Design of Robot for Solar Panel Tempered Glass Pick and Place on Edge Handling Conveyor

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Abbreviations and Acronyms

DOF: Degrees of Freedom
UR: Universal Robot
VAVE: Value Analysis and Value Engineering

Abstract

In the solar panel manufacturing industry, the precise handling of delicate materials, such as solar panel glass, is critical to ensure product quality and efficiency. The integration of robots equipped with carefully designed end effectors addresses specific necessity of transferring solar panel glass to an edge handling conveyor without leaving any smudges on glass surface. This abstract explores essential factors driving design of robots and selection of suitable end effectors to achieve a smudge-free solar panel glass handling process.

1. **Precision and Delicacy:** Solar panel glass is fragile and prone to damage. Robots equipped with precise movements and sensors ensure gentle handling, minimizing the risk of breakage or scratches. The selection of an appropriate end effector, tailored to the glass's dimensions and weight, further guarantees accurate manipulation.
2. **Efficiency and Speed:** Robots operate consistently at high speeds, leading to increased throughput in the manufacturing process. By swiftly transferring the glass panels to edge handling conveyor, robots optimize production, meeting industry demands effectively.
3. **Safety**: Automating glass handling mitigates the risk of injuries associated with manual intervention. Robots can navigate sharp edges and handle heavy loads, ensuring a safe working environment for human operators.
4. **Customization and Adaptability:** Solar panels come in various sizes and shapes. Designing robots with adaptable end effectors allows seamless customization for different panel dimensions. This flexibility ensures compatibility with diverse manufacturing requirements, enhancing overall productivity.
5. **Integration with Conveyor Systems:** Properly designed robots seamlessly integrate with edge-handling conveyors. The choice of the end effector is critical in ensuring a smooth transition of panels from the robot to the conveyor. Well-coordinated automation streamlines the workflow, minimizing downtime and maximizing efficiency.
6. **Quality Assurance:** Consistency in handling, made possible by robots, guarantees uniformity in the manufacturing process. Precise movements and controlled placement facilitated by the right end effector contribute significantly to the quality of the final product, meeting industry standards.
7. **Cost-Effectiveness:** While initial investments are involved in robot implementation, the long-term benefits outweigh costs. Reduced labour requirements minimized wastage due to damage, and enhanced production efficiency lead to substantial cost savings over time.

In conclusion, the integration of robots with tailored end effectors for solar panel glass handling is imperative in the solar panel manufacturing industry. This automation ensures precise, efficient, and safe material handling, ultimately contributing to the industry's growth, product quality, and competitiveness in the global market.

1 Introduction

The main goal of this project would be to design a robot and a gripper in order to effectively pick and place solar panel glass on a edge-handling conveyor, and the main requirement here is that the gripper should not leave any scratches or smudges on the glass. Here we aim to select the robot depending on the crucial parameters such as performance and cost in path of meeting the industry's requirements.

The requirement of industry for the automation handled workpiece (Glass) is as follows:

Table 1.1 Industry specified information for the Glass Pick and Place

Sl. No.	Parameter	Value
1.	Sheet Size - Length	1.5 m
2.	Sheet Size - Width	0.9 m
3.	Sheet Thickness	3 mm
4.	Number of Sheet in Stack	25

Now depending upon these parameters, we arrive upon the specifications of the robot to perform its duties as prescribed.

The following figure describes the Flow of Objectives followed in project completion:

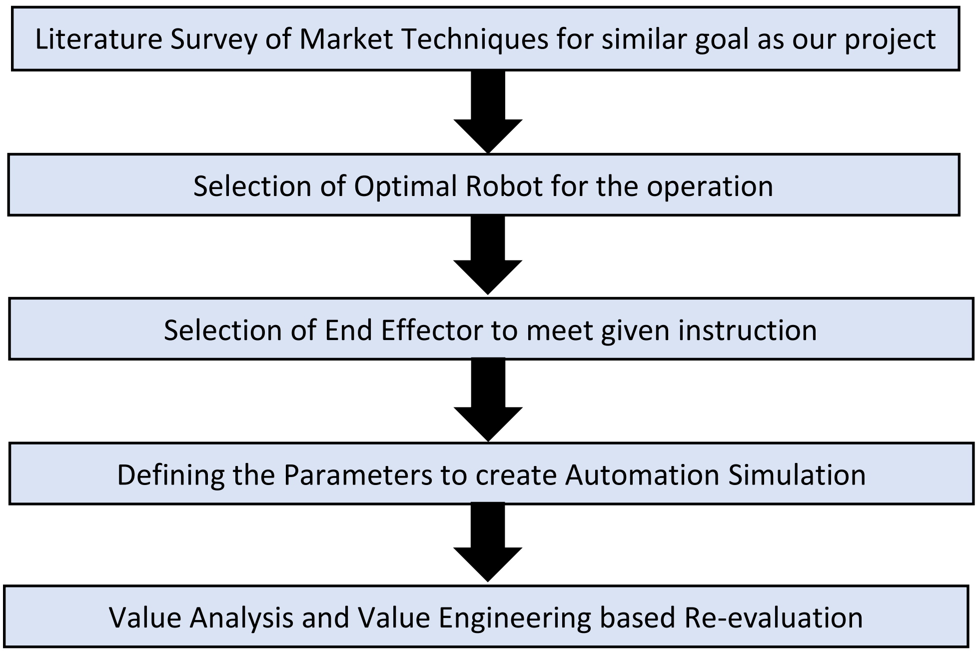


Figure 1.1 Workflow diagram of project objectives

2 Literature Review

2.1 Introduction

This chapter summarizes the required techniques and methodologies followed by Robotic developers performing the operation of Pick and Place in industrial setup.

Selecting a robot for pick and place of solar panel tempered glass sheets requires careful consideration of several factors to ensure efficient, precise, and safe handling. Here are the key considerations:

1. **Payload Capacity**: Determine the weight of the solar panel tempered glass sheets to be handled. Choose a robot with a payload capacity that exceeds the weight of the heaviest glass sheet to ensure safe and stable handling.
2. **Reach and Workspace**: Consider the size and layout of the work area. Choose a robot with an appropriate reach and workspace dimensions to cover the entire area where glass sheets need to be picked and placed. Ensure that the robot's arm length and height meet the spatial requirements of the production line.
3. **End Effector Design**: The end effector, or gripper, is crucial for handling glass sheets. Select or design an end effector that securely grips the glass without damage. Vacuum-based grippers or soft robotic grippers are used for fragile objects like glass sheets.
4. **Accuracy and Repeatability**: Precision is vital in handling delicate glass sheets. Look for a robot with high accuracy and repeatability ratings to ensure that the placement of the glass sheets is consistent and aligned accurately during the manufacturing process.
5. **Speed and Cycle Time**: Consider the production speed requirements. Choose a robot that can handle glass sheets swiftly to meet production targets. Balance speed with accuracy to maintain a high-quality standard.
6. **Programming and Control**: Evaluate the ease of programming and control interfaces. User-friendly programming software and intuitive control systems simplify the setup and operation of the robot. Look for robots that support offline programming, allowing for simulation and programming without disrupting the production line.
7. **Safety Features**: Ensure that the robot is equipped with safety features such as collision detection, force/torque sensing, and emergency stop mechanisms. Safety sensors and systems prevent accidents and protect both equipment and personnel working in vicinity.
8. **Integration Capabilities:** Consider the robot's compatibility with other automation equipment and control systems in the manufacturing process. A robot that can seamlessly integrate with conveyor systems, sensors, and PLCs simplifies overall automation setup.
9. **Maintenance and Reliability:** Choose a robot from a reputable manufacturer known for reliability and ease of maintenance. Consider factors such as mean time between failures (MTBF) and the availability of local technical support and spare parts.
10. **Cost**: Evaluate the initial cost of the robot and its long-term return on investment. Consider factors like reduced labor costs, increased productivity, and minimized material wastage when assessing the overall cost-effectiveness of the robotic solution.

By carefully evaluating these considerations, you can select a robot that is well-suited for pick and place solar panel tempered glass sheets, ensuring an efficient manufacturing process.

