alignment and close jaws	Confirm alignment and close jaws
5	Lift pallet roll 1	Lift staged roll 2
6	Move from pallet position 1 to staged position 2	Move from staged position 2 to far home position
7	Lower pallet roll 1 and place in staging chuck 2	Wait for crane 1 step 7 to complete
8	Lift empty crane 1 head	Wait for crane 1 step 8 to complete
9	Move to near home position	Move to empty pallet roll 1 position.
10	Wait at near home position	Lower staged roll 2 and place in empty pallet roll 1 position
11	Wait at near home position	Lift empty crane 2 head
12	Wait at near home position	Move to near home position

Table 5: Test scenario used to develop algorithm for changing out rolls

The IP requested an operational flowchart for a generalized program that would control the changeover system, as seen below. Specific positions were replaced with variables, and edge cases were designed for the possibility of empty or preloaded rolls in the cranes.

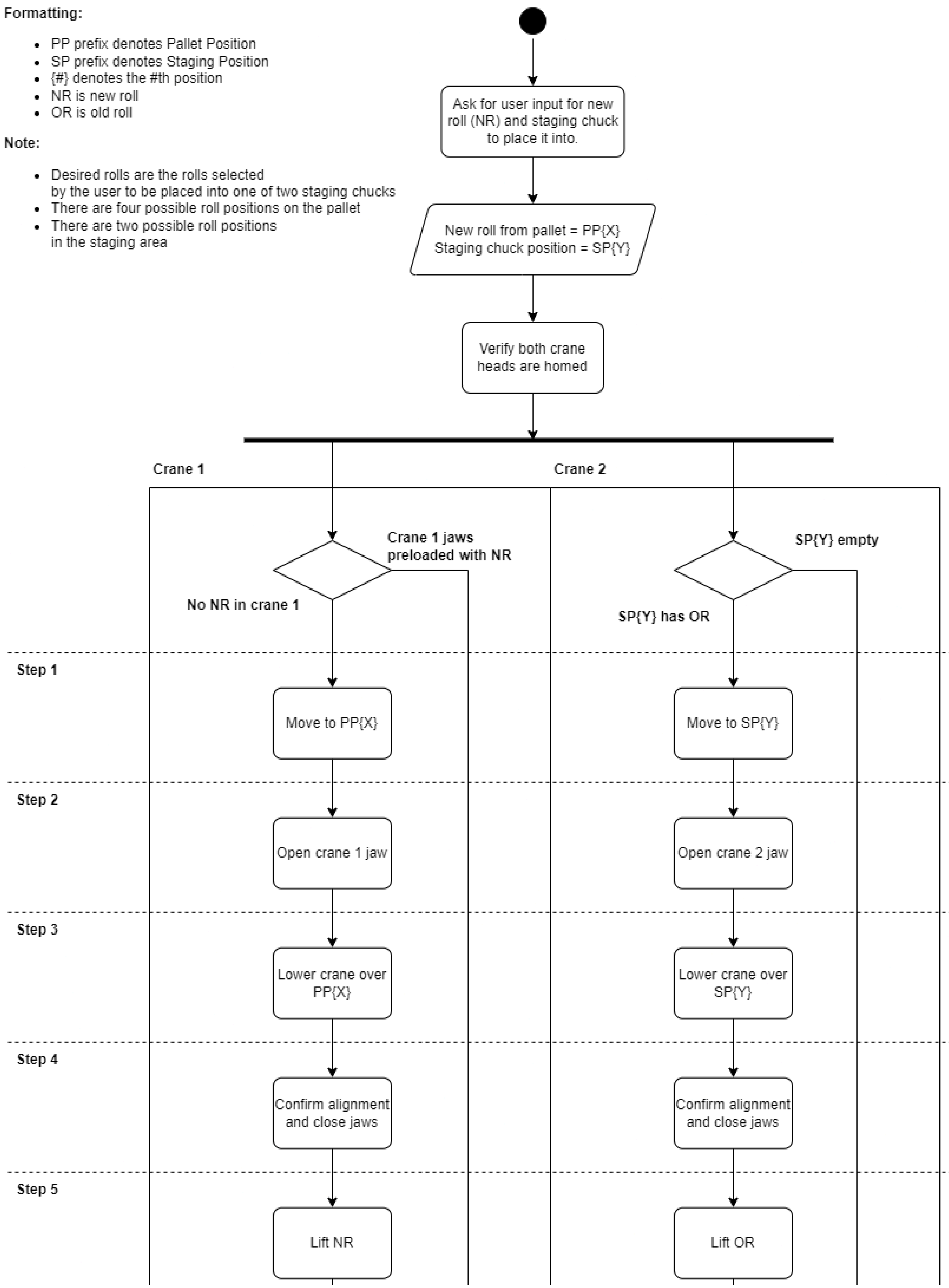

Figure 29: First half of operational flowchart.

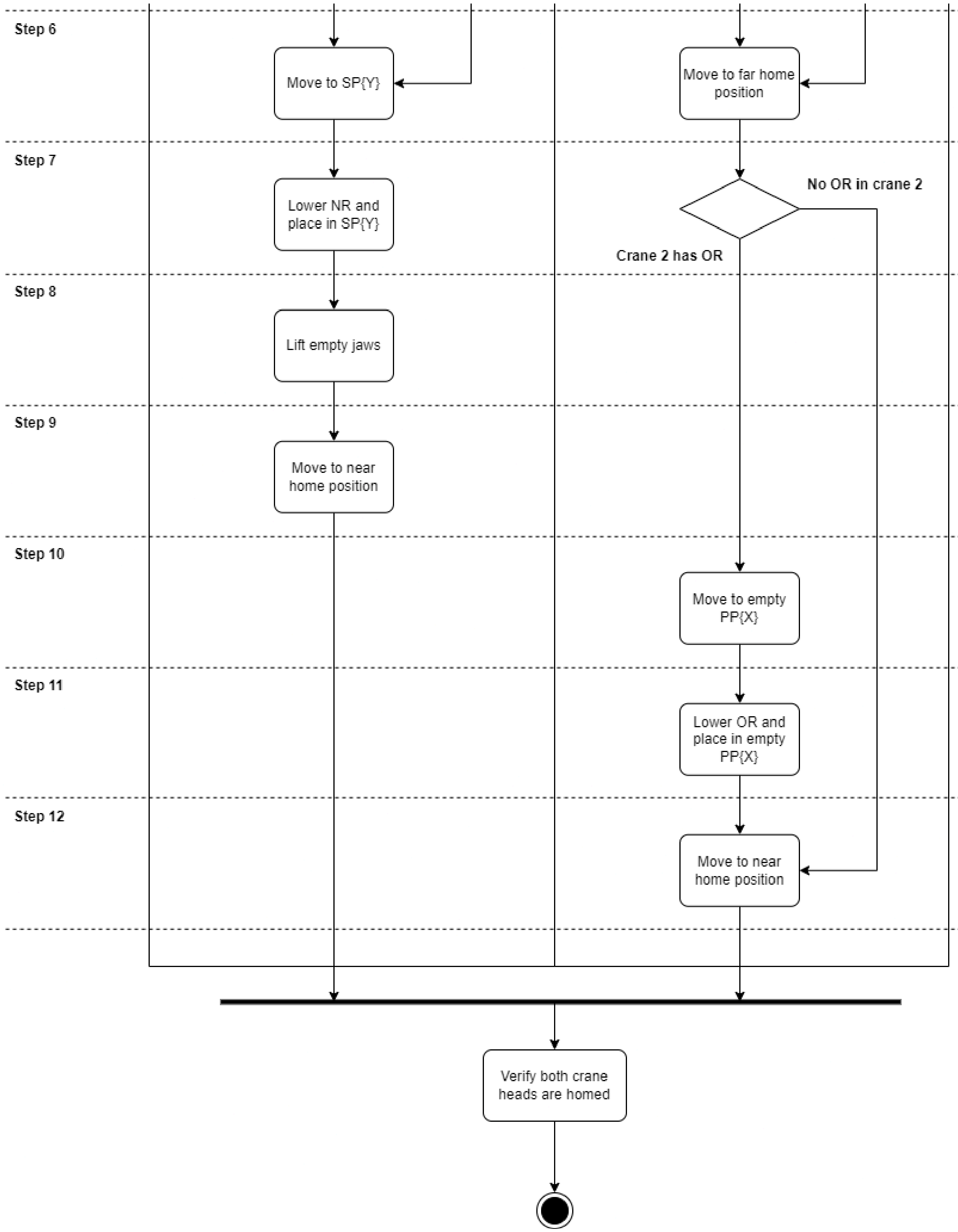

Figure 30: Second half of operational flowchart.

