# Insert Base Automated Foam Gasket Installation

## Melet Plastics

### Final Design Report

**MECH 4860 – Engineering Design**

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# Executive Summary

Melet Plastics Inc. has tasked Team 15 with designing an automated method of installing a foam gasket onto a plastic insert base. The current installation process is done manually, which is costly, tedious, fast paced, and makes the operator prone to repetitive strain injury. Melet aims to automate the entire process from installation to packaging.

To meet the objectives of the project, the project scope, client needs, technical specifications, and constraints and limitations were defined. To verify the practicality and achievability of the final design, the client required a feasibility study and a cost estimate along with the final machine design concept at the end of the project.

The final design phase involved generating detailed designs for the two layouts that were selected from the conceptual design phase. After sourcing all the required parts for each layout from suppliers, a feasibility study was conducted on each layout. The feasibility study analyzed the financial and technical feasibility, as well as an assessment of the risks of each layout. Based on the results from the study, the final design that was selected is the Gantry Layout due to the ability of maintaining the current cycle time of four parts every 21 seconds, fitting within the current system footprint, and meeting a payback period of $140,000 over two years.

The Gantry Layout design starts with a shuttle system consists of two belt-driven linear actuators. Each actuator transports a jig table that secures the insert bases in place. The shuttle system delivers the insert bases directly from the machine arm that receives the bases from the injection molding machine, to the gantry system for gasket installation. The gantry system consists of a pick-and-place machine that utilizes needle grippers to install the foam gaskets. After the gaskets are installed onto the insert bases, the shuttle system transports the finished products to the packaging area. To unload the insert bases from the shuttle system, a six-axis robot is used to pick the finished products from the jig table and place them in a packaging box. The final estimated cost of the Gantry Layout design is $127,000.

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# 1.0 Introduction

Melet Plastics, a manufacturing company that specializes in engineered plastic and composite solutions, has tasked Team 15 with designing an automated method to install a foam perimeter gasket onto a plastic insert base. This section summarizes the background information, problem statement, objectives, and scope of the project. Finally, the client's needs, as well as the technical specifications, constraints, and limitations of the project are explained.

## 1.1 Project Background

Melet currently produces a plastic insert base with a foam perimeter gasket for the assembly of an electric water heater [1]. An insert base with an installed foam perimeter gasket is shown in Figure 1.

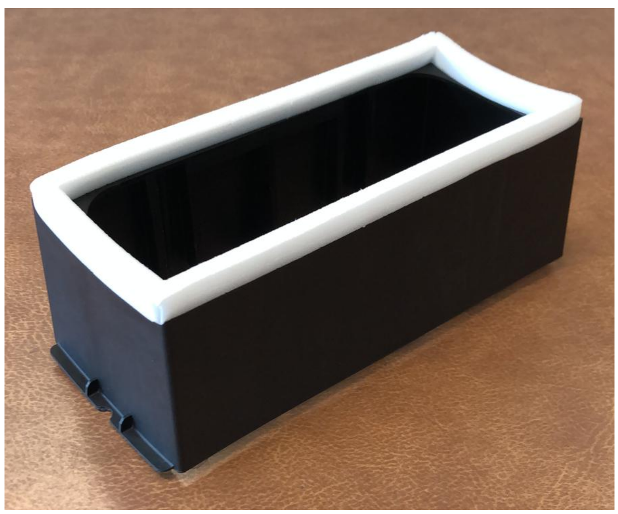

Figure 1: Finished insert base with an installed foam gasket

This plastic insert base is installed in the thermostat area of the water heater and acts as an enclosure to prevent the urethane foam insulation of the water heater from entering thermostat cavities [1].

The current work station layout where the designs are to be implemented is shown in Figure 2.

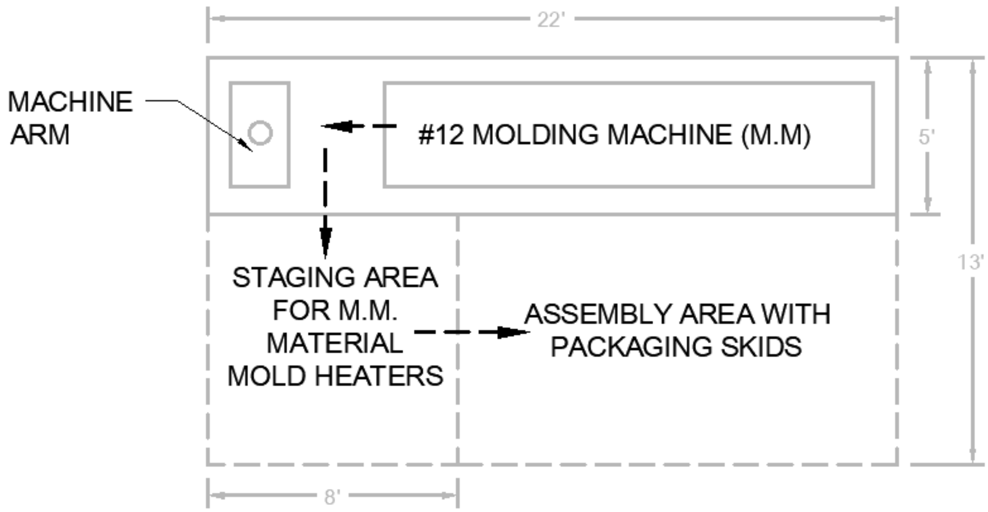


Figure 2: Existing manufacturing cell layout schematic

The existing layout is shown in light gray. The current footprint of the system is 22 feet in length and 13 feet in width. The insert bases are produced through injection molding. The existing machine arm picks up the insert bases from the injection modeling machine, horizontally moves to the staging area, lowers the arm and drops the insert bases into a trough. This process is shown in Figure 3.

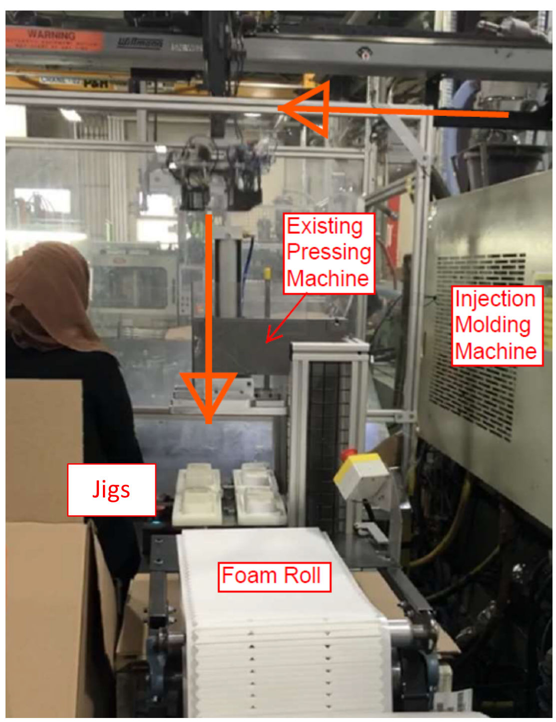


Figure 3: Existing manufacturing cell layout

The foam gaskets that are to be installed on top of the insert bases are die-cut. They initially come in a pre-collapsed orientation on a roll with an adhesive layer on the roll side of the gasket as shown in Figure 4.

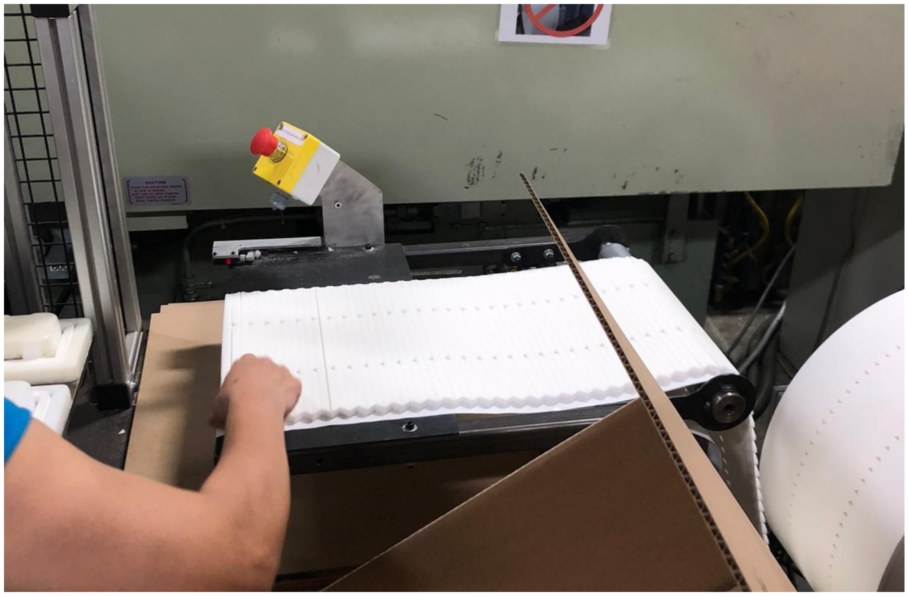

Figure 4: Foam gasket roll

Installation of the foam gaskets starts with manually removing the gaskets from the roll, expanding the gaskets, and placing the expanded gaskets in a jig with the adhesive side facing upwards. Then operator retrieves the insert bases that were dropped in the trough and places them in a jig on top of the foam gaskets as shown in Figures 5 and 6.

Figure 6: Operator waiting for plastic parts


Figure 5: Jigs that operator places parts on

A press controlled by the operator is then used to fully attach the gaskets to the insert bases to ensure a complete adhesion. The insert bases with the applied foam gaskets are then removed from the jig, inspected, and packaged by the operator in a box as shown in Figures 7 and 8.

Figure 8: Foam gasket installation by the press

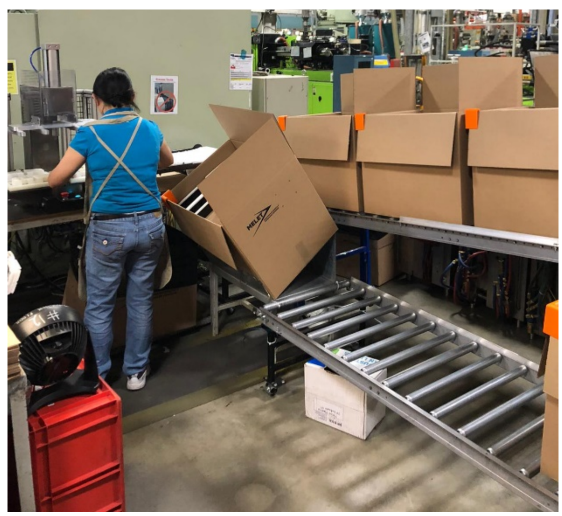

Figure 7: Packaging of finished parts

For the packaging process, the operator places parts in a 2 by 6 orientation as partly shown in Figure 9.

Figure 9: Packaging box with finished parts

The parts are then stacked by placing a cardboard sheet in between each layer until the box is full. At which point, the operator removes the box from the station and replaces it with an empty one.

Melet Plastics has tasked team 15 with designing an automated method to accurately remove the die-cut foam gaskets from a roll, expand the gaskets, and install the foam perimeter gaskets to the insert bases. This design mainly focuses on the foam gasket installation process, but if the timeline permits, the design will also include the process of conducting camera inspections, and packaging the finished products in boxes as well.

## 1.2 Problem Statement

The current manual process of installing the foam perimeter gasket to the plastic base insert is tedious and costly. Furthermore, the nature of the work is fast paced which makes operators prone to repetitive strain injury [1]. The installation process was automated in the past. However, due to the large footprint of the system, as well as the high frequency of required maintenance, the installation process was reverted back to manual operation.

## 1.3 Project Objectives

The objective of this project was to design a feasible automated process that is able to install the foam gasket onto different sizes of plastic parts while meeting the client's needs of maintaining the target production level and minimizing the operator interaction. The project team worked closely with the client to develop various concept designs and recommend the preferred alternatives. The final design benefits Melet by reducing the operator number, increasing automation level, and minimizing the maintenance requirement.

## 1.4 Project Scope

The project's scope of work shall include, but is not limited to the following:

1. Final machine design concept layouts.
2. Cost estimate and analysis.
3. Feasibility study of the selected concept design.

The following items are not be included in this project:

1. Concept prototype and testing.
2. Stress and fatigue analysis.
3. Programming for CNC or Industrial robot.

## 1.5 Client Needs

The team gathered the required information from the client, interpreted the obtained data, organized the needs into a hierarchy, prioritized them with relative importance, and obtained client approval for the prioritized needs. A summarized table is shown in Table I.

TABLE I: ORGANIZED CLIENT NEEDS HIERARCHY

| Number | Client Need Description | | Importance |
|---|---|---|---|
| 1.0 | The system | maintains the target production level | 5 |
| 2.0 | The system | requires minimal operator interaction | 5 |
| 3.0 | The system | is adaptable for different part sizes | 5 |
| 4.0 | The system | is safe to operate | 4 |
| 5.0 | The system | maintains the foam gasket shape from supplier | 4 |
| 6.0 | The system | maintains the size of the finished product packaging box | 4 |
| 7.0 | The cost | of the system is kept to a minimum | 3 |
| 8.0 | The system | is space-saving | 3 |
| 9.0 | The system | produces the parts with required quality | 3 |
| 10.0 | The client | is able to implement the system easily | 3 |
| 11.0 | The system | is user-friendly | 2 |
| 12.0 | The system | Is durable | 2 |
| 13.0 | The system | is convenient to install | 1 |

The first two needs (production level and operator number) were explicitly provided by the client while the rest were determined and prioritized by observation of the current process and discussion with clients during the site visit. Priority levels are rated from one to five, with five being the highest priority and one being the lowest.

The relative importance of each need was determined by the interview and importance assessment with the client. The client needs of the highest priority are considered throughout the entire design process while the needs with lower priorities were kept in mind, but are not essential to the project’s success.

### 1.6 Technical Specifications

After determining the main client needs, the quantified metrics were established based on the discussion and approval with the client. The goal is to achieve all target values in the detailed design. All metrics with relative importance is summarized in Table II.

TABLE II: TECHNICAL SPECIFICATIONS

| Metric # | Metric | Unit | Current Value | Marginal Value | Target Value | Priority |
|---|---|---|---|---|---|---|
| 1 | System cycle time | second | 21 | 21 | 15 | 5 |
| 2 | Operator number | person | 1.5 | 1 | 0.5 | 5 |
| 3 | Level of operator interaction | Subjective | Manual | Semi-Automated | Fully Automated | 4 |
| 4 | Process is adjustable for different part heights | inch | N/A | N/A | 1.6 | 5 |
| 5 | Hazard Analysis | Yes/No | Yes | Yes | Yes | 4 |
| 6 | Payback period time | month | N/A | 24 | 12 | 3 |
| 7 | System Footprint, length × width | feet | 22 × 13 | 50 × 30 | 22 × 13 | 3 |
| 8 | Foam deviation of the finished product | inches | N/A | 1/8 | 0 | 3 |
| 9 | Percent outsourced products/services | % | N/A | <20 | 0 | 3 |
| 10 | Time for maintenance | Days/ Month | 2 | 2 | 1 | 2 |
| 11 | Cost for maintenance | $ | $5,000 | $15,000 | $10,000 | 2 |
| 12 | Continuous Operation Time | Hours/Day | 6 | 8 | 8 | 2 |
| 13 | Number of re-adjusted processes | number | N/A | <3 | 0 | 1 |

A table for descriptions of certain metrics that need further details for a complete understanding is shown in Table III.

TABLE III: METRIC DETAILED DESCRIPTION

| Metric # | Detailed Description |
|---|---|
| 2 | Indicates that the current value and target value have units of 0.5 persons. This means that the operator only works 4 hours of an 8-hour shift. |
| 3 | To ensure that the system can apply the foam gasket on parts of varying heights of 1.6”. The plastic insert base has the same front profile where the foam gasket is installed, but they have different heights which need to be accounted for in the potential solution. |
| 5 | To ensure that the system’s hazards have been identified and all company and governmental codes/standards have been met, Manitoba Safe Work hazard identification system was used [2]. This includes identifying common hazards such as pinch points, sharp edges, unguarded machines, fast moving equipment, and others depending on the final design details. |
| 8 | To ensure the foam gasket is installed properly and does not interfere with the inside opening of the insert base and does not overhang off the edge by more than a 1/8 of an inch. |
| 10 & 11 | Estimates made for time and cost of maintenance needed for the system. These estimates will be changed as needed if they are later determined to be unreasonable. |

A house of quality (HOQ) which summarizes the client needs and technical specifications is shown in Appendix B.

## 1.7 Constraints and Limitations

This project would operate within a set of constraints and limitations that are unique to this project. The team identified the project constraints and limitations and summarized them in Table IV.

TABLE IV: CONSTRAINTS AND LIMITATIONS

| Constraints | | |
|---|---|---|
| **Constraint Number** | **Constraint** | **Detailed Description** |
| 1 | Payback Period/Budget | The proposed design is constrained by the target payback period of $70,000 per year. The total budget of the automation system shall not exceed 2 years. |
| 2 | Project Deadline | The team must submit the required deliverables by the target deadlines (both internal and external deadlines), which were presented previously in Table 1 in Section 2.2 |
| 3 | Source Constraints | Robotics simulation software usage. |
| **Limitations** | | |
| **Limitation Number** | **Limitation** | **Detailed Description** |
| 1 | Existing Machine Modification | The existing injection molding process and machine can not be modified due to the budget limit. |
| 2 | System Footprint | The automation system footprint shall not exceed 50 × 30 feet in length × width. |
| 3 | Adaptability for the existing power system | The automation system shall be fully functional in the existing power system and shall comply with all applicable national and local electrical codes. |

# 2.0 Conceptual Design

This project requires an overall layout design to demonstrate the overall work flow and sub-concept designs for each process to illustrate how to implement the corresponding function. Thus, the conceptual design process started with the benchmarking system research, and then the team brainstormed a list of layout concepts and preliminary designs for each working step. The team then performed a primary screening of the layout concepts based on client's input and suggestions. Finally, the sub-concepts were evaluated and combined with the selected layouts to generate the best option by using a Weighted Decision Matrix (WDM).

## 2.1 Concept Generation

The team considered the main client needs and details of requirements and constraints to generate the preliminary design solutions for the automation system. The sketches from the team members for the layout and working process concept follow separately.

### 2.1.1 Layout Concepts

The preliminary layout concepts are presented below with description details. These designs were aimed at maximizing the level of automation and minimizing the physical footprint while being able to meet the production level.

**Concept A: Two Robots Layout**

The first layout, which uses two robots as main components, is shown in Figure 10.

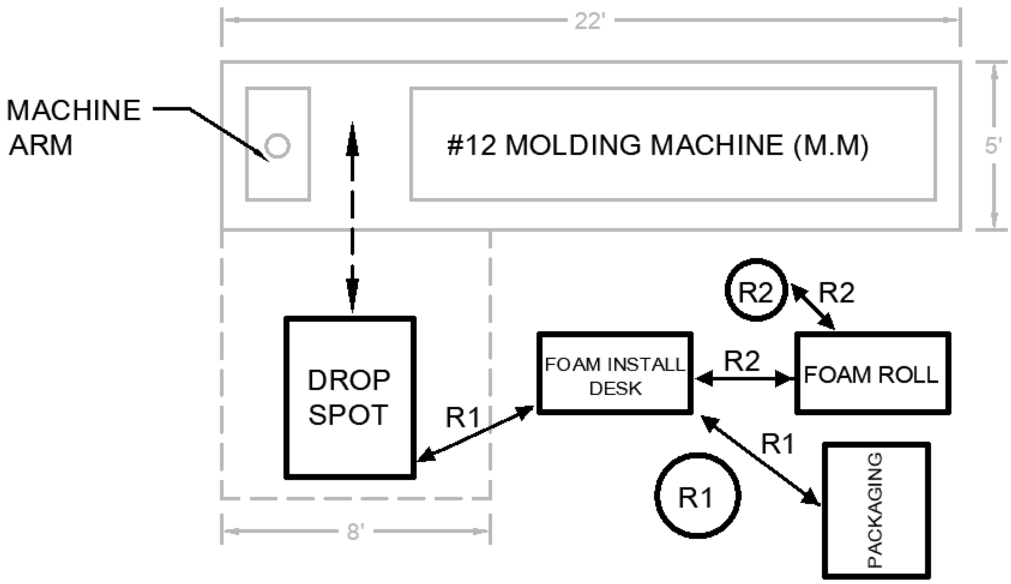


Figure 10: Two-robots layout

When the plastic parts are dropped off from the existing machine arm, robot 1 (shown as R1) picks up the parts and places them on the jigs of the installation desk. Then a second robot (shown as R2) removes, expands, and installs the foam onto the part. After this, robot 1 performs the inspection, removes the finished parts from the desk and packages them in the packaging area. The two robots must be multi-axis robots in order to perform the required complex operations.

With the use of two robots, this concept is able to minimize the level of operator involvement. Also, the addition of the arm robots would not require any change to the existing layout other than maintaining enough operating and maintenance space for the robots. However, the overall cost and the required footprint are considerably higher.

**Concept B: One Robot Layout**

The second layout concept is shown in Figure 11.

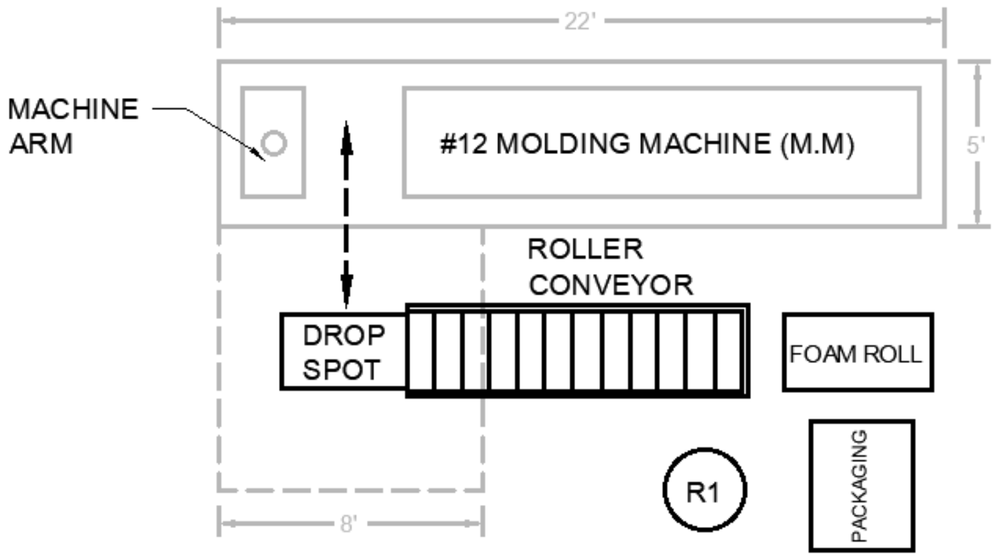


Figure 11: One-robot layout

When the plastic parts are dropped off from the existing machine arm, they are directly dropped on the jigs on the roller conveyor beneath through a chute system. The jigs are retractable so they would not interfere the motion of the roller conveyor during the process. The conveyor then transports the parts forward such that the robot (shown as R1) can pick up and install the foam onto the plastic parts. The process ends with R1 inspecting and packaging the finished parts in the packaging area.

Comparing to the two-robots layout concept, this one-robot concept can significantly reduce the cost and the required footprint. However, the required programming complexity and degrees of freedom are consequently higher since the robot merges the functions of picking up, installation, inspection, and packaging. What is more, the retractable jig design on the roller conveyor requires customized manufacturing and introduces additional cost.

**Concept C: Cartesian Gantry Layout**

The third layout concept is shown in Figure 12.

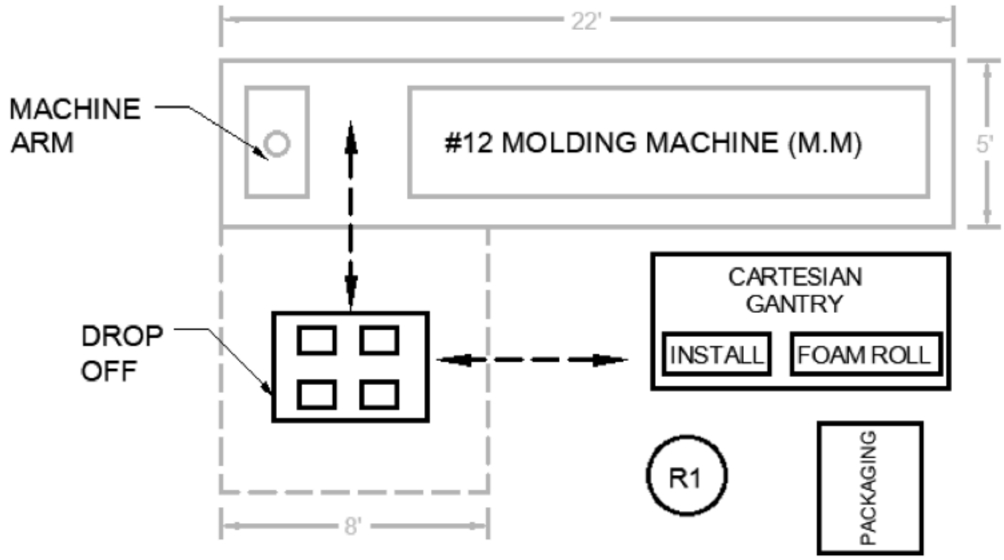


Figure 12: Cartesian gantry Layout

When the plastic parts are dropped off from the existing machine arm, they are placed onto a linear shuttle system with a plate that has four jigs for the insert bases. Once the parts are on the jigs, the shuttle brings them over to the foam install station where a pick and place gantry style machine picks up foam from the roll and install on the insert bases. Once the foam has been installed, a robot (shown as R1) removes the completed parts and place them in the final packaging box. For this layout, a camera inspection system could be installed overhead at the foam install station or it could be implemented into the robot end effector. Comparing to the one-robot concept, this concept requires extra main components, and increases the complexity and costs of the system.

**Concept D: Central Rotor Layout**

The final layout concept is shown in Figure 13.

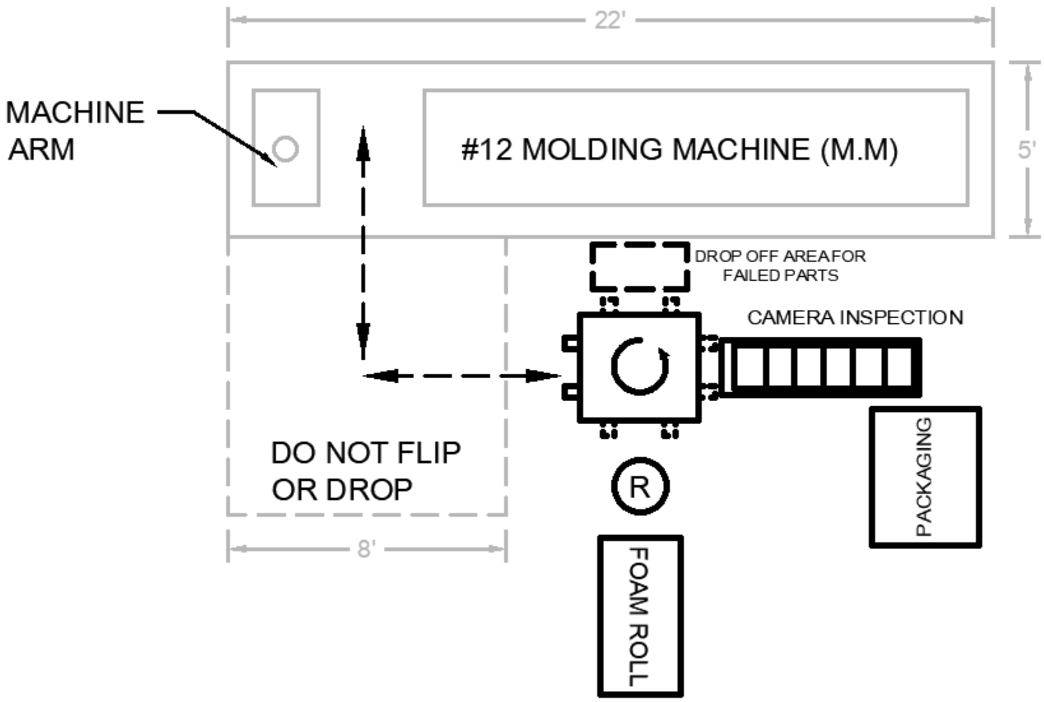


Figure 13: Central rotor layout

When the machine arm picks up the plastic parts form the injection molding machine, instead of dropping off the parts, the arm transports the parts forward directly to the central rotary carrier where the two extended jigs would pick up and hold the parts. Then the rotary carrier rotates 90° while keeping holding the plastic parts vertically. The robot is used to pick up and expand the foam gasket, and install the foam onto the vertical parts on the other side. After the foam installation, the rotary carrier rotates another 90° and lets the camera above the roller conveyor perform the inspection of the finished parts. The parts are dropped on the roller conveyor through a chute delivery system once the inspection is finished, and get manually packaged at the end packaging area. The failed parts are dropped off by rotating the rotary carrier for the last 90° if they did not pass the inspection.

For this concept, there are multiple existing technologies to function as the rotary carrier shown in the layout. Also, it is technologically feasible to use a simple mechanical system to pick up and install the foam gasket (shown as R) rather than use a CNC machine arm, which could reduce the overall cost. It should be noted that the operation involvement still exists since operators are needed for the manual packaging step. Another alternative for the packaging is to use a 6-axis robot arm to remove the finished parts and finish the packaging process instead of using roller conveyors and have manual packing.

