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BEng (Hons) Mechanical Engineering

Independent Project

Design & Development of an Automation Machine for Electronic Product Testing

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2023

Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:  *Date: 18/05/2023*

Acknowledgements

Supervisor and faculty members: One would like to thank Rob Goodson for his continuous support throughout this project. The guidance and advice have led this project to its' quality. One would also like to thank the University of Wales Trinity Saint David faculty members for their continued support and the knowledge they have provided.

Peers and colleagues: One would like to thank the colleagues at Sony UK Technology Centre for their continued support, supplying knowledge and expertise throughout this project.

Family and friends: Furthermore, one would like to show appreciation for the emotional support and encouragement provided by family and friends during this project.

Abstract

Background: Sony UK Technology Centre is renowned for high-quality products. Quality standards must be maintained due to exponential growth in third-party manufacturing contracts. Several processes are conducted solely for quality assurance. However, these are Non-Value-Added tasks that consume time, resources, and effort without directly contributing to a product's value.

Problem Statement: Product “Testing” is a Non-Value-Added task but a necessary process for quality assurance. However, it decreases output efficiency and increases costs. Manual testing of "Product A," an Electronic Circuit Board, reduces company profits and production output without adding value.

Project Aim and Objectives: This project aims to design and develop an automation machine that can mitigate the Non-Value-Added tasks for Product A by automating the testing of the product within a specified cycle time to quality and safety standards whilst meeting safety requirements.

Solution: Utilising various design methods, the automated solution uses systems to feed and scan Product A, whilst a low-cost Gantry system places the product into a Test Jig for testing. Once the test outcome is determined, the Gantry system moves the product to an appropriate Conveyor system to transport the product to packing or rework. The machine requires six Test Jigs and two Gantry systems, each with its own Feeder system for redundancy and efficiency. Powered by 230V AC and 6 Bar pneumatic pressure, the machine is controlled by a Programmable Logic Controller.

Outcome: The machine initially outputted 7,408 products per week, below the design requirement of 9,000. After a Failure Mode Effect Analysis, modifications increased output to 11,960 products per week. During Production testing, the output was 7,095 per week, but after addressing various issues discovered from a problem analysis, the output reached 9,395 per week. With a Machine Efficiency of 67.57% and an additional 85% Operational Downtime Efficiency incorporated for contingencies, calculations show an estimated average output of 9,305 products per week, thus, representing a successful outcome.

Conclusion: Although the machine operates at 67.57% efficiency, it achieves the target while costing £40,000, which is £10,000 below the £50,000 budget. It requires one operator, offering a Return on Investment in under a year. This project demonstrates the importance of automation in the UK, mitigating Non-Value-Added tasks and fostering employee growth. Savings enable employee development and product cost reduction, benefiting the company, and employees, whilst maintaining UK competitiveness in manufacturing.

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List of Abbreviations

Artificial Intelligence (AI)

Bill of Materials (BOM)

British Standard (BS)

British Standards Institution (BSI)

Carbon Fibre Reinforced Plastic (CFRP)

Computer Numerical Control (CNC)

Computer-Aided Design (CAD)

Conformité Européene (CE)

Critical Path Analysis (CPA)

Define, Measure, Analyse, Improve and Control (DMAIC)

Design Failure Mode and Effects Analysis (DFMEA)

Design for Assembly (DFA)

Design for Manufacturing (DFM)

Design for Reliability (DFR)

Design for Safety (DFS)

Design for X (DFX)

Diagnostic Coverage (DC)

DXF (Drawing Exchange Format)

Failure Mode and Effects Analysis (FMEA)

Fused Deposition Modelling (FDM)

Gross Domestic Product (GDP)

Institution of Mechanical Engineers (IMechE)

International Organisation for Standardisation (ISO)

Light Emitting Diode (LED)

Manufacturing Technology Centre (MTC)

Master Control Board (MCB)

Mean Time to Dangerous Failure (MTTDF)

Non-Value-Added (NVA)

Performance Level (PL)

Personal Computers (PCs)

Polylactic Acid (PLA)

Portable Document Format (PDF)

Printed Circuit Board (PCB)

Programmable Logic Controller (PLC)

Provision and Use of Work Equipment Regulations (PUWER)

Quick Response (QR)

Return on Investment (ROI)

Risk Priority Number (RPN)

Sacrificial Interface Board (SIB)

Science, Technology, Engineering, and Mathematics (STEM)

Selective Laser Sintering (SLS)

Sintered Metal Corporation (SMC)

Sony UK Technology Centre (SUTC)

Standard for the Exchange of Product Data (STEP)

Stereolithography (SLA)

Stereolithography (STL)

UK Conformity Assessed (UKCA)

Universal Robot (UR)

Chapter One - Project Introduction

This chapter provides critical information surrounding the project's background, outlining the problem statement, further providing a purpose of the project, and identifying key areas which can aid the manufacturing industry, thus, providing its significance.

1.1. Background of the Project

1.1.1. Sony UK Technology Centre

The project is being carried out for **Sony UK Technology Centre (SUTC)**, a Sony Europe division located in Pencoed, Bridgend, UK. The centre manufactures high-tech Broadcast and Professional Cameras and Systems for worldwide markets.

SUTC is International Organisation for Standardisation (ISO) certified in Quality, Environment, Health and Safety, and Energy and has won numerous accolades for its outstanding manufacturing practises. The centre has obtained multiple honours, including the British Quality Award, the Best Electronics & Electrical Plant Award, and the title of Best Factory in Britain in 2013.

SUTC also has a Business Incubation Centre, home to several independent businesses in sectors such as Digital Technology, Renewable Energy, Media, and Gaming. Furthermore, SUTC is dedicated to enhancing its offerings, as demonstrated by its diverse portfolio and investment in machinery and processes.

One significant aspect of its operations is contracted electronics solutions, utilising a skilled and flexible workforce combined with the latest electronics manufacturing equipment and processes, which has enabled SUTC to partner with many global companies, producing world-class products from Light Emitting Diode (LED) Technology, Medical Devices and also Raspberry Pi Micro-Computers (*About Us*, 2023).

1.1.2. Problem Statement

SUTC is known for its high-quality products; thus, many processes for third-party manufacturing contracts are growing exponentially.

Many processes completed for quality purposes are Non-Value-Added (NVA) tasks. According to Kumar (2019), NVA tasks are actions or processes within manufacturing which

do not directly contribute to product creation, consuming time, resources, and effort, without adding value to the product. Some examples include