BOM

BOM is presented below for X-axis, Z-axis, and Y-axis. It outlines the specific parts and their manufacturers used in each axis. Additionally, Isola mandated the team to only use US-based manufacturers and/or suppliers for better maintenance. The table provides a concise overview of the BOM and the associated costs for each axis. The team was not required to mention the cost of manufacturing each custom part used in the assembly.

X axis (horizontal)			
x drive motor	HK-RT2034WBJ	Mitsubishi	
x drive motor driver	MR-J5-200G4	Mitsubishi	
x drive main pulley	8MX-60S-62	Gates Corp	$ 500.00
x drive main pulley bushing	3020 24MM 7859-6524	Gates Corp	$ 50.50
x drive Idler pulley bushing	Gates 3020 25MM Bushing	Gates Corp	
x drive Idler pulley tensioner	TUUFLN25	Misumi	$ 100.00
x drive motor pulley	8MX-30S-21	Gates Corp	$ 200.00
x drive motor pulley bushing	1108/19mm 7858-0119	Gates Corp	$ 30.00
x drive drive pulley	8MX-60S-21	Gates Corp	$ 200.00
x drive drive pulley bushing	2012 24MM 7858-2524	Gates Corp	$ 30.00
x axis pillow block bearing	Ultra Class Series UCP - Pillow Block - Wide Inner Ring, Set Screw (UCP-7/8)	Misumi	$ 80.00
x drive belt	LL8MGT-036 (inquire about 62)	Gates Corp	$ 100.00
x reducer belt	8MGT-1120 P.L. 44.09 140 Teeth	Gates Corp	$ 100.00
x axis linear rail	HGW35CA2R3700ZBCII	HIWIN	-
x optical limit switches	PR-F51CP	Keyence	$ 150.00

Table . X-axis BOM

Z axis (lift)			
z drive motor	HK-RT2034W	Mitsubishi	$ 2,000.00
z ball screw	RBS-R40-10T4-FSI-600-822-0.05-M	Hiwin	-
z linear shaft	SSPJ 30-1000	Misumi	$ 894.80
z linear shaft bearings	LMK 30 MUU	Misumi	$ 227.00
z linear shaft mounts	SSTHWS30b	Misumi	$ 150.00
z drive coupling	SCXW55-19-25	Misumi	$ 50.00
z limit switches	PR-M51CP	Keyence	$ 150.00
z ball screw supports	FK-30B	Hiwin	$ 300.00
z locating pins	AJP B5-P6-B8-G5-RAC	Misumi	$ 5.48

Table 6: Z-axis BOM

Y axis (end effector)			
y actuation motor	86N-DHT-A6MD1	Dynamic Motor Motion	$ 292.00
y motor driver	DYN4-H01A2-00	Dynamic Motor Motion	$ 235.00
y Pinion	GEAS1.5-30-15-B-13	Misumi	$ 45.00
y Rack	RGEAS1.5-300-Z	Misumi	$ 186.00
y linear rail	SSE2BWML16G-669	Misumi	$ 543.00
y through beam	PR-G51CP	Keyence	$ 150.00
y limit switches	KSK6-AP-4H	Automation Direct	$ 35.00
y limit switch bracket	ST18C7W	Automation Direct	$ 7.25
Total			$6,779

Table 7: Y-BOM

Testing Criteria 1: Number of rolls

Initial Information

Test level: System level

Test type: Capacity

Methodology:

- There is no testing to be done, this is trivial and entirely up to design.

Isola's current solution holds 4 copper rolls on standby, with one roll staged in the machine. The number of rolls that Isola wants to achieve with the new design is between 4 and 6. Having 4 rolls on standby, one staged on the machine, and one that can be held temporarily by the lifter will satisfy the criteria with a total of 6 rolls available.

Resources needed:

- CAD software

Analysis

The design Team 24 came up with allows one extra roll to be held, 5 rolls in total. This is due to the extra lifter being able to hold one more roll. Team 24 met the success criteria.

Testing Criteria 2: Changeover time

Initial Information

Test level: System level

Test type: Timing

Methodology:

- Generate simplified CAD design
- Model design in MATLAB analytically
- Simulate with MATLAB
- Determine what acceleration and changeover time is with a given model.
- Evaluate results, determine if success criteria are met, and decide how to iterate on initial design

One of Isola's primary goals is to decrease the time it takes to change out a copper roll. The average time spent with the current process is about 1 or 2 minutes. By decreasing it to 40 seconds or less, it will increase productivity.

Resources needed:

- CAD software
- MATLAB
- Simulink

Testing

To test this Team 24 first had to get the weight of each axis, this was done by using the 3d models that the team made. The team then assumed that the roll the robot was lifting was 1000lb. Next, the team had to come up with a step-by-step plan on how the robot was going to move, to test this the team only used the furthest distance the robot would have to travel. By using the furthest distance the team can learn the worst-case time. Shown below are the steps the robot takes in the worst-case scenario.

1: Move Z-Axis Down 14 in (0.3556m)

2: Move Y-Axis in

3: Move Z-Axis Up 14in (0.3556m)

4: Move X-Axis 3.7m (This is what makes it worst case scenario)

5: Move Z-Axis down

6: Move Y-Axis out

7: Move Z-Axis up

With these steps the team knew what they needed to test. To test this the team made a MATLAB/SIMULINK model that used torque as an input and robot position as an output. That model is shown below.