### 2.1.2 Sub Concepts for Each Process

The work flow was divided into three processes: Part pick up including orientation adjustment and delivery, part preparation for the foam installation, and foam gasket removal and installation. In total, 15 initial concepts were generated. The concepts for different processes were denoted with concept number E-1 to E-5, F-1 to F-4, and G-1 to G-6, respectively. These initial concepts are shown in Appendix C.

## 2.2 Concept Evaluation and Client Input

The initial concepts underwent a rigorous analysis process to select the best design, which included a preliminary screening and a sensitivity analysis. The detailed process is shown in Appendix D. Based on the analysis process, concept C, the Cartesian Gantry Layout was selected by the team.

A group meeting with the client was conducted to review and analyze the selected concept. The recommendations from the client are shown in Table V.

TABLE V: CLIENT INPUT

| Client Recommendations | Concepts Affected |
|---|---|
| Robotic are expensive and have high maintenance costs. | A, B, D |
| Design should install at least two gaskets at a time in order to meet the required cycle time and throughput. | All |
| Only one operator who works half-time (4 hours per day) should be used on occasion for changing the roll or moving the packaged boxes. | All |
| Design should minimize the distance between the newly injected molded insert bases and the gasket installation process. | All |
| Consider using a shuttle system instead of a robotic arm to move the parts from the drop spot area to the gasket installation area. | A, D |
| Horizontal rotary table can be used instead of a vertical one to simplify the complexities of clamping the insert bases vertically. | D |

With the input as shown in Table V, the team decided to move forward with concepts C and D. Both the client and the team believed that these two layouts would be the most realistic and feasible designs.

## 2.3 Concept Development

After deciding to explore Layout Concept C and D, details of these layouts were developed in the following section.

**Concept C: Cartesian Gantry Layout**

The Cartesian gantry layout concept uses a linear shuttle system to transport the parts from the initial drop-off station to the foam installation station. There are a variety of linear actuator options that could be used for this application which include belt driven, air powered cylinder, lead screw, linear steppers. For a low cost and easily accessible option, a belt driven or lead screw actuator for the shuttle system are the most likely choice, which are shown in Figure 14.


Figure 14: Belt-driven and lead screw driven actuator [3]

A lead screw actuator is capable of handling larger loads at slower speeds and becomes more expensive as the travelling distances become longer [3]. For this application, a shuttle system that transports the lightweight parts roughly 500-1000mm at higher speeds, a belt driven actuator is the ideal choice due to its lower cost.

The shuttle system has a plate attached to the belt driven linear actuator with 4 jigs that sit on top of the plate. Using Concepts F-2 and F-4, these jigs would have locating fixtures at the outside corners or along the perimeter of the inside edge to accommodate for the different insert base heights as shown in Figure 15.

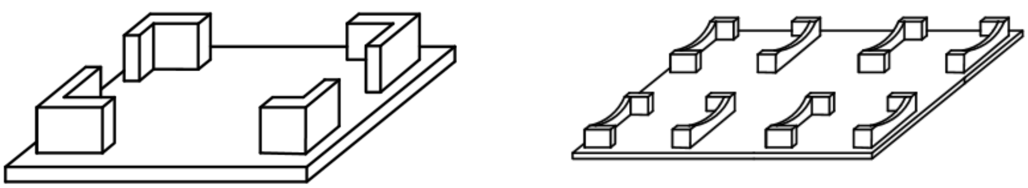

Figure 15: Shuttle system jigs at corners and perimeter edge

Once the parts are shuttled to the foam installation station, a few options are available for foam installation. The first option is to have a Form-In-Place-Foam-Gasket (FIPFG) system, which uses an automated machine to extrude foam directly onto the surface that requires a gasket, as shown in Figure 16.


Figure 16: FIPFG system [4]

While a FIPFG system would simplify the installation process of the foam gaskets, the system would be costly and complex to implement and maintain. These systems are generally more effective for complex-shaped objects that make gasket installation timely and difficult [5].

Another possibility is a 3-axis pick-and-place machine to remove four foam gaskets from the roll, spread them and place them on the waiting insert bases. Concept H-1 and H-2 would be ideal for this application. A needle or thin cylindrical shaped end effector with a slight hook at the end would allow for insertion in the middle of the gasket and lifting before spreading into the final rectangular shape. This robot needs four end effectors that can pick up one gasket each and install them on the insert bases sitting in a 2 by 2 orientation as they arrive from the injection molding machine. This means the robot picks up one foam gasket, moves over horizontally and picks up another gasket with the next gripper, and then move vertically to repeat the process for two more gaskets. The spreading needles would be protruding from the bottom side of a plate so that when the gasket is spread and placed on the insert base, it would have complete pressure application throughout the gasket. This spreading needle concept could be achieved by using air cylinders to extend and retract the needles. Alternatively, the motor could utilize a cam design with spring loaded needles to spread and retract.

The pick-and-place robot that has this needle-style end effector needs to be a 3-axis machine that accommodates motion in the x-y-z directions. For repeatability and easier motion control, two options could be implemented: a gantry or a Cartesian robot system. A Cartesian robot would take up less workspace in the work cell and cost less having fewer components [6], and is shown in Figure 17.

Image not available due to copyright infringement

Figure 17: 3-axis cartesian robot [6]

However, the Cartesian robot is limited by its reach range and orientation. As shown in Figure 17, the Cartesian robot overhangs from the base has a limited reach in the vertical axis. With a large gripper design used to install 4 foam gaskets at once in a 2x2 orientation, a Cartesian system would need to extend a substantial amount to avoid interference, which would be costly.

To solve the problem of a limited reach, Figure 18 illustrates the structure of a gantry styled robot and the ability to have a larger, customized gripper.

Image not available due to copyright infringement

Figure 18: Gantry robots [7] [8]

In this scenario, a gantry robot is a better choice to accommodate a large gripper as the end-effector can hang down without interfering [9].

Another component to source for this layout concept is the system that removes the completed parts from the shuttle after foam has been installed and into the packaging station. A 6-axis robotic arm with a gripper that could pick up all four completed parts would be an effective solution. Some potential options include Fanuc, Motoman, and Kuka robots, which are shown in Figure 19.


Figure 19: 6-axis robotic arms [10] [11] [12]

This robotic arm would allow for the potential placing of cardboard sheets in an automated fashion while it waits to place more completed parts. The cardboard sheets are used between layers of completed insert bases in the packaging box for separation. The operator in this station would then only need to be responsible for removing the box once it was full and placing a new empty box in its place so the robot could continue its process.

**Concept D: Central Rotary Layout**

The central rotary concept uses a rotary rotor as a main component to pick up and transport the parts from the initial drop-off stage to the final inspection stage. There are several industrial applications that could be used for this function including a rotary indexing table transfer machine and a computer numerical controlled (CNC) work-holding tombstone.

A rotary indexing table transfer machine has the ability to provide accurate rotary motion and have a wide range of applications in the automation equipment, medical device, machine tool, energy, welding, robotics, automotive, aerospace, semiconductor, and heavy equipment industries, as well as many others [13].

In a rotary transfer system, the workpieces can be held firmly in fixtures on a continuous rotating table, which can bring the workpieces to different stations. During each revolution, the table can stop for a pre-programmed period of time such that an operation can be performed at each station. The rotary indexing table usually utilizes a rack and gear mechanism to convert linear motion to rotary motion of the table [14]. The workpiece arrangement and an isometric view of a rotary indexing table is shown in Figure 20.


Figure 20: Workpiece arrangement of a rotary indexing table [15]

As is shown in the figure above, indexing tables normally consist of a circular steel plate, one or multiple spindles, a drive system, and pins/stations. Using concepts F-1 or F-2, the designed jigs can be assembled to the stations to hold the workpieces in place during rotation. A typical indexing table carries 6 to 8 stations around it, and can be as high as 16. The table size and number of stations can be adjusted based on workpiece size [14] [15]. By using delivery concepts E-1 or E-2, the newly molded plastic parts can be transported and fall onto the jigs on the indexing table. The indexing table can then rotate and bring the parts for the foam installation and final inspection.

Using a rotary indexing table can save space and also permits the workpieces to be stayed at a single location without having to interrupt the entire work flow. It is a commonly used industrial method for automatic assembly of a product, which suits for our project problem [14].

Another industrial application can be used in the Central Rotary Layout is a CNC tombstone fixture.

A tombstone is a work-holding machine to secure the work-piece in place, and it is widely applied to autonomous manufacturing. A tombstone can meet the strict tolerance requirements for flatness, parallelism, perpendicularity, surface finish, and cavity (hole) location [16]. A general view of the tombstone is shown in Figure 21.


Figure 21: Tombstone fixture [17]

As is shown, a set of cavities/holes can be placed at the surface of tombstone to assemble the different types of gripper or holder design. The accurate position and size of the hole can be designed according to specific project requirements. Manufacturers can also directly embed the gripper into the tombstone design such that it is a one-piece product. It should be noted that the embedded gripper can be retractable based on the customized design to simplify the process of picking up and releasing the workpieces.

Unlike the indexing table, it is possible for a tombstone directly pick up the plastic parts without a delivery system. When the existing machine arm holds the newly molded parts and lowers to the same level, the gripper/holder embedded in a tombstone could then extend and hold the parts. A simple sketch to illustrate this operation is shown Figure 22. As long as a rotating unit is assembled to the tombstone, tombstone is able to pick up the plastic parts and rotate for other operations.

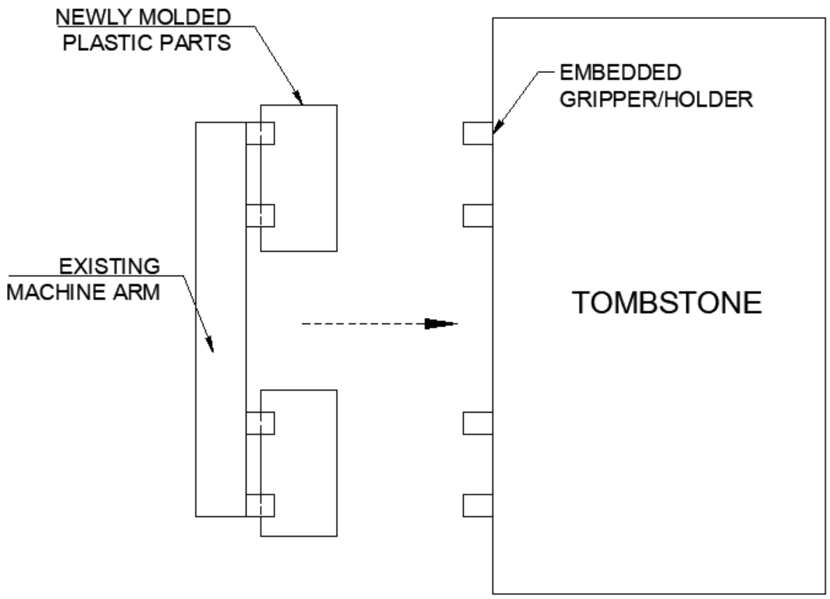


Figure 22: Tombstone picks up the parts through retractable gripper

Another advantage of the tombstone fixture over an indexing table is the ability to hold four plastic parts at the same time. With the appropriate gripper/holder design, a tombstone fixture can install all four foam gaskets onto the plastic parts at the same time. Due to the circular geometry of the rotating indexing table, working with more than two plastic parts at the same time would be technically challenging.

# 3.0 Detailed Design

After the conceptual design phase, the team decided to perform a feasibility study on different gripper designs for picking and placing the foam gaskets. However, after a discussion with the client, the team was recommended to switch this focus, as the gripper design was proving to be a difficult task that may not have been completed in the given timeline. Thus, the team decided to source a customized needle gripper from an end effector supplier, and change the focus on performing a feasibility study on the two primary layout designs. This section provides more detail of these layouts so that a thorough study could be performed.

## 3.1 Option 1 - Cartesian Gantry Layout

A recommendation that the client provided was to add an additional shuttle to ensure that the specified cycle time is satisfied. A schematic of the updated layout is shown in Figure 23.

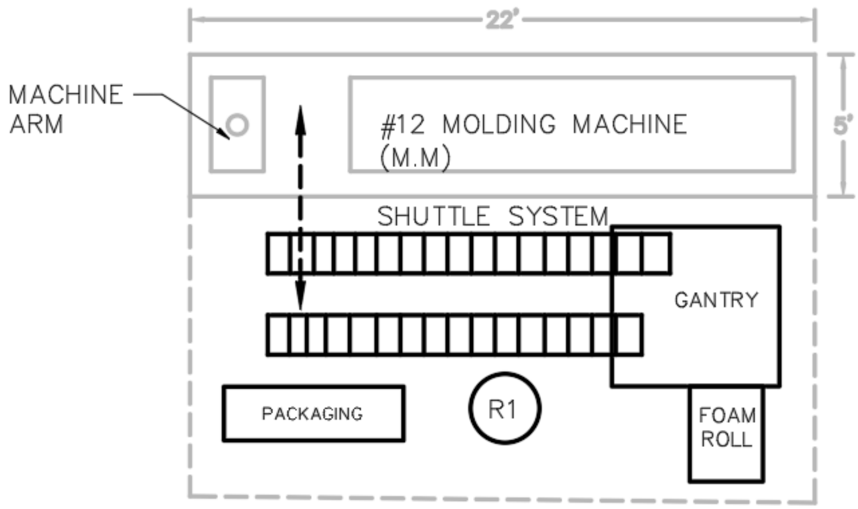


Figure 23: Gantry layout schematic

As seen in Figure 23, the updated gantry layout now consists of two shuttles from the drop off point that transport the insert bases to the gantry system so that the foam gaskets could be installed. The finished products then transport to the pick-up point, where a 6-axis robotic arm can be used to pick and package the finished parts.

### 3.1.1 Shuttle System

The shuttle system consists of two shuttles in which each shuttle utilizes a linear belt driven actuator to transport a jig table. The jig tables are able to hold insert bases from the pickup point to the gasket installation and packaging stations. The Macron MSA-14S actuator is capable of providing the necessary speed and accuracy to transport the insert bases to the required locations. The MSA-14S actuator is shown in Figure 24.


Figure 24: Macron MSA-14S actuator [18]

The MSA-14S actuator has a shaft that extrudes out of one end. This shaft is attached to a gearbox and a motor that powers the actuator. The MSA-R14S actuator has a maximum speed of 10,160 mm/s, and is able to support a load up to 200 lbs [18].

The shuttle system uses two MSA-14S actuators that have travel distances of 3750 mm and 3500 mm respectively. The shuttle system assembly is shown in Figure 25.

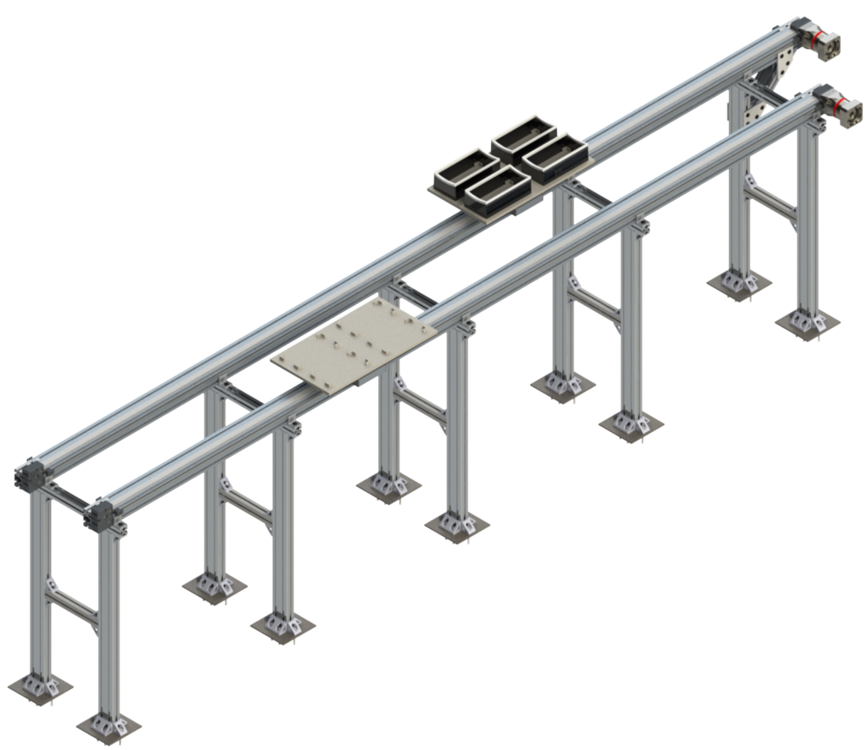

Figure 25: Shuttle system assembly

The difference in travel distances of each actuator is to accommodate for the space that each attached gearbox and motor takes up. Gearbox that attached to each actuator is the Macron MPG-084 inline gearbox, which provides a 3:1 gear ratio to the actuator. The gearboxes will attach at the right end and right side of each actuator as shown in Figure 26.

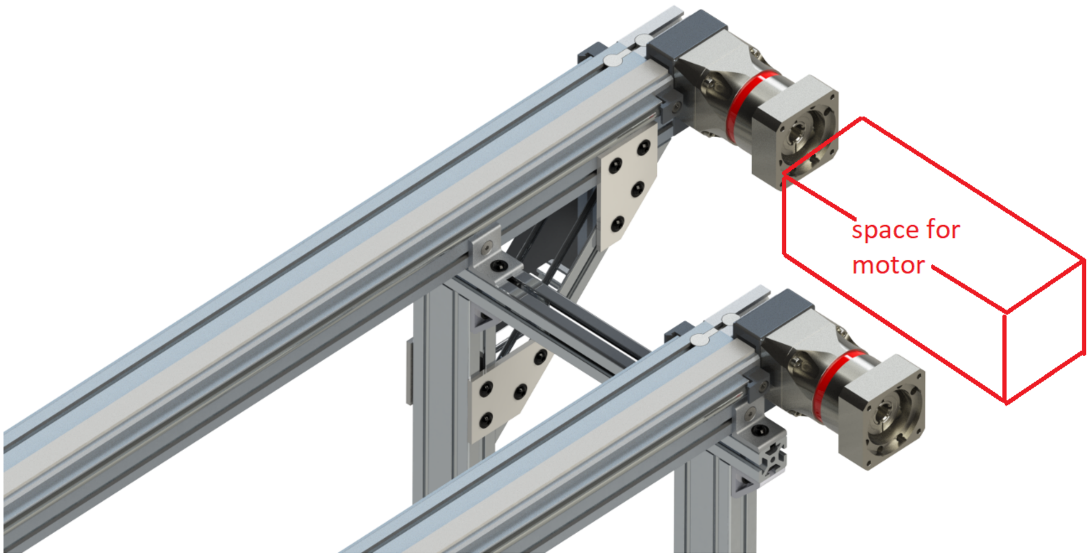


Figure 26: Location of MPG-084 gearboxes

As shown in Figure 26, a 45-degree aluminum extrusion is used to support the gearbox and motor on the longer actuator. As for the motors attached to the gearboxes, the selection of the motors will be at the discretion of the client. However, as for the purposes of the cost estimate in the later stage, the selected motor is the same model as the one used in the gantry system, which will be discussed later.

Furthermore, a customized jig table is attached to the carrier of each actuator. This table is used for mounting the insert bases as shown in Figure 27.

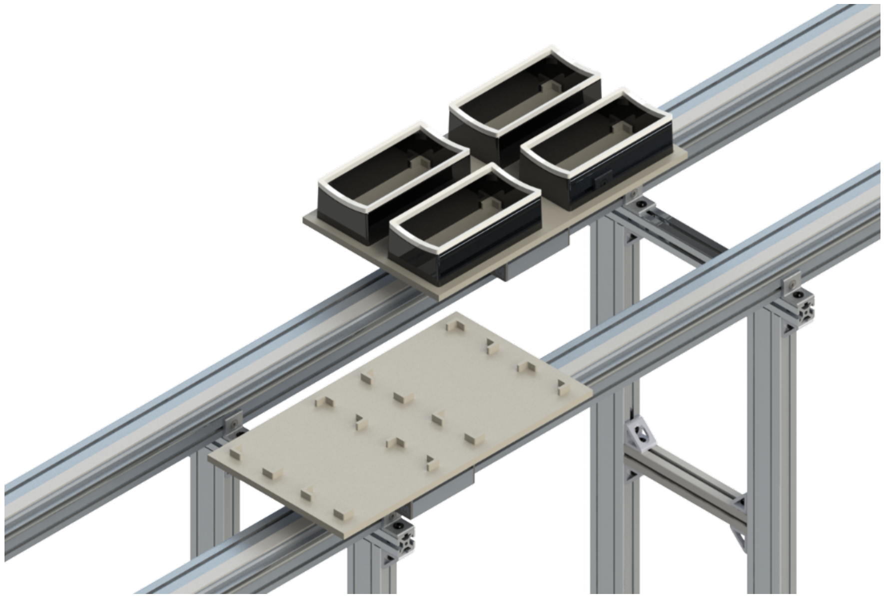

Figure 27: Tables for mounting the insert bases

Each jig table has sixteen extrusions. Each set of four extrusions is used to mount one insert base in place so that the insert bases are secured during transportation and gasket installation.

To ensure that the two actuators are secured at the appropriate working height, five equally spaced supports are located along the 3500 mm actuator as previously shown in Figure 25. These supports consist of a combination of aluminum extrusions, mounting brackets, and T-slotted fasteners. The top section of each support is attached to each actuator, as shown in Figure 28.

Figure 28: Top section of each support of the shuttle system

The top section of each support consists of a horizontal single rail 6360 aluminum extrusion that is attached to two vertical double rail 6360 aluminum extrusions through the use of mounting and gusset brackets.

The middle and bottom sections of each support are shown in Figure 29.

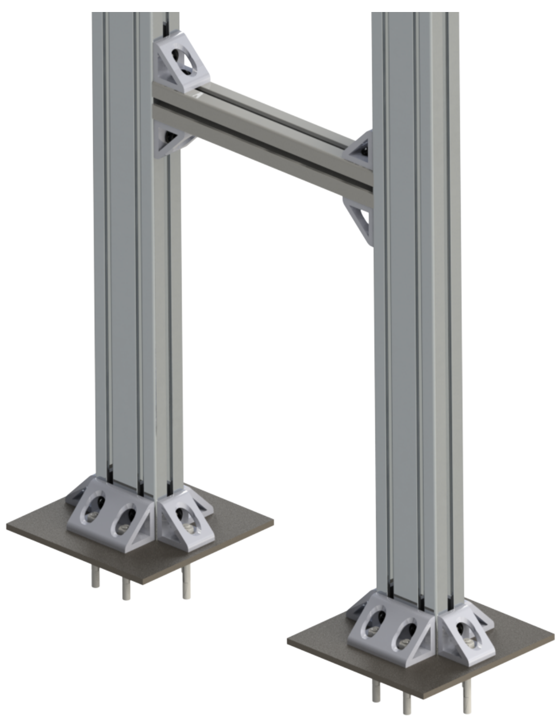

Figure 29: Middle and bottom sections of each support of the shuttle system

The middle section of the support consists of a horizontal single rail 6360 aluminum extrusion that is attached in-between the two vertical extrusions through the use of gusset brackets. Each bottom section of the support consists of mounting plate that is attached to the end of each vertical extrusion through the use of gusset brackets. Concrete anchor bolts are used to fasten the mounting plates to the floor.

Furthermore, in order to make the shuttle system collaborate with the gantry system and six-axis robot, each shuttle utilizes three sensors that detects each table's respective location on the shuttle. The locations of the sensors on each shuttle is shown in Figure 30.

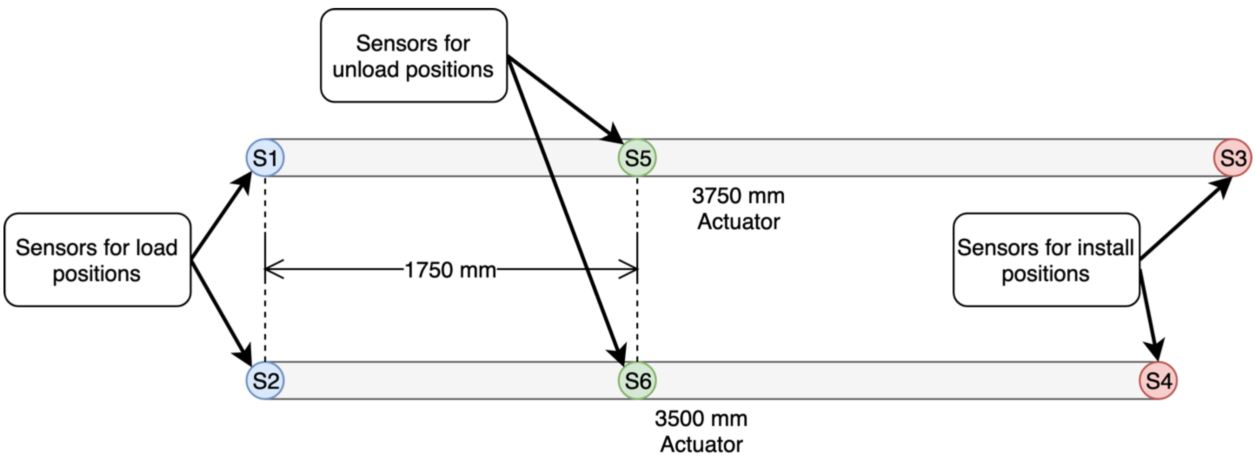


Figure 30: Location of sensors on shuttle system

As shown in Figure 30, there are three distinct sections where the sensors are located along the shuttle system. As shown in the blue circles, S1 and S2 detect the locations of the load positions in which the insert bases are loaded onto the jig tables of the shuttle system. As shown in the red circles, S3 and S4 detect the locations of the installation positions in which the gantry system installs the foam gaskets onto the insert bases. Lastly, as shown in the green circles, S5 and S6 detect the locations of the unload positions in which the finished insert bases with the installed gaskets get unloaded from the shuttle system by a six-axis robot.

### 3.1.2 Gantry System

Once the parts have been transported by the alternating shuttle system, a 3-axis overhead gantry robot is utilized to pick the foam gaskets from the roll and install them onto the waiting parts. The gantry robot allows for an overhead control of the custom end-effector that is able to pick-and-place the gaskets, while maintaining the required linear X-Y axis motions. The insert base parts come from the injection molding machine from the robotic arm with the orientation shown in Figure 31.

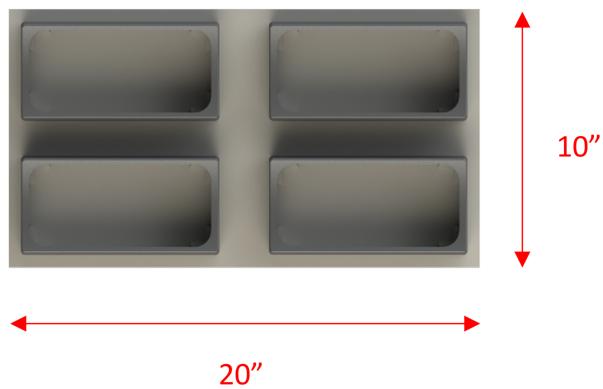


Figure 31: Insert base orientation dimension

In order for the custom gripper to pick up 4 foam gaskets from the stationary roll, the gantry needs to be able to move one insert base width and length beyond the dimensions shown in Figure 31 while staying overtop of the foam. Furthermore, because of the two shuttle tracks, the space requirement in the y-axis will be doubled on top of what is needed for the foam roll without interference. The required range of motion of the gripper is illustrated by the red rectangles in Figure 32.

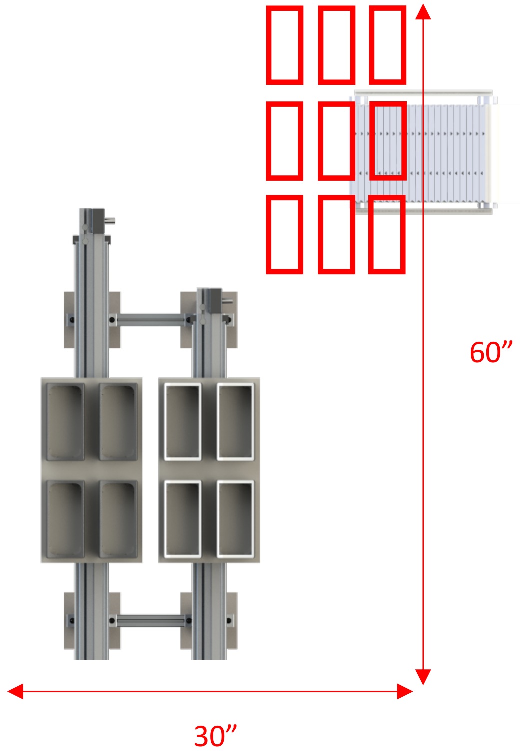


Figure 32: Overall dimension of the gantry system

As seen in the schematic above, in order to install the gaskets, the gantry needs roughly a range of 1500mm in the x-axis, 1000mm in the y-axis, and motion in the z-axis to actuate and press foam firmly on insert base. Macron Dynamics Inc. has a X/Y/Z Heavy Duty Cartesian Gantry system that allows for customized ranges of motions with a minimum range of 150mm in the z-axis [19]. The MCS-UC1 model shown in Figure 33 is capable of supporting 75lbs (34kg) and can access the specified x and y ranges of motions. It also has T-slot sensors that fit in the extrusions to determine the home position during calibration.