2.2 Literature Review

In response to the evolving demands of the Flat Panel Display (FPD) industry, characterized by the need for "large display, high performance, and low cost" products [1], there is a critical emphasis on making glass substrates both larger and thinner. Consequently, the development of handling robots has shifted towards attributes of large scale, high speed, and high precision. In this context, a novel glass substrate-handling robot is introduced, notable for its exceptional traveling speed of 2.5 meters per second and innovative adoption of bionic end-suction technology to enhance grip. Structurally, the robot comprises a travel track, robot body, and an end-effector, with a unique manipulator design allowing rapid extension for efficient handling. This robot can simultaneously transfer two glass substrates, optimizing working efficiency. The article also details the establishment of kinematic and dynamic models for accurate performance prediction. Experimental results affirm the robot's high precision during handling operations. Ultimately, these robots are positioned as valuable assets for large-scale glass substrate handling in the FPD industry, aligning with the industry's evolving requirements.

The [2] refers to advancements in the field of robotics applications as significant, with an expanding array of potential uses anticipated in space exploration, military applications, and everyday life. Robots, mechanical devices capable of automated tasks based on predefined programs or general guidelines, are increasingly replacing or enhancing human labor in activities such as manufacturing, construction, and handling heavy or hazardous materials. These robots have become pivotal in automating flexible manufacturing systems, addressing the rising demand for quality with ISO standards and increasing labor costs. Material handling, a critical aspect of automation, has seen innovative approaches, such as pneumatic systems integrating vacuum suckers and gripper mechanisms in material handling robots, especially in the context of glass substrate pick and drop operations. This literature review also highlights related research efforts, including the design of pick-and-place robots for industrial workstations, the importance of universal grippers in industrial applications, and the automation of mobile pick-and-place robotic systems for the food industry. These studies collectively underscore the continuous evolution of robotic technology to meet diverse and demanding industrial needs, focusing on efficiency, precision, and adaptability in various applications.

The [3] discusses the design constraints and importance of vacuum grippers for robots in various industrial applications. Vacuum grippers serve as crucial tools in robotic manipulators, allowing them to grasp and manipulate objects effectively. The primary focus of this review is on the development of vacuum grippers tailored for handling a wide range of materials, particularly in industrial contexts where delicate, variable-sized, and weighty objects need to be manipulated. It highlights the need for grippers capable of accommodating the specific requirements of different applications. The review also provides insights into the technology behind vacuum grippers, emphasizing the use of suction cups and the principles of pressure differentials to securely hold objects. Furthermore, it outlines various factors influencing the design parameters of vacuum grippers, such as materials, temperature considerations, and safety factors, emphasizing the importance of achieving precision and safety in robotic operations. The literature review also touches on the application areas of vacuum grippers, spanning heavy industries, manufacturing, packaging, and more, underscoring their versatility and significance in modern industrial automation. Overall, it sheds light on the evolving field of vacuum gripper design and its pivotal role in enhancing robotic capabilities across industries.

In the realm of logistics automation, where efficiency is paramount, the development of swift pick-and-place robotics employing suction cups plays a pivotal role. The study in [4] tackles the challenge of achieving "critically fast" object transport without compromising safety and reliability while maintaining low computational overhead. The proposed approach encompasses three key components: (a) a comprehensive model for understanding the intricate dynamics of suction cup-object contacts, (b) a systematic procedure to pinpoint the critical contact stability constraints based on the established model, and (c) an innovative pipeline for the time-optimal parameterization of diverse geometric paths while adhering to the identified contact stability constraints. Through rigorous experimentation on a physical robot system, this research substantiates the practical viability of the proposed pipeline, demonstrating that typical pick-and-place tasks can be executed in under 5 seconds, encompassing both planning and execution phases. This contribution represents a significant stride towards enabling swift and dependable pick-and-place operations, thereby facilitating the advancement of automation in logistics and related industries.

The paper [5] provides information about vacuum-operated vehicle glass handling systems. The system consists of multiple suction cups connected to the vacuum source, providing suction to each cup, which leads to the lifting of vehicle glass. Moreover, another study [6] discusses the development of a new generation of collaborative robots deployed for handling materials because of increased efficiency and safety. Collaborative robotics are used to bridge the gap between fully automatic and manual technology. Collaborative robots offer solutions to complex assembly tasks by combining human judgment and robot repeatability, making them valuable.

Research is focused on developing gripping systems effectively designed for lifting flat objects such as glass and wood. The gripping systems are designed to be adaptable to the shape and size of the objects to be handled. In addition, computer vision systems have a major role in material handling operations. The integration of cameras and sensors provides the manipulator with real-time feedback, improving its ability to locate and identify as well as grasp glass objects accurately.

The review [7] contains information on the application of industrial robotics in sectors with substantial manual labor involved, such as health, food, and agriculture. The benefits of human and robot collaboration are discussed, such as complex control systems being possible. The paper identifies the challenges in robot deployment and focuses on the robotization tasks requiring a specialized working environment, additional sensors, and complex algorithms. In addition, the study discusses the potential benefits of employing collaborative technologies, such as flexibility and cost-effectiveness. The key parameters while designing automated handling systems are robot choice, control systems, and COBOTS (Collaborative robotics) application.

The study in [9] discusses automated material handling systems (AMHS) used in the TFT-LCD panel manufacturing facility. It emphasizes the need to develop a more capable glass handling system for lifting heavier mother glasses. As such, the AMHS system technology has not been updated in the past decade. The paper [10] provides information on the LCD glass handling robot powered by a permanent magnet synchronous motor (PMSM). Three dynamic models were considered, namely rigid and flexible, with appropriate independent variables. The paper applied the Real-coded genetic algorithm (RGA) to calculate parameters such as inductance, resistance, and torque constant. The flexible model indicated a better agreement with parameters and had more convincing results. In a nutshell, the paper successfully formulated LCD glass-handling robots using RGA parameter identification.

3 Aims and Objectives

Aim:

To Design a robot to pick and place tempered glass to a edge handling conveyor in a solar panel manufacturing plant

Objectives:

1. To Select a Robotic Gripper
2. To Validate deflection on the glass plate due to the arrived configuration of grippers.
3. To arrive at the concept of Robotic Automation.
4. To arrive at the specification of Robot
5. To define parameters for automation simulation
6. To simulate the automation

4 Design of Automation System

4.1 Introduction

In the dynamic landscape of the solar panel industry, automation plays a pivotal role in streamlining manufacturing processes, ensuring precision, and enhancing productivity. One of the critical aspects of automation in this industry involves the pick and place of delicate glass panels, a task demanding both accuracy and efficiency. This introduction focuses on the design of an advanced automation system specifically tailored for this purpose, emphasizing the selection of Cartesian robots.

1. **Understanding the Challenge:**

Handling fragile glass panels in the solar panel industry requires a sophisticated approach. These panels are not only heavy but also prone to breakage if not handled with utmost care. The automation system must guarantee the safe and precise movement of these panels from one station to another in the manufacturing process.

2. **Role of Cartesian Robots:**

Cartesian robots, with their linear motion along the X, Y, and Z axes, offer a compelling solution for pick and place operations involving large, flat objects like glass panels. Their precision, repeatability, and ability to cover extensive workspaces make them ideal candidates for this task. By understanding the specific requirements of the solar panel industry, the right Cartesian robot can be selected to meet the demands of the application.

3. **Customization for Glass Handling:**

The design of the automation system must include customization tailored to the unique characteristics of glass panels. This includes specialized end effectors, grippers, or vacuum systems specifically engineered to handle the size, weight, and fragility of the glass. Additionally, integrating sensors and vision systems ensures the robot can identify the correct position and orientation of the glass panels for seamless pick and place operations.

4. **Ensuring Safety and Efficiency:**

Safety features are paramount. The selected Cartesian robot should incorporate advanced sensors and collision detection systems to prevent accidents and minimize downtime. The system's speed and cycle times need to be optimized to strike a balance between efficiency and precision, ensuring a smooth workflow without compromising the safety of the manufacturing environment.

In essence, the design of an automation system for the pick and place of glass panels in the solar panel industry requires a meticulous approach. By understanding the challenges, leveraging the capabilities of Cartesian robots, customizing the system for glass handling, ensuring safety, and planning for future advancements, manufacturers can create a robust and efficient solution that not only meets current demands but also anticipates the needs of tomorrow's solar panel production processes.