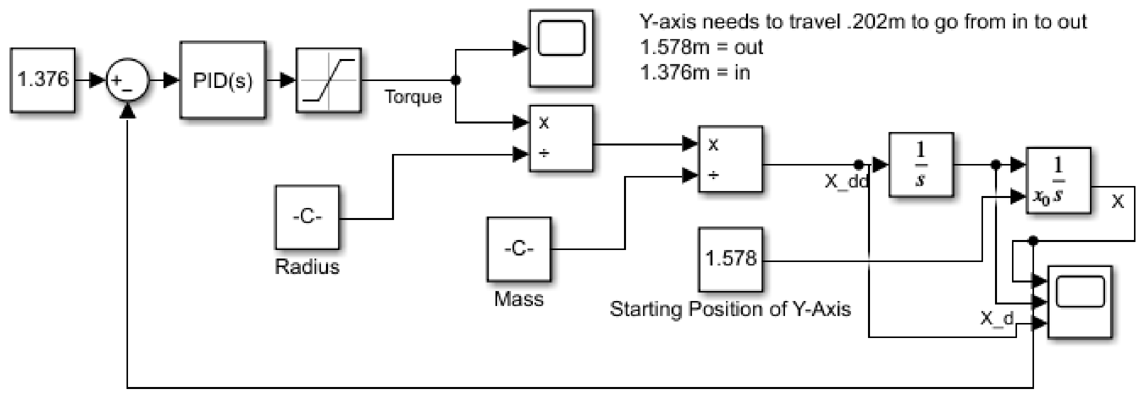

Figure 31: Y-Axis Simulink model

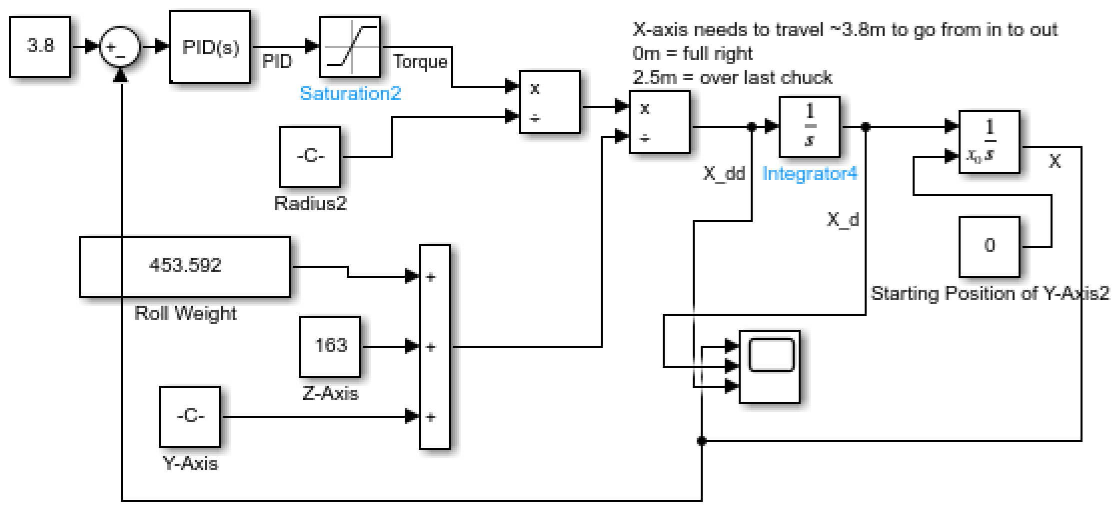

Figure 32: X-Axis Simulink model

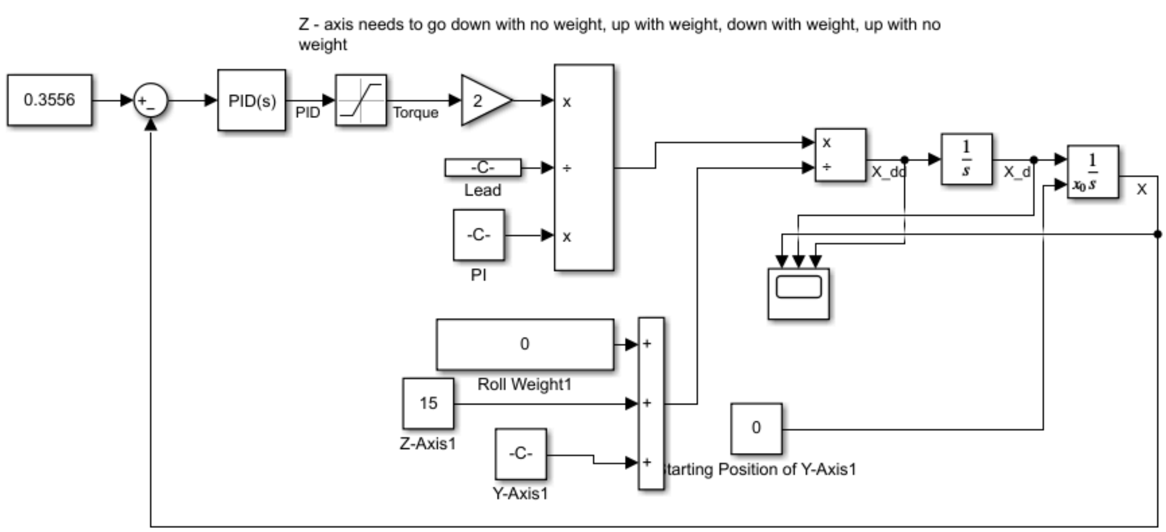

Figure 33: Z-Axis Simulink model

Analysis

Shown below are the results from the testing.

1: Move Z-Axis Down 14 in (0.3556m) -

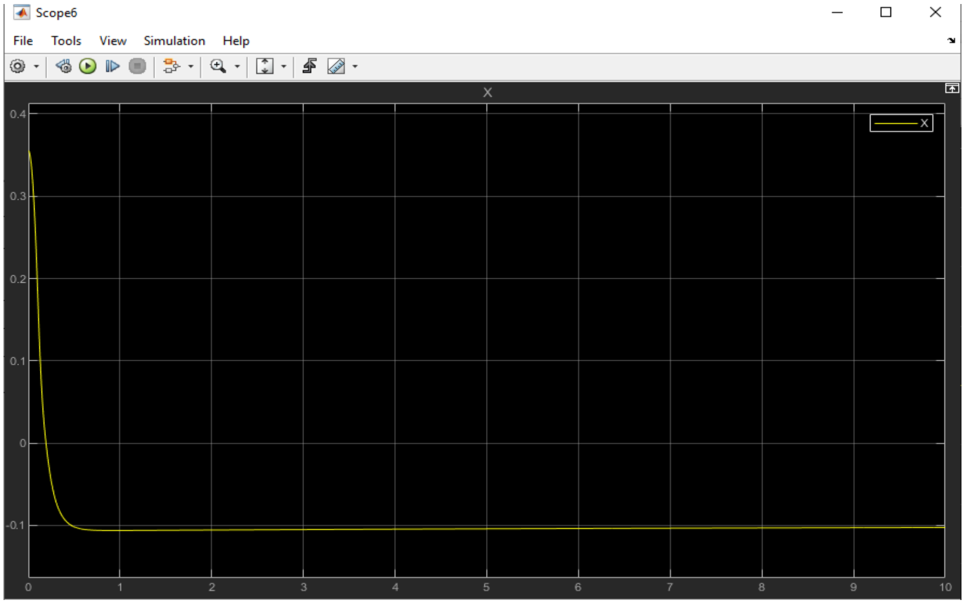

Figure 34: Z-Axis Moving Down Without Roll

The Z-axis moving down (with no roll) took ~1.5 seconds.

2: Move Y-Axis in

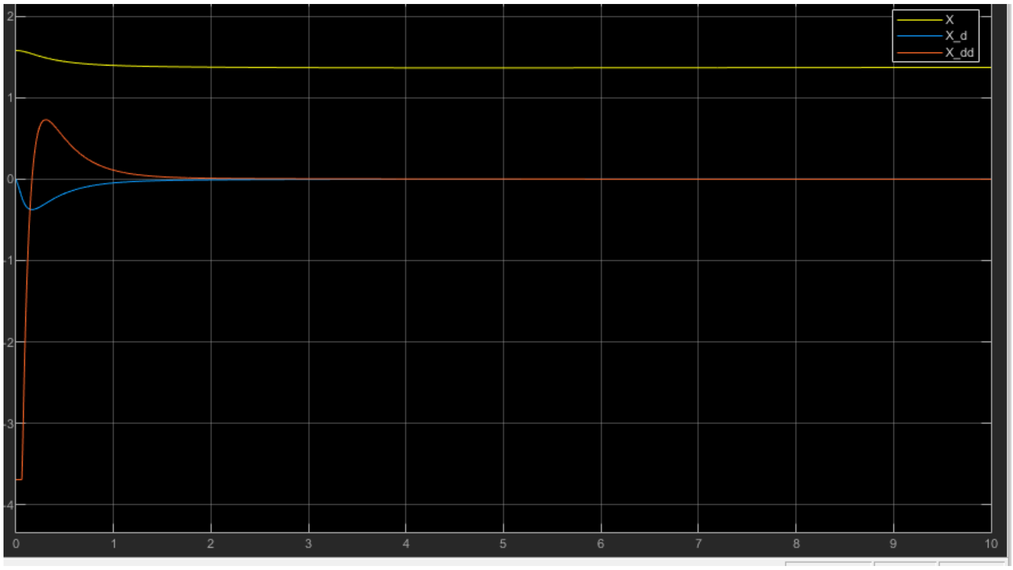

Figure 35: Y-Axis Moving In

The Y-axis moving in took ~2 seconds.

3: Move Z-Axis Up 14in (0.3556m)