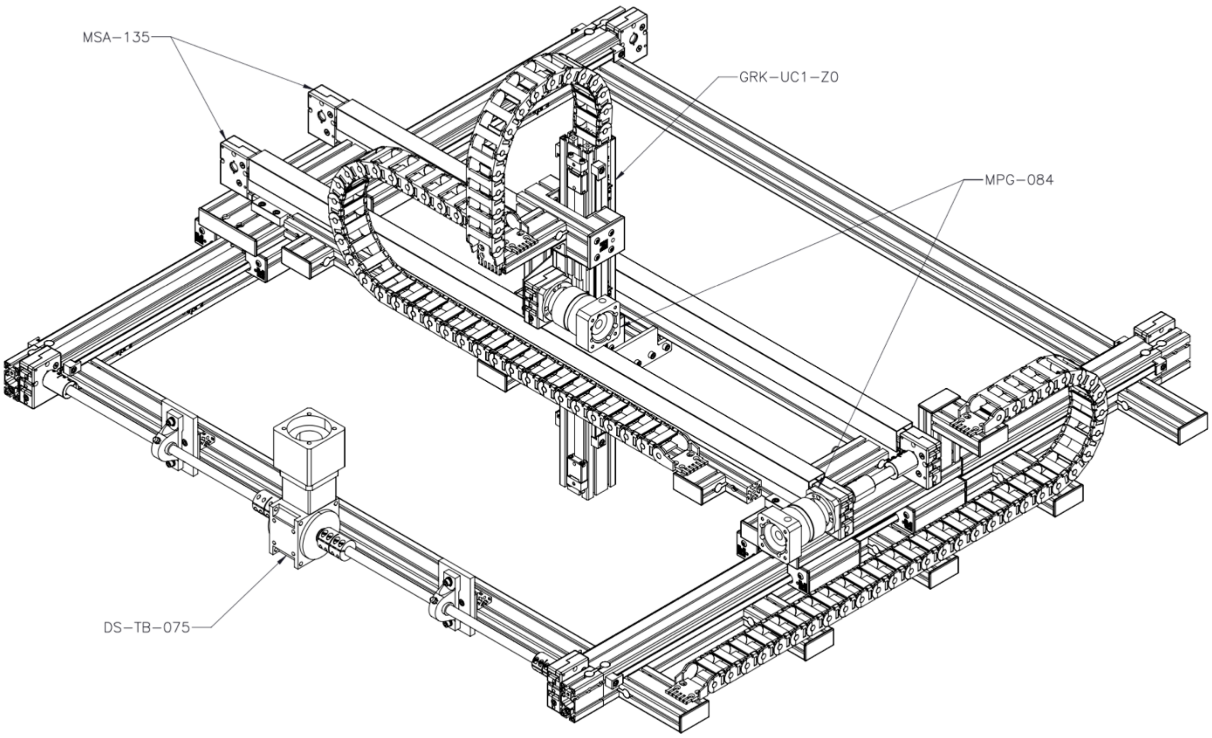


Figure 33: MCS-UC1 gantry system [19]

The system uses planetary gearboxes with a 5:1 ratio that can produce a nominal output torque and input speed of 50Nm and 3000rpm, respectively to move the belt drives. These three gearboxes have customizable mounting plates depending on the size and type of the motor used with a maximum input shaft diameter of 19 mm. For the given end effector weighing roughly 20kg, a brushless DC motors with Hall Effect sensors will work to control the x, y, and z axis motions. The low speed and high accuracy requirement of the foam installation process in the gantry system makes a brushless DC motor a suitable choice. The ATO-80WD-M02430-24V motor from ATO has 7.5Nm of torque and can operate at up to 3600rpm. Three ATOTH-G motor controllers from ATO, will also be sourced to control the DC motors.

The system will be mounted on vertical aluminum extrusions to elevate it at the proper height. This height allows for proper interfacing with the shuttle system as it takes parts from the injection moulding machine arm at a certain height. The overall gantry assembly is shown in Figure 34 with lower cross-members to support the system.

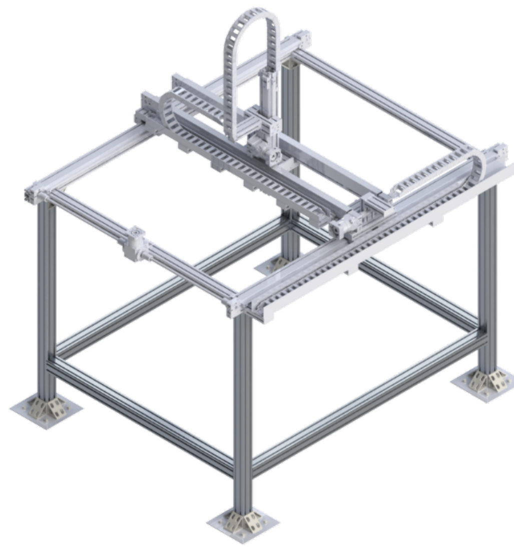

Figure 34: Gantry assembly

The corners will be mounted by two t-slot gusset brackets from McMaster-Carr as shown in Figure 35.

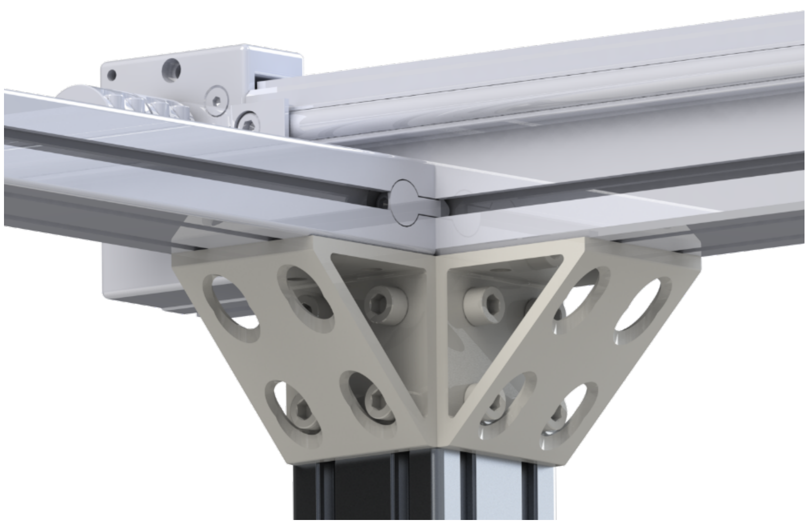

Figure 35: Upper gantry support brackets

The vertical 8080 aluminum extrusions are supported by 4 gusset brackets on each side of the extrusion and mounted onto a steel plate that rests on the floor. Four steel stud anchor bolts for concrete are then used to secure the plate and the supporting vertical members as shown in Figure 36.

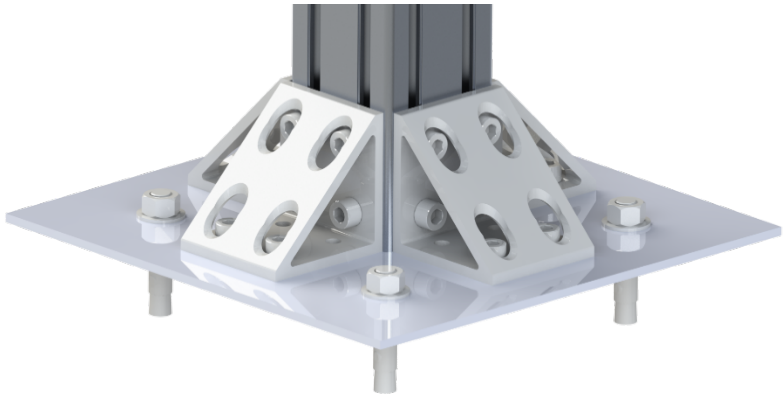

Figure 36: Gantry floor mounting assembly

The current foam roll dispensing system will be utilized in the Gantry Layout system. This includes the proximity sensor and motored conveyor that detects if a part has been picked and feeds the roll one gasket width forward so that the next gasket is ready to be picked. The foam roll support structures shown in Figure 37 are for visualizing the location of the roll and integration into the full assembly.

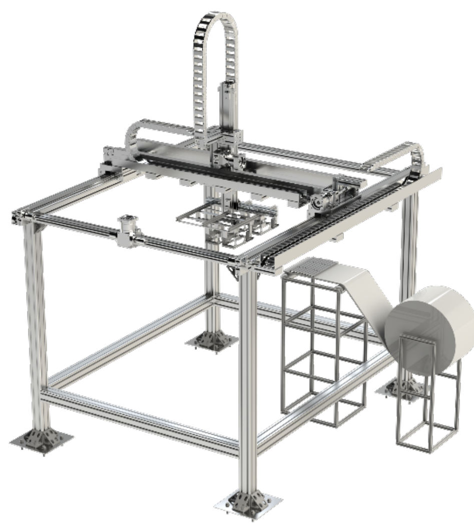

Figure 37: Foam roll support reorientation

The flatten conveyor section of the current foam roll system will be underneath the gantry robot while the actual roll will be outside the footprint of the gantry. This allows for safe changing of the foam roll without having an operator enter into the gantry robot's work envelope.

### 3.1.3 Needle Gripper

As mentioned, the gripper was no longer the main focus of the final design, but details are provided for understanding of the concept and so that a specialty product could be sourced from a supplier. The exact details of the custom end effector including a manufacturing plan and technical drawings are not outlined in this report as it would be futile without dimensions of the needle grippers. It was agreed with the client that the design team efforts were better spent focusing on the layout details of the system.

Various options were explored for removing foam from the supplier roll, expanding the gasket and then pressing it onto the insert base. With individual research and client input based on what was used in the previous automated process, needle grippers seemed to be the most effective solution. Figure 38 illustrates standard needle grippers with a cross-penetrating profile.

Image not available due to copyright infringement

Figure 38: FIPA needle grippers [20]

The off-the-shelf product from most suppliers was too large for the restricted area of the foam gasket, but a custom smaller product would be obtainable at roughly 1.5 times the cost of the standard needle gripper.

In order to achieve the fast cycle time required for the production of the insert base parts, an end effector in the gantry system with a 2x2 orientation was utilized so that 4 foam gaskets could be picked from the roll in order and installed simultaneously. Figure 39 shows details of the full end effector assembly including placeholder needle grippers.

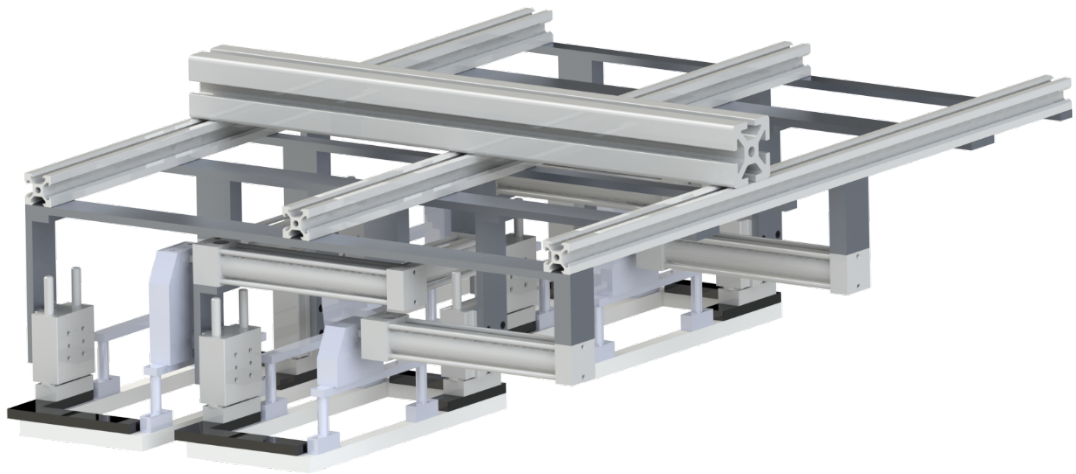

Figure 39: Complete end effector assembly

Starting the foam picking process, the full assembly seen in Figure 39 has components hidden for clarity. Two needle grippers would engage in the foam along one of the long edges of the gasket, while two other grippers would engage on the other long edge as shown in Figure 40.

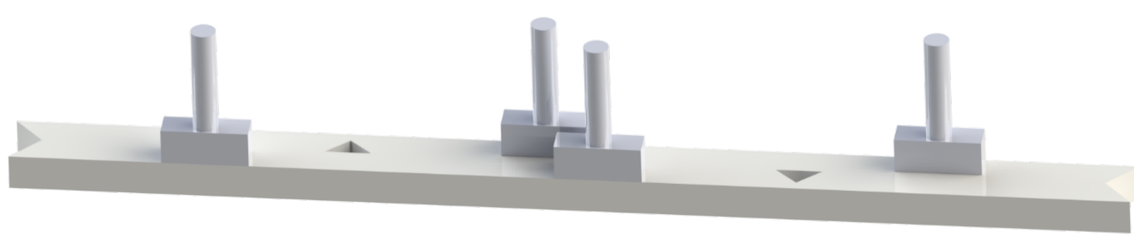

Figure 40: Unexpanded gasket initial gripping

This assembly would be attached to the gantry end-effector and lift up, removing the part from the roll. Once the gasket had been removed, the gantry would shift its end effector in such a way that the next set of needle grippers could repeat this process another 3 times on the next foam gaskets on the roll. With all 4 assemblies holding a gasket, two of the needle grippers would move vertically and the other two would move horizontally with the help of linear actuators, expanding foam to the desired rectangular shape as shown in Figure 41.

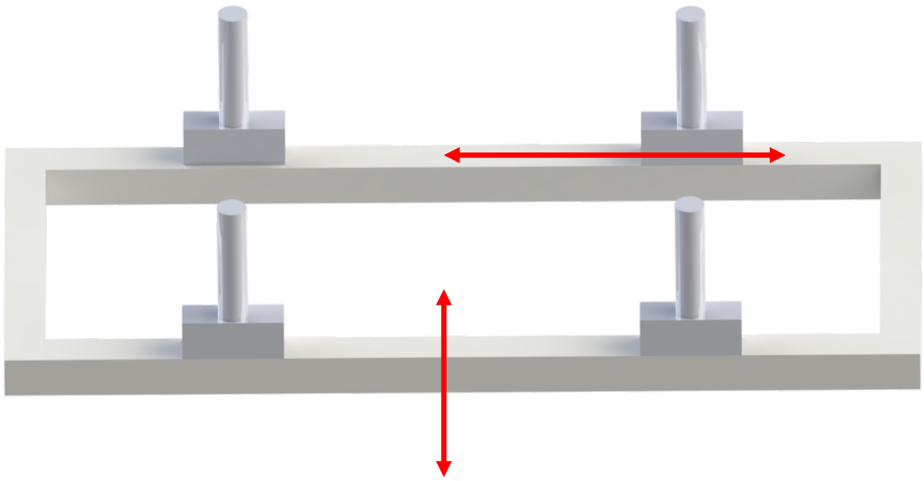

Figure 41: Expanded gasket

Figure 42 also illustrates these gasket expansion motions with the rest of the assembly visible.

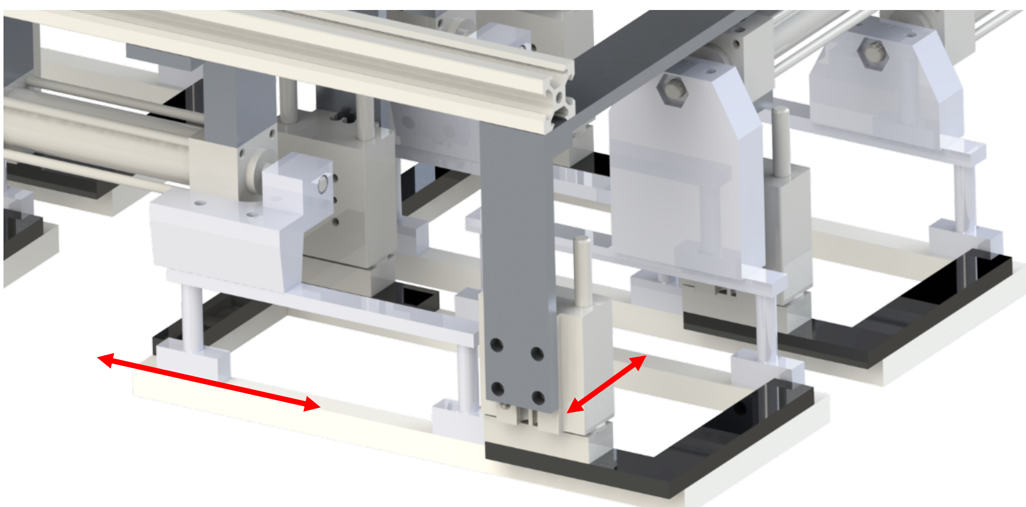

Figure 42: Gasket expansion assembly view

The gantry system would then move the expanded gaskets over to the insert base parts waiting on the shuttle system, where a motion in the z-axis would press them on for final installation. Thrusters with a plastic attachment matching the face of the insert base would then engage vertically downwards for 2 seconds to ensure the foam gasket has proper adhesion to the insert base as shown in Figure 43.

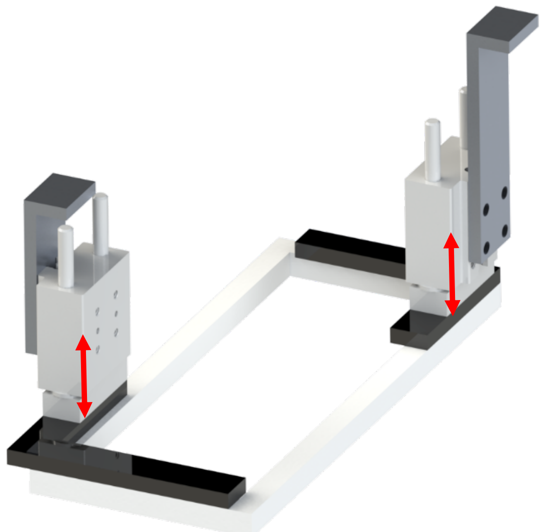

Figure 43: Foam press operation

After installation, the needle grippers would retract their needles and the gantry would retract, allowing for the process to repeat on the next set of insert base parts arriving on the other shuttle track. The end effector assembly is supported by aluminum extrusions for simple mounting to the z-axis of the MCS-UC1 gantry system. A gusset bracket will be used to mount the assembly as shown in Figure 44.

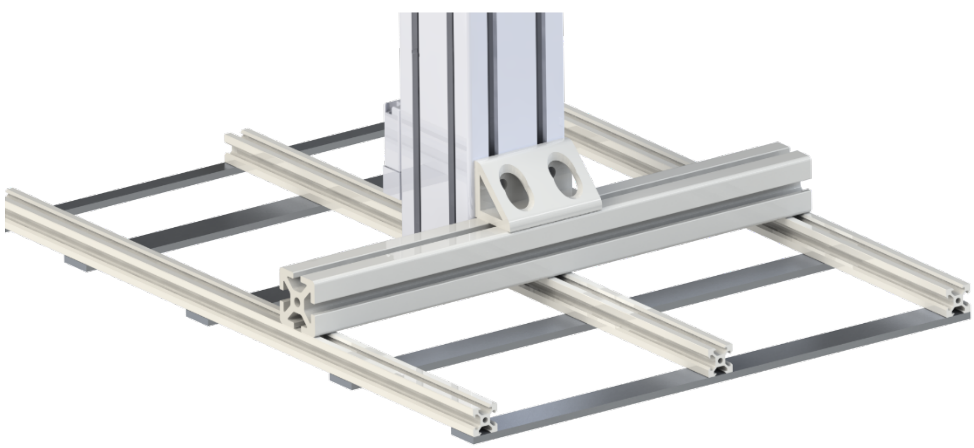

Figure 44: End effector mounting system

With an approximate weight of 20 kg (subject to change depending on the specialty needle gripper), the end effector is under the 34kg maximum weight capable of being supported by the MCS-UC1 gantry system.

### 3.1.4 Six-Axis Robot

Once the foam gaskets have been installed onto the insert bases, the shuttle system will transport the tables to the unload positions. A six-axis robot will be used to pick the insert bases from the tables and package them in a box. The Kuka KR 8 R1620 has the necessary reach and rotational speed to pick and package the insert bases in a timely manner. The KR 8 R1620 robotic arm is shown in Figure 45.

Image not available due to copyright infringement

Figure 45: Kuka KR 8 R1620 [21]

The KR 8 R1620 in Figure 45 is rated for a payload of 8 kg, has maximum reach of 1620 mm, and rotates at a minimum speed of 210 degrees per second [21]. Attached at the end of the Kuka robot is the OnRobot dual quick changer as shown in Figure 46.

Figure 46: OnRobot dual quick changer [22]

The OnRobot dual quick changer increases productivity by enabling the use of two end-of-arm tools together in a single cycle [22]. One of the end-of-arm tools that is attached to the dual quick changer is the OnRobot RG6 gripper, which is shown in Figure 47.

Figure 47: OnRobot RG6 gripper [23]

The RG6 gripper is rated for a payload of 6kg and will be used to pick the insert bases from the tables and place them in the packaging boxes [23]. The second end-arm-tool attached to the dual quick changer is the OnRobot VG10 electric vacuum gripper, which is shown in Figure 48.


Figure 48: OnRobot VG10 electric vacuum gripper [24]

The VG10 gripper is rated for a payload of 10 kg and will be used to pick and place the plastic separators in the packaging box, as well as move the boxes themselves [24]. The entire end effector of the robotic arm, which includes the RG6 gripper, VG10 gripper, and dual quick changer is shown in Figure 49.

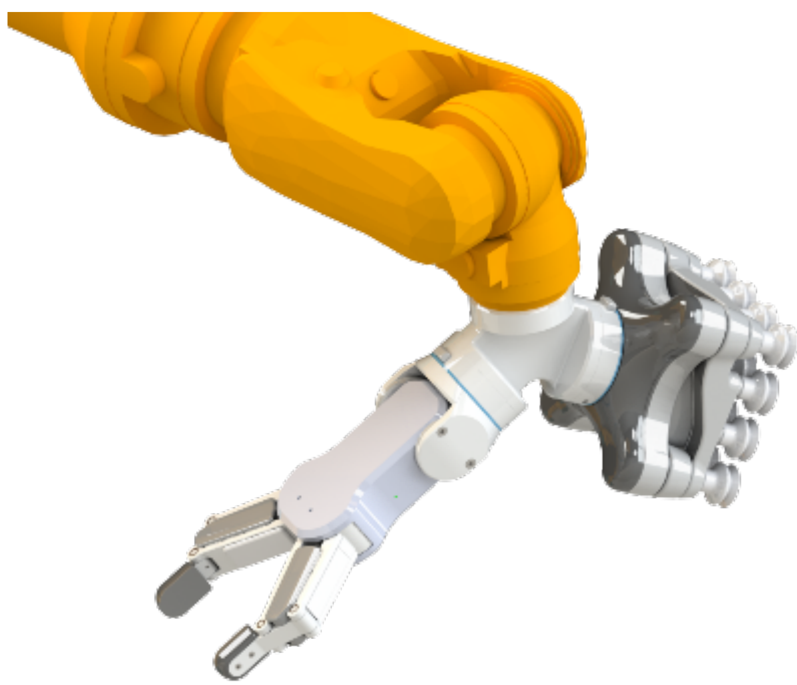

Figure 49: End effector of the robotic arm

Utilizing the two end-of-arm tools on the Kuka robot allows the robot to perform multiple tasks and eliminates the need for additional robots or tool changes.

### 3.1.5 Packaging

The packaging system consists of the current roller conveyors used for the packaging boxes, the six-axis Kuka robot, and a stand for the cardboard sheets that go in between the layers of finished parts. These components are shown in Figure 50.

Figure 50: Packaging system assembly

The Kuka robot will pick up the completed parts in the unloading station with the pinching end effector. The unloading station will be located halfway between loading and foam install on the shuttle system. Once picked up, the parts will be placed in the box located in position #1 shown in Figure 51.

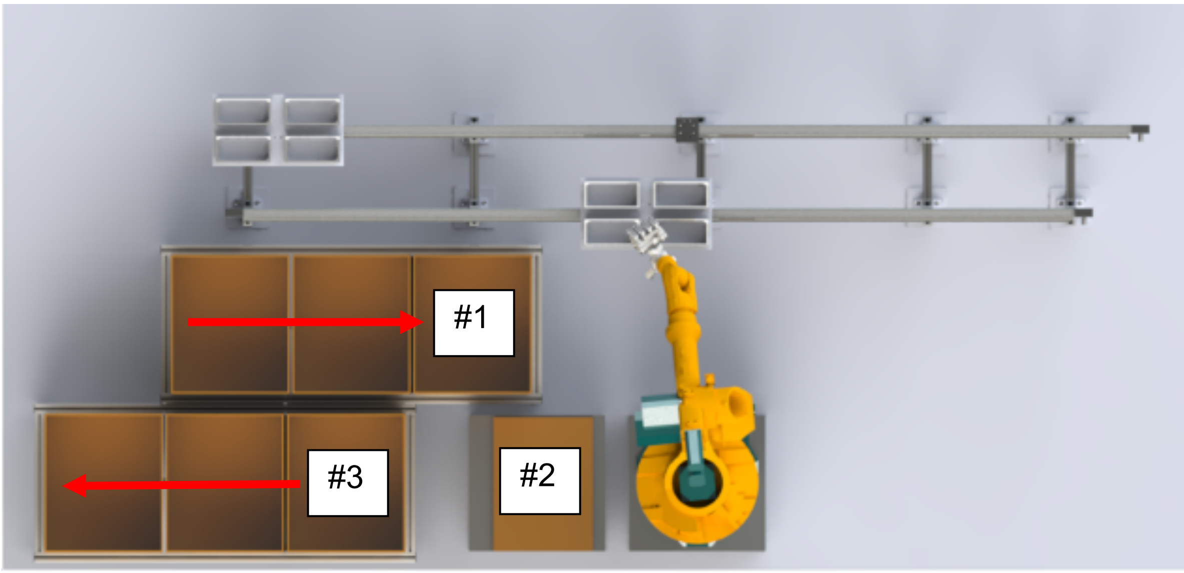


Figure 51: Packaging system top view

After the robot has filled the first layer of the box, it will rotate its end effector to use the suction gripper, pick up a sheet of cardboard from position #2 and place it in the box. The robot will continue this process until the box is full and then use its suction gripper to lift the box from position #1 to position #3. Gravity will feed the boxes into position #1 and away from position #3 as shown by the red arrows in Figure 51. This will require the operator to remove 3 full boxes every 15 minutes so the robot can continue to place full boxes in position #3. The robot will be programmed in such a way that it will incrementally descend when retrieving cardboard sheets from position #2 to account for the stack getting shorter after each retrieval. This process will be in a loop so that the operator can replenish the cardboard sheets every time they remove full boxes.

## 3.2 Option 2 - Central Rotor Layout

Based on the discussion with the client, an updated central rotor layout is shown in Figure 52.

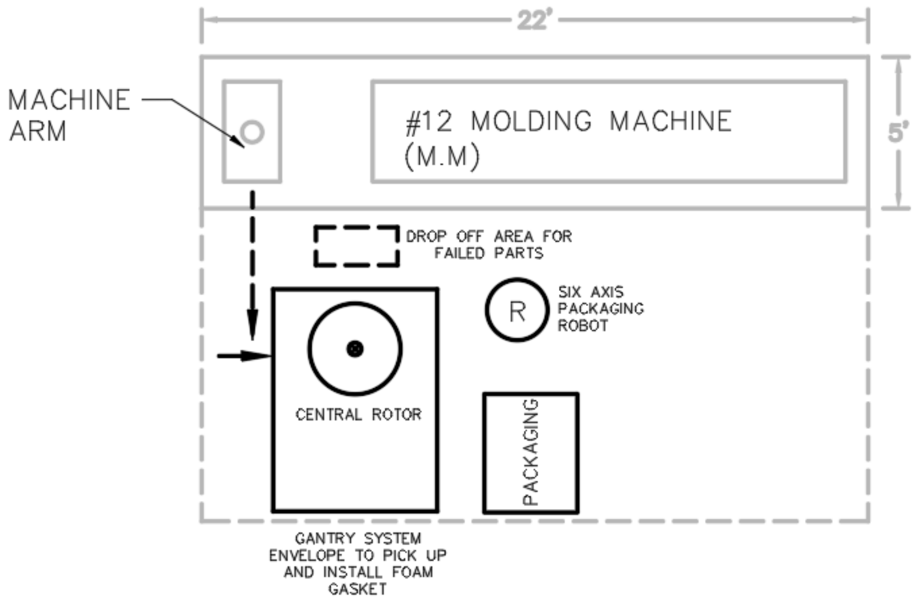


Figure 52: Updated central rotor layout

The central rotor moved closer to the original insert base drop off area to minimize the existing machine arm moving distance, which also leaves more space for the failure parts drop off area. This would require the removal and disassembly of the existing drop off station. The originally proposed roller conveyor system, a camera inspection system, and manual packaging was replaced by one six-axis robot, which is the same robot in the cartesian gantry layout discussed in section 3.1.4. Also, the originally proposed robot arm used to pick up and expand the foam gasket was replaced with the gantry system and needle grippers discussed in section 3.1.2. The purpose of replacing the robot arm with the gantry system is to reduce the cost and maximize the working efficiency since the gantry system with the end effectors is able to work with four foam gaskets at the same time.

### 3.2.1 Option 2A - Rotary Indexing Table

The first technical option of the central rotor layout is the rotary indexing table, which can ensure a smooth transition of the plastic parts and provide an accurate rotary motion. Since the number of stations can be customized based on the design requirements, two options of the rotary indexing table were specified in this section.

Through market screening and research, RDM series low profile roller dial indexing tables from Destaco Ltd. were selected due to its superior thrust and moment capacity and large output mounting surface that is supported by a 4-point contact bearing, as shown in Figure 53 [25].