4.2 Design of Gipper

There are various Parameters which need to be taken care of when the gripper is being designed for glass handling industry.

1. Suction Cup Design:
Choose suction cups specifically designed for handling glass panels. These cups often have specialized materials or coatings to enhance grip and prevent scratches on the glass surface.

2. **Suction Cup Size and Configuration:**

Ensure the suction cup size and configuration match the dimensions and shape of the glass panels. Proper sizing allows for efficient vacuum distribution, maximizing the grip on the glass surface.

3. **Vacuum Flow and Pressure:**

Calibrate the vacuum flow and pressure based on the weight and surface characteristics of the glass panels. Proper adjustment ensures a secure grip without causing damage to the glass.

4. **Vacuum System:**

Invest in a reliable vacuum system capable of providing consistent suction power. The system should have appropriate filters and sensors to maintain optimal performance and prevent contaminants from affecting the suction cups' efficiency.

5. **Adaptability and Flexibility**:

Choose vacuum end effectors that can be easily adjusted or customized to handle various sizes and types of glass panels. Flexibility in the end effector design allows for seamless transitions between different products in the manufacturing process.

6. **Durability and Maintenance:**

It is better to opt for high-quality materials that are resistant to wear and tear. Regular maintenance and timely replacement of worn-out components are crucial to ensure the longevity and efficiency of the vacuum end effector.

By carefully considering these factors during the selection process, manufacturers in the solar panel industry can implement Cartesian robots with vacuum end effectors specifically tailored for efficient, precise, and safe pick and place operations of glass panels, ultimately enhancing the overall automation and productivity of the manufacturing process.

Numerical Arrival of Parameters for Suction Cup Design

To calculate the theoretical holding force, we show and describe the three most important and most frequently occurring load cases (handling sequences).

Dimensions:

1. Length = 1.5 m
2. Width = 0.9 m
3. Thickness = 3mm

Material Properties:

1. Density of Glass = 2500 kg/m^3
2. Coefficient of Friction (μ) = 0.5

Design assumptions:

1. Factor of Safety (FOS) = 2
2. Acceleration (a) = 5 m/s^{2w}
3. Calculated weight of Glass (m) = 10.12 kg ≈ 11 kg

Design Calculations:

1. **Calculation of Holding Forces:**

   I. **The direction of Force is Vertical and he direction of suction cup is horizontal:**

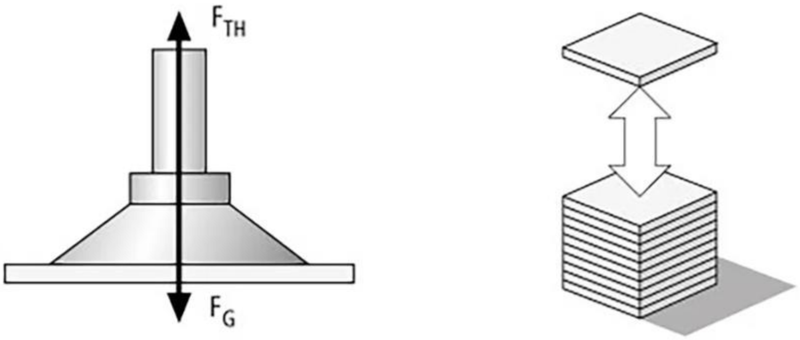


Figure 4.1 Vertical lift without transverse movement [12]

$$F_{th} = m \times (g+a) \times FOS$$

$$= (11) \times (9.81+5) \times 2$$

$$\underline{F_{th} = 325.82\ N}$$

F_S = Suction force

F_{TH} = Theoretical holding force

n = Number of suction cups

II. The direction of Force is Horizontal and Suction Cup is Horizontal

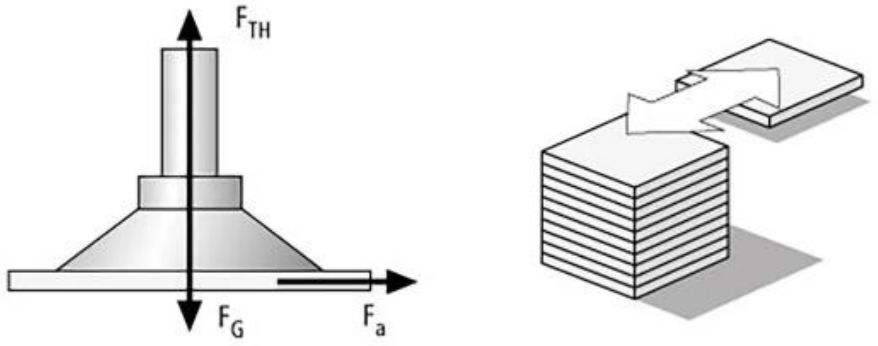


Figure 4.2Horizontal lift with Transverse movement [12]

The workpiece is already lifted and been transported horizontally.

$$F_{th} = m \text{ x } (g+ \frac{a}{\mu})\text{x FOS}$$

$$= 11 \text{ x } (9.81 + \frac{5}{0.5}) \text{ x } 2$$

$\underline{F_{th} = 435.82 \text{ N}}$

III. **The direction of Force is vertical and suction cup is vertical**

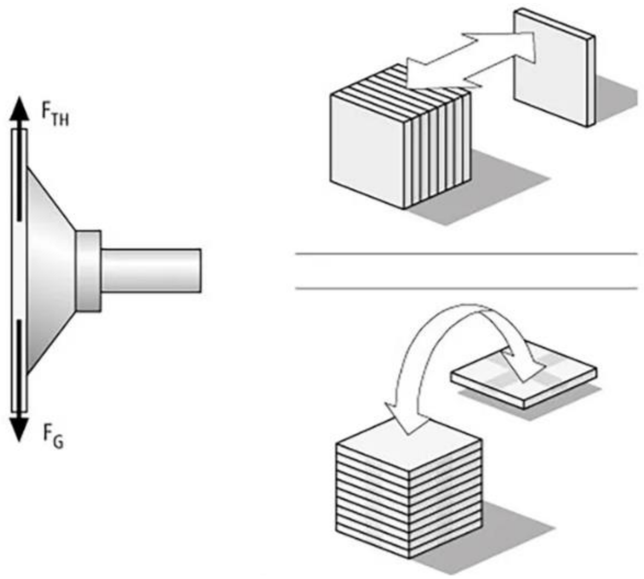


Figure 4.3 Lift with Rotary Motion [12]

$$F_{th} = \frac{m}{\mu} \text{ x } (g+ a) \text{ x FOS}$$

$$= \frac{11}{0.5} \text{ x } (9.81 + 5) \text{ x } 2$$

$\underline{F_{th} = 651.6 \text{ N}}$

2. Calculation of Suction Cups:

$$F_s = \frac{Fth(\max)}{n}$$

Where,

F_S = Suction force

F_{TH} = Theoretical holding force

n = Number of suction cups

By substituting the values in the above equation, we get:

$$= \frac{651.6}{6} = 108.6 \approx 110 \text{ N}$$

F_s = 110 N

Now, from the force calculations, suction force per cup and provided condition of no scratches we have selected Bellows Suction Cups FSGPL (by Schmalz) **[1]**

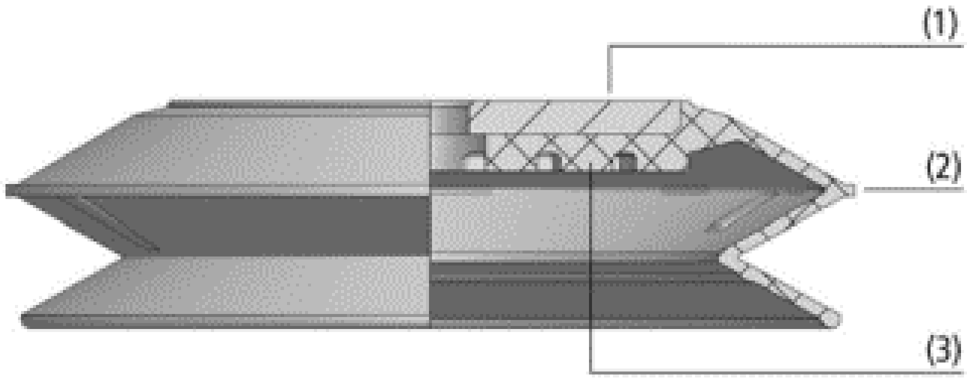


Figure 4.4 System design bellows suction cups FSGPL [13]

Where,

1 -Steel support plate with female thread vulcanized to the suction cup for high forces, especially horizontal forces.
2 - Bellows suction cup FSGPL and very flexible and adaptable sealing lip.
3 - Bellows suction cup FSGPL with 1.5 folds (2) and very flexible and adaptable sealing lip.