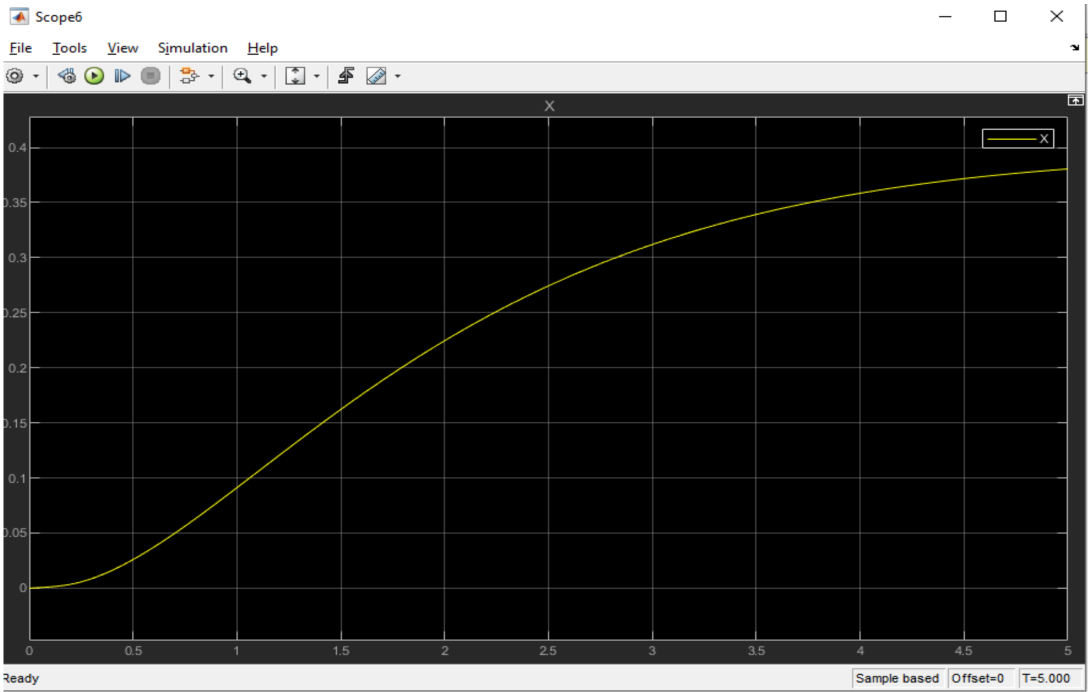

Figure 36: Z-Axis Moving Up With Roll

The Z-Axis moving up with a roll took ~5 seconds.

4: Move X-Axis 3.7m

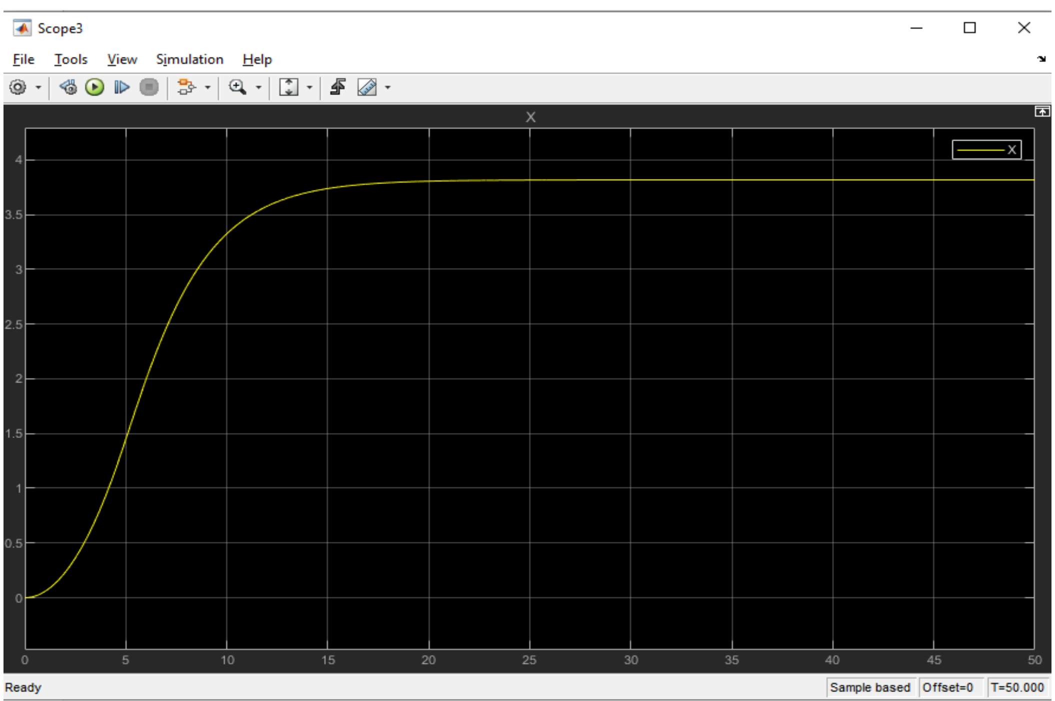

Figure 37: X-Axis Moving To Chuck

The X-axis moving took ~20 seconds to complete.

5: Move Z-Axis down

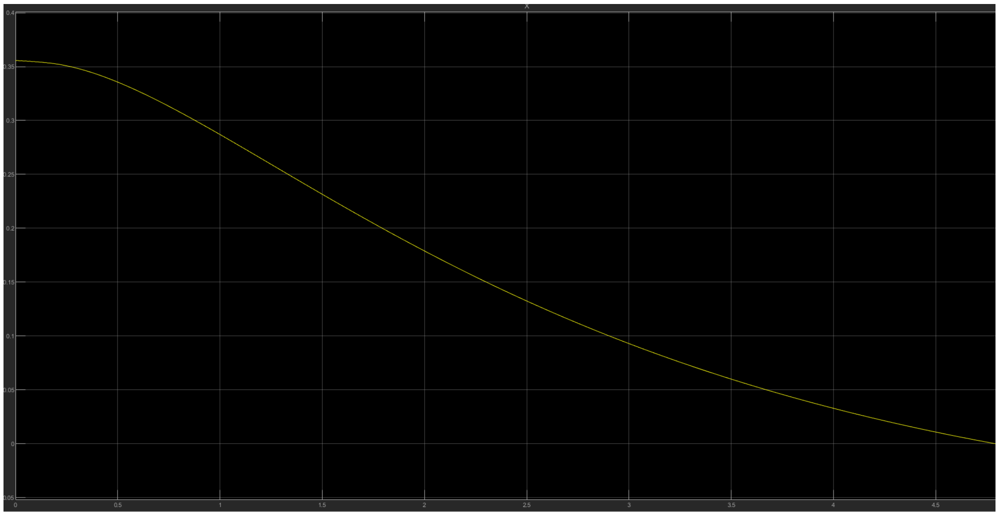

Figure 38: Y-Axis Moving Down With Roll

The Y-Axis moving down with a roll took ~4.5 seconds to complete.

6: Move Y-Axis out

This action (as there are no external forces acting on the robot) takes the same amount of time as going in, therefore it takes ~2 seconds to complete the motion.

7: Move Z-Axis up

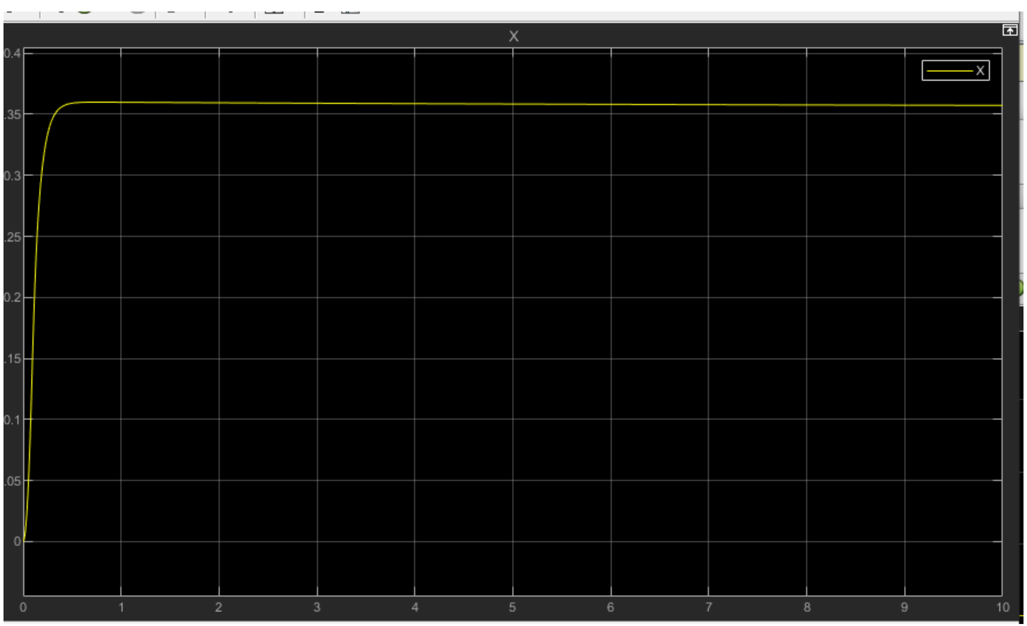

Figure 39: Y-Axis Moving Up Without Roll

The Y-Axis moving up without a roll takes ~1.5 seconds to complete.

In conclusion, the times added up take 36 seconds to complete. The team's target was 40 seconds, meaning this success criteria was met.