Figure 53: RDM series rotary indexing table [25]

To minimize the footprint as well as the cost of the rotary table, a 4-station indexing table Model 601RDM4H24-330 MSC.33 can be specified to work with two parts at the same time. Two jigs that have the same dimension of the plastic parts would be installed at each station, as is shown in Figure 54.

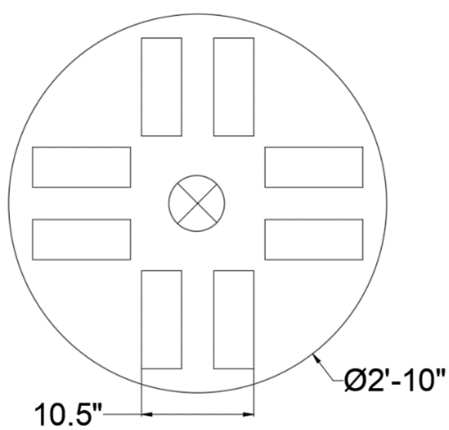


Figure 54: 4-station rotary indexing table

This indexing table has a short index time, i.e., the time used for one 90-degree rotation, of 1.769 seconds that can allow the plastic parts to quickly move through each working process. The motor stop time for each rotation was specified to be 5 seconds, which leaves enough operating time for foam installation or finished parts removal at each step. The total diameter of the indexing table can be minimized to 36 inches and help to reduce the footprint of the overall system.

However, due to the fact that the existing machine arm used to drop off the newly injection molded plastic parts can only work with four parts at the same time, i.e., the four end effectors installed on the machine arm are controlled by the same motor and do not have the ability to drop two of the four parts separately, it is preferable that indexing table can have 8 stations instead of 4 stations. The distance between the installed jigs is the same as the existing jig molds and is shown in Figure 55.

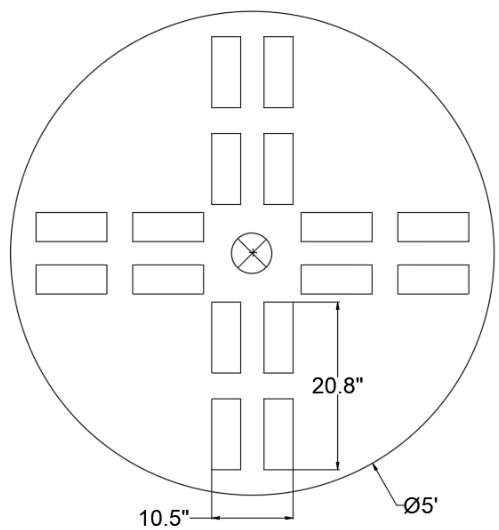


Figure 55: 8-station rotary indexing table

Since the end effectors installed on the existing machine arm have the same arrangement with the jig molds, the plastic parts can be directly dropped on the 8-station indexing table Model 902RDM4H32-330 MSC.33 without the issue of dropping two of the four parts at a time, and greatly improve the working efficiency. However, the trade-off of the high efficiency would be the large footprint and high cost, as the diameter of the 8-station indexing table would increase to 60 inches, and the cost of the large 8-station indexing table would be nearly twice of the 4-station table.

### 3.2.2 Gantry System for Rotary Indexing Table Layout

Once the plastic parts have been dropped on the rotary table, an overhead gantry system with the gripper installed at the end would be used to pick up and expand the foam gasket and further install them on the waiting parts on the rotary table. The working principle of the gantry system is the same as discussed in section 3.1.1, and to keep consistency, the MCS-UC1 Gantry system would be specified. To specify the working envelope dimension of the gantry system, a sketch for both 4-staion and 8-station rotary indexing tables are shown in Figure 56 and Figure 57.

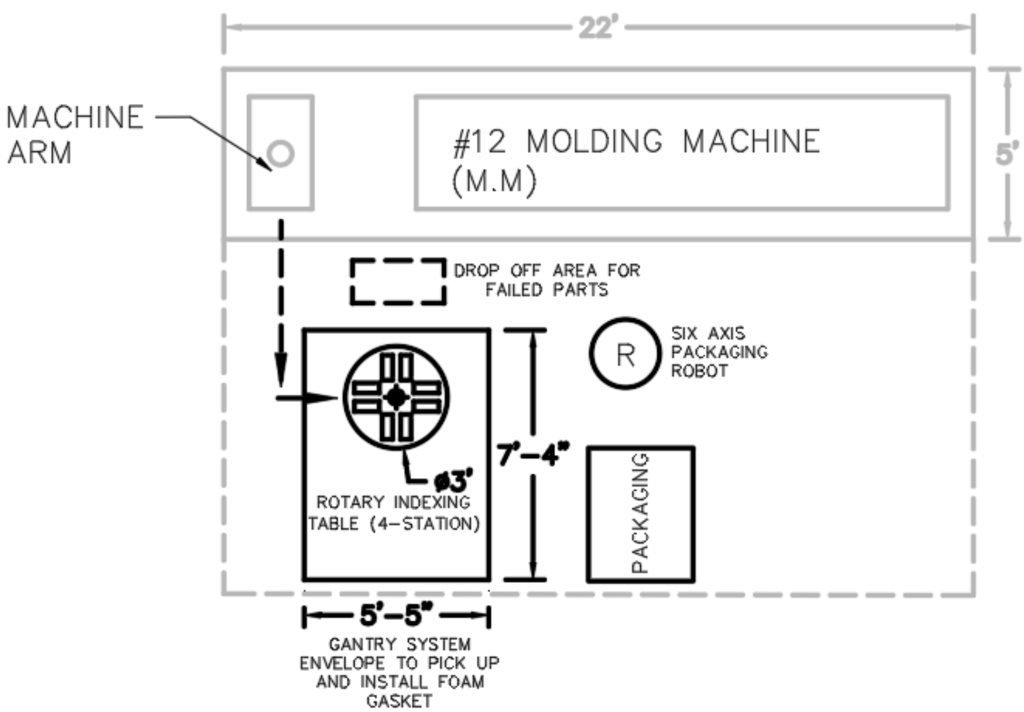


Figure 56: Overall layout for 4-station rotary indexing table

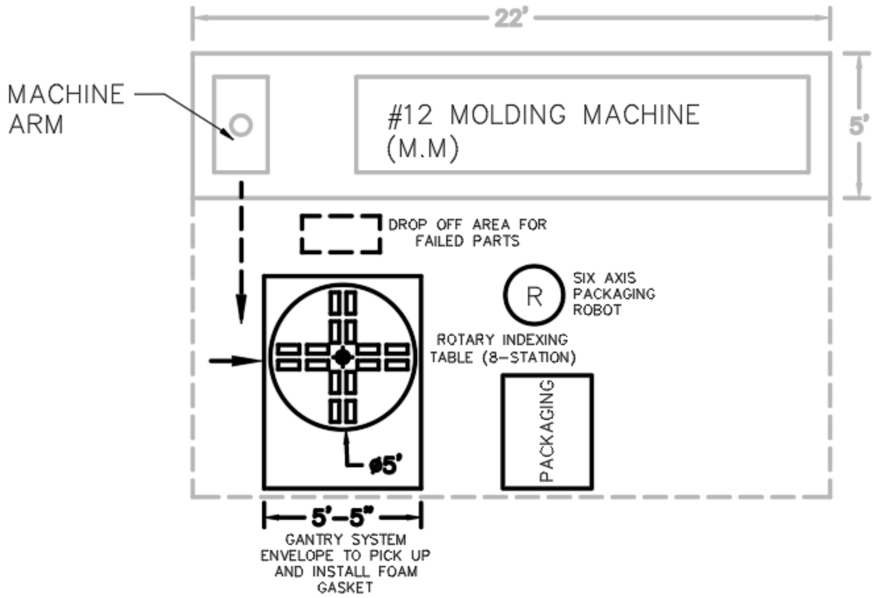


Figure 57: Overall layout for 8-station rotary indexing table

As shown above, to install the foam gasket onto the rotary indexing tables underneath the gantry system, a minimum of 1650 mm in the x-axis and 2250 mm in the y-axis working envelope is required to cover the rotary table. Since the gantry system is close to the existing machine arm, to avoid interference between the gantry system and the machine arm it is necessary to raise the height of the gantry system such that the machine arm would not contact the top of the gantry system. Based on a rough height estimate of the existing drop off station, which is 1.25 m, and the consideration of leaving enough operating space for the existing machine arm, a working envelope of 450 mm in the z-axis for the gantry system, and a height of 1.8 m for the gantry system support (i.e., the vertical aluminum extrusions used to elevate the gantry system) were specified. A side view and an isometric view of the gantry assembly are shown in Figure 58 and Figure 59.

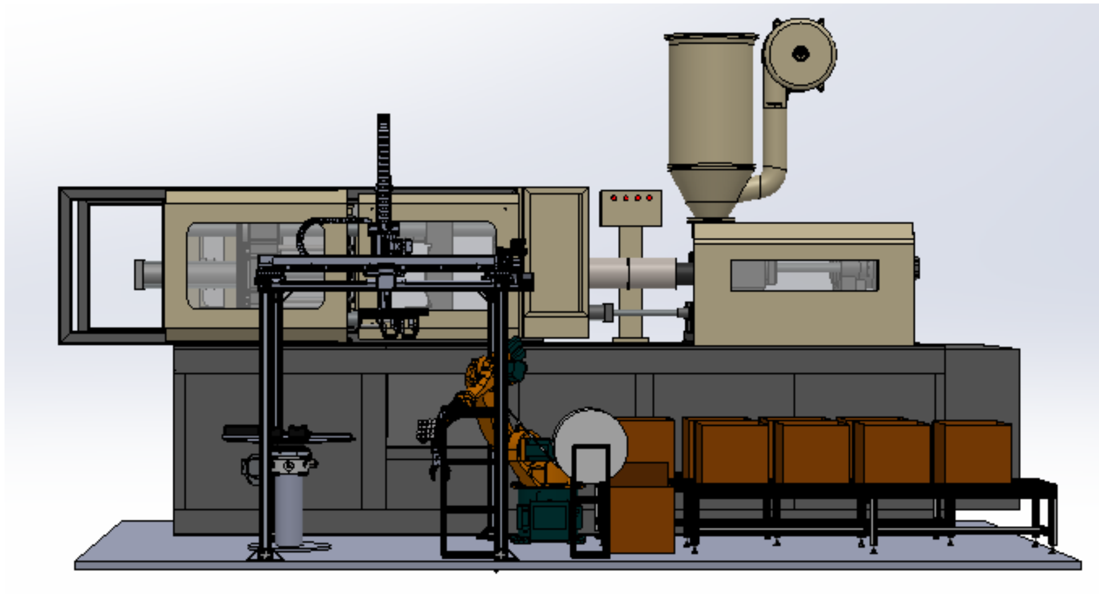

Figure 58: Side view for 4-station rotary indexing table layout assembly

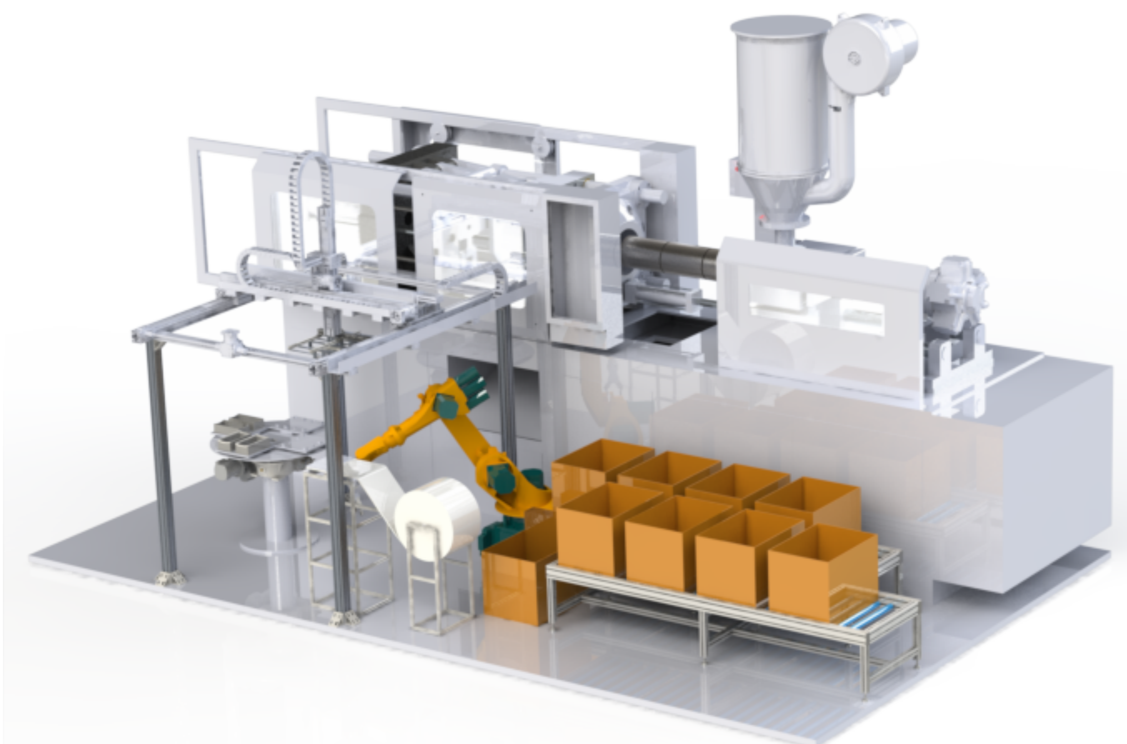

Figure 59: Isometric view for 4-station rotary indexing table layout assembly

Note that the same gusset brackets and steel stud anchor bolts discussed in section 3.1.1 were used to secure the plate and support the vertical aluminum members.

### 3.2.3 Option 2B - Tombstone Fixture

As another technical option for the central rotor layout, a tombstone fixture can be used to accurately pick up and deliver the plastic parts to the desired locations. Since the tombstone fixture is a computer numerical controlled (CNC) machine, it can have a high accuracy up to 0.001”, while a rotary indexing table typically has an accuracy range of 0.195 to 0.22” [26]. A modular hydraulic tombstone fixture M13138 was specified from New Ulm Precision Tool, Inc. and is shown in Figure 60 [27].

Image not available due to copyright infringement

Figure 60: Modular hydraulic tombstone fixture M13138 [27]

The rotary union installed on the top of the tombstone fixture can provide the 90-degree rotations during the work process. Also, due to the modular design of the tombstone fixture, the sub fixtures and grippers installed on each side of the tombstone can be easily changed and customized, which provides more flexibility to meet the technical requirements. An approximate overview of the tombstone fixture is shown in Figure 61.

Figure 61: Tombstone fixture with the jig fixtures installed

Note that since a 3D model of the specified M13138 model could not be obtained due to the copyright agreement of New Ulm, a model from TombstoneCity BP08 series was used to represent the final tombstone assembly after the jig fixtures installation on each side of the tombstone [26].

The use of flush style hydraulic couplers and ball lock retainers in the design of the tombstone fixture allows a quick and easy changeover for the sub fixtures, and ensures the ability to hold four parts firmly at the same time. However, due to the technical advantages of the tombstone fixture, the cost for a customized gripper and sub fixture design would be inevitably higher even though an accurate quote for the customized design can not be obtained due to the lack of detailed design information.

### 3.2.4 Gantry System for Tombstone Fixture

Regarding the gantry system for the tombstone fixture, due to the fact that a tombstone would hold the workpiece vertically throughout the process, a vertical gantry system or a horizontal gantry system with a rotary motion at the end effector would be needed.

### *3.2.4.1 Option 2B.1 - Vertical Gantry System and Vertical Conveyor System*

Since a tombstone fixture vertically holds the workpiece, the gantry system needs to have the same ability to vertically picks up and install the foam gasket onto the workpieces on the tombstone. IntelLiDrives Inc. has a vertical XY gantry system TYPE2 BEMA-W60 with a working stroke of 1500 mm in both x and y axis. Since this system was designed for automated accurate positioning application, the accuracy/repeatability of the motorized belt actuators can be up to +/- 50 microns [28]. The specified vertical gantry system is shown in Figure 62.


Figure 62: Vertical gantry system BEMA-W60 [28]

Since the standard load capacity of this system is only 15 kg, which is less than the estimated end gripper mounting system (20 kg), a customized design might be needed. Moreover, a vertical XYZ gantry system with linear motors is also available in IntelLiDrives if an extra Z axis motion is needed due to the possibility of interfering with other components.

Similarly, the foam roll needs to be held vertically such that the vertical gantry system can directly pick up the foam gasket from the roll. A vertical conveyor system needs to be specified. A view of a typical product is shown in Figure 63.


Figure 63: Dorner AquaPruf 7600 VBT conveyors [29]

Since this type of belt conveyors are normally used for elevating bulk products instead of vertically holding the products, it is challenging to keep the foam roll steady during the foam removal operation. Certain types of locking or fixture system would be needed to be designed to clamp the foam roll while the external gantry system removing the foam gasket from the roll, which is costly and time consuming. Also, such system would waste large useful floor space due to its footprint and necessary support system. Thus, instead of using a vertical conveyor system, the existing conveyor belt and the previous clamping system could be reused and is shown in Figure 64.

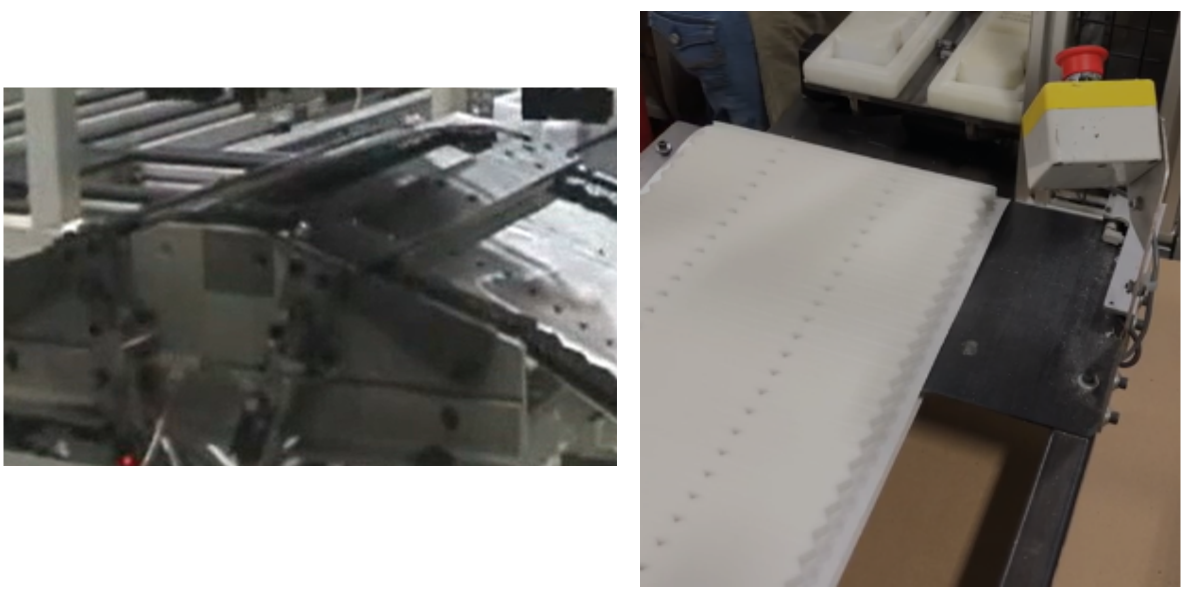

Figure 64: Clamping system of the previous automation system and existing foam roll conveyor system

To vertically hold the foam roll, a simple support base with an appropriate height can be placed underneath the existing conveyor system such that the roll feeds vertically upwards. The clamping system can then be installed onto the side of the support base and ensure the firm and steady motion of the foam roll. A close up view of the vertical assembly is shown in Figure 65.

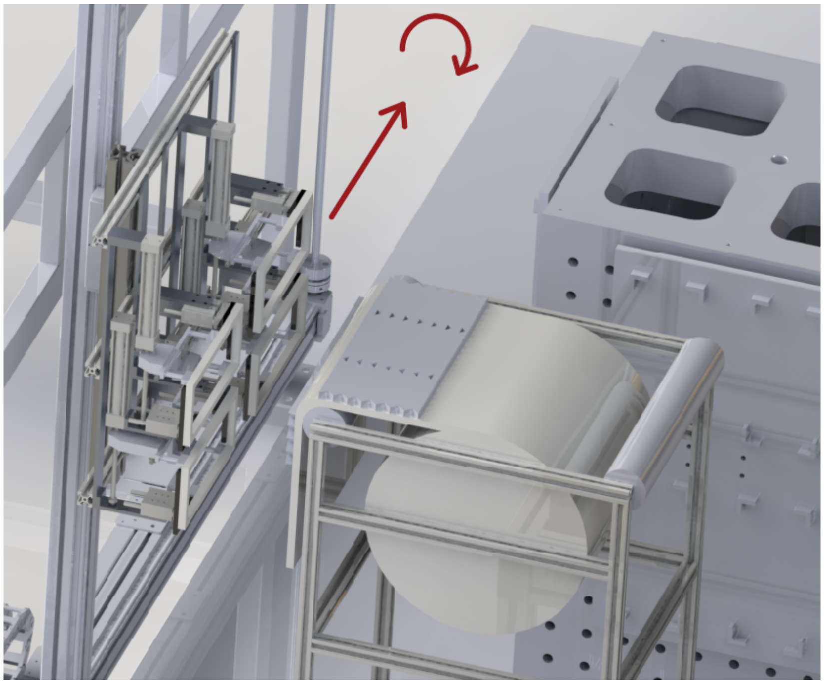

Figure 65: Vertical gantry and vertical foam roll

As shown in Figure 65, after picking up the foam gaskets from the roll, the vertical gantry system needs to have a 90-degree rotation such that the orientation of the foam gaskets is the same as the jig fixtures installed on the tombstone, as shown in Figure 66.

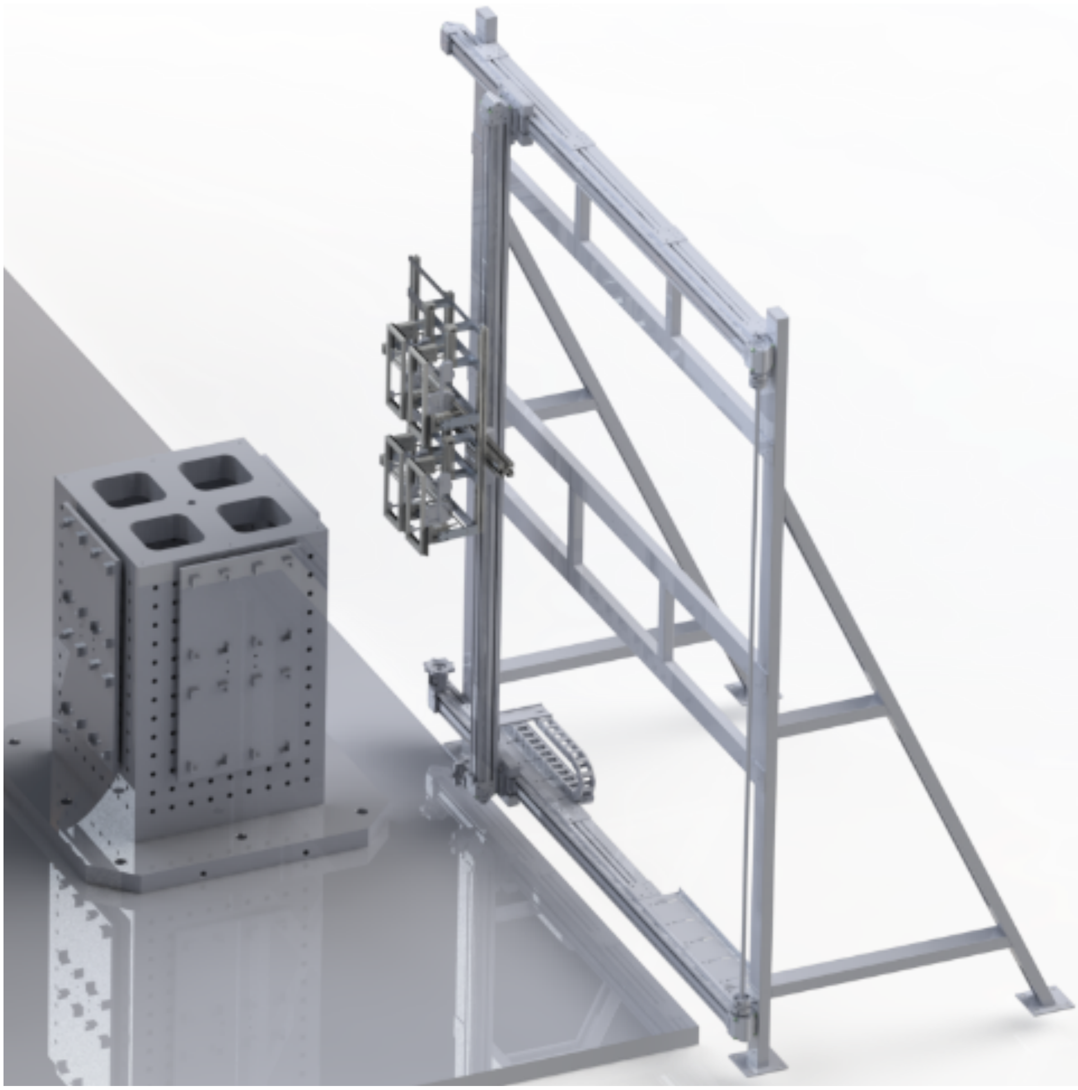

Figure 66: Overall view of the vertical gantry system

Thus, a NC(D)RA1-Z rotary actuator from SMC Inc. needs to be specified for the vertical gantry system and the details are shown in section 3.2.4.2.

#### 3.2.4.2 Option 2B.2 - Horizontal Gantry with an End Rotary Actuator

Instead of specifying a vertical gantry system, which is not normally used in the industry, a horizontal gantry system can still be used, but need to an extra rotary motion at the end effectors/grippers. Once the grippers at the end of the gantry system picks up and expand the foam gasket from the horizontal work plane, the rotary actuator would provide a 90-degree rotation of the entire assembly such that the foam gaskets are in the correct position.

The horizontal gantry system was specified to be the same one discussed in section 3.2.2, and a rotary actuator modelled NC(D)RA1-Z from SMC Inc. was specified, which is shown in Figure 67.


Figure 67: NCRA1 series rotary actuator [30]

This rack and pinion rotary actuator offers high torque-to-size and accurate positioning such that the foam gasket can be accurately installed on the plastic parts. The rail type mounting of the actuator also allows an easy adjustment of the position switch. It should be noted, however, due to the dimension of the gantry system (about 25” by 60”), the operating envelope of the gantry system needs to account for the extra space when the gantry system is having the 90-degree rotation after picking up the foam gasket and ready for the foam installation.

## 3.3 Hazard Identification

During the design and implementation process, it is important to identify possible hazards that may cause worker’s health problem, equipment damage and even lead to property loss of company. Several safety standards and guidelines regarding the industrial robot and automation control system were researched. The considered safety standards include the standards from International Organization for Standardization (ISO), American National Standards Institute (ANSI) and Canadian Standards Association (CSA). The identified safety hazards that are relevant to the two options are shown in Table VI.

TABLE VI: GENERAL SAFETY HAZARDS FOR INDUSTRIAL ROBOTS AND AUTOMATION SYSTEM

| Component/System | Hazard Description | Safety Measures | Reference Safety Standards |
|---|---|---|---|
| **Overall system** | Hazards generated by noise, such as hearing loss or other physiological disorders (e.g., tinnitus, loss of balance, loss of awareness) due to the operation noise of robots and the injection molding machine. | Hearing protections shall be worn at all time | CSA Z432 [31] |
| | Hazards generated by inhalation of harmful dusts | Hearing protections shall be worn if needed | CSA Z432 [31] |
| | Mechanical hazards generated by the sharp edges of the needle grippers that would be installed on the robot machine arm | Operators shall not enter the operating envelope of the needle gripper during operation | CSA Z432 [31] |
| | Slipping and tripping hazards | Keep walkways free of debris, clutter and obstacles | CSA Z432 [31] |

| Component/System | Hazard Description | Safety Measures | Reference Safety Standards |
|---|---|---|---|
| **Overall system** | Inconvenient access (i.e., ingress and egress paths) and escape paths | Iterative design consideration during the layout design | ISO 11161 [32] |
| | Unexpected start-up, overrun or overspeed due to errors made by the operator | Sufficient training and safety shut off device | CSA Z432 [31] |
| **Industrial Robot** | Potential crushing hazard between moving parts and rigid objects | A clearance distance of at least 500 mm, measured from robot operating envelope to the rigid structures, between the moving parts and rigid objects should be maintained. | ISO 10218 [33] |
| | Potential physical hazard during the machinery operation, such as radiation, heat, and debris or other flying objects | Robot safeguarded area is protected with adequate means against potential hazards | ISO 11161 [32] ISO 10218 [33] |
| | Improper control of the robot mode | A suitable mode of the robot shall be selected before the operator enters the robot safeguarded area | ISO 10218 [33] |

| Component/System | Hazard Description | Safety Measures | Reference Safety Standards |
|---|---|---|---|
| **Industrial Robot** | Operator enters the robot safeguarded area while the robot is operating | A detection and emergency protective stop system shall be installed to ensure the operator can be detected when entering the robot safeguarded area. After a stop command has been initiated, the stop condition shall be maintained until a manual reset device is actuated. | ISO 11161 [32]<br>ISO 10218 [33]<br>ISO 13849 [34] |
| **Electrical Components** | The contact of persons with the parts that carry a voltage due to an insulation layer damage. Electric current may cause electric shock to worker, damage to equipment and even cause fire | Regular inspection and maintenance | CSA Z432 [31] |

| Component/System | Hazard Description | Safety Measures | Reference Safety Standards |
|---|---|---|---|
| **Electrical Components** | Thermal radiation, such as projection of molten particles and chemical hazards due to short-circuits and overloads | Minimum clearance distance of the equipment and regular inspection and maintenance | CSA Z432 [31] |
| **Packaging Machinery** | Sudden hazardous movement of a hose due to leakage or component failure | Regular inspection and maintenance, and safety shut off device/valve | ANSI B155 [35] |

It should be noted that in this section, possible hazards were only identified. A risk assessment which analyze the severity of risks arising from those hazards and decide the appropriate risk reduction would be discussed in the following feasibility study section.