Specifications:

Diameter – 100 mm

Maximum Suction Force Capacity – 150 N

➢ **Suction Cup Characteristics for Glass Handling**

Suction cups should possess structural design and material that does not produce the marking on the glass and should be able to provide the required suction force for separating the glass sheets while picking operation. Separation powder is used to reduce the adhesion between the glass sheets.

Thin glass should be handled sensitively to prevent potential deformation, suction cup should be meticulously designed to distribute surface pressure evenly across the glass, minimizing the localized stress and reducing the chances of deformation. The material HT1 of Schmalz offers the best results – non-marking and minimum chemical fingerprint.

Table 4.1 Selection Matrix comparison of Suction Cups based on Material [14]

Criteria	HT-1 (Non-marking Materia)	EPDM (Ethylenepropylenecaoutchuc)	NBR (Nitrile caoutchuc)	VU1 (Vulkollan)	ED (Elastodur)	NK (Natural Rubber)
Example						
Wear Resistance	XXX	XX	XX	XXXX	XXXX	XX
Non/Low Marking	√				√	
Silicon Free	√	√	√	√	√	√
Clean Room Application	√				√	
Oil Resistance	XXXX	XX	XXXX	XXX	XXX	X

- **Challenges in Solar Glass Picking**:

- **Fragility**

Solar glass panels are typically thin and brittle, making them prone to breakage. Designing a gripper that can handle the fragility of the glass without causing damage during the picking process is a significant challenge.

- **Weight Distribution:**

Solar glass panels can be large and heavy, and the weight distribution may not be uniform. Ensuring that the gripper can securely hold and balance the weight of the panel without causing stress points or structural damage is a critical consideration.

- **Integration with Robotic Systems:**

Integrating the picking mechanism with robotic systems involves complex coordination and programming. Ensuring smooth communication between the gripper and the robot, and optimizing the overall efficiency of the picking process, is a challenge.

- **The Clean room for usage of suction cups is crucial:**

A clean room environment is essential. Solar panels, especially those meant for commercial and residential use, need to maintain a high level of cleanliness to prevent any contamination. Dust particles or impurities can affect the efficiency of solar panels. The usage of suction cups necessitates a clean room to avoid any foreign particles adhering to the cups or the glass surface. Even a small particle can create micro-scratches on the glass, impacting its optical properties and long-term durability.

- **The force required for initial glass picking is comparatively higher:**

Solar glass panels are typically heavy and fragile. When picking them, a significant amount of force is required to initiate the separation from the stack or the production line. This initial force requirement poses a challenge because applying too much force can lead to breakage, while applying too little force can result in inefficient handling. Precise calibration of the equipment used for picking, such as robotic arms or suction devices, is crucial to applying the optimal force required for safe glass picking.

- **There should be no jerks during the handling process of the glass:**

Glass is inherently brittle, and any sudden movements or jerks during the handling process can lead to breakage. This challenge is particularly relevant during the transportation and placement of glass panels. Even a minor jerk can cause the glass to flex, leading to cracks or shattering. To mitigate this risk, handling systems must be designed with precision and advanced controls. This may include the use of shock-absorbing materials, intelligent automation, or employing operators trained in delicate handling techniques.
Addressing these challenges requires a combination of advanced technology, precise engineering, and adherence to strict protocols. Robotics and automation play a significant role in ensuring controlled and gentle handling of solar glass panels. Additionally, continuous research and development efforts are essential to improving technology and methodologies involved in solar glass picking, making process more efficient, safer, and cost-effective.

➢ **Arrived Gripper Configuration**

Figure 4.5 Gipper Configuration for Minimum deflection

To verify the above diagram a Finite Element Analysis was conducted on the glass sheet of given dimensions to validate the deflections. The glass being a highly brittle material the aim was to arrive at a configuration which equally distributes the force during the vacuum suction operation and panel transport.

Further as observed in the calculation before the maximum force required during the transport would be 650 N. Hence, this force is the overall force, when split among 6 grippers it is 108 N per gripper.

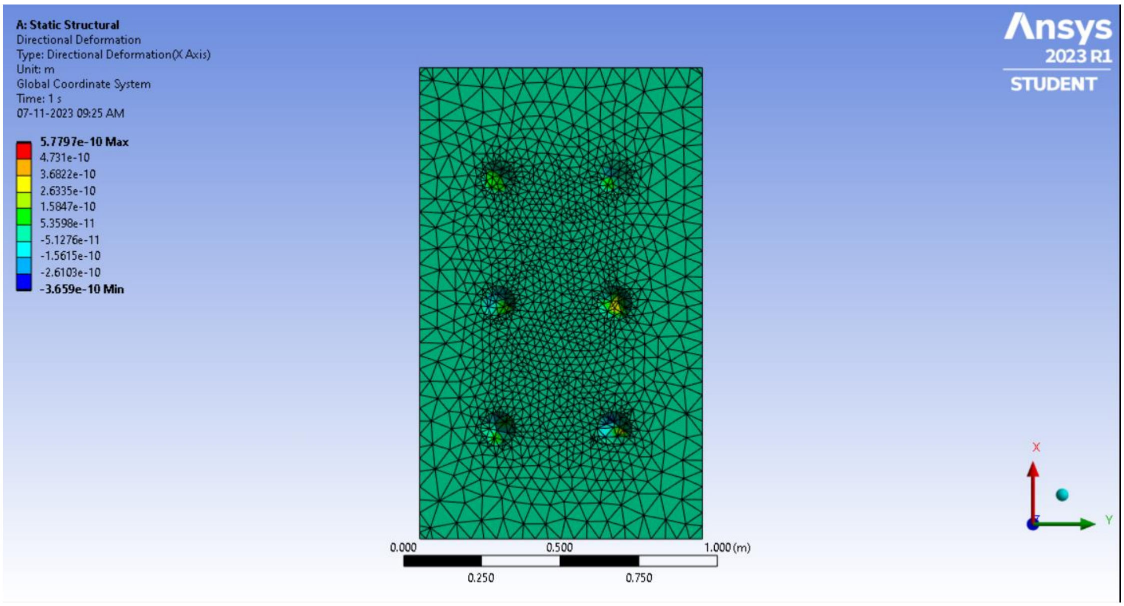


Figure 4.6 FEM analysis for glass deformation for 630 N of Suction force

Clearly, the maximum deflection seen is 5.7297 x 10^{-10} mm, which is not sufficient to cause the breakage of the glass sheet. Hence the arrived configuration of the gripper is suitable for the transport purpose of the glass sheet in the solar panel industry.

4.3 Design of Robot

Goals

1. Select a Robot for Tempered Glass Pick and Place of Specific Dimensions

•Purpose: Address the unique requirements of handling tempered glass sheets with predefined dimensions.

•Criteria: Ensure the robot is tailored to handle the specified glass dimensions accurately and securely.

2. Cost-Effective Solution

•Purpose: Optimize the investment by identifying a robot solution that offers the best balance between functionality and cost.

•Criteria: Conduct a comprehensive cost analysis, considering initial investment, maintenance expenses, and potential long-term savings in labour costs.

3. Higher Repeatability

•Purpose: Enhance operational consistency and accuracy in pick and place operations for tempered glass.

•Criteria: Choose a robot with a demonstrated capability for precise and repeatable movements, minimizing variations in the glass placement process.

4. Optimized Cycle Time

•Purpose: Improve overall production efficiency by minimizing the time required for pick and place operations.

•Criteria: Select a robot that can execute pick and place tasks swiftly, contributing to shorter cycle times and increased throughput

5. Selection of Robot Compatible with Bellows Suction Cups (FSGPL by Schmalz)

•Purpose: Ensure compatibility with specialized end-of-arm tooling, specifically Bellows Suction Cups (FSGPL by Schmalz).