Testing Criteria 3: Weight capacity

Test level: System level

Test type: Capacity

Methodology:

- Isolate affected parts of assembly
- Add constraints and loads
- Run static FEA
- If passed, run dynamic FEA
- Evaluate results, determine if success criteria are met, and decide how to iterate on initial design

The machine needs to carry copper rolls that are an average of 700 pounds when full. They have to be able to change out rolls several times in an hour. The weight capacity is important because the new design has to be able to lift and move the rolls without being damaged irreversibly.

Resources needed:

- CAD software
- FEA software

Analysis

<u>Z-axis Weight Capacity Analysis - Solidworks Simulations</u>

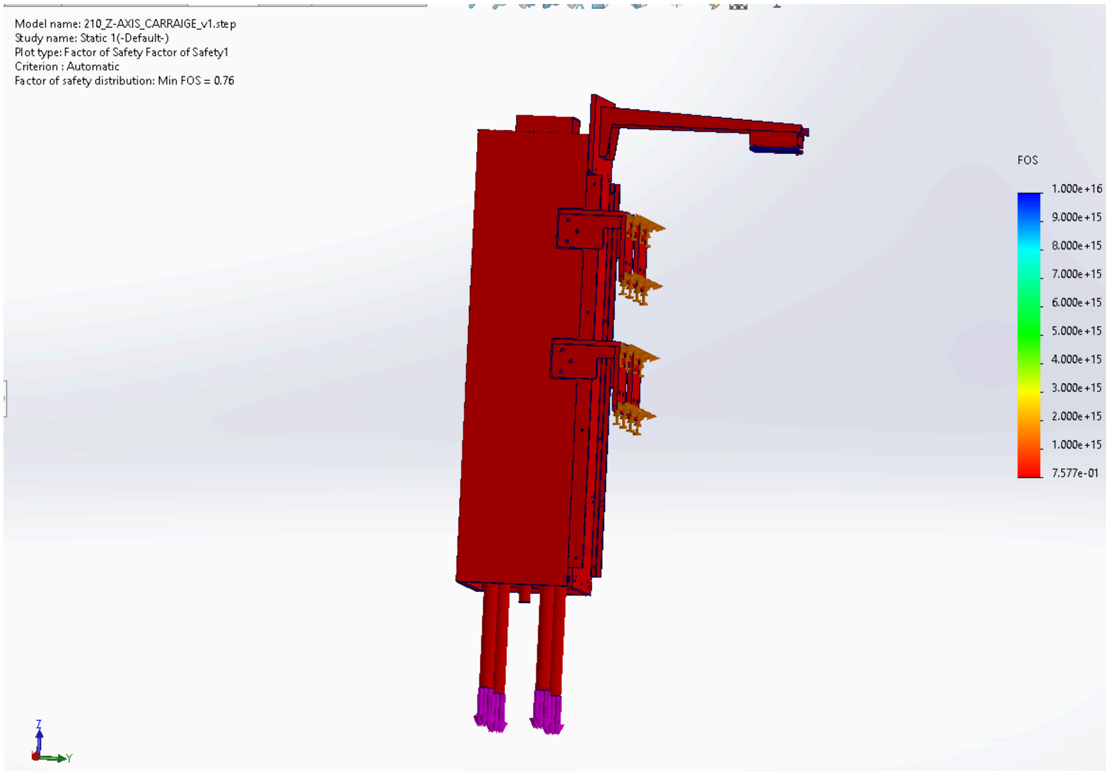

Figure 40: Z-axis Weight Capacity Analysis

- FOS of .76 with 1300 lbf
    - 1000lbs for copper roll (highest weight possible)
    - 300lbs for y-axis
- CAD software
    - Fusion 360
- Stress Analysis Report
    - Appendix C

Y-axis Weight Capacity Analysis - Solidworks Simulations

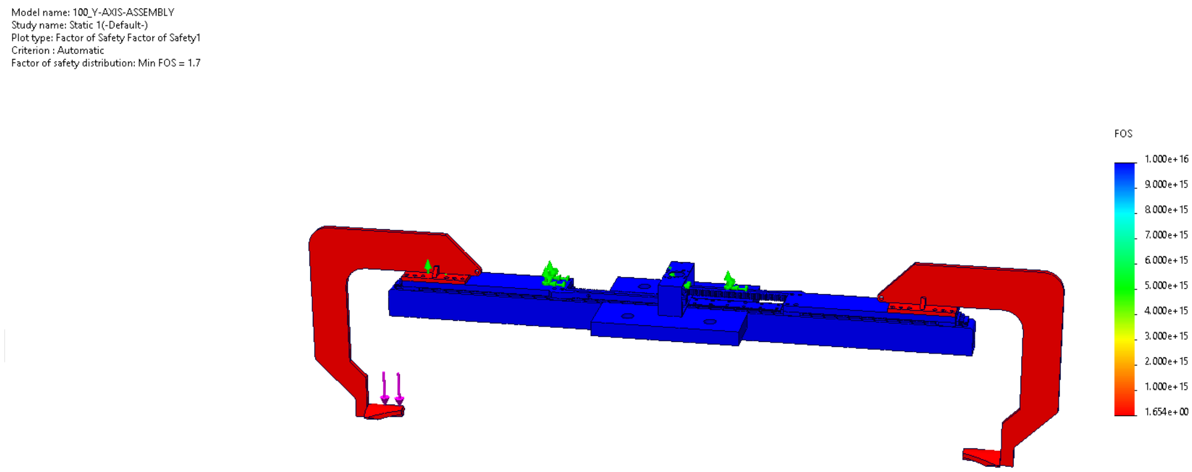

Figure 41: Y-axis Weight Capacity Analysis

- FOS of 1.7 with 1000 lbf
- CAD software
    - Solidworks
- Stress Analysis Report
    - Appendix C

CAD Model of End Effector

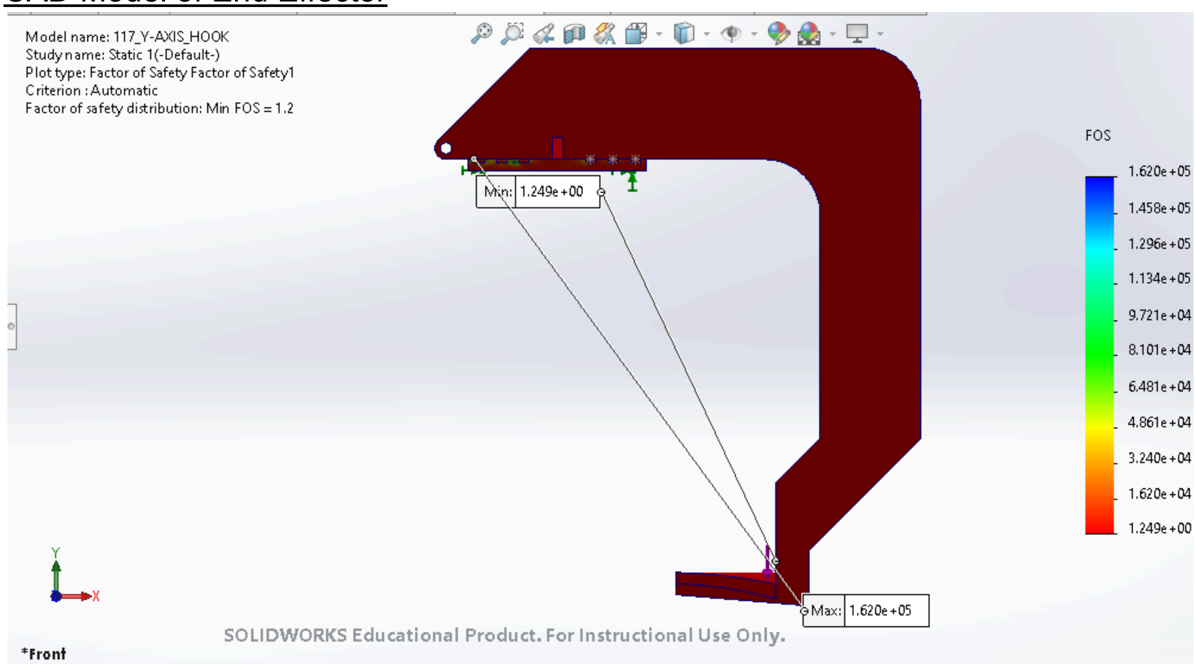

Figure 42: End Effector weight capacity

- 1000 lbf downwards on where the copper roll would be placed

- Safety factor of 1.2
    - Can hold a maximum of 1200 lbf
- Stress Analysis Report
    - Appendix C