# 4.0 Feasibility Study

In this section, a feasibility study regarding the different options of the cartesian gantry and central rotor layout was performed to determine the best possible layout. Three main aspects, including financial feasibility, technical feasibility, and risk analysis/failure modes and effects analysis (FMEA) were discussed to assess the practicability of the proposed design.

## 4.1 Financial Feasibility

In this section, the equipment and energy costs were initially estimated. Then a preliminary cash flow estimation was performed to determine if the proposed option is economically viable. For simplicity, the time value of money, the effects of taxes, depreciation, and amortization were not be considered [36]. The accuracy level of the cost estimate was estimated to be +/- 25%. Note that all the price estimated were in Canadian dollars and an exchange rate of 1 American dollar to 1.33 Canadian dollar was used when the obtained quote was in American currency.

The purpose behind the following cost estimate and payback period analysis was to compare the overall cost of the proposed layouts with Melet's current design. Due to the limitation of the price information provided by the supplier, the cost estimate was limited only to the main equipment of the layout. The cost related to the installation, maintenance, readjustment of the existing layout, the design and installation cost of the gripper to pick up and install the forma gasket, and other miscellaneous items were excluded.

### 4.1.1 Option 1 - Cartesian Gantry Layout

The costs of the main components were obtained by researching and contacting with the possible suppliers, and requesting the quotes for the specified models. Due to the resource limit, the obtained quote and cost estimate may not reflect the lowest possible price and the stability of the quote price cannot be guaranteed.

A cost breakdown of the cartesian gantry layout is shown in Table VII. The final decision of the motor type and brand would be at the discretion of the client.

TABLE VII: GANTRY LAYOUT COST BREAKDOWN

| Component | Model | Quantity | Estimated Cost |
|---|---|---|---|
| Shuttle System | Macron: MSA-14S, MPG-084-003 | 4 | $10,010 |
| Shuttle System Assembly Support | Various Hardware | 1 | $2000 |
| Gantry System | MCS-UC1 | 1 | $21,790 |
| Gantry Support | Various Hardware | 1 | $840 |
| Gantry Motor Gearbox | MPG-084-005 | 3 | $4,760 |
| Gantry Motor | ATO-80WDM02430 | 3 | $1,915 |
| Gantry Motor Controller | ATOTH-G | 3 | $1,580 |
| Needle Gripper | Custom | 16 | *$15,000 |
| Needle Gripper Actuator | 6453K114/K118 | 8 | $1,080 |
| Foam Press Actuator | 6311K120 | 8 | $1,570 |
| Gripper Assembly Supports | Miscellaneous | N/A | $650 |
| 6 Axis Packaging Robot | Kuka KR 8 R1620 | 1 | $50,000 |
| 6 Axis Robot Gripper Equipment | OnRobot: RG6, VG10, Dual Quick Changer | 3 | $15,000 |
| **Total Cost** | | | **$126,195** |

*The needle gripper price is a cost estimate from Schmalz as custom work required a confirmation of order for an exact cost.

### 4.1.2 Option 2 - Central Rotor Layout

A summary of the estimated costs for the main components of the central rotor layout for both rotary indexing table and tombstone fixture options are shown in Table VIII and Table IX, respectively. Note that the price of the needle grippers, gantry system supports, the 6-axis packaging robot, and the dual changer on the gripper were the same as the cartesian gantry system layout.

TABLE VIII: ROTARY INDEXING TABLE LAYOUT COST BREAKDOWN

| Component | | Model | Quantity | Estimated Cost |
|---|---|---|---|---|
| 4-station Rotary Table | Rotary Indexing Table (4-station) | Destaco, 902RDM4H32-330 MSC.33 | 1 set | $7430 |
| | Rotary Indexing Table Motor | Kebco 230/460V/60Hz 3 Phase | 1 | |
| 8-station Rotary Table | Rotary Indexing Table (8-station) | Destaco, 601RDM4H24-330 MSC .33 | 1 set | $13,150 |
| | Rotary Indexing Table Motor | Kebco 230/460V/60Hz 3 Phase | 1 | |
| Gantry system (need for both options) | Gantry System | MCS-UC1 | 1 | $23,770 |
| | Gantry Support | Various Hardware | 1 | $840 |
| | Gantry Motor Gearbox | MPG-084-005 | 3 | $4,760 |
| | Gantry Motor | ATO-80WDM02430 | 3 | $1,915 |
| | Gantry Motor Controller | ATOTH-G | 3 | $1,580 |
| | Needle Gripper | Customized Design | 16 | $15,000 |
| | Needle Gripper Actuator | 6453K114/K118 | 8 | $1,080 |
| | Foam Press Actuator | 6311K120 | 8 | $1,570 |

| Component | | Model | Quantity | Estimated Cost |
|---|---|---|---|---|
| | Gripper Assembly Supports | Miscellaneous | N/A | $650 |
| | 6 Axis Packaging Robot | Kuka KR 8 R1620 | 1 | $50,000 |
| | 6 Axis Robot Gripper Equipment | OnRobot: RG6, VG10, Dual Quick Changer | 3 | $15,000 |
| **Total Cost (4-station)** | | | | **$123,595** |
| **Total Cost (8-station)** | | | | **$129,315** |

TABLE IX: TOMBSTONE LAYOUT COST BREAKDOWN

| Component | | Model | Quantity | Estimated Cost |
|---|---|---|---|---|
| Tombstone Work-holding Fixture | | New Ulm M13138 | 1 | *$29,000 |
| Vertical Gantry and conveyor system | Vertical Gantry System | TYPE2 BEMA-W60 | 1 | *$23,940 |
| | Vertical Gantry Motor | Nema 23 | 1 | |
| | Vertical Conveyor Support System | Miscellaneous | N/A | $600 |
| | Rotary Actuator | NCDRA1BS63-90CZ | 1 | $410 |
| Horizontal Gantry system with an end rotary actuator | Horizontal Gantry System | MCS-UC1 | 1 | $23,770 |
| | Rotary Actuator | NCDRA1BS63-90CZ | 1 | $410 |
| | Gantry Support | Various Hardware | 1 | $840 |
| | Gantry Motor Gearbox | MPG-084-005 | 3 | $4,760 |
| | Gantry Motor | ATO-80WDM02430 | 3 | $1,915 |
| | Gantry Motor Controller | ATOTH-G | 3 | $1,580 |
| | Needle Gripper | Customized Design | 16 | *$15,000 |

| Component | | Model | Quantity | Estimated Cost |
|---|---|---|---|---|
| Needed for both options | Needle Gripper Actuator | 6453K114/K118 | 8 | $1,080 |
| | Foam Press Actuator | 6311K120 | 8 | $1,570 |
| | Gripper Assembly Supports | Miscellaneous | N/A | $650 |
| | 6 Axis Packaging Robot | Kuka KR 8 R1620 | 1 | $50,000 |
| | 6 Axis Robot Gripper Equipment | OnRobot: RG6, VG10, Dual Quick Changer | 3 | $15,000 |
| **Total Cost (vertical Gantry and conveyor system)** | | | | **$137,250** |
| **Total Cost (horizontal Gantry with an end rotary actuator)** | | | | **$145,575** |

*The tombstone fixture cost could not be obtained due to the lack of detailed design information. The cost shown was based on the cost of the available product Jergens 16 station vise columns 49418 [37] and TombstoneCity BP08-800800-1000-5 [26].

*The vertical Gantry system price is for the standard system which has a load capacity of 15 kg only. The quote of a customized design for 20 kg load capacity cannot be obtained until a purchase order is placed.

### 4.1.3 Energy Cost and Payback Period Analysis

The energy cost for all the electric motors used to operate the main components in the system were calculated to determine the annual operating cost. The estimation assumed that the motors runs at full load the duration of the working time. By assuming a cost of electricity of 4.211 ₵/kWh [38], a normal working time of 52 working weeks with 28 working hours per week (assume 70% utilization), and with the technical specifications for the motors of the main components, the energy cost for running the proposed system at maximum load conditions can be calculated. The following equation is used to calculate the annual energy cost:

$$E = \frac{P}{PF} \times T \times 0.04211 \quad (1)$$

Where *E* is the energy cost, *P* is the power output, *PF* is the motor power factor, and *T* is the working time. By using equation (1) and assuming a power factor (*PF*) of 0.85, the energy cost results are shown from Table X to XII.

TABLE X: ANNUAL ENERGY COST OF CARTESIAN GANTRY SYSTEM

| **Component** | **Power Output (kW)** | **Annual Energy Cost** |
|---|---|---|
| Gantry System | 0.75 [39] | $55 |
| Shuttle System | 2 (estimated) | $145 |
| 6 Axis Packaging Robot | 2 (estimated) | $145 |
| **Total Annual Energy Cost** | | **$345** |

TABLE XI: ANNUAL ENERGY COST OF ROTARY INDEXING TABLE SYSTEM

| **Component** | **Power Output (kW)** | **Annual Energy Cost** |
|---|---|---|
| Rotary Indexing Table | 0.5 [40] | $40 |
| Gantry System | 0.75 [39] | $55 |
| 6 Axis Packaging Robot | 2 (estimated) | $145 |
| **Total Annual Energy Cost** | | **$240** |

TABLE XII: ANNUAL ENERGY COST OF TOMBSTONE FIXTURE SYSTEM

| **Component** | **Power Output (kW)** | **Annual Energy Cost** |
|---|---|---|
| Tombstone Fixture | 0.6 (estimated) | $45 |
| Gantry System | 0.75 [39] | $55 |
| 6 Axis Packaging Robot | 2 (estimated) | $145 |
| **Total Annual Energy Cost** | | **$245** |

To determine the period of time in years required to break even on the initial capital investment, a payback period analysis can be performed and the following equation can be utilized to calculate the payback time:

$$T = (I + E \times T)/C$$
$$\Rightarrow T = I/(C - E) \quad (2)$$

Where *T* is the payback time, *I* is the required total investment, and *C* is the average annual cash flow if the proposed design is implemented. The ideal budget was set to be 140,000 for a two-year payback time, which means an average annual cash flow of $70,000. By using the payback time equation and the summarized cost estimate information, the payback period for each layout is summarized in Table XIII. The remaining budgets for each layout option, which accounts for the installation, maintenance, and other miscellaneous costs were calculated as well.

TABLE XIII: PAYBACK PERIOD FOR EACH LAYOUT

| System | Cartesian Gantry | Rotary Indexing Table | | Tombstone Fixture | |
|---|---|---|---|---|---|
| | | 4-station | 8-station | Vertical Gantry | Horizontal Gantry |
| Main Equipment Cost ($) | 126,195 | 123,595 | 129,315 | 137,250 | 145,575 |
| Annual Energy Cost ($) | 345 | 240 | 240 | 245 | 245 |
| **Total Cost ($)** | **126,830** | **124,030** | **129,760** | **137,740** | **146,090** |
| Remaining Budget ($) | 13,170 | 15,970 | 10,240 | 2,260 | N/A (-6,090) |
| Simple Payback Time (years) | **1.81** | **1.77** | **1.85** | **1.97** | **2.09** |

A detailed payback period analysis was not covered in this report due to the fact that some other costs were excluded, and the complexity of the gripper design could possibly influence the price of the rotary indexing table and tombstone fixture as well. However, by comparing the annual costs of both layout options, it is clear that except the tombstone fixture layout with a horizontal gantry system, all other designs can meet the target of a 2-year payback period.

## 4.2 Technical Feasibility

In this section, the feasibility study elaborates on the technical aspects of the design including space and footprint, cycle time, and comparing similar designs using benchmarking.

### 4.2.1 System Footprint

The physical footprint of the automation system is an important factor when assessing the feasibility of the design since one of the main issues with the previous automation system is the large footprint and the accompanying maintenance issues. Thus, a technical specification of maintaining the current system footprint was set and a space estimate study of the proposed layout designed was performed in this section.

#### *4.2.1.1 Gantry System Footprint*

Figure 68 illustrates the complete assembly of the gantry system and the concrete floor depicts the dimensions of the current system.

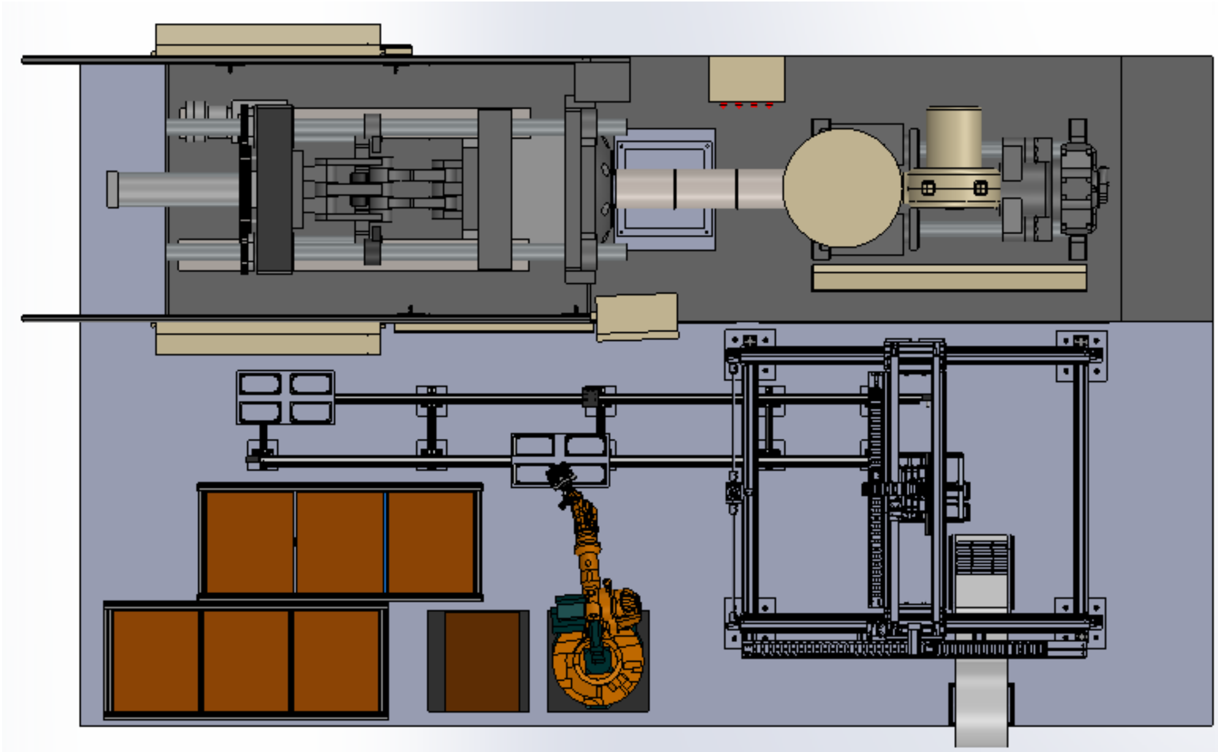

Figure 68: Gantry layout top view

All of the specified equipment fits within this work footprint and therefore, the space technical specification is met by maintaining the existing footprint of 22 feet by 13 feet.

#### 4.2.1.2 Rotary Indexing Table System Footprint

As is shown in Figure 69 and Figure 70, the overall views of the rotary indexing table systems show that both options can be fit in the existing footprint.

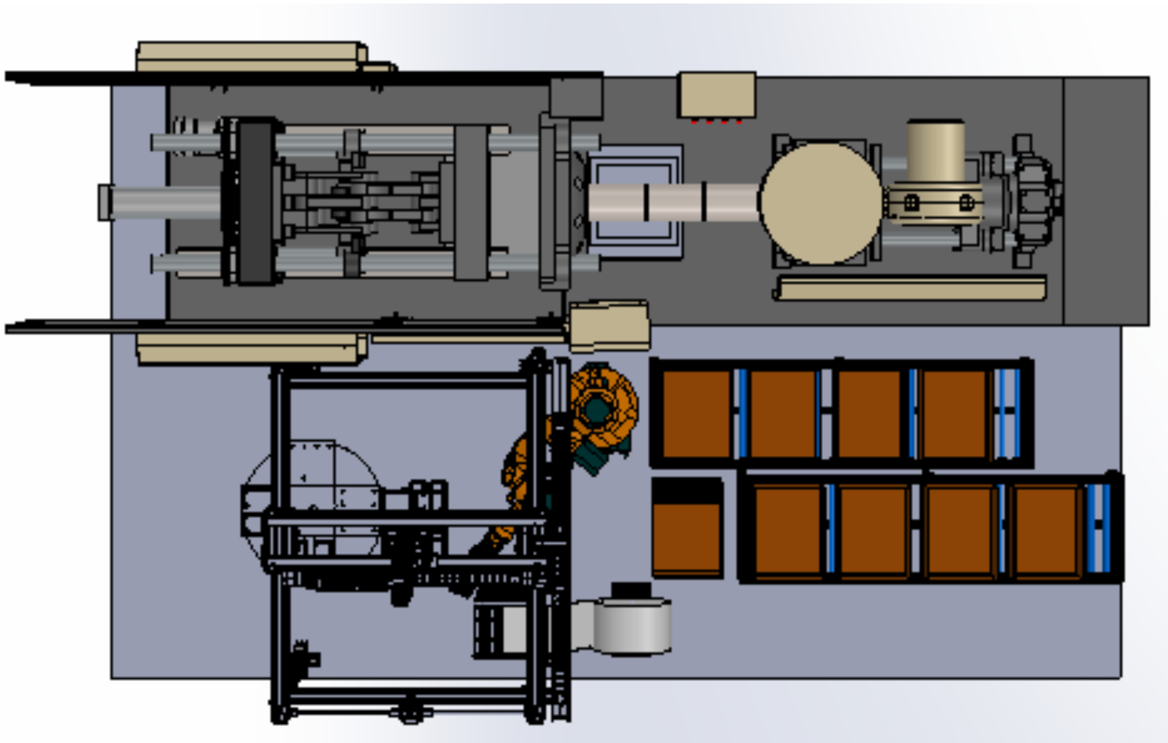

Figure 69: 4-station rotary indexing table layout top view

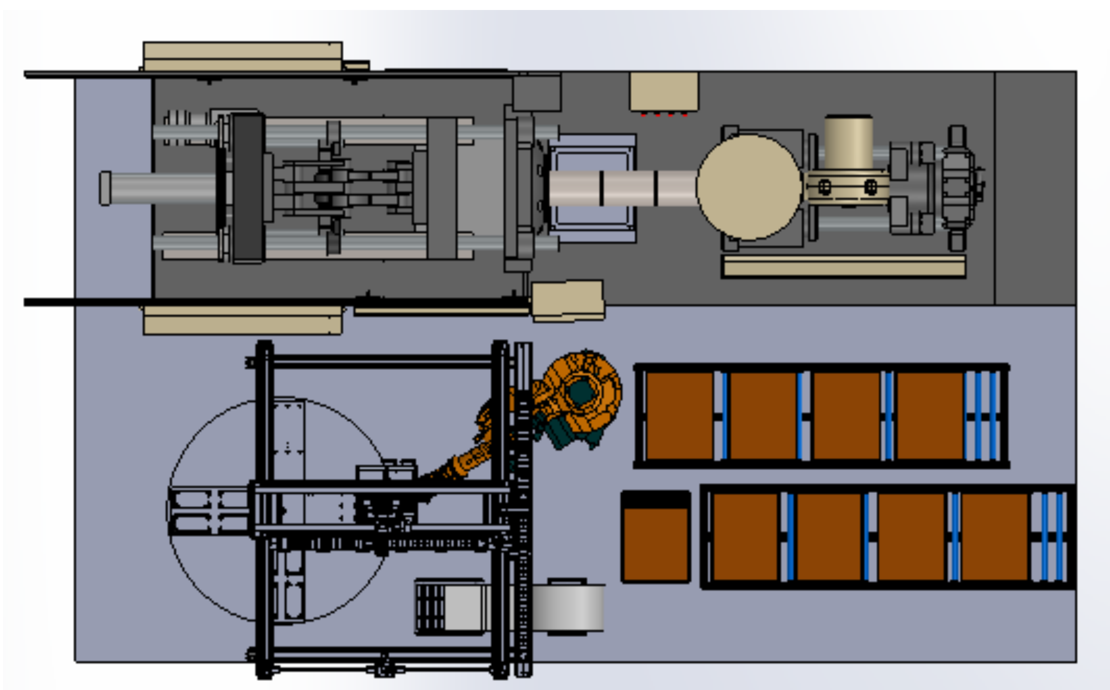

Figure 70: 8-station rotary indexing table layout top view

However, due to the large diameter of the 8-station rotary table, the tight space behind the rotary table and packaging robot would cause issues when performing inspection and maintenance.

#### 4.2.1.3 Tombstone Fixture System Footprint

Figure 71 and Figure 72 demonstrates the overall layout of the tombstone fixture system layouts.

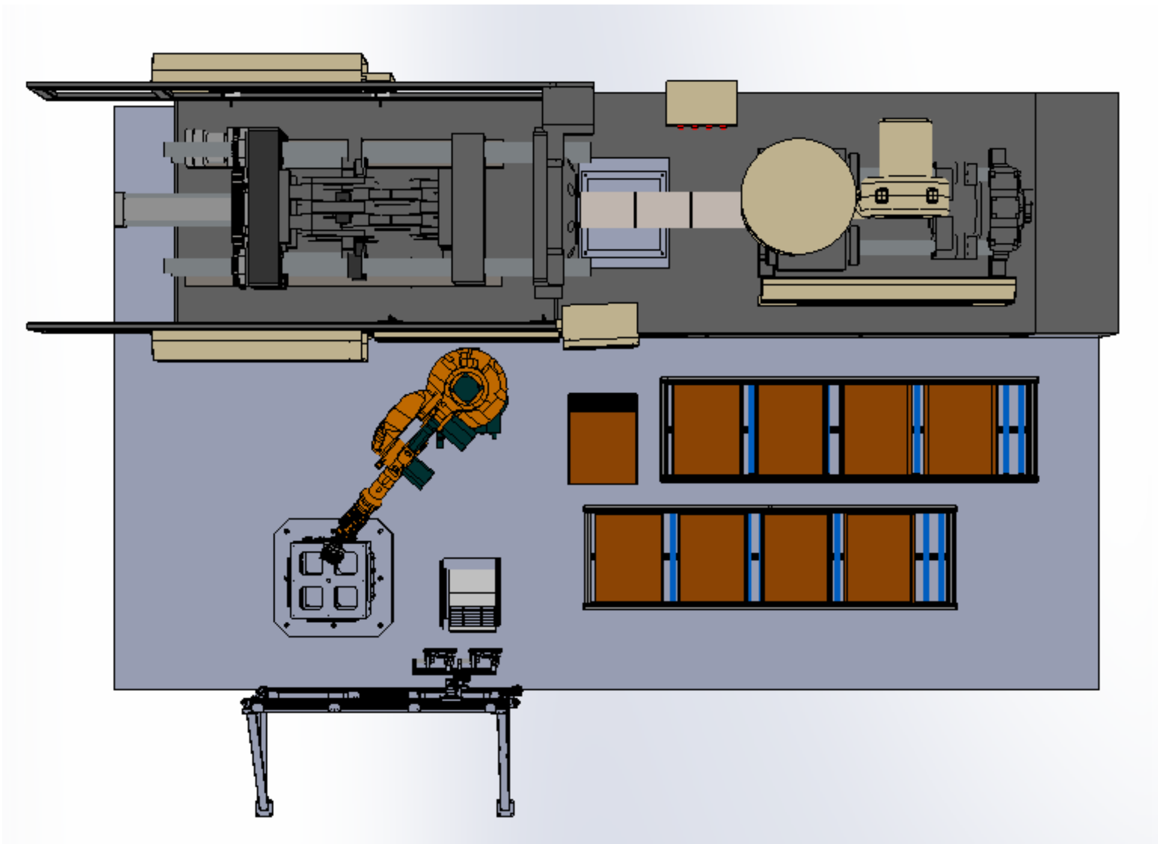

Figure 71: Tombstone with a vertical gantry system layout top view

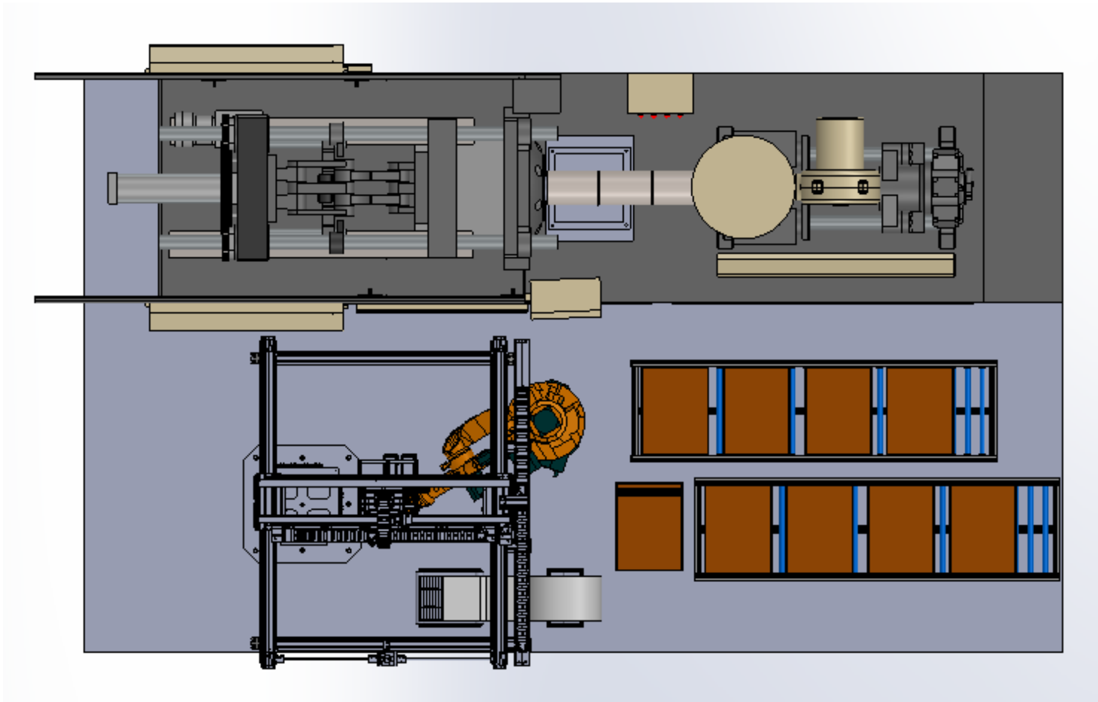

Figure 72: Tombstone with a horizontal gantry system layout top view

Note that due to the support beam of the vertical gantry, the tombstone with a vertical gantry system layout exceeds the existing footprint by the length of the support beam, which is 865 mm. Thus, this layout option would not satisfy the set footprint specification.

### 4.2.2 Cycle Time

In order to ensure the cycle time of 4 parts produced every 21 seconds would be achieved, an estimated time study was completed for the different layouts. The start of the cycle was considered to be the moment when the existing machine arm retrieves the insert bases from the injection molding machine, and the end of the cycle was considered to be the moment when the packaging robot successfully places the finished pars into the packaging box. Note that these processes are estimates only and further testing would need to be conducted with the various equipment to determine a more accurate cycle time.

#### *4.2.2.1 Gantry Layout Cycle Time*

The gantry layout system will have an initialization bias that must be accounted for when calculating the cycle time. This bias comes from the gantry not being able to pick up foam gaskets simultaneously during its downtime on the first cycle. After the first cycle, the gantry would be able to pick up and expand foam gaskets while the shuttles are transporting the insert bases for loading and unloading processes. Table XIV gives a detailed description of the time required for each operation in the cycle. This includes the assumption that it takes two seconds to pick up each gasket and four seconds to unload the finished parts and place them in the packaging box (8 and 16 seconds total respectively).