•Criteria: Verify that the chosen robot is designed to seamlessly integrate with and effectively utilize the specified suction cup technology.

6. Safety Solution

•Purpose: Prioritize the safety of personnel and the tempered glass material during the handling process.

•Criteria: Select a robot equipped with advanced safety features, including collision detection and emergency stop capabilities, in compliance with industry standards.

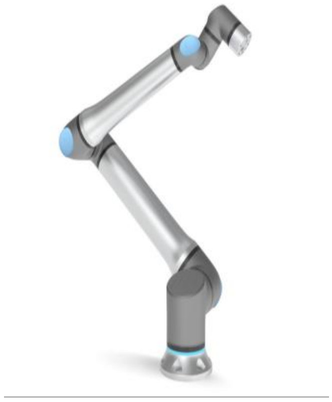
7. Objective: Ease of Programming

•Purpose: Facilitate efficient adaptation to various glass dimensions and configurations through user-friendly programming interfaces.

•Criteria: Choose a robot that simplifies the programming process, allowing operators to program new pick and place tasks quickly and intuitively.

Robot Survey

UR-20



Payload 20 kg

Reach 1750 mm (68.9 in)

Precision F=5.5 N

T=0.2 Nm

Pose repeatability per = ± 0.1 mm

Pick and place setup cost: $105,000.

Figure 4.7 UR-20 [15]

SCARA Robot Epson G10

Payload: 10 Kg

Reach 650 mm

Repeatability Joints 1, 2 ±0.025 mm

Joint 3 ±0.010 mm

Joint 4 ±0.005 deg

Pick and place setup cost: : $50,000

Figure 4.8 SCARA Robot Epson G10 [16]

ABB IRB2600

Payload 15 kg

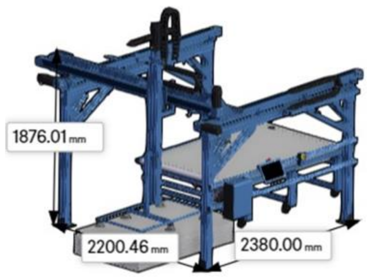
Reach 1650 mm

Repeatability 0.04 mm

Pick and place setup cost: $65000

Figure 4.9 ABB IRB2600 [17]

Gantry Robot



Payload- 300 Kg

Reach - 2050 mm in X and Y direction and Z

Repeatability- 0.025 mm

Accuracy- 0.05 mm per 300 mm of length

Robot cost - 24000 USD

Figure 4.10 Gantry Robot

Design of Robot - Parameter Comparison Table

Table 4.2 Comparison of Robots type in the market

Sl. No.	Parameters	Cartesian	Articulate	SCARA
1	Reach	Highest along straight line Motion	Good	Limited
2	Repeatability	Highest repeatability for gantry	Limited and dependent on DOF	Higher than Articulated Robot
3	Precision	Higher precision as it has only linear motion which is easy to calibrate	Limited	Higher than articulated
4	Payload	Industrial gantry robots have highest payload capacity	Limited compared to cartesian or SCARA	Good payload capacity
5	Cost	Least	Costliest	Cheaper than articulated robot
6	Ease of programming	Easiest	Toughest	Tougher than Gantry

After a thorough examination of the Robot Parameter Comparison Table, it is evident that Cartesian or Gantry robots emerge as the most suitable choice for our specific application. These robots exhibit commendable attributes such as high accuracy, precision, and an extensive reach, aligning seamlessly with the requirements of our application. Notably, their performance in these critical parameters is complemented by a cost-effective profile, making them a compelling choice for our intended setup.

Considering this comprehensive analysis, the decision has been made to select a Gantry robot for our cell setup. This choice reflects a strategic alignment with our application's demands, ensuring that the robot not only meets the necessary performance criteria but also does so in a manner that is economically prudent. The Gantry robot's inherent capabilities make it an optimal solution for achieving the desired levels of accuracy, precision, and cost-effectiveness within the scope of our application.

4.3.1 Design of Gantry Robot

1. Heavy Duty Timing Belt Actuator (Y and X Axis Linear Actuator)

This product comes equipped with pre-installed guideways and sensor mounts, offering a convenient and hassle-free setup. Its design is dust-resistant and engineered without any pinch points, ensuring safety and smooth operation. The heavy-duty version of this product boasts an enhanced load capacity due to its incorporation of two bearings in the guiding system, surpassing the standard model. Additionally, this version introduces new mounting possibilities, a refined shaft design, and features magnetic retention of the steel cover for improved durability and ease of use.

Considering the width of the tempered glass 900 mm and the width of the timing belt conveyor is 1350 mm. Moreover, the length of the tempered glass and conveyor belt as 1500 mm and 1800 mm, respectively. The required range of the linear actuators selected have range of 2295 mm in X and Y axis.

Figure 4.11 Heavy Duty Timing Belt Actuator [18]

Table 4.3 General Specifications [18]

Sr. No.	Particulars	Specifications
1.	Weight	37.097588 kg
2.	Dimensions *(L x W x H)*	2542.5 x 270.0 x 112.5 mm
3.	Unit Price	$4,584.83 USD
4.	Material	Aluminum, Steel
5.	Surface finish	Blue Anodized, 10 um
6.	Max Output Force	1200 N
7.	Load Capacity	5000 N
8.	Stroke	2050 mm
9.	Repeatability	0.025 mm
10.	Max Linear Speed	2500 mm/s
11.	Max Acceleration	2000 mm/s^2

2. Enclosed Ball Screw Actuator (Z axis Linear Actuator)

The Selected enclosed ball screw actuator offers a comprehensive solution for handling heavy loads. This product comes with pre-installed guideways and sensor mounts, simplifying the assembly process. Its design is dust-resistant and free from pinch points, ensuring both durability and safety. Furthermore, considering the height of the glass stack and conveyor belt as 370 mm and 410 mm respectively the liner actuator in Z-direction in the range of 1530 mm is been selected to enable picking of glass from the bottom of the glass stack and placing it on the conveyor belt.

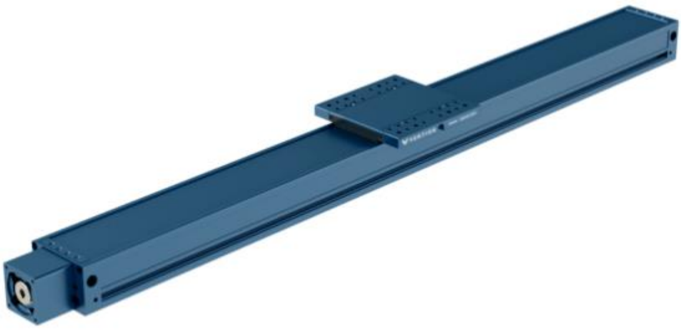


Figure 4.12 Enclosed Ball Screw Actuator [19]

Table 4.4 Technical Specifications [19]

Sr. No.	Particulars	Specifications
1.	Weight	28.5499 kg
2.	Dimensions *(L x W x H)*	1672.5 x 270.0 x 112.5 mm
3.	Unit Price	$3,810.65 USD
4.	Material	Steel, Aluminum
5.	Surface finish	Dark Blue Anodized
6.	Max Output Force	3250 N
7.	Load Capacity	5000 N
8.	Stroke	1315 mm
9.	Repeatability	0.025 mm
10.	Max Linear Speed	400 mm/s
11.	Max Acceleration	466 mm/s^2
12	Displacement Ratio	16 mm/turn