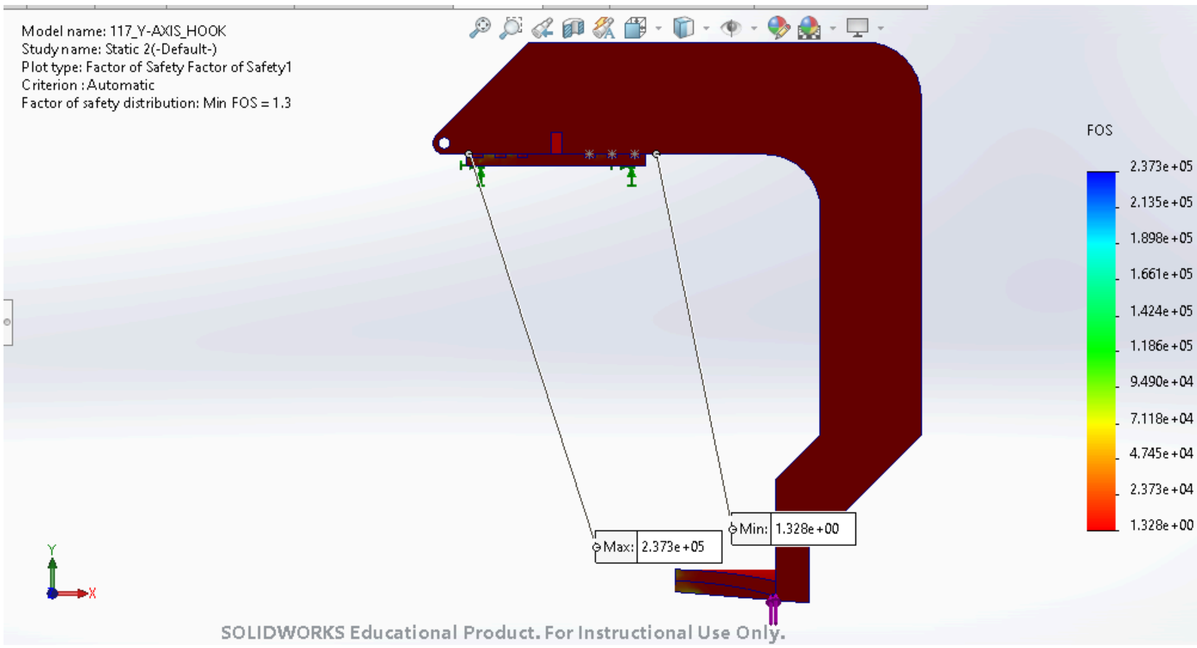

Figure 43: End Effector weight sideways acceleration

- 626 N + 100 N applied sideways to simulate fast acceleration
- Safety factor of 1.3
    - Can withstand acceleration up to 943 N
- Stress Analysis Report
    - Appendix C

Testing Criteria 4: Clean room standard

Test level: System level

Test type: Compliance

Methodology:

- Review particulate standards for all materials involved
- Compile into spreadsheet
- Estimate overall particulate shedding over lifetime
- Compared to ISO Class 6 Clean Room Standards

Isola wants the solution to comply with the ISO Class 6 clean room standards. This means they want the air inside to be controlled to a cleanliness standard to keep the copper from being contaminated. An ISO Class 6 cleanroom requires that there are less than 35,200 particles per cubic meter with a size of >0.5 microns and less than 293 particles per cubic meter with a size of >5 microns. Since Isola is already in charge of maintaining the air changes, the team just needs to make sure that the new device does not produce more particles than the air handling system can compensate for [5].

Resources needed:

- Manufacturer datasheets
- ISO Class 6 clean room standard set

Analysis

The team made sure this was the correct way to make sure all parts selected were Class 6. For the created parts, of them are made out of stainless steel and as such fall under Class 6 clean room standards. Because of this Success Criteria 4 was met.

Project management

Project schedule

The table below describes the Team's initial major milestones that were discussed before the winter break.

Milestone	***Due Date***
Design Review	Oct 31st
Preliminary Prototype Plan	Nov 2nd
Sourcing Parts both electrical and mechanical	Nov 9th
Prototype Complete (CAD model and Analysis) & Design Review	Jan 31st
Second Design Review	Feb 28th
Final project delivery date	Apr 15th

Table 8: Initial Project Milestone and Due Dates

The table below describes the schedule of the Team's major milestones according to the updated Gantt chart.

Milestone	***Due Date***
Design Review	Oct 31st
Preliminary Prototype Plan	Nov 2nd
Sourcing Parts both electrical and mechanical	Feb 5th
Initial Prototype Complete (CAD model and Analysis) & Design Review	Jan 23st
Second Design Review	Mar 5th
Final project delivery date	Apr 28th

Table 9: Final Project Milestone and Due Dates

Color Key	
Completed on time	Green

Was late less than one week	Yellow
Was late more than one week	RED

Table 10: Project Milestone Color key

After conducting a thorough comparison of both tables, the team successfully achieved all major milestones within the designated time frame. However, the sourcing of parts encountered a delay as the team had to make necessary adjustments as specified by the Industrial Partner. Regrettably, the team was unable to meet the secondary design review deadline by a margin of 10 days, primarily due to the unavailability of the Industrial Partner, as well as the need for the team to make mechanical and electrical corrections. Consequently, the final project delivery date had to be rescheduled to April 23, 2023, to align with the innovation showcase deadline.

The final Gantt Chart is posted in the Appendix . The team does not have any expenditure besides the BOMB that needed to be delivered to the IP.

Risks

The team has successfully avoided encountering any of the following risks outlined below:

Description	***Type***	***Severity***
The industrial partner may not be able to meet on a regular schedule since he is the Plant Engineering Manager	Communication	Medium
The team may not be able to properly model the full-scale system with a smaller scale prototype, leading to uncertainties in the design.	Communication	Medium
The team cannot test if the solution will have a 20 year lifespan, only make estimates and design in safety factors, so it is possible that the final solution may not last that long.	Technical	Low
The Return on Investment (ROI) of the project may not be under 2 years if the final solution is too expensive	Financial	High

Table 11: Risks

Broader Context

Design

The twin hoist system proposed was designed with a focus on safety and efficiency, and with adherence to OSHA standards. The system features an electromagnetic brake on the Z-axis that eliminates the possibility of the copper roll dropping unexpectedly, ensuring operator safety. The new system also increases changeover capacity, which will lead to increased production, generating more value for Isola and boosting the economy. However, the increase in production capacity could also lead to a larger carbon footprint, posing a threat to public health. To mitigate this, Isola should consider implementing environmentally friendly measures to reduce the impact of the increased production capacity. The solution was designed to reduce the workload on the lay-up operators, which leads to employee satisfaction, positively impacting public welfare. The design of the system should also consider cultural factors such as changes in the workflow, ensuring that it doesn't negatively impact the workplace culture. It is also essential to ensure that the solution doesn't compromise the quality of the PCBs as it could adversely impact Isola's reputation and its customer base.

Professional

The proposed twin hoist system has a significant impact on various stakeholders. The increase in production capacity will make Isola more competitive locally and globally, boosting economic growth. The system's efficiency and speed will increase the company's ability to deliver products to customers faster, improving customer satisfaction and increasing sales, positively impacting the economy. The implementation of environmentally friendly measures to mitigate the increase in carbon footprint will ensure the solution doesn't have negative environmental impacts. Improved working conditions for lay-up operators will improve employee satisfaction, enhancing public welfare. However, the solution should not compromise the safety of the workers on the line. By adhering to OSHA standards, Isola can ensure that the solution doesn't pose any risks to the workers. The system's design should also consider cultural factors, ensuring that the changes don't negatively impact the workplace culture. Finally, the system's design should also consider social factors, ensuring that it doesn't cause job losses and that it enhances the quality of life for the workers and the community at large.

Constraints

Motors need to be Baldor, Marathon, or a US Based supplier. Sensors and switches should be from Omron or Keyence. Circuit Protection needs to be from Schneider Electric, Allen Bradley, or Eaton. Pneumatics need to be from SMC. PLC/IO needs to be from Mitsubishi. CAD files should be Solidworks-based. Needs to fit within the work area without obstructing other machines. The team has closely followed the constraint but one. One of the axes was modeled with Fusion 360 initially, but it was later imported into Solidworks to meet this constraint.