TABLE XIV: GANTRY LAYOUT TIME STUDY

| Step | Process | Start Time (s) | Finish Time (s) |
|---|---|---|---|
| 1 | Shuttle 1 transport parts from load to foam install position | 0 | 1 |
| 2 | Pickup foam gaskets from roll | 0 | 8 |
| 3 | Expand foam gaskets | 8 | 9 |
| 4 | Press foam gaskets onto insert bases | 9 | 11 |
| 5 | Shuttle 1 transport parts from foam install to unload position | 11 | 11.5 |
| 6 | Unload parts from shuttle 1 and place in final packaging box | 11.5 | 27.5 |
| 7 | Shuttle 2 transport parts from load to foam install position | 21 | 22 |
| 8 | Pickup foam gaskets from roll | 11 | 19 |
| 9 | Expand foam gaskets | 19 | 20 |
| 10 | Press foam gaskets onto insert bases | 22 | 24 |
| 11 | Shuttle 2 transport parts from foam install to unload position | 24 | 24.5 |
| 12 | Pickup foam gaskets from roll | 24 | 32 |
| 13 | Unload parts from shuttle 2 and place in final packaging box | 24.5 | 40.5 |

| Step | Process | Start Time (s) | Finish Time (s) |
|---|---|---|---|
| 14 | Transport empty shuttle 1 from unload to part load position | 27.5 | **28** |
| 15 | Expand foam gaskets | 32 | 33 |
| 16 | Transport empty shuttle 2 from unload to part load position | 40.5 | **41** |
| 17 | Shuttle 1 transport parts from load to foam install position | 42 | 43 |
| 18 | Press foam gaskets onto insert bases | 43 | 45 |
| 19 | Shuttle 1 transport parts from foam install to unload position | 45 | 45.5 |
| 20 | Pickup foam gaskets from roll | 45 | 53 |
| 21 | Unload parts from shuttle 1 and place in final packaging box | 45.5 | 61.5 |
| 22 | Expand foam gaskets | 53 | 55 |
| 23 | Transport empty shuttle 1 from unload to part load position | 61.5 | **62** |
| 23 | Shuttle 2 transport parts from load to foam install position | 63 | 64 |
| 24 | Press foam gaskets onto insert bases | 64 | 66 |
| 25 | Shuttle 2 transport parts from foam install to unload position | 66 | 66.5 |
| 26 | Unload parts from shuttle 2 and place in final packaging box | 66.5 | 82.5 |
| 27 | Transport empty shuttle 2 from unload to part load position | 82.5 | **83** |

Table XIV shows the initialization bias causing the first cycle to be over the maximum cycle time at 28 seconds while the second, third and fourth cycle (Step 16, 23, and 27) finish in 21 seconds. Steps 17 and 23 illustrate the downtime of the system as the shuttle systems are waiting for the injection molding machine to produce another set of insert bases. This downtime ensures that even if the process time estimates were not conservative enough, there is a safety factor that will maintain the required cycle time of 21 seconds. If after testing the time estimates were determined to be accurate, the processes could be slowed down to reduce maintenance costs and wear on equipment.

#### 4.2.2.2 Central Rotor Layout Cycle Time

The specified rotary indexing tables are the cycle-on-demand type, which is a system that the camshaft of the indexing table can be stopped in dwell for a specified amount of time, and then be re-started. Thus, the stop/dwell time of the system is variable and can be programmed to fit the time requirement [40]. Similar to a rotary indexing table, the amount of stop time of a CNC tombstone fixture is completely up to the programming of the machine as well.

For a 4-station rotary table, since four stations are rotating simultaneously, the plastic parts can be picked up, processed and dropped off continuously and in turn. Thus, its work capacity is two parts per cycle. The four sides of the rotary table are explained in Figure 73 for the clarity of the time estimate.

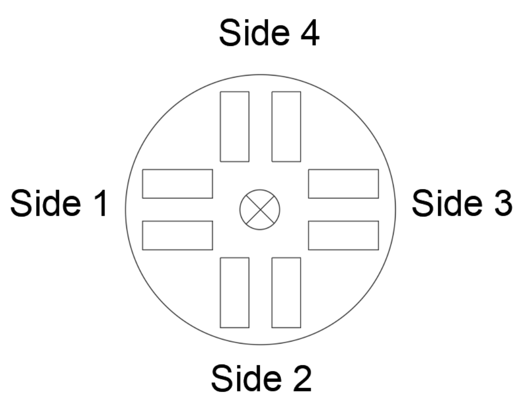


Figure 73: Numbering of the rotary table sides

Sides 1 to 4 start at the left end of the rotary table and counting counterclockwise, which faces to the existing machine arm, the foam assembly station, the packaging robot, and the wasted parts drop off station, respectively.

Based on the standard motion time 1.769 seconds of the specified 4-station rotary table, which is the time required for a 90-degree rotation, a time estimate of the overall process is shown in Table XV. To be conservative, assume both the foam gasket installation and final packaging would require the same 16 seconds since if the two operations spend different amounts of time, the longer operation at one side would not be finished when the rotary table starts to rotate.

TABLE XV: 4-STATION ROTARY INDEXING TABLE LAYOUT TIME STUDY

| Step | Process | Start Time (s) | Finish Time (s) |
|---|---|---|---|
| 1 | Rotary table stays for 5 seconds for the existing machine arm picking up and dropping off 2 parts on the side 1 (Initial set up) | 0 | 5 |
| 2 | Plastic parts transferred to the side 2 for foam gasket installation (90-degree rotation) | 5 | 6.8 |
| 3 | Foam gasket pick up and expand | 0 | 14 |
| 4 | Foam Installation | 14 | 16 |
| 5 | Parts transferred to the side 3 for finished part removal and packaging (90-degree rotation) | 16 | 17.8 |
| 6 | Parts unloading and final packaging | 17.8 | 33.8 |
| 7 | Second batch of 2 parts transferred to side 2 for foam gasket installation | 16 | 17.8 |
| 8 | Foam gasket pick up and expand | 16 | 30 |
| 9 | Foam Installation (for the second batch of plastic parts) | 30 | 32 |
| 10 | Parts transferred to the side 3 for finished part removal and packaging (90-degree rotation) | 33.8 | 35.6 |
| 11 | Parts unloading and final packaging | 35.6 | **51.6** |
| 12 | 2 new parts transferred to the side 3 for finished part removal and packaging | 51.6 | 53.2 |
| 13 | Parts unloading and final packaging | 53.2 | 69.2 |

| Step | Process | Start Time (s) | Finish Time (s) |
|---|---|---|---|
| 14 | 2 new parts transferred to the side 3 for finished part removal and packaging | 69.2 | 70.8 |
| 15 | Parts unloading and final packaging | 70.8 | **86.8** |

Similar to the Gantry system layout, the initial set up option causing the first cycle to be ended at 51.6 seconds while the second cycle (Step 15) finish at 86.8 seconds with a consistent cycle time 35.2 seconds per cycle after the first cycle.

Due to the low working efficiency of working with only two parts at a time, the rotary indexing table would not be able to meet the cycle time requirement unless both the foam installation and the final packaging processes can be limited to 8.7 seconds per operation. In that case, the first cycle would end at 29.7 seconds with the following cycles finished within 21 seconds.

Regarding an 8-station rotary table with a motion time of 3.185 seconds, since the larger diameter allows the table to carry four plastic parts at the same time, the operation time of the foam installation and final packaging can be prolonged to 17.8 seconds. A time estimate of the overall process is shown in Table XVI.

TABLE XVI: 8-STATION ROTARY INDEXING TABLE LAYOUT TIME STUDY

| Step | Process | Start Time (s) | Finish Time (s) |
|---|---|---|---|
| 1 | Rotary table stays for 5 seconds for the existing machine arm picking up and dropping off 4 parts on the side 1 (Initial set up) | 0 | 5 |
| 2 | Plastic parts transferred to the side 2 for foam gasket installation (90-degree rotation) | 5 | 8.2 |
| 3 | Foam gasket pick up and expand | 0 | 14 |
| 4 | Foam Installation | 14 | 16 |

| Step | Process | Start Time (s) | Finish Time (s) |
|---|---|---|---|
| 5 | Parts transferred to the side 3 for finished part removal and packaging (90-degree rotation) | 16 | 19.2 |
| 6 | Parts unloading and final packaging | 19.2 | **35.2** |
| 7 | Second batch of 4 parts transferred to side 2 for foam gasket installation | 16 | 19.2 |
| 8 | Foam gasket pick up and expand | 16 | 30 |
| 9 | Foam Installation (for the second batch of plastic parts) | 30 | 32 |
| 10 | Parts transferred to the side 3 for finished part removal and packaging (90-degree rotation) | 35.2 | 38.4 |
| 11 | Parts unloading and final packaging | 38.4 | **54.4** |
| 12 | 4 new parts transferred to the side 3 for finished part removal and packaging | 54.4 | 57.6 |
| 13 | Parts unloading and final packaging | 57.6 | **73.6** |

It shown that that the first cycle ends at 35.2 seconds, and the following cycles would be finished at 19.2 seconds per cycle, which is less than the existing process time. Thus, the operation time can be extended to 17.8 seconds rather than the estimated 16 seconds to reduce wear on the equipment.

### 4.2.3 Benchmarking Systems

Looking at other systems in industry that are using similar methods is a useful way for the design team to assess the technical feasibility of the proposed design. In this section, benchmarking systems for each design concept were researched to demonstrate the successful examples used in the industry.

#### *4.2.3.1 Gantry System Benchmark System*

SoftWear is a company that uses robotics to automate the fabrication of textile products. Their Sewbots use a variety of custom grippers including needle grippers supported mainly by gantry style robots. The Lowry G-Series Sewbot in particular is very similar in nature to the gantry foam install station in the insert base automation system [41]. The Lowry Sewbot has a low to medium weight range for it's end effector and has roughly 1500-1000-150 x-y-z range of motion while dealing with porous materials that are difficult to handle with traditional grippers [42]. See Figure 74 for details of the Sewbot.


Figure 74: Lowry G-series textile Sewbot

The success and similarity of the Lowry G-Series Sewbots to the given application leads the design team to believe that the system could work beyond the theoretical solution presented.

#### *4.2.3.2 Rotary Indexing Table Benchmarking System*

DONG GUAN LMET TEAP TECHNOLOGY CO.,LTD (lmeTTeap) is a company that focuses on assembly automation solutions. Their newly designed rotary screwing machine utilizes multiple machine arms to drop the raw products onto the rotary indexing table and place the finished products to linking conveyors to transport to the next station. The designed fixtures are mounted on the rotary table to hold and carry products from one station to another to achieve different working processes, which is the same design concept with the central rotor layout design. The multiple stations (4, 6, and 8 workstations available) of the rotary table enable the ability of assembling the product, performing inspection, and conducting the final unloading synchronously [43].

The overall production rate and work efficiency is greatly improved for modern screwing and assembling by this rotary screwing machine. An overall view of the machine is shown in Figure 75.


Figure 75: ImeTTeap 8-station rotary screw driving machine

A close up of the working processes are shown from Figure 76 to Figure 78.


Figure 76: Worker manually loads the workpiece onto the rotary table [44]


Figure 77: Screwing of the workpiece [44]


Figure 78: Unloading of the finished part [44]

Compared to the central rotor layout design, this rotary screwing machine embedded multiple spindles/machine arms inside the rotary table itself, which serves the same purpose but greatly reduces the overall footprint. The central rotor layout design could utilize the same concept and integrate the function of foam installation and finished parts removal into the rotary table itself. However, due to the budget limit, a customized design of a such design would be economically undesirable.

#### *4.2.3.3 Tombstone Fixture Benchmark System*

Kurt Manufacturing is a global leader in the manufacturing of CNC Precision machined parts and assemblies. They have been designing and engineering high quality and performance workholding solutions for over 50 years. Kurt Manufacturing offers several types of workholding machines, including towers, tombstones, modular vises, and more. A successful product designed for Tier One Automotive Supplier is shown in Figure 79 [45].

Image not available due to copyright infringement

Figure 79: Kurt 400 mm HMC tombstone with hydraulic clamping [45]

The tombstone shown above is a design dedicated for the throttle body. The hydraulic swing clamps installed at each side would secure and hold the parts, which is the same design concept with the proposed theoretical solution. However, it is worth noting that since the tombstone is usually used in the precision machining industry and the fixture is designed for holding heavy work pieces (usually metal), the tombstone fixture on the market usually has a high material strength and a small size to minimize the cost. Thus, a light duty with a large sized tombstone for our application is hard to find and would require extra cost based on the design requirements.

### 4.3 Risk Assessment

In this section, a failure modes and effects analysis (FMEA) and a risk assessment for both cartesian gantry and central rotor layouts was performed. The purpose of the FMEA was to identify the possible ways of the design failure, and how to reduce or eliminate the risk of these failures. A qualitative risk analysis was conducted by using Table XVII, Table XVIII, and Table XIX, which assessed and combined the probability of risk occurrence and impact.

TABLE XVII: SEVERITY RATING SCALE

| **Severity of Effect** | | **Ranking** |
|---|---|---|
| Minor | Unreasonable to expect that the minor nature of this failure would cause any substantial effect on system performance or on a subsequent process or service operation. Customer unlikely to either notice or care about the failure | 1 |
| Low | Low severity ranking due to nature of failure causing only a slight customer annoyance. Customer will probably notice only a minor degradation of the service performance, or a slight impact on a subsequent action; i.e., some quick, minor rework | 2, 3 |
| Moderate | Failure causes some customer dissatisfaction. Customer is made uncomfortable or is annoyed by the failure. Customer will experience some very noticeable inconvenience or performance degradation. May cause either delay due to rework or irreversible damage. | 4, 5, 6 |
| High | High degree of customer dissatisfaction due to negative impact of the failure such as an inaccurate payroll run, loss of vital data or an inoperable convenience system (i.e., computer crashes). Does not involve safety or noncompliance to government regulations. May cause serious disruption to subsequent processing; may require major rework or loss to customer and/or create significant financial hardship. | 7, 8 |

| Severity of Effect | | Ranking |
|---|---|---|
| Very High | Failure mode involves serious personal safety hazards, potential for civil litigation or noncompliance with government regulations. | 9, 10 |

TABLE XVIII: FREQUENCY RATING SCALE

| Probability of failure | Ranking | Possible failure rates |
|---|---|---|
| **Remote**: Failure is unlikely. No failures ever associated with almost identical processes | 1 | <1 in 20,000 |
| **Very low**: Process is in statistical control. Only isolated failures associated with almost identical processes | 2 | 1 in 20,000 |
| **Low**: Process is in statistical control. Isolated failures associated with similar processes. | 3 | 1 in 4,000 |
| **Moderate**: Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions. Process is in statistical control | 4<br>5<br>6 | 1 in 1,000<br>1 in 400<br>1 in 80 |
| **High**: Generally associated with processes similar to previous processes that have often failed. Process is not in statistical control | 7<br>8 | 1 in 40<br>1 in 20 |
| **Very high**: Failure is almost inevitable | 9<br>10 | 1 in 8<br>1 in 2 |

TABLE XIX: DETECTION RATING SCALE

| Likelihood of detection | | Ranking |
|---|---|---|
| Very high | Current controls will almost certainly prevent the failure (process automatically prevents most failures) | 1, 2 |
| High | Current controls have a good chance of detecting the failure | 3, 4 |
| Moderate | Current controls may detect failure | 5, 6 |
| Low | Current controls have a poor chance of detecting the failure | 7, 8 |
| Very low | Current controls probably will not detect the failure | 9 |
| Absolute certainty of non-detection | Current controls will not or cannot detect the failure | 10 |

To avoid and minimize the bias of one person to another, the team performed the analysis individually and average values were used in the analysis. The complete risk ratings are shown in Table XX. Note that the risk priority number (RPN) in the last column of Table XX was the product of severity, frequency, and detection and can be used to determine the risk priority for the future action.

TABLE XX: FAILURE MODES AND EFFECTS ANALYSIS

| Process | Potential Failure Mode | Potential Effects of Failure | SEV | Potential Causes | OCC | Process Control Prevention | Process Control Detection | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|
| Plastic parts pick up and preparation | Existing arm did not pick up the parts from the injection molding machine | Bottleneck process<br><br>Production line jamming | 3 | Aging equipment | 1 | Add an extra position sensor and feedback loop to ensure the accurate alignment | Position feedback and operator visual confirmation | 2 | 3 |
| | Insert bases were not successfully transferred to the rotary table/tombstone fixture | Bottleneck process<br><br>Production line jamming | 3 | Poor jig design, or inappropriate programming of the machine arm tool path | 2 | Add an extra position sensor and feedback loop to ensure the accurate alignment | Position feedback and operator visual confirmation | 1 | 6 |
| | Machine arm got stuck | Bottleneck process<br><br>Production line jamming | 3 | Insufficient movement space for the machine arm due to a compact layout design | 2 | Stop and move machine arm back to previous position. | operator visual confirmation | 1 | 6 |

| Process | Potential Failure Mode | Potential Effects of Failure | SEV | Potential Causes | OCC | Process Control Prevention | Process Control Detection | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|
| | Machine arm has a low working speed | Slow production line | 2 | Low rotating speed of rotary table or tombstone fixture | 3 | Add an extra velocity sensor and feedback loop to ensure the accurate speed | velocity feedback | 2 | 12 |
| Foam Preparation and Installation | Foam gasket was broken or ripped off when removing from the foam roll | Increase cycle time and material waste | 2 | Poor gripper design | 3 | Add sensors to check whether foam is in position | Sensor feedback and operator visual confirmation | 2 | 12 |
| | Foam gasket was not expanded to the expected rectangular shape | Increase cycle time and material waste | 2 | Poor gripper tool path design | 3 | Recalibrate and test gripper | operator visual confirmation | 2 | 12 |
| | Foam gasket was not fully attached to the insert base | Increase cycle time and material waste | 2 | Calibration error | 3 | Add sensor to check whether foam is in position | Sensor feedback | 2 | 12 |
| Part Removal and Packaging | Finished part was not able to be removed from the rotary table/tombstone fixture | Bottleneck process<br><br>Production line jamming | 3 | Poor gripper design (embedded on the tombstone fixture or on the horizontal rotary table) | 2 | Increase the force of gripper. | operator visual confirmation | 2 | 12 |

## 4.4 Comparison of Alternatives

Each proposed layout option demonstrated above has benefits and drawbacks when performing the feasibility study. These are summarized in Table XXI. Due to the low cost, appropriate system footprint, and the ease of implementation, the Cartesian Gantry layout is determined to be the most feasible solution to automate the existing process.

TABLE XXI: SUMMARY OF OVERALL LAYOUT ALTERNATIVES

| Option | Technology Type | Pros | Cons | Meets Requirements | Est. Cost of Instrument and Operation (CAD) | Installation Effort / Complexity |
|---|---|---|---|---|---|---|
| 1 | Shuttle and Gantry System | • The addition of the second shuttle improves the working efficiency<br>• Relatively low cost with high precision<br>• The use of sensors of the shuttle system allows a close communication between each system and ensures the accuracy of the foam installation as well as the quality of the final product<br>• Reliable and proven technology | • Frequent use of the shuttle system may introduce the equipment wear issue | - Financial: Yes<br>- Space: Yes<br>- Cycle Time: Yes | 126,830 | Low to Medium |

| Option | Technology Type | Pros | Cons | Meets Requirements | Est. Cost of Instrument and Operation (CAD) | Installation Effort / Complexity |
|---|---|---|---|---|---|---|
| 2A.1 | Rotary Indexing Table – 36 inches diameter | • Relatively low footprint<br>• Lowest cost compared to other options<br>• Reliable and proven technology | • Requires extra support underneath the rotary indexing table to elevate the table to the appropriate height<br>• Hard to access the enclosure space to perform maintenance and inspection,<br>• Relatively low accuracy<br>• Long initial set up time<br>• Low working efficiency<br>• Possibility of interfering with the existing machine arm and the packaging robot | - Financial: Yes<br>- Space: Yes<br>- Cycle Time: No | 124,030 | Low |

| Option | Technology Type | Pros | Cons | Meets Requirements | Est. Cost of Instrument and Operation (CAD) | Installation Effort / Complexity |
|---|---|---|---|---|---|---|
| 2A.2 | Rotary Indexing Table – 60 inches diameter | • High working efficiency<br>• Reliable and proven technology | • Extra support to elevate the rotary table<br>• Maintenance issue due to the large diameter of the rotary table<br>• Low accuracy<br>• Possibility of interfering with the existing machine arm and the packaging robot | - Financial: Yes<br>- Space: No<br>- Cycle Time: Yes | 129,760 | Low |
| 2B.1 | Tombstone Fixture with Vertical Gantry System | • Enough space for maintenance and inspection<br>• High working efficiency, the number of workpieces can be more than four<br>• High accuracy up to +/- 0.001” | • High cost<br>• Extra design required for the vertical conveyor system support<br>• Tombstone is usually used for heavy duty metal parts machining. Hard to find the required sized model in the market | - Financial: Yes, but very close to the set limit<br>- Space: No<br>- Cycle Time: Yes | 137,740 | Medium |

| Option | Technology Type | Pros | Cons | Meets Requirements | Est. Cost of Instrument and Operation (CAD) | Installation Effort / Complexity |
|---|---|---|---|---|---|---|
| 2B.1 | Tombstone Fixture with Horizontal Gantry System | • High working efficiency, the number of workpieces can be more than four | • Possibility of interfering with the existing machine arm and the packaging robot during the 90-degree rotation of the end effector assembly<br>• Highest cost compared to other options<br>• Tombstone is usually used for heavy duty metal parts machining. Hard to find the required sized model in the market | - Financial: No<br>- Space: Yes<br>- Cycle Time: Yes | 146,090 | Medium |

## 5.0 Design Summary and Recommendation

After performing a feasibility study of the Cartesian Gantry and Central Rotor Layout systems, considering financial, technical, and risk aspects, the design team determined the Cartesian Gantry Layout to be the most feasible solution for the insert base automated foam installation project due to its high working efficiency, high accuracy and low cost.

As described in the detailed design section, the layout will consist of an alternating dual track shuttle system using linear belt driven actuators that will transport insert base parts from the load position to the foam install position. The foam install position will be situated underneath the three-axis gantry robot controlled by three brushless DC motors connected to planetary gearboxes and corresponding motor controllers. The gantry's end effector will use custom needle grippers to pick four foam gaskets from the supplier roll and expand them before pressing them simultaneously on the insert base parts at the install position. After installation, the shuttle table will transport the parts backwards to the unload position where a six-axis robotic arm with a pinching gripper will remove the parts and place them in the final packaging box. The robotic arm will utilize a dual gripper system so that it can also have a suction gripper to place divider cardboard sheets between the layers of finished parts and move the full boxes between the roller conveyors. Finally, the empty shuttle will return to the load position and wait for the injection molding machine to produce the next set of insert bases. The flow process of the system is illustrated in Figure 80 with the orange boxes being the operations of the first shuttle track, the yellow boxes for the foam installation gantry robot and end effector, and the blue boxes for the operations of the second shuttle track.

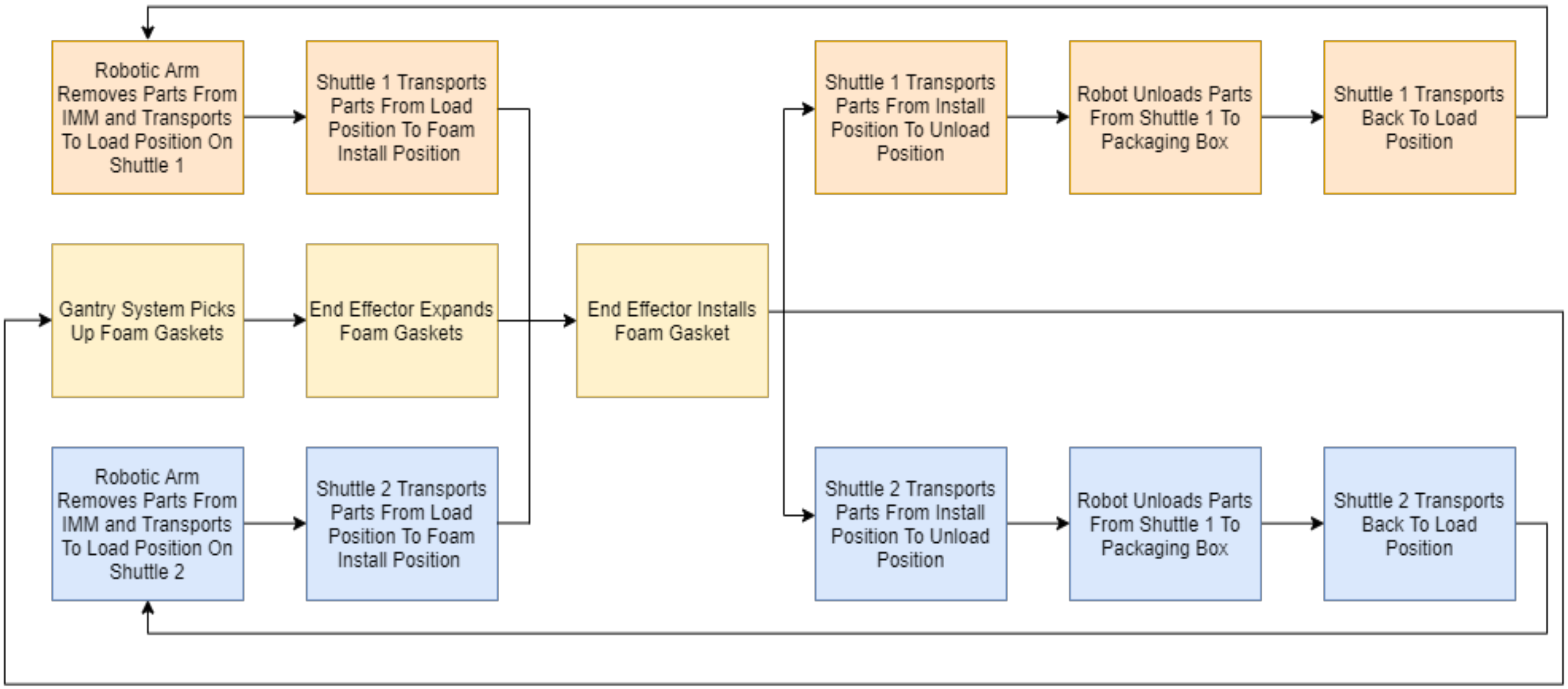


Figure 80: Final design flow process

After considering the initialization bias of the system that caused the first cycle to be 28s, the system was able to achieve a cycle time of 21s per 4 parts. The final Cartesian Gantry assembly and all of its components is shown in Figure 81.

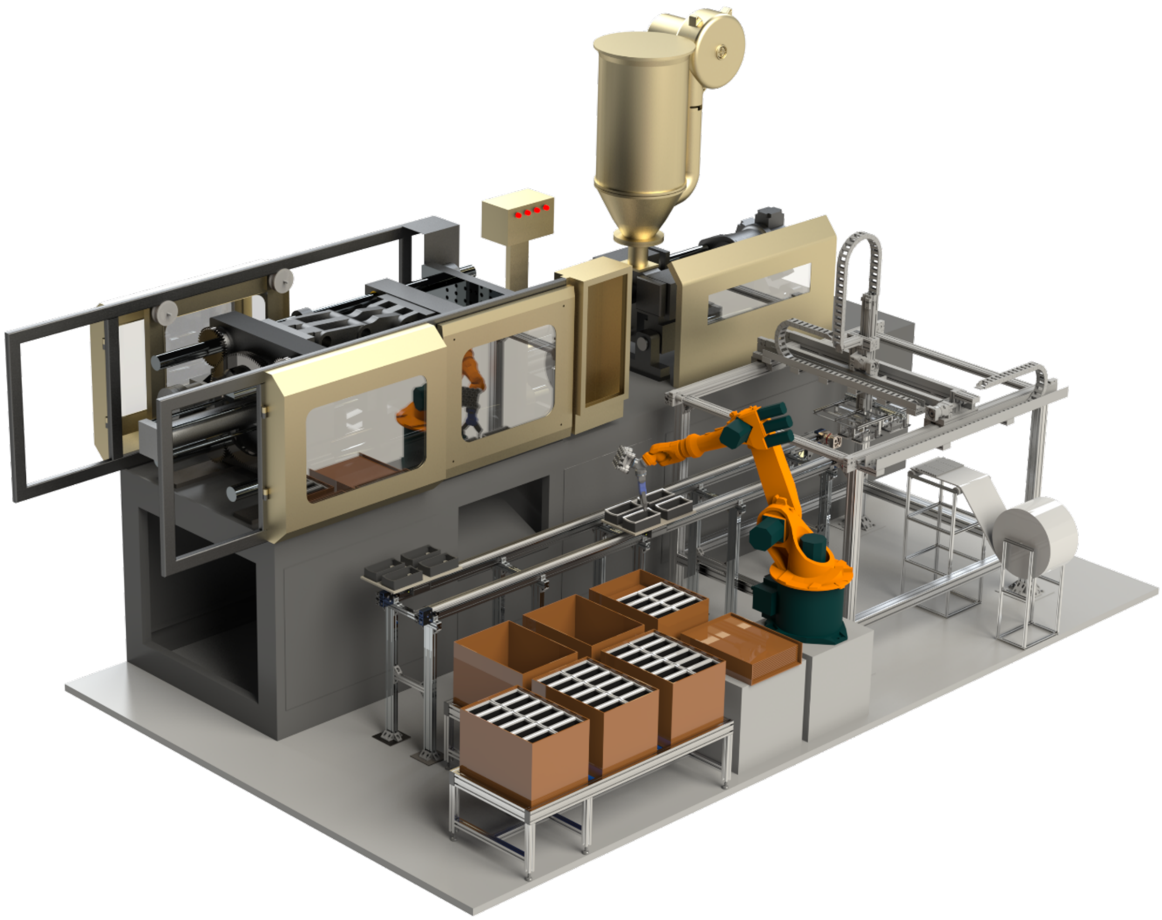

Figure 81: Full gantry assembly

The initial cost of the Cartesian Gantry Layout system was estimated to be $126,195 with an annual operating cost of $345. With a rounded total cost estimate of $127,000 over the first two years, the payback period of $140,000 over two years was achieved, leaving $13,000 for maintenance costs.

The team is confident that the final design has met all of the client needs. However, further work is required before the procurement of the components and the implementation of the design.

The team recommends a detailed needle gripper design should be completed and the gripper supplier should be sourced to ensure such a customized design can be delivered. Due to the technical difficulty of entirely removing the foam gasket from the roll without breaking it, the gripper design would need substantial effort to be finished. The team also recommends the foam roll design can be changed as well to ease the difficulty of the gripper design.