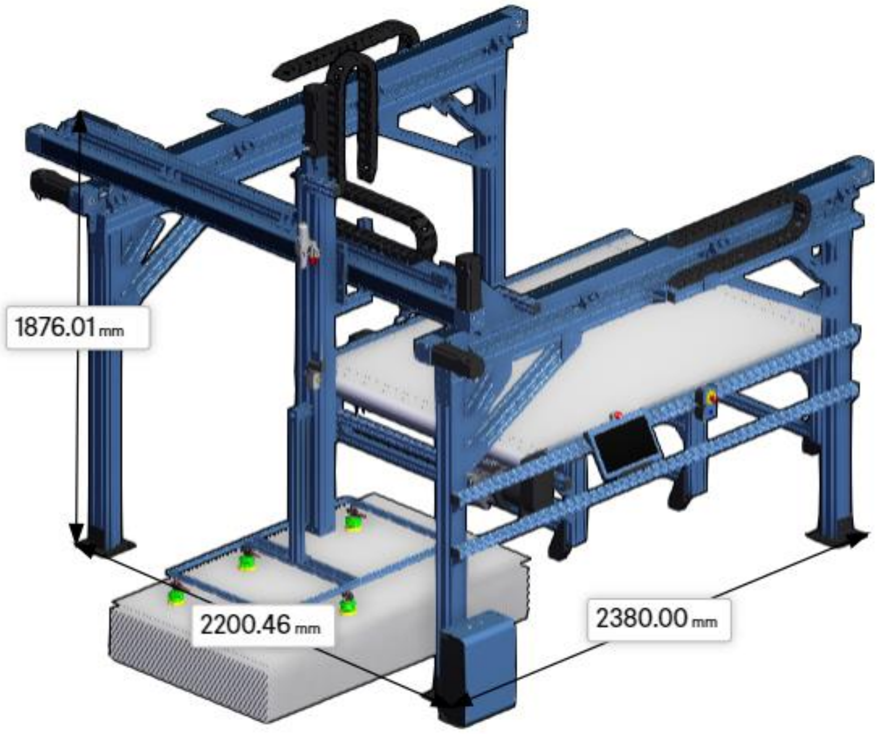


Figure 4.13 Final arrived Robotic Configuration (Isometric View)

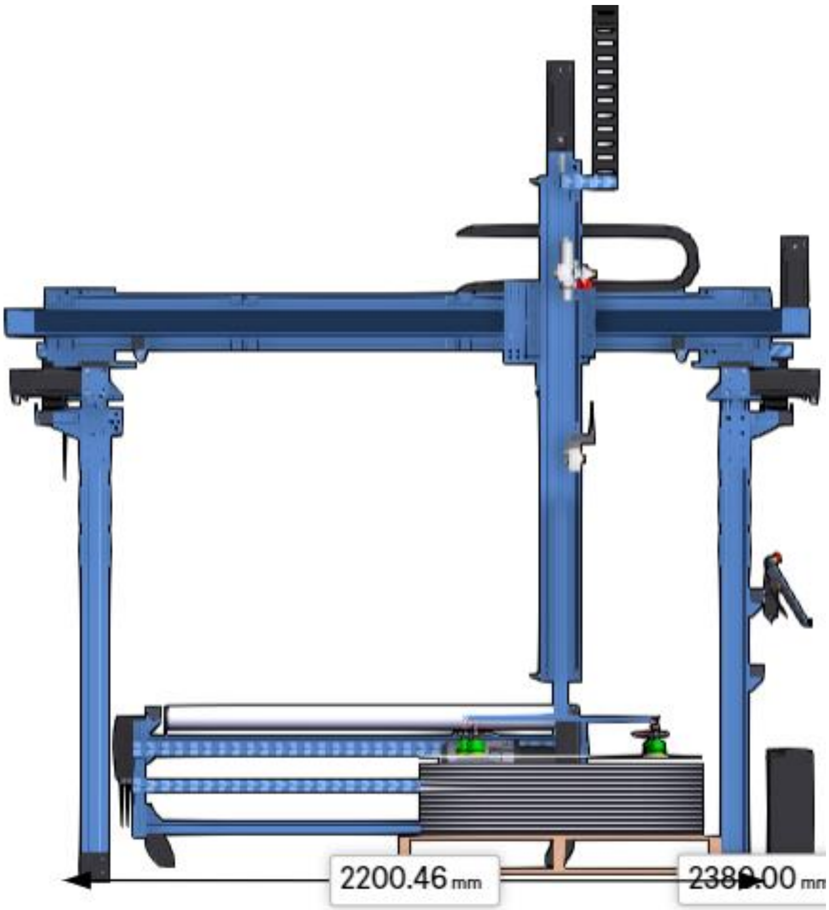


Figure 4.14 Final arrived Robotic Configuration (Front View)

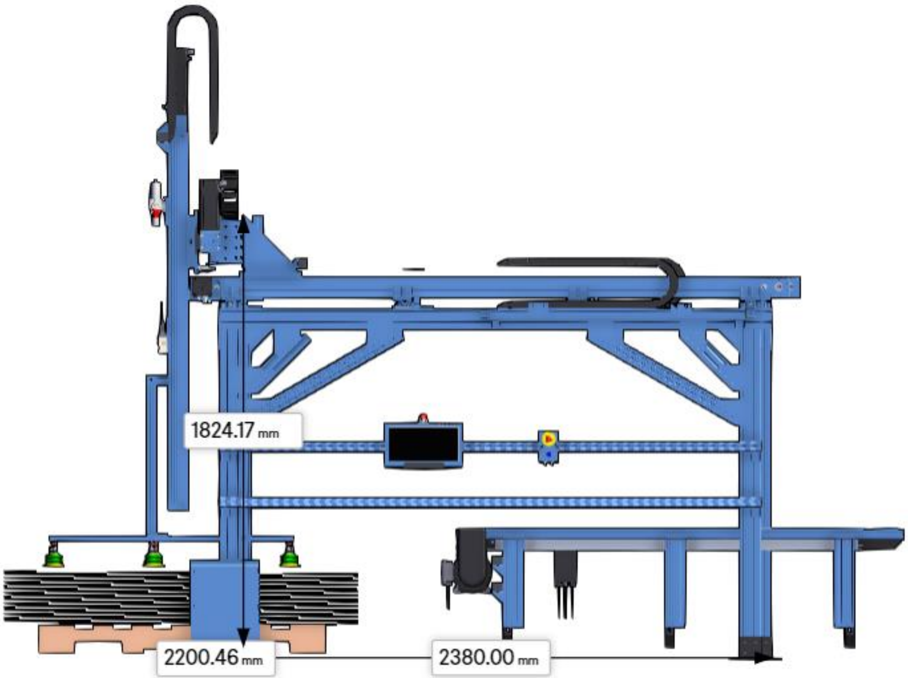


Figure 4.15 Final arrived Robotic Configuration (Side View)

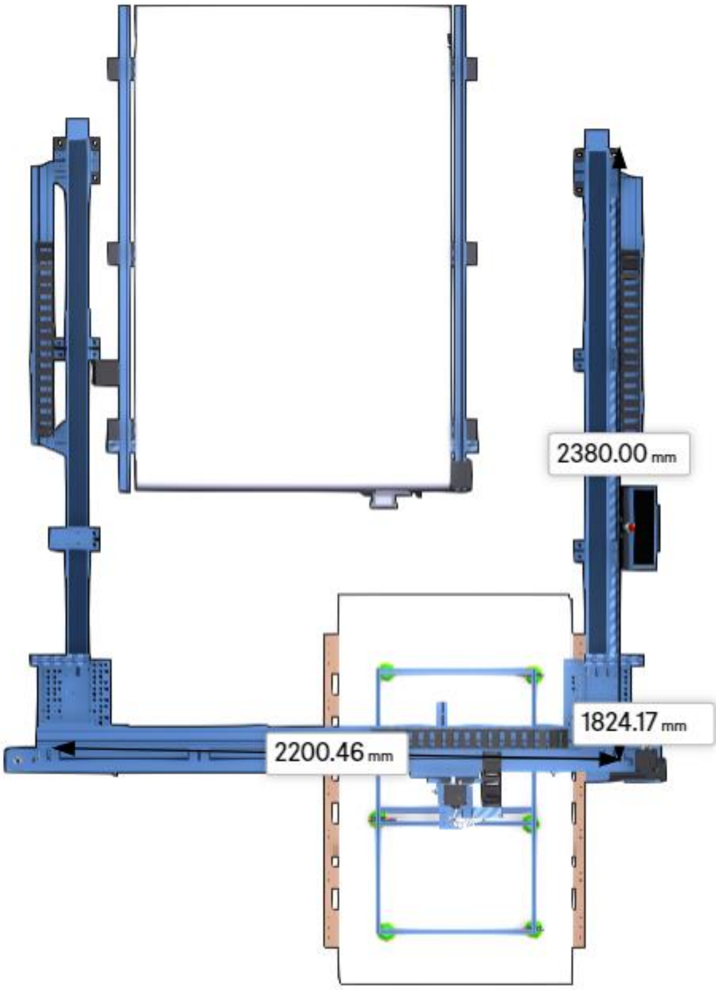


Figure 4.16 Final arrived Robotic Configuration (Top View)