Engineering Standards

Device followed the following OSHA standards: 1910, 1926, and 1809. The device followed Class 6 clean room standards. The device was built using ISO 724 Metric threaded hardware. The device can interface with Mitsubishi PLC control systems by following IEC 61131-3.

Lessons Learned

One of the axes was modeled in Fusion 360 and then imported into Solidworks. This resulted in some issues and wasted time. To overcome this issue, the team learned about best practices for modeling and importing CAD models, such as ensuring compatibility and file type conversions. The team also learned to communicate more effectively when collaborating on CAD models. The team's strategy for gaining this knowledge was to research online forums, watch video tutorials, and seek advice from the instructor and industrial partner. The team found these resources to be effective and learned a great deal about CAD modeling and importation. However, the team could have improved its approach by seeking advice from experts in the field, such as professional CAD designers.

The team realized that they lacked in-depth knowledge about industrial standards and how industrial equipment is designed. This was a critical knowledge gap, as the team's solution needed to meet specific industry standards to be successful. To overcome this issue, the team researched industry standards and regulations, such as ISO 9001 and OSHA. The team also consulted with the IP and the instructor to gain further insights into these standards. The team found that this approach was highly effective, as they were able to develop a comprehensive understanding of industry standards and apply them to their design. However, the team could have improved its approach by seeking out additional resources, such as online courses or consulting with experts in the field. This would have allowed the team to gain a deeper understanding of the nuances of industrial standards.

The team initially had no knowledge about timing analysis. However, as they started testing the device, they realized that they needed more accurate and sophisticated testing methods to capture the data accurately. To overcome this issue, the team researched testing methods like Simulink Simscape and analysis software. The team also consulted with the industrial partner to gain further insights into testing and validation methods. The team found that this approach was highly effective, as they were able to capture accurate data and make design changes accordingly. However, the team could have improved its approach by seeking out additional resources, such as consulting with experts in the field or attending relevant training programs such as running a simulation Robot Operating System (ROS). This would have allowed the team to gain a deeper understanding of testing and validation methods and ensure that their approach was the most effective and meet industry standards.

Conclusion

Isola's current copper foil roll changeover solution is largely a manual process and takes 2 minutes, which is far longer than it should, decreasing their ability to fill out next-day laminate orders. Along with that, it currently can only hold 2 rolls, which is a bottleneck and results in longer production times and halts the processes that are before and after lamination. This directly affects the production capacity, and improving this would help the company to have shorter lead times, reach out to more customers, have faster production, and help in the economic growth of the company.

The success of this product would remove the bottleneck at the copper foil loading step. This allows Isola to manufacture laminate at a faster rate, allowing it to deliver the products to its customers faster. This allows them to take on more clients, fill more orders, and produce more value. The team managed to get the entire concept to change the roles in under 36 seconds (under the worst-case scenario) which means the team's design is 70% faster than Isola's current hoist. Adding to that the hoist is semi-autonomous and requires the workers to control the hoist at a distance making it safer to operate.

The team designed a solution that meets all of their criteria and delivered a detailed mechanical and electrical design, and a bill of materials (BOM) of the solution. The team sourced US-based part suppliers and compiled a BOM. The scope of the solution is limited to the beginning at the copper foil pallet staged at the machine and the end at loading the copper foil rolls onto the existing chucks. The team noted the voice of the customer and derived the success criteria and project requirements.

Criterion (Requirement)	***Threshold (Halt & Review)***	***Team's Design***	**Stretch**	***POR Risk (H, M, L)***	***Comments***
Number of rolls staged on machine	4	5	>6	L	The dual hoist system adds extra roll space
Changeover Time	40 sec	36 sec (worst-case scenario)	20 sec	M	Even in the worst case scenario the team is able to keep the change over time under 40 sec.
Per roll weight capacity	500 lb	1000 lbs	1000 lb	L	Controllable by design
Clean room standard	Class 6	Class 6	Class 6	L	The components used in the design rated to maintain air cleanliness levels of a maximum of 1,000 particles per cubic

					meter

Table 12: Success Criteria

The team divided its high-level test plan into the following criteria: Changeover time, Weight capacity, Number of rolls staged on the machine, and Clean Room standards. The device was tested under these criteria and the team's solution met or exceeded all of the success criteria and found valuable info about how well the solution met them. The team's device solution can change roll in under 36 seconds along with that the device is able to hold more than 700 lbs. The team designed a more efficient solution with better functionality that fits the needs of Isola. The team's success was due to working closely with the Industrial partner and instructor.

The team was able to deliver the complete project within the time and was able to closely match the schedule that it initially proposed. Additionally, the team has successfully avoided encountering any of the risks.

Future Work

1. Implementation of the Solution

The team designed a successful solution to Isola's problem. The next step would be working with Isola to integrate the new hoist. The team can talk to the manufacturers of the custom parts to improve them and increase their manufacturability. The team also aims to offer support during the building of the solution and help with troubleshooting any issues that may arise.

2. Software integration:

The team may expand upon the software integration and develop the algorithm for the hoists using ladder logic.

3. Gather Feedback:

After the solution is designed the team can get in-depth design not just from Jeremiah but also from the workers there. After implementing the hoist, the team may gather feedback from Isola to see how well it is working. The feedback can be used to make tweaks and improvements to ensure that it continues to meet Isola's needs.

4. Expand Scope:

The team can expand upon the scope of this project. The team's solution is limited to a staged area and layup machine. After this project is designed, there will be new bottlenecks at Isola in the storage area where they store more roles that may need improvements.

References

[1] Isola Group, “Isola Overview - ASU Capstone Project.” Isola Group, Chandler, Jul-2022.

[2] J. Adams, S. S. T. Meesala, S. Strasser, and R. Gillespie, “Voice of the Customer,” 12-Sep-2022.

[3] E. Jimener, S. S. T. Meesala, S. Strasser , and R. Gillespie, “Copper Roll Changeover Machine Questionnaire,” 13-Sep-2022.

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[5] M. Magusara, “ISO 6: Defining cleanroom classification guidelines,” *ISO Cleanroom*, 02-Feb-2022. [Online]. Available: https://isocleanroom.co.uk/blog/iso-6-defining-cleanroom-classification-guidelines/. [Accessed: 05-Dec-2022].

Appendices

Appendix A

Contributions of all team members to the report

Section/Task	Sai Srinivas Tatwik Meesala	Samir Strasser	Reagan Gillespie	Litzi Matancillas
Executive Summary	40%	0%	50%	10%
Introduction	90%	0%	10%	0%
Final Detailed Design	25%	25%	25%	25%
Analysis	0%	65%	0%	35%
Prototype Construction	25%	25%	25%	25%
Testing: Success Criteria	0%	65%	0%	35%
Project Management	100%	0%	0%	0%
Conclusions	100%	0%	0%	0%
References	25%	25%	25%	25%
Final Editing	25%	25%	25%	25%
Final Formatting	25%	25%	25%	25%

Appendix B: Gantt Charts

The Following pictures below describe Team 24’s Gantt chart.