Another recommendation the team suggests is to perform a system and process simulation as well as equipment testing of each specified component. Due to the resource limit, the team could not build a prototype of the system to test the equipment performance. Thus, process simulation and equipment testing are necessary to ensure the designed system could work as expected.

It is recommended to perform a detailed time study of the system based on the actual operating time of each system. The team estimated the operation times for picking up the foam gasket, expanding and installing the foam onto the parts, and unloading the parts from the shuttle system. However, the actual time could change based on the performance of the components.

Due to the time and resource limitations, the detailed programmable logic controller (PLC) programming was not developed in this project. The team recommends that a detailed analysis should be conducted to perform the proposed motions of the 6-axis robot and the shuttle system can be successfully completed.

## 6.0 Conclusion

The design team was tasked with automating the manual process of retrieving and installing foam gaskets onto plastic insert base parts, and placing the completed assembly in the packaging box. Melet Plastics required this process to produce 4 parts every 21s, remain within the current system footprint, reduce the number of operators from 1.5 to 0.5 (an operator spending 4 working hours per day maintaining the system), and have a payback period of two years with an ideal budget limit of $140,000. A feasibility study and a cost estimate, along with the final machine design concept report were required to be the main deliverables.

During the concept development phase, the design was divided into individual systems based on the automation process: an insert base transportation system, a foam pickup, expansion and install system, and a packaging system. The concept development phase originally led to a final layout design, with plans to perform a feasibility study on the foam gasket gripper concepts. However, after considering client feedback and the amount of work required to finalize various detailed gripper designs along with the rest of the automation system, it was decided that the feasibility study should be performed on the two best layouts from the concept development phase. Needle grippers were sourced from a supplier and further details of the gripper design were not explored.

The two layout designs that were finalized with more detail included the Cartesian Gantry and Central Rotor layouts. The Cartesian Gantry Layout consisted of a shuttle system, a gantry system, and a 6-axis robot packaging system. The shuttle system consists of two belt-driven linear actuators which transport the jig tables with the secured insert bases to the gantry system for gasket installation. The gantry system utilizes needle grippers to install the foam gaskets. After the gaskets are installed onto the insert bases, the shuttle system transports the finished products to the packaging area. A six-axis robot is used in the packaging area to unload the insert bases from the shuttle system and place the finished parts in a packaging box.

The Central Rotor Layout had two options, which were using a rotary indexing table or a tombstone fixture as the main component to deliver the insert bases from the existing machine arm to different work stations. Similar gantry system with a larger working reach and the same 6-acis robot were used in the Central Rotor Layout to install the foam gasket and unload the finished parts.

A feasibility study which includes the analysis of financial feasibility, technical feasibility, and risk assessment was performed on two different layout designs. After comparing the pros and cos of each layout, the Cartesian Gantry Layout was selected as the final design with a final estimated cost of approximately $127,000, due to its superior performance on meeting the client needs of cycle time, physical footprint, and the final cost. However, the team recommended that a further detailed analysis should be conducted before implementation, including the needle gripper detailed design, a system and process simulation, equipment testing, a detailed time study, and the detailed PLC programming.

The major client requirements for maintaining the productivity and minimizing the operator number has been achieved by the final design. Each system of the design has been evaluated to ensure the reliability and future performance. With the completion of the further detailed analysis, the team believes the automated design could successfully reduce the operator number to 0.5 while producing 4 finish products every 21 seconds.

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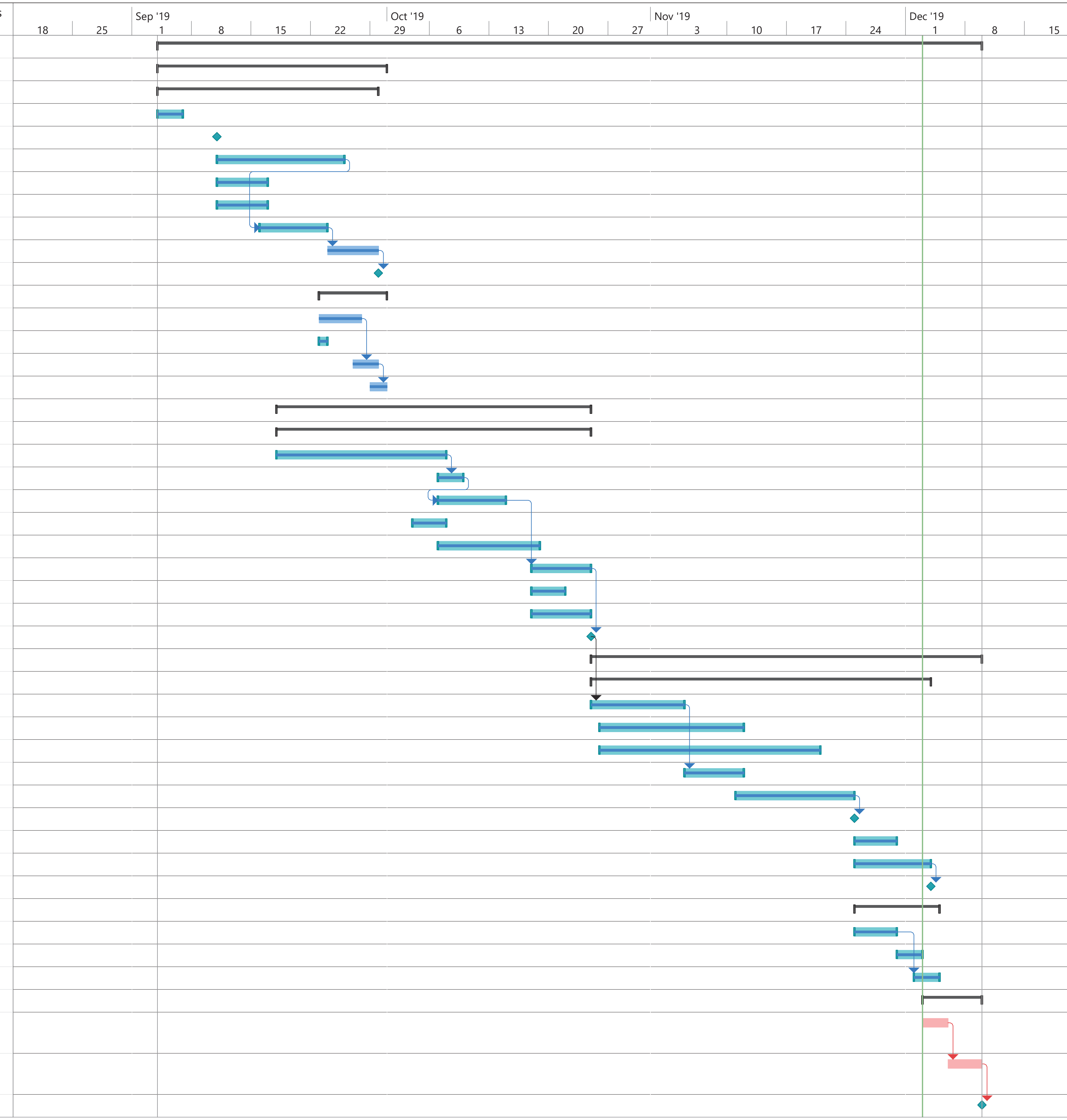
# Appendix A:

# Updated Gantt Chart

| ID | WBS | Task Name | Duration | Start | Finish | Total Slack | Predecessors |
|---|---|---|---|---|---|---|---|
| 1 | **1** | **Melet Insert Base Automated Foam Gasket Installation** | **69 days** | **Wed 9/4/19** | **Vion 12/9/19** | **0 days** | |
| 2 | **1.1** | **Project Initiation and Planning** | **19 days** | **Wed 9/4/19** | **Vion 9/30/19** | **0 days** | |
| 3 | **1.1.1** | **Project Definition Report** | **18 days** | **Wed 9/4/19** | **Vion 9/30/19** | **0 days** | |
| 4 | 1.1.1.1 | Determine Project Team | 3 days | Wed 9/4/19 | Fri 9/6/19 | 0 days | |
| 5 | 1.1.1.2 | Project Team Kickoff Meeting and Site Visit | 0 days | Wed 9/11/19 | Wed 9/11/19 | 0 days | |
| 6 | 1.1.1.3 | Verify & Validate Client Needs and Requirements | 11 days | Wed 9/11/19 | Wed 9/25/19 | 0 days | |
| 7 | 1.1.1.4 | Develop Project Plan | 4 days | Wed 9/11/19 | Mon 9/16/19 | 0 days | |
| 8 | 1.1.1.5 | Develop Project Charter | 4 days | Wed 9/11/19 | Mon 9/16/19 | 0 days | |
| 9 | 1.1.1.6 | Develop Definition Report Drafts | 6 days | Mon 9/16/19 | Mon 9/23/19 | 0 days | 6 |
| 10 | 1.1.1.7 | Definition Report Review and Compilation | 6 days | Tue 9/24/19 | Sun 9/29/19 | 0 days | 9 |
| 11 | 1.1.1.8 | Submit Project Definition Report | 0 days | Mon 9/30/19 | Mon 9/30/19 | 0 days | 10 |
| 12 | **1.1.2** | **Oral Presentation** | **6 days** | **Vion 9/23/19** | **Vion 9/30/19** | **0 days** | |
| 13 | 1.1.2.1 | Distribute and Divide Team's Workload | 5 days | Mon 9/23/19 | Fri 9/27/19 | 0 days | |
| 14 | 1.1.2.2 | Assess Team's Section Progress | 1 day | Mon 9/23/19 | Mon 9/23/19 | 0 days | |
| 15 | 1.1.2.3 | Prepare Oral Presentation | 3 days | Fri 9/27/19 | Sun 9/29/19 | 0 days | 13 |
| 16 | 1.1.2.4 | Review and Compile to Submit | 1 day | Sun 9/29/19 | Mon 9/30/19 | 0 days | 15 |
| 17 | **1.2** | **Project Execution** | **27 days** | **Ned 9/18/19** | **Fri 10/25/19** | **0 days** | |
| 18 | **1.2.1** | **Concept Design Report** | **27 days** | **Ned 9/18/19** | **Fri 10/25/19** | **0 days** | |
| 19 | 1.2.1.1 | Brainstorm and Formulate Concept Ideas | 14 days | Wed 9/18/19 | Mon 10/7/19 | 0 days | |
| 20 | 1.2.1.2 | Concept Analysis/Evaluation and Selection | 3 days | Mon 10/7/19 | Wed 10/9/19 | 0 days | 19 |
| 21 | 1.2.1.3 | Client Input and Discussion | 6 days | Mon 10/7/19 | Ion 10/14/19 | 0 days | 20 |
| 22 | 1.2.1.4 | Distribute and Divide Team's Workload | 2 days | Fri 10/4/19 | Mon 10/7/19 | 0 days | |
| 23 | 1.2.1.5 | Develop Concept Design Report Drafts | 10 days | Mon 10/7/19 | Fri 10/18/19 | 0 days | |
| 24 | 1.2.1.6 | Draft Review and Format/ Revision | 5 days | Fri 10/18/19 | 'hu 10/24/19 | 0 days | 21 |
| 25 | 1.2.1.7 | Advisor Review | 2 days | Fri 10/18/19 | Ion 10/21/19 | 0 days | |
| 26 | 1.2.1.8 | Client Review and Draft Revision | 5 days | Fri 10/18/19 | 'hu 10/24/19 | 0 days | |
| 27 | 1.2.1.9 | Submit Concept Design Report | 0 days | Fri 10/25/19 | Fri 10/25/19 | 0 days | 24 |
| 28 | **1.3** | **Project Closeout** | **32 days** | **Fri 10/25/19** | **Vion 12/9/19** | **0 days** | |
| 29 | **1.3.1** | **Final Design Report** | **28 days** | **Fri 10/25/19** | **Ned 12/4/19** | **0 days** | |
| 30 | 1.3.1.1 | Risk Assessment and Mitigation: (FMEA) | 7 days | Fri 10/25/19 | Mon 11/4/19 | 0 days | 27 |
| 31 | 1.3.1.2 | Cost Estimate | 12 days | Sat 10/26/19 | Ion 11/11/19 | 0 days | |
| 32 | 1.3.1.3 | Finalize Proposed Solution | 19 days | Sat 10/26/19 | /ed 11/20/19 | 0 days | |
| 33 | 1.3.1.4 | Perform Feasibility Study | 5 days | Tue 11/5/19 | Ion 11/11/19 | 0 days | 30 |
| 34 | 1.3.1.5 | Develop Final Report Draft | 11 days | Ion 11/11/19 | iun 11/24/19 | 0 days | |
| 35 | 1.3.1.6 | Submit Draft Report | 0 days | Ion 11/25/19 | Ion 11/25/19 | 0 days | 34 |
| 36 | 1.3.1.7 | Advisor Review | 5 days | Ion 11/25/19 | Fri 11/29/19 | 0 days | |
| 37 | 1.3.1.8 | Client Review and Draft Revision | 7 days | Ion 11/25/19 | Tue 12/3/19 | 0 days | |
| 38 | 1.3.1.9 | Submit Final Report | 0 days | Wed 12/4/19 | Wed 12/4/19 | 0 days | 37 |
| 39 | **1.3.2** | **Final Oral Presentation and Poster Display** | **8 days** | **Ion 11/25/19** | **Ned 12/4/19** | **0 days** | |
| 40 | 1.3.2.1 | Prepare Final Presentation | 5 days | Ion 11/25/19 | Fri 11/29/19 | 0 days | |
| 41 | 1.3.2.2 | Develop Final Poster | 2 days | Sat 11/30/19 | Mon 12/2/19 | 0 days | |
| 42 | 1.3.2.3 | Review and Compile to Submit | 3 days | Mon 12/2/19 | Wed 12/4/19 | 0 days | 40 |
| 43 | **1.3.3** | **Project File/Documents** | **5 days** | **Tue 12/3/19** | **Vion 12/9/19** | **0 days** | |
| 44 | 1.3.3.1 | Compile Revision History (Documents Written Review) | 3 days | Tue 12/3/19 | Thu 12/5/19 | 0 days | |
| 45 | 1.3.3.2 | Review and Compile Project Management Documents | 2 days | Fri 12/6/19 | Mon 12/9/19 | 0 days | 44 |
| 46 | 1.3.3.3 | Submit Documents | 0 days | Mon 12/9/19 | Mon 12/9/19 | 0 days | 45 |




| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Critical | | Milestone | ◆ | Project Summary | | Inactive Milestone | | Manual Summary Rollup | | External Tasks | |
| Critical Split | | Slack | | Rolled Up Critical | | Inactive Summary | | Manual Summary | | External Milestone | |
| Task | | Slippage | | Rolled Up Critical Split | | Manual Task | | Start-only | [ | Deadline | |
| Split | | Summary | | Inactive Task | | Duration-only | | Finish-only | ] | Progress | |

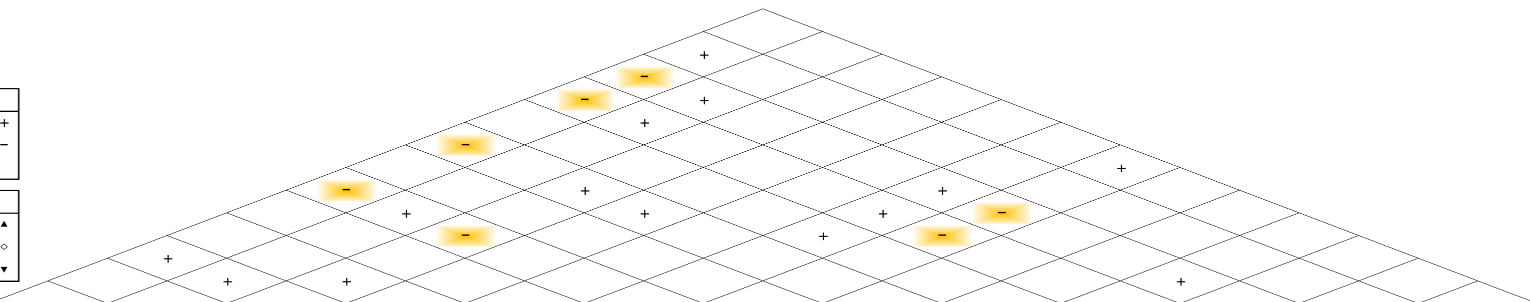
# Appendix B:

# House of Quality

As a summary of the client needs of the project and their metrics, a house of quality (HOD) can be seen in the following Figure B-1.

**Correlations**
Positive +
Negative −
No Correlation

**Direction of Improvement**
Maximize ▲
Target ◇
Minimize ▼



| Client Need Importance | | Client Need \ Technical Specifications | System Cycle Time | Operator Number | Level of Operator Interaction | Adjustable Process | Hazard Analysis | Payback Period Time | System Footprint | Percent Foam Deviation | Percent Outsourced Products/Services | Maintenance Time | Maintenance Cost | Continuous Operation Time | Number of Re-adjusted Processes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Metric # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| | | Direction of Improvement | ◇ | ▼ | ▲ | ▲ | ▼ | ◇ | ▼ | ▼ | ▼ | ▼ | ▼ | ◇ | ▼ |
| 5 | Production Level | Target Cycle Time | • | | | | | | | | | | | | |
| 5 | | Throughput Quantity | • | | | | | | | | | | | | |
| 5 | Minimal Operator Interaction | Number of Operators | | • | • | | | | | | | | | | |
| 4 | | Automation Level | | • | • | | | | | | | | | | |
| 5 | Adaptability | Produces the most common sized parts | | | | • | | | | | | | | | |
| 4 | | Does not require manual changes for different sized parts | | | | • | | | | | | | | | |
| 4 | Safety | Emergency Shutdown Mechanism | | | • | | • | | | | | | | | |
| 3 | Cost | Total Cost | | | | | | • | | | | | | | |
| 3 | Space | Does not exceed the existing footprint | | | | | | | • | | | | | | • |
| 3 | Quality | Installation process with high accuracy | | | | | | | | • | | | | | |
| 2 | | Inspection and Packaging System | | | • | | | | | • | | | | | |
| 3 | Client Satisfaction | Available methods and resources | | | | | | | | | • | | • | | • |
| 2 | User-Friendly | Operator Buy-in | | | • | | | | | | | • | | | |
| 2 | Durability | Low Level of Maintenance | | | | | | • | | | | • | • | | |
| 3 | | Continous operation for a full day's shift | | | | | | | | | | | | • | |
| 1 | Compatibility | Minimum changes to the existing layout | | | | | | | | | | | | | • |
| | | Metric Unit | Second | Person | Subjective | Inch | Yes/No | Month | Feet | Percentage | Percentage | Days /Month | $ | Hours/Day | Number |
| | | Current Value | 21 | 1.5 | Manual | N/A | Yes | N/A | 22 × 13 | N/A | N/A | 2 | $5,000 | 6 | N/A |
| | | Matginal Value | 21 | 1 | Semi-Automated | N/A | Yes | 24 | 50 × 30 | <5 | <20 | 2 | $15,000 | 8 | <3 |
| | | Target Value | 15 | 0.5 | Fully Automated | 1.6 | Yes | 6 | 22 × 13 | 0 | 0 | 1 | $10,000 | 8 | 0 |
| | | Metric Priority | 5 | 5 | 4 | 5 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 1 |

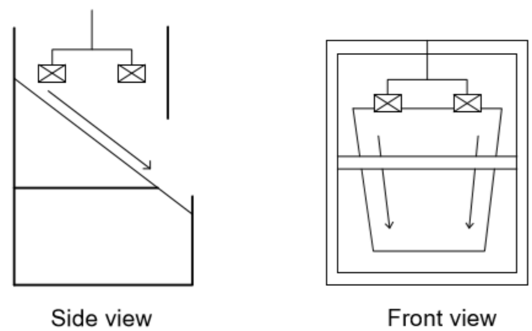
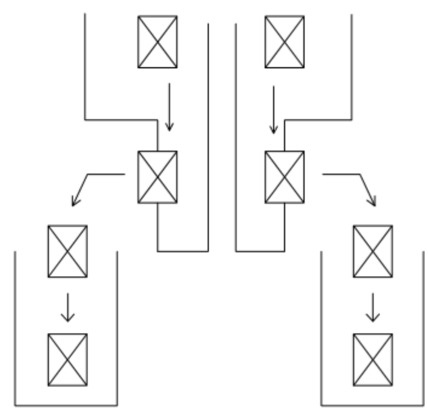
Figure B-1: House of quality

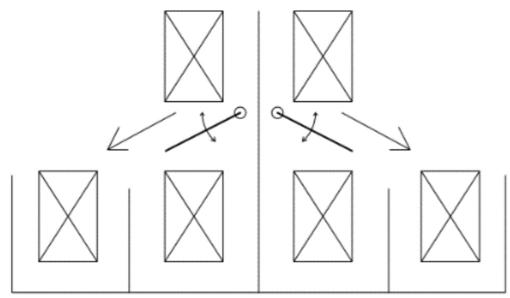
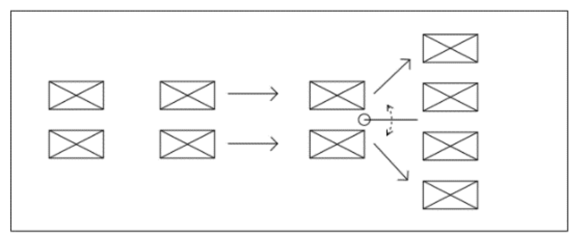
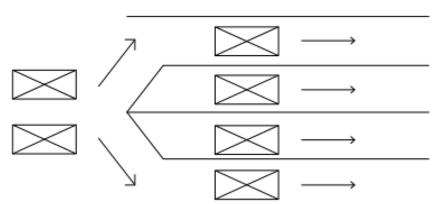
# Appendix C:

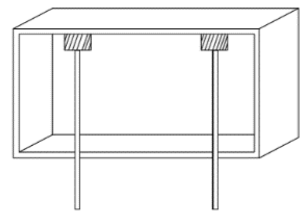
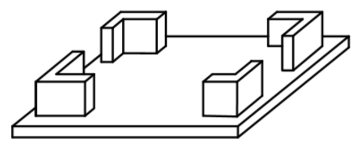
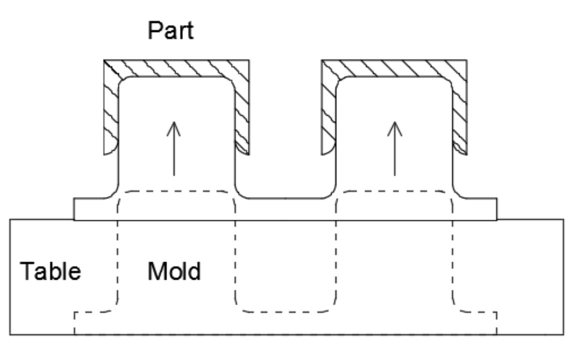
# Preliminary Design Concept

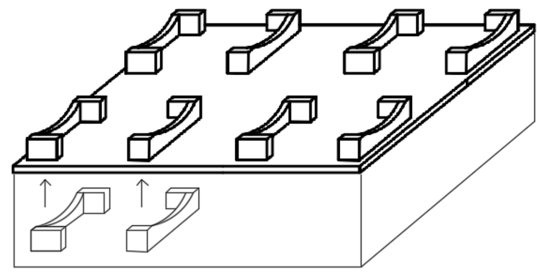
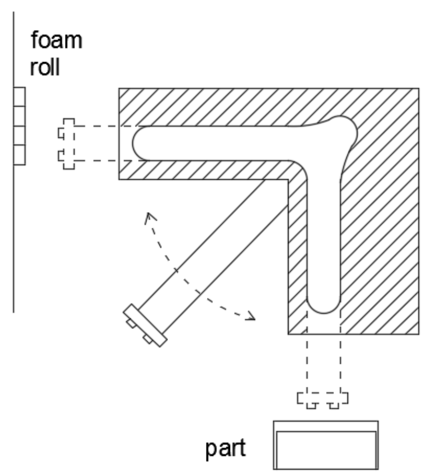
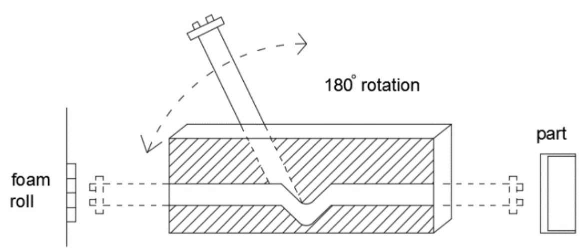
The sketches of the design concepts for each work process were created and is shown in Table C-I.

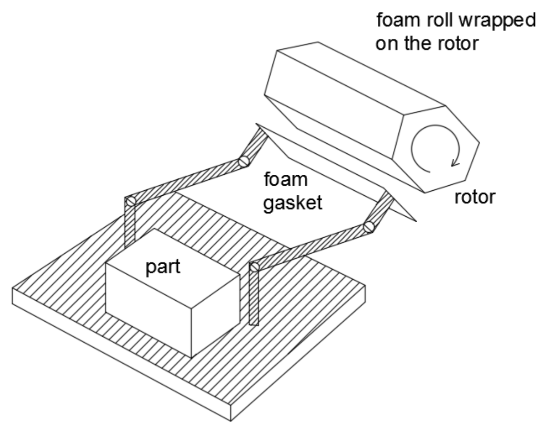
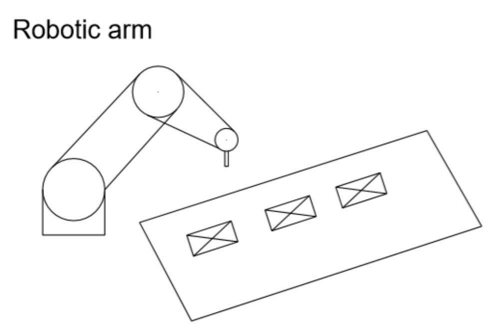
TABLE C-I: PRELIMINARY DESIGN CONCEPTS

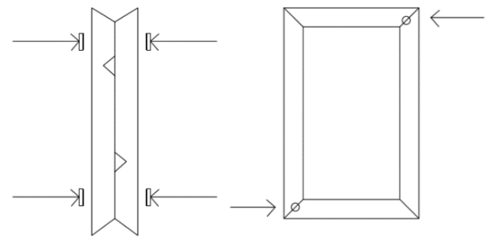
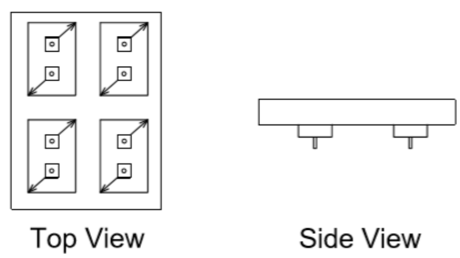
| Description | Sketch |
|---|---|
| **Part Pick-up and Delivery** | |
| **Concept E-1: Chute Delivery System**<br><br>Use a chute delivery system to transport the released parts down two separate channels from the existing robot gripper, instead of falling randomly and disorganized in the current trough system used. This system would leave parts so that the side that gets foam installed is upwards. | <br> |
| **Concept E-2: Guided Chute System**<br><br>Use a guided chute system that has a half-way end at each side, which would force the dropped off plastic parts to flip over at the end and fall down to the next stage. |  |

| Description | Sketch |
|---|---|
| **Concept E-3: Separated Chute System**<br><br>Use a separated chute system with actuating gates to direct the plastic parts into individual compartments, which is easy for the foam installation in the later stages. |  |
| **Concept E-4: Roller Conveyor System**<br><br>Use a roller conveyor system to transport the plastic parts. The parts are dropped onto the conveyor belt that carries and splits the parts using guides or gates. |  |
| **Concept E-5: Angled Chute System**<br><br>Parts are dropped into an angled chute system that splits the parts immediately into a 4 x 1 row. Parts can then be held in a position ready for pickup by robotic arms, or a chute system could deliver the parts directly onto jig for foam installation. |  |

| Description | Sketch |
|---|---|
| **Part Preparation** | |
| **Concept F-1: Extruding Rod Jig**<br><br>Part sits on the extruding rods that are designed for the largest part size to ensure the parts is held at the same height regardless of size. The rods would be inserted in the four cavity holes of the plastic part. |  |
| **Concept F-2: Extruding Mold**<br><br>Part sits on an extruding mold/jig that is designed for the largest part size to ensure the parts is held at the same height regardless of size. The mold would contact the upper lip of the plastic part to hold it in place. |  |
| **Concept F-3: Adjustable Extruding Mold**<br><br>Similar to concept F-2, a mold/jig would be used to hold the part in place. To account for the different sizes of the parts, the mold/jig is able to move up and down to accommodate for the press that is used to fully install the gasket onto the plastic part. |  |

| Description | Sketch |
|---|---|
| **Concept F-4: Extruding Mold**<br><br>Similar to concept F-2, a mold/jig would be used to hold the part in place and in which the mold/jig extrudes upwards when needed |  |
| **Foam Gasket Removal and Installation** | |
| **Concept G-1: 90° Gripper**<br><br>The gripper would pick up the foam from the vertical roll, and expand the foam by using needle-like end effectors or a guiding track, and finally press the foam onto the horizontal plastic parts. The total process would have a 90° rotation. |  |
| **Concept G-2: 180° Gripper**<br><br>The gripper would pick up the foam from the vertical roll, and expand the foam by using needle-like end effectors or a guiding track above the machine during the 180° rotation, and finally flip over the foam gasket to install the foam onto the plastic parts on the other side. |  |

| Description | Sketch |
|---|---|
| **Concept G-3: Rotary Foam Roll**<br><br>This concept design would wrap the foam roll on a rotor which would ease the process of removing the foam from the roll. As the rotor is rotating, the gripper is able to easily remove the foam and install it onto the plastic parts. |  |
| **Concept G-4: Two/Four Pieced Foam Roll**<br><br>This concept would use the machine arm to pick up several plastic parts at the same time (preferably 4 parts) and press the plastic parts on the foam roll to install the foam gasket. This design would however need to change the design of the existing foam roll from a single piece to multi-piece (two or four pieces). |  |

| Description | Sketch |
|---|---|
| **Concept G-5: Six Contact-Point Gripper**<br><br>The gripper picks up the foam gasket through the four contact points at each end. The contact points clip and hold the part to move to the next stage. Two pins then insert into the cavity holes of the existing foam design and are able to expand the foam gasket to the correct shape. |  |
| **Concept G-6: 2 by 2 Pin Gripper**<br><br>This gripper design would utilize the methodology of the six-contact gripper but with a 2x2 orientation so that 4 foam gaskets can be picked up in sequence and installed at the same time. |  |

# Appendix D:

# Concept Screening Results

## List of Tables

To sort out and determine which layout concepts are eligible for further concept development, a preliminary screening was conducted. A list of criteria that was used to screen the concepts was compiled as shown in Table D-I.

TABLE D-I: LIST OF CRITERIA FOR CONCEPT SELECTION

| ID | Criterion | Description |
|---|---|---|
| A | Purchasing Cost | Higher ratings correspond to lower purchasing costs. |
| B | Space | Higher ratings correspond to a lower overall system footprint. |
| C | Complexity | Higher ratings correspond to lower number of moving parts and collaborative systems. |
| D | Ease of implementation | Higher ratings correspond to fewer changes to the existing layout, and fewer number of additional system components that need to be installed. |
| E | Maintenance | Higher ratings correspond to lower frequency and cost of required maintenance. |

To narrow down the layout concepts generated, a decision matrix that uses the existing layout (manual process) as a reference to compare with others was used. Each design was rated as better, equal, or worse, which would be marked as +, -, and 0, respectively. The decision matrix of the preliminary screening is shown in Table D-II.

TABLE D-II: LAYOUT CONCEPT PRELIMINARY SCREENING

| Selection Criteria | Existing Layout | Two robot Layout | One Robot Layout | Cartesian Gantry Layout | Central Rotor Layout |
|---|---|---|---|---|---|
| Cost | 0 | - | 0 | + | 0 |
| Space | 0 | - | + | + | + |
| Complexity | 0 | 0 | 0 | 0 | + |
| Ease of Implementation | 0 | - | - | + | 0 |
| Maintenance | 0 | 0 | + | 0 | 0 |
| | | | | | |
| Plus | 0 | 0 | 2 | 3 | 2 |
| Same | 5 | 2 | 2 | 2 | 3 |
| Minus | 0 | 3 | 1 | 0 | 0 |
| | | | | | |
| Net Score | 0 | -3 | 1 | 3 | 2 |
| Rank | 5 | 4 | 3 | 1 | 2 |
| Continue? | No | No | No | Yes | Yes |

Using the same criteria, a sensitivity analysis was performed to assign each criterion their appropriate weight. The assignment of each specific weight was determined using a weighting matrix as shown in Table D-III.

TABLE D-III: CRITERIA WEIGHTING MATRIX

| | | Purchasing Cost | Space | Complexity | Ease of implementation | Maintenance |
|---|---|---|---|---|---|---|
| **Criteria** | | **A** | **B** | **C** | **D** | **E** |
| **A** | Purchasing Cost | | A | A | A | A |
| **B** | Space | | | B | D | B |
| **C** | Complexity | | | | C | E |
| **D** | Ease of implementation | | | | | E |
| **E** | Maintenance | | | | | |
| **Total Hits** | | 4 | 2 | 1 | 1 | 2 |
| **Weightings** | | 0.4 | 0.2 | 0.1 | 0.1 | 0.2 |

Using the criteria and their respective assigned weights, analysis of concepts C, D1, and D2 was performed using a weighted decision matrix as shown in Table D-IV. Each concept is rated with a rank from 1 to 3 with 1 being the worst and 3 being the best.

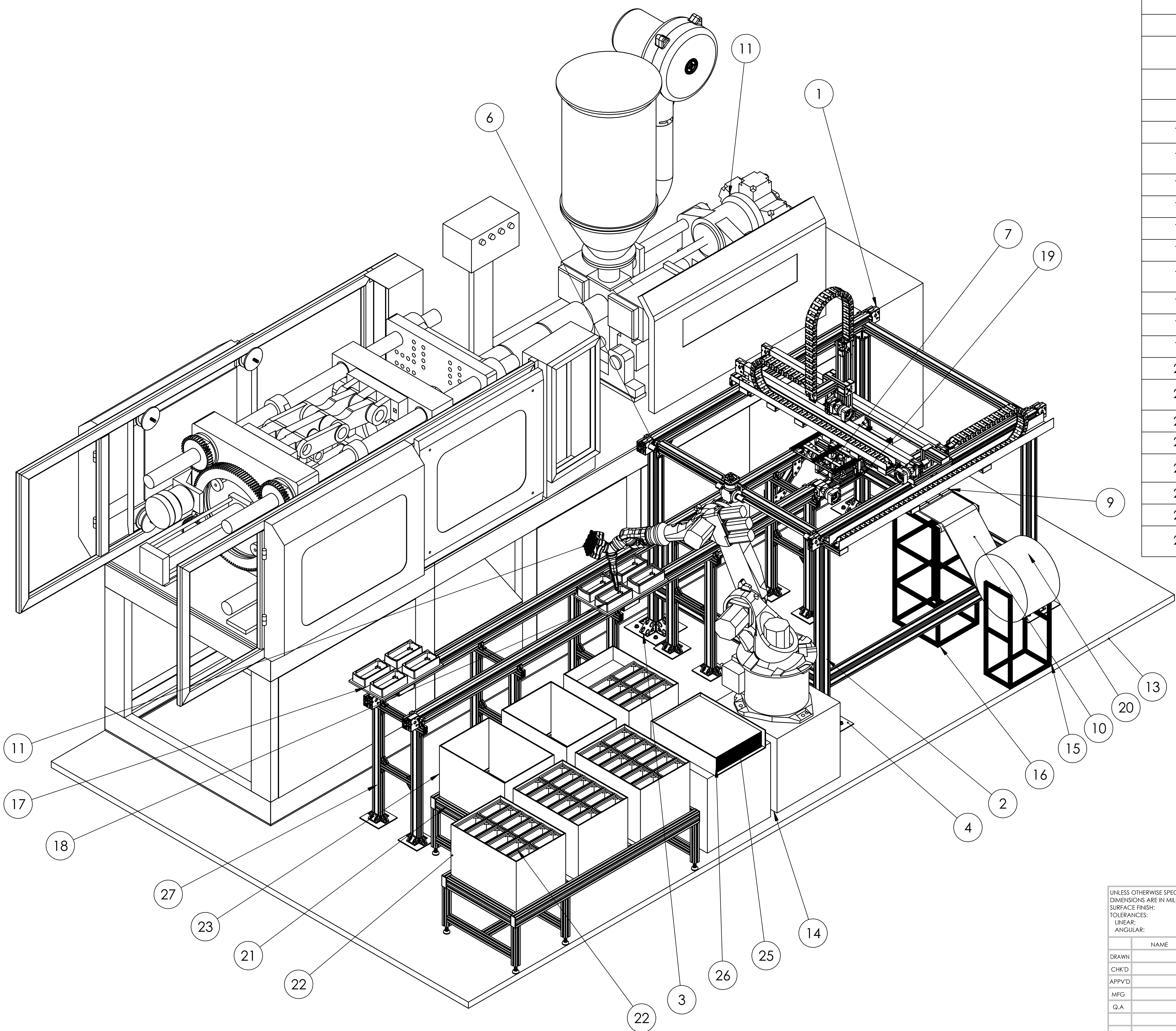
TABLE D-IV: WEIGHTED DECISION MATRIX

| | | Concepts | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Concept C: Cartesian Gantry Layout** | | **Concept D1: Rotary Indexing Table** | | **Concept D2: Central Rotor Layout** | |
| Selection Criteria | Weight % | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score |
| **Purchasing Cost** | 40 | 3 | 1.2 | 2 | 0.8 | 2 | 0.8 |
| **Space** | 20 | 3 | 0.6 | 2 | 0.4 | 2 | 0.4 |
| **Complexity** | 10 | 2 | 0.2 | 3 | 0.3 | 1 | 0.1 |
| **Ease of Implementation** | 10 | 3 | 0.3 | 2 | 0.2 | 1 | 0.1 |
| **Maintenance** | 20 | 2 | 0.4 | 2 | 0.4 | 1 | 0.2 |
| | **Total** | 2.7 | | 2.1 | | 1.6 | |
| **Selected Concept?** | | Yes | | No | | No | |

# Appendix E:

# Assembly Drawings

# Gantry Layout




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | MCS-UC1-1600-1000-250.STEP | Gantry System | 1 |
| 2 | 8080 Aluminum Extrusion Profile | 8080 Aluminum Extrusion Profile | 4 |
| 3 | 5537T600_T-SLOTTED FRAMING | Gantry Gusset Brackets | 24 |
| 4 | Floor Plate | Floor Plate | 4 |
| 5 | 91578A115 | M9 Bolt | 16 |
| 6 | 96144A262 | 1/2" Anchor Bolt | 21 |
| 7 | 2x2 Needle Gripper - Stacked | Needle Gripper | 1 |
| 8 | 5537T665_T-SLOTTED FRAMING | Gantry Gusset Brackets | 1 |
| 9 | Gasket | Gasket | 9 |
| 10 | Foam Roll | Foam Roll | 1 |
| 11 | Injection Molding Machine | Injection Molding Machine | 1 |
| 12 | KUKA_KR6 | KUKA_KR6 | 1 |
| 13 | Concrete Slab | Concrete Slab | 1 |
| 14 | Kuka Platform | Kuka Platform | 2 |
| 15 | Foam Roll Fixture | Foam Roll Fixture | 1 |
| 16 | Foam Roll Secondary Fixture | Foam Roll Secondary Fixture | 1 |
| 17 | Insert Base | Insert Base | 4 |
| 18 | Foam Gakset Installed | Foam Gakset Installed | 4 |
| 19 | Cross Member | Cross Member | 2 |
| 20 | Cross Member 2 | Cross Member 2 | 2 |
| 21 | lower packaging area - Copy | lower packaging area - Copy | 2 |
| 22 | Full Box | Full Box | 3 |
| 23 | Packaging Box | Packaging Box | 3 |
| 24 | Small Insert Base w Foam Gasket | Small Insert Base w Foam Gasket | 8 |
| 25 | cardboard Sheet | cardboard Sheet | 14 |
| 26 | Cardboard Stack | Cardboard Stack | 1 |
| 27 | Final Shuttle System Assembly | Final Shuttle System Assembly | 1 |

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

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| | NAME | SIGNATURE | DATE |
|---|---|---|---|
| DRAWN | | | |
| CHK'D | | | |
| APPV'D | | | |
| MFG | | | |
| Q.A | | | |

MATERIAL:

WEIGHT:

TITLE: Gantry Layout

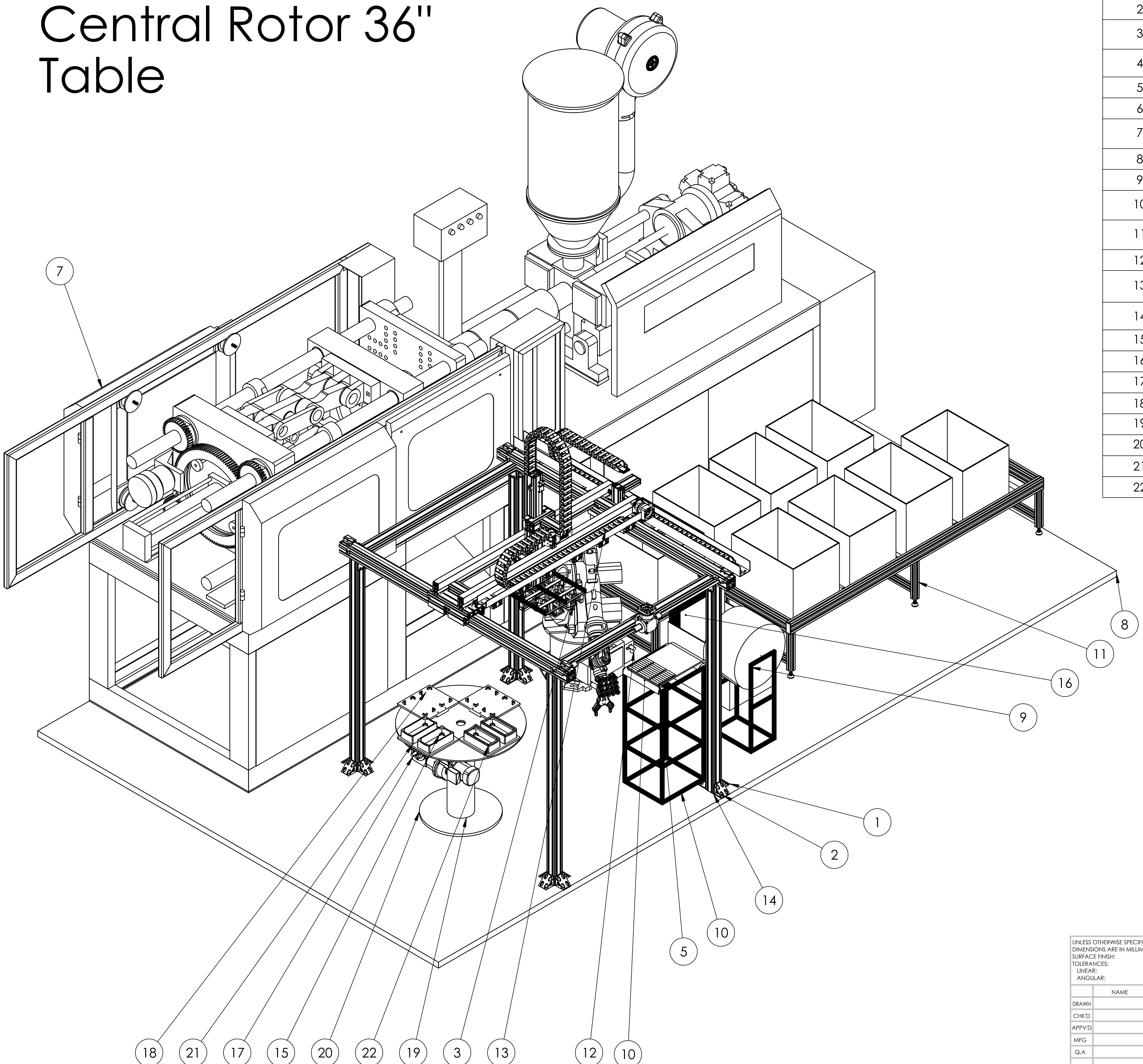
DWG NO.

A2

SCALE:1:50

SHEET 1 OF 1

# Central Rotor 36" Table




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 5537T600_T-SLOTTED FRAMING | 5537T600_T-SLOTTED FRAMING | 24 |
| 2 | 96144A262 | 96144A262 | 21 |
| 3 | 2x2 Fake Needle Gripper - Stacked | Needle Gripper | 1 |
| 4 | 5537T665_T-SLOTTED FRAMING | 5537T665_T-SLOTTED FRAMING | 1 |
| 5 | Gasket | Gasket | 9 |
| 6 | Foam Roll | Foam Roll | 1 |
| 7 | Injection Molding Machine | Injection Molding Machine | 1 |
| 8 | Concrete Slab | Concrete Slab | 1 |
| 9 | Foam Roll Fixture | Foam Roll Fixture | 1 |
| 10 | Foam Roll Secondary Fixture | Foam Roll Secondary Fixture | 1 |
| 11 | lower packaging area | lower packaging area | 2 |
| 12 | KUKA_KR6 | KUKA_KR6 | 1 |
| 13 | MCS-UC1-1600-1000-250 | Gantry System | 1 |
| 14 | 8080 Aluminum Extrusion Profile | 8080 Aluminum Extrusion Profile | 4 |
| 15 | Mounting Table_half | Mounting Table | 4 |
| 16 | Cardboard Storage | Cardboard Storage | 1 |
| 17 | rotary_table | rotary_table | 1 |
| 18 | desk_36 | desk_36 | 1 |
| 19 | support | support | 1 |
| 20 | support-base | support-base | 1 |
| 21 | Insert Base | Insert Base | 2 |
| 22 | Foam Gakset Installed | Foam Gakset Installed | 2 |

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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

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REVISION

| | NAME | SIGNATURE | DATE |
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| DRAWN | | | |
| CHK'D | | | |
| APPV'D | | | |
| MFG | | | |
| Q.A | | | |

MATERIAL:

WEIGHT:

TITLE: Central Rotor 36"

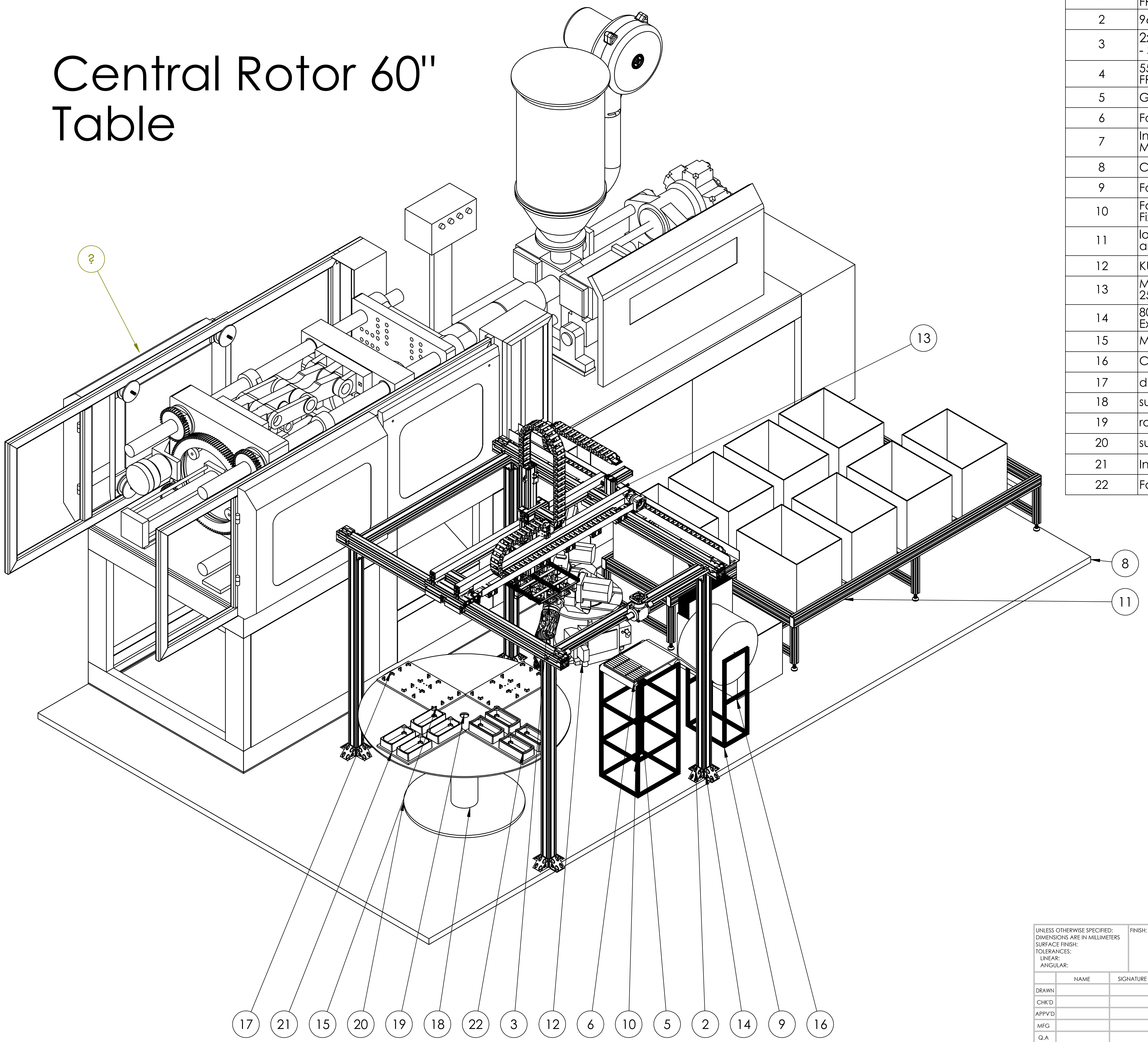
DWG NO.

A2

SCALE:1:50

SHEET 1 OF 1

# Central Rotor 60" Table




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 5537T600_T-SLOTTED FRAMING | Gusset Bracket | 24 |
| 2 | 96144A262 | M9 Bolt | 21 |
| 3 | 2x2 Needle Gripper - Stacked | Needle Gripper | 1 |
| 4 | 5537T665_T-SLOTTED FRAMING | Gusset Bracket | 1 |
| 5 | Gasket | Gasket | 9 |
| 6 | Foam Roll | Foam Roll | 1 |
| 7 | Injection Molding Machine | Injection Molding Machine | 1 |
| 8 | Concrete Slab | Concrete Slab | 1 |
| 9 | Foam Roll Fixture | Foam Roll Fixture | 1 |
| 10 | Foam Roll Secondary Fixture | Foam Roll Secondary Fixture | 1 |
| 11 | lower packaging area | lower packaging area | 2 |
| 12 | KUKA_KR6 | KUKA_KR6 | 1 |
| 13 | MCS-UC1-1600-1000-250_zhifanFu | Gantry System | 1 |
| 14 | 8080 Aluminum Extrusion Profile | 8080 Aluminum Extrusion Profile | 4 |
| 15 | Mounting Table | Mounting Table | 4 |
| 16 | Cardboard Storage | Cardboard Storage | 1 |
| 17 | desk_60 | desk_60 | 1 |
| 18 | support | support | 1 |
| 19 | rotary_table | rotary_table | 1 |
| 20 | support-base-60 | support-base-60 | 1 |
| 21 | Insert Base | Insert Base | 4 |
| 22 | Foam Gakset Installed | Foam Gakset Installed | 4 |

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TOLERANCES:
LINEAR:
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FINISH:

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| | NAME | SIGNATURE | DATE |
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| DRAWN | | | |
| CHK'D | | | |
| APPV'D | | | |
| MFG | | | |
| Q.A | | | |

MATERIAL:

WEIGHT:

TITLE: Central Rotor 60"

DWG NO.

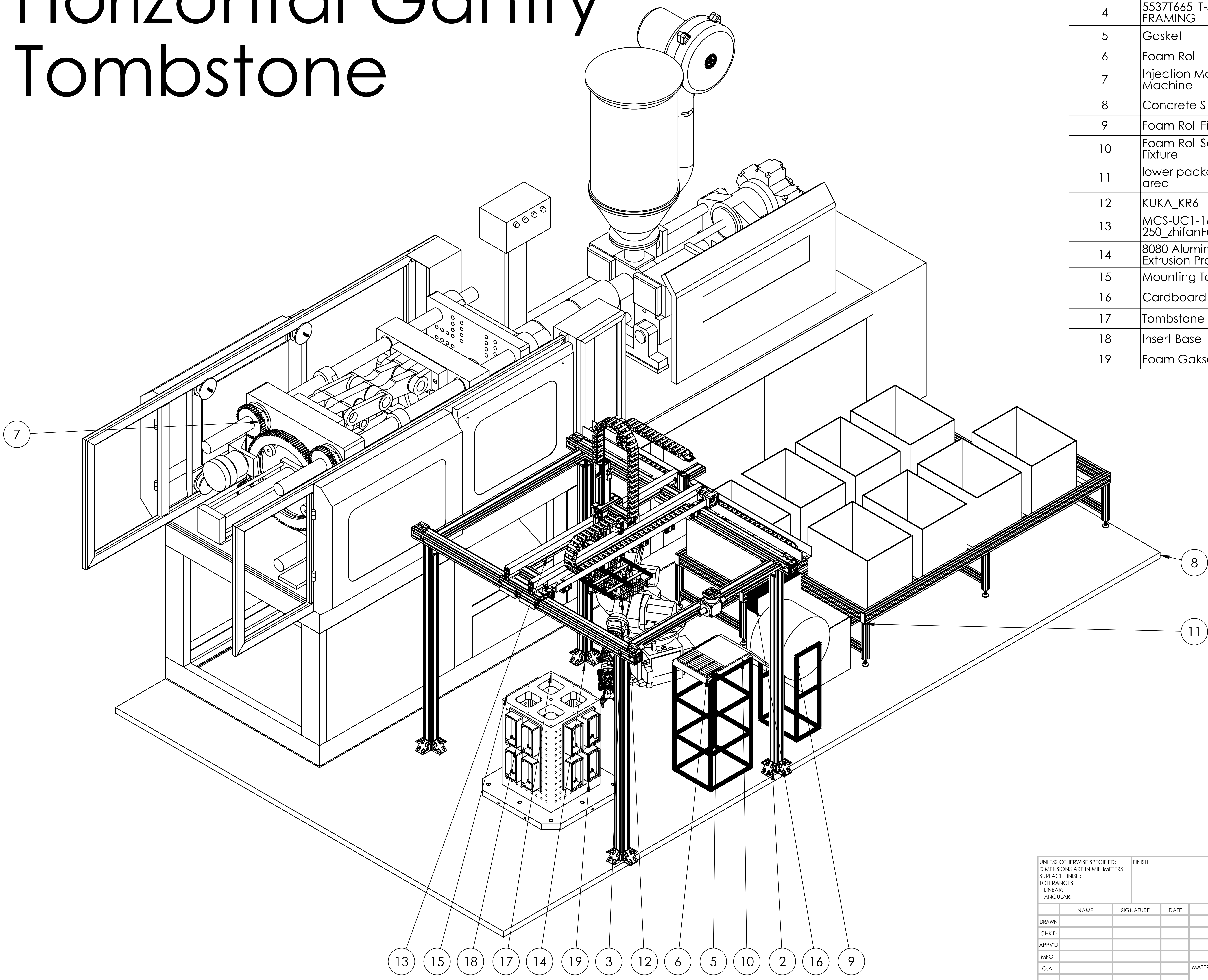
A2

SCALE:1:50

SHEET 1 OF 1

# Horizontal Gantry Tombstone

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 5537T600_T-SLOTTED FRAMING | Gusset Bracket | 24 |
| 2 | 96144A262 | M9 Bolt | 21 |
| 3 | 2x2 Needle Gripper - Stacked | Needle Gripper | 1 |
| 4 | 5537T665_T-SLOTTED FRAMING | Gusset Bracket | 1 |
| 5 | Gasket | Gasket | 9 |
| 6 | Foam Roll | Foam Roll | 1 |
| 7 | Injection Molding Machine | Injection Molding Machine | 1 |
| 8 | Concrete Slab | Concrete Slab | 1 |
| 9 | Foam Roll Fixture | Foam Roll Fixture | 1 |
| 10 | Foam Roll Secondary Fixture | Foam Roll Secondary Fixture | 1 |
| 11 | lower packaging area | lower packaging area | 2 |
| 12 | KUKA_KR6 | KUKA_KR6 | 1 |
| 13 | MCS-UC1-1600-1000-250_zhifanFu | Gantry System | 1 |
| 14 | 8080 Aluminum Extrusion Profile | 8080 Aluminum Extrusion Profile | 4 |
| 15 | Mounting Table | Mounting Table | 4 |
| 16 | Cardboard Storage | Cardboard Storage | 1 |
| 17 | Tombstone | Tombstone | 1 |
| 18 | Insert Base | Insert Base | 4 |
| 19 | Foam Gakset Installed | Foam Gakset Installed | 4 |

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DIMENSIONS ARE IN MILLIMETERS
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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

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REVISION

| | NAME | SIGNATURE | DATE |
|---|---|---|---|
| DRAWN | | | |
| CHK'D | | | |
| APPV'D | | | |
| MFG | | | |
| Q.A | | | |

MATERIAL:

WEIGHT:

TITLE:

Horizontal Gantry Tombstone

DWG NO.

A2

SCALE:1:50

SHEET 1 OF 1

# Vertical Gantry Tombstone


| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 2x2 Needle Gripper - Stacked | Needle Gripper | 1 |
| 2 | Gasket | Gasket | 11 |
| 3 | Injection Molding Machine | Injection Molding Machine | 1 |
| 4 | Concrete Slab | Concrete Slab | 1 |
| 5 | Foam Roll Secondary Fixture | Foam Roll Secondary Fixture | 1 |
| 6 | lower packaging area | lower packaging area | 2 |
| 7 | W60 1500x1500 vertical gantry type2 | Vertical gantry | 1 |
| 8 | KUKA_KR6 | KUKA_KR6 | 1 |
| 9 | Tombstone | Tombstone | 1 |
| 10 | Mounting Table | Mounting Table | 4 |
| 11 | Cardboard Storage | Cardboard Storage | 1 |
| 12 | Foam Roll_tunbstone | Foam Roll_tunbstone | 1 |
| 13 | aluminum extrusion 7 | aluminum extrusion 7 | 2 |
| 14 | Insert Base | Insert Base | 4 |
| 15 | Foam Gakset Installed | Foam Gakset Installed | 4 |

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

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REVISION

| | NAME | SIGNATURE | DATE |
|---|---|---|---|
| DRAWN | | | |
| CHK'D | | | |
| APPV'D | | | |
| MFG | | | |
| Q.A | | | |

MATERIAL:

WEIGHT:

TITLE: Vertical Gantry Tombstone

DWG NO.

A2

SCALE:1:50

SHEET 1 OF 1