3. Sensors

I. X – Axis Sensor

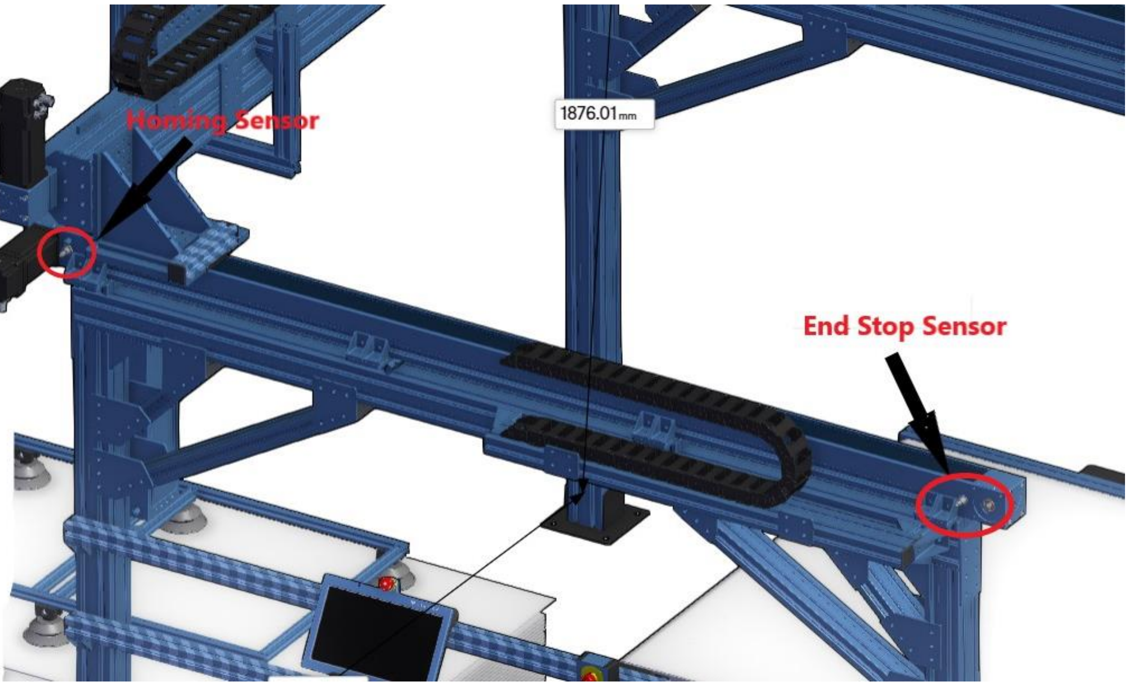


Figure 4.17 X axis Sensors

II. Y – Axis Sensor

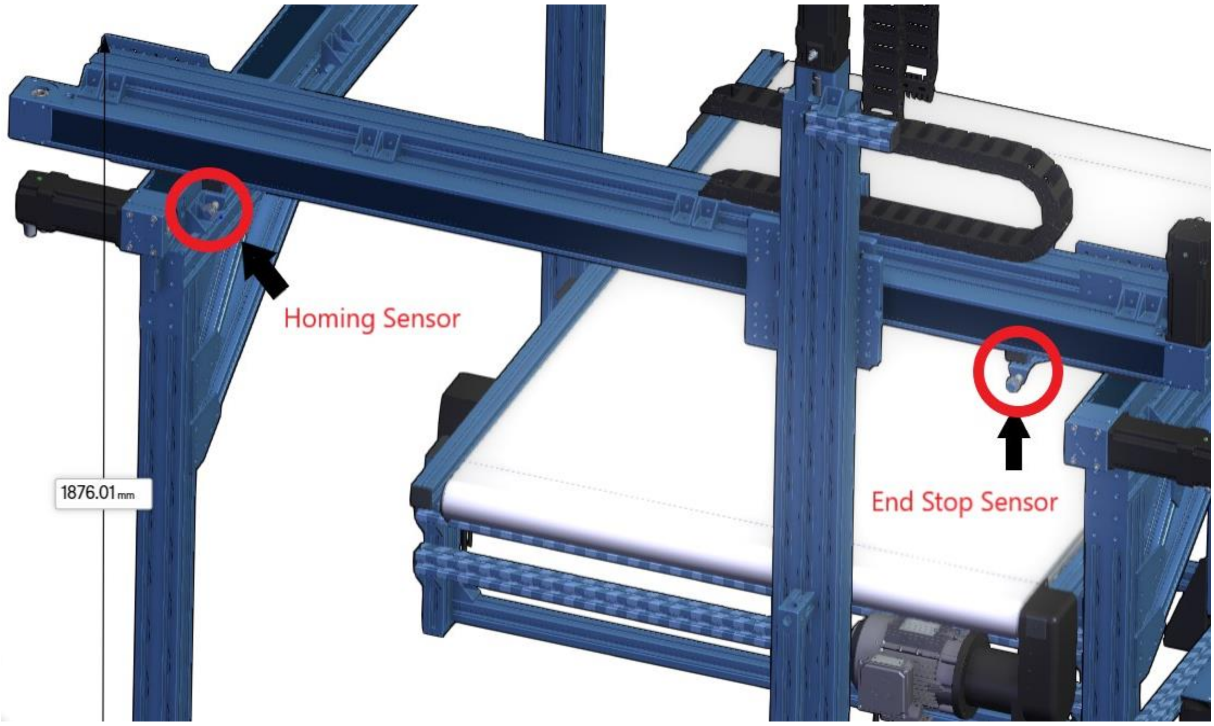


Figure 4.18 Y Axis Sensors

III. Z – Axis Sensors

Figure 4.19 Y Axis Sensors

All these Homing and End Stop Sensors are Non-Flush Inductive Proximity Sensor

Figure 4.20 Non-Flush Inductive Proximity Sensor [20]

M18 inductive proximity sensor designed for non-flush mounting. Capable of detecting metallic objects both in front and on the side of its sensing end, with a range of 10 mm. It comes with a 5-meter cable for connecting to the Machine Motion controller.

Table 4.5 Specifications of Non-Flush Inductive Proximity Sensor [20]

Sr. No.	Particulars	Specifications
1.	Weight	0.276 kg
2.	Dimensions (L x W x H)	110.0 x 18.0 x 18.0 mm
3.	Unit Price	$83.56 USD
4.	Material	Stainless Steel
5.	Cable Length	4 to 10 mm
6.	Supply Voltage	10 to 30 V
7.	IP Rating	IP65
8.	Temperature Range	-40 to 58 °C

4.4 Pneumatic System

The Pneumatic system consists of air preparation station, pneumatic valve, and Vacuum generator. The air preparation station is where the air enters the system, the filtration of the air takes place as well as the pressure is also measured. Pneumatic valves have been electrically controlled Normally closed on/off pneumatic valve. At last, the vacuum generator at each suction cup generates vacuum enough to lift the glass sheets.

4.4.1 Air Preparation Station

A comprehensive pneumatic air preparation station featured an all-in-one combination of a filter and regulator. It includes a manual shutoff and exhaust valve. This unit comes equipped with an integrated pressure gauge that indicates megapascals (MPa) pressure. Vention supplies the component.

Table 4.6 Air Preparation System specifications [21]

Sr. No.	Particulars	Specifications
1.	Weight	1.2 kg
2.	Dimensions (L x W x H)	214.0 x 203.0 x 98.0 mm
3.	Unit Price	$157.94 USD
4.	Material	Various (die-cast aluminum main housing, polycarbonate bowl)
5.	Temperature Range	-5 to 60 °C

4.4.2 On/Off Pneumatic Valve, Normally Closed

A normally closed on/off pneumatic valve remains in its default state and prevents airflow inside the vacuum system. When energized by electric energy, the valve opens, allowing the air to flow inside. Upon removing the electrical energy, the valve returns to its default closed position, shutting the valve.

Table 4.7 Specifications of 2 On/Off Pneumatic Valve [22]

Sr. No.	Particulars	Specifications
1.	Weight	1.2 kg
2.	Dimensions (L x W x H)	157.0 x 115.0 x 38.0mm
3.	Unit Price	$301.27 USD
4.	Material	Various (die-cast aluminum valve housing, 6061-T6 backing plate)
5.	Temperature Range	-10 to 50 °C

4.4.3 Vacuum Generator

The Piab VGS venturi vacuum generator is compatible with any suction cup by attaching a suitable fitting. A maximum Vacuum of -75 Kpa can be generated.

Table 4.8 Specifications of Vacuum Generator [23]

Sr. No.	Particulars	Specifications
1.	Weight	0.094 kg
2.	Dimensions (L x W x H)	111.0 x 23.0 x 55.0 mm
3.	Unit Price	$233.30 USD

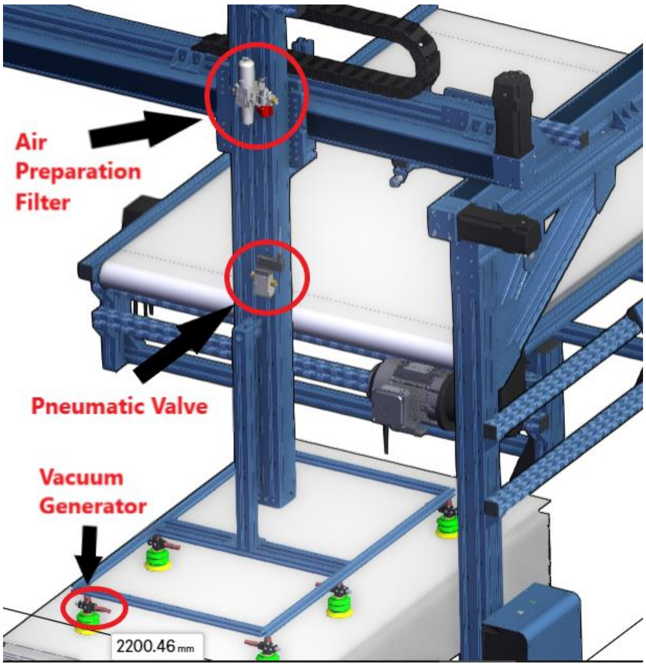


Figure 4.21 Pneumatic System

Table 4.9 Total Cost of Project

Sr. No.	Item Name	Cost (USD)
1	Linear Actuators	13,000
2	Edge Conveyor Belt with Motor	8000
3	Pneumatic System (Air Filtration, Vacuum Generation, Valve)	1900
4	Miscellaneous (Teach Pendant, Control systems and sensors	17200
5	Aluminum Structure	11,000

4.5 Arrived Specification of Robots

The project comprises a well-thought-out selection of components, each contributing to its overall functionality and efficiency.

1. **Linear Actuators:**

Cost (USD): $13,000
Description: The inclusion of linear actuators adds precision and controlled movement to the project, ensuring a dynamic and responsive system.

2. **Edge Conveyor Belt with Motor:**
Cost (USD): $8,000
Description: The edge conveyor belt, complemented by a motor, plays a crucial role in seamless material handling, facilitating the smooth flow of items within the project.

3. **Pneumatic System (Air Filtration, Vacuum Generation, Valve):**
Cost (USD): $1,900
Description: The pneumatic system, incorporating air filtration, vacuum generation, and valves, brings essential functionalities to the project, promoting efficient and controlled operations.

4**. Miscellaneous (Teach Pendant, Control systems, and sensors):**
Cost (USD): $17,200
Description: The miscellaneous category, encompassing items such as teach pendants, control systems, and sensors, forms the intelligence and control hub of the project, ensuring adaptability and responsiveness.

5. **Aluminium Structure**:
Cost (USD): $11,000
Description: The aluminum structure serves as the robust foundation of the project, providing a durable and lightweight framework that supports the various components and ensures structural integrity.
The cumulative cost reflects a strategic investment in components that collectively enhance project's capabilities, underscoring commitment to both functionality and cost-effectiveness.

5 Conclusion

5.1 Introduction

This chapter summarizes the outcomes and technical milestones achieved in the project

Efficiency: The effectiveness of the robot and gripper design would be a key factor. If the system can reliably and efficiently pick up solar glass panels and place them accurately, it would be considered a success.

Safety: Safety is paramount, especially when dealing with fragile materials like solar glass panels. The conclusion would likely address the safety features implemented to prevent damage to the panels and ensure the well-being of workers and the equipment itself.

Adaptability: A well-designed system should demonstrate adaptability to different sizes and shapes of solar glass panels. The conclusion might discuss how the robot and gripper can handle variations in panel dimensions.

Reliability: The reliability of the system under various environmental conditions, such as changes in lighting, temperature, or panel surface conditions, would be a crucial aspect.

Cost-effectiveness: An assessment of the cost-effectiveness of the design, considering factors like production costs, maintenance, and the overall return on investment.

5.2 Conclusion and Outcome

The vacuum gripper has been found reliable to pick and place fragile solar panel glass safely. The maximum holding force required is 650 N, distributed among the 6 grippers at 108 N per gripper. Maximum Deflection of glass is 5.7297 x 10^-10 mm, which ensures no breakage of the glass sheet. The vacuum gripper is adaptable for handling glass of different shapes and sizes. The necessary safety arrangements, such as area scanners, have been included to ensure human safety. Furthermore, the layout of the solar panel glass and edge conveyor has been optimized to ensure the fastest deliverable cycle time possible. Out of the Articulated, SCARA and cartesian. The linear gantry robot has been selected for optimizing the overall cost. Upon comparing the Articulated UR 20 robot with the gantry robot the project cost for the gantry robot is 48000 USD lower than UR 20. Furthermore, the cycle time in UR 20 is 77 seconds whereas for the gantry robot it is 26 second. Gantry robot being consisting of three linear actuators have higher repeatability, easy to program because of a simple inverse kinematics solution, and cheaper to maintain when compared to articulated robots. In conclusion, the Gantry robot system provides the fastest cycle time and the lowest installation and operational cost.

5.3 Suggestions for Future Work

The Suggestions for the Selection of Cartesian Robot and Vacuum End Effector in the Solar Panel Industry:

1. Sustainability and Energy Efficiency:

Consider energy-efficient robotic systems and vacuum solutions to align with the industry's focus on sustainability. Energy-efficient robots can reduce operational costs and environmental impact.

2. Collaborative Robots (Cobots):

Explore the use of collaborative robots designed to work alongside human operators. Cobots can enhance flexibility in the manufacturing process, especially in tasks where human-robot collaboration is essential.

3. Advanced Vision Systems:

Integrate advanced vision systems, such as 3D cameras and machine learning algorithms, to enhance the robot's ability to recognize, orient, and handle glass panels of various shapes and sizes. This technology can improve accuracy and adaptability.

4. IoT Integration:

Utilize Internet of Things (IoT) technology to enable real-time monitoring and control of robotic systems. IoT integration allows remote monitoring, data analytics, and predictive maintenance, leading to optimized operations.

5. Simulation and Digital Twin Technology:

Use simulation software and digital twin technology to model and simulate the robotic pick and place process. This approach helps in optimizing robot movements, testing different end effector designs, and validating the overall system before implementation.

6. Customization and Modularity:

Opt for robotic systems and vacuum end effectors that offer customization and modularity. Modular designs allow easy upgrades, replacements, or adaptations to different glass panel sizes and shapes, ensuring long-term flexibility.

7. **Artificial Intelligence (AI) and Machine Learning:**

Implement AI algorithms and machine learning models to enable robots to learn from experience. AI can optimize pick and place strategies, enhance path planning, and improve overall efficiency based on historical data and real-time feedback.

8. **Haptic Feedback Systems:**

Explore haptic feedback systems that provide tactile sensations to operators or robots. Integrating haptic feedback can enhance the robot's ability to handle delicate objects by simulating the sense of touch, ensuring gentle and precise gripping.

By exploring these suggestions and engaging in future research areas, the selection of Cartesian robots and vacuum end effectors for pick and place operations in the solar panel industry can continue to evolve, leading to more efficient, precise, and intelligent manufacturing processes.

END of Content

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