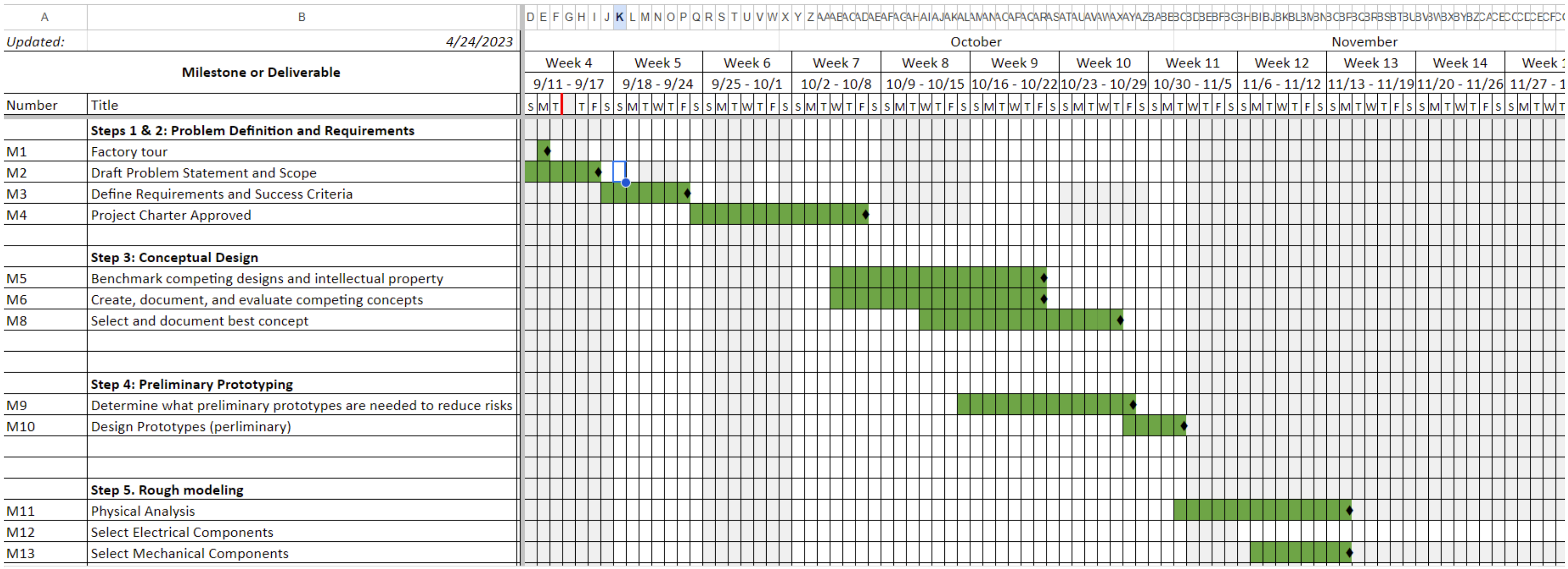

Figure (a). Gantt Chart

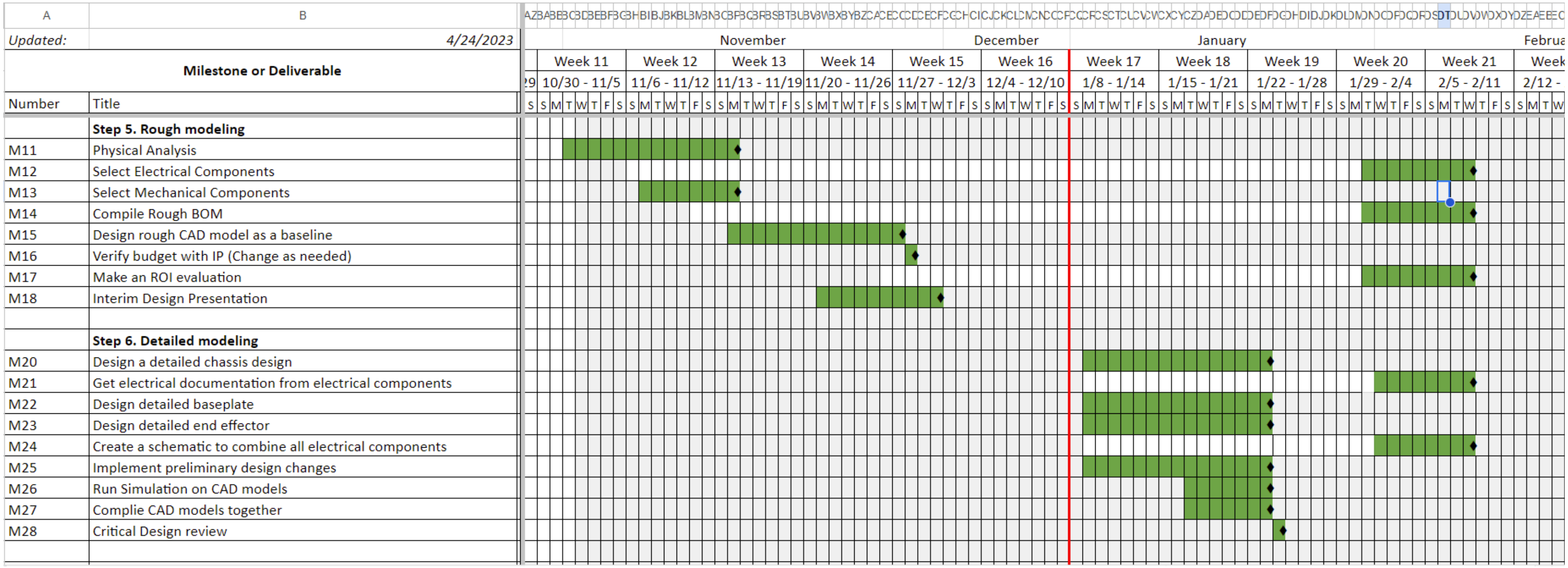

Figure (b). Gantt Chart

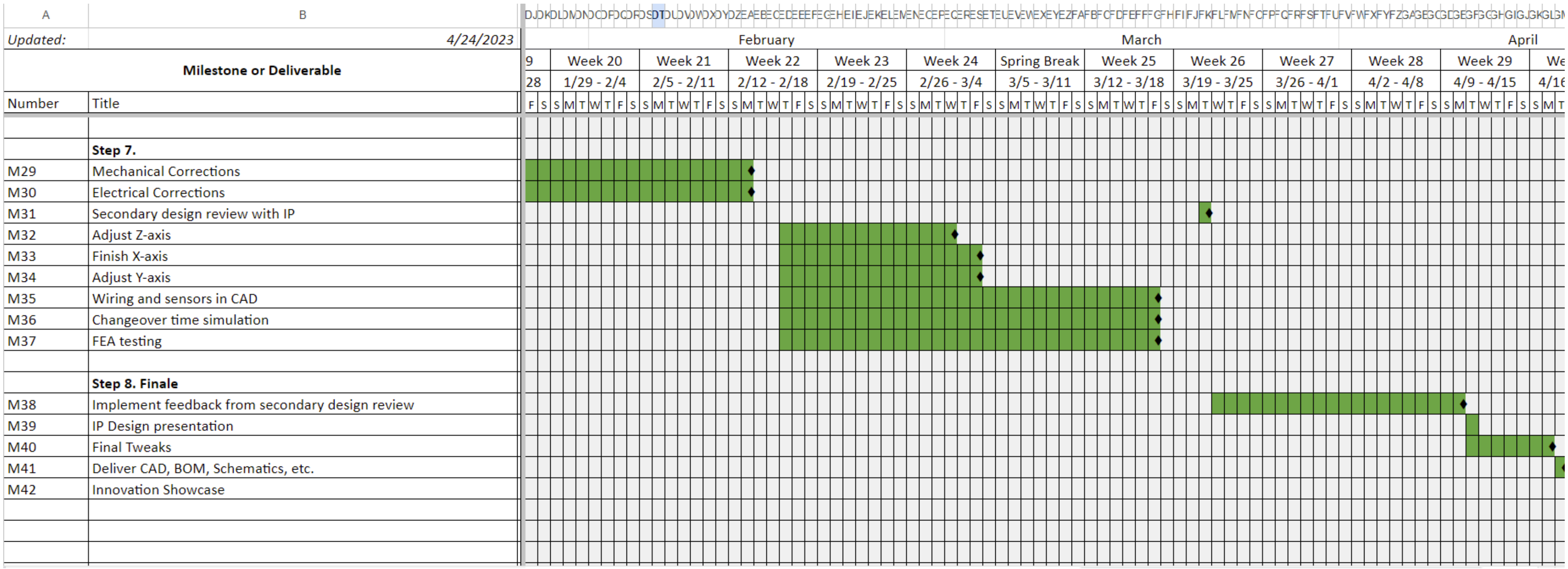

Figure (c). Gantt Chart

APPENDIX C: Analysis reports

Y-axis Weight Capacity Analysis

- Stress analysis report
    - 210_Z-AXIS_CARRAIGE.docx

X-axis Weight Capacity Analysis

- Stress analysis report
    - 100_Y-AXIS-ASSEMBLY-Static.docx

End Effector

- Stress analysis report Acceleration
    - 117_Y-AXIS_HOOK_1-Static_2-1_Acceleration.docx
- Stress analysis report weight capacity
    - 117_Y-AXIS_HOOK_-Static_1-1 Weight.docx

APPENDIX D: CAD Drawings

Y-axis CAD drawings

- y-axis.pdf

X-axis CAD Drawings

- X-AXIS.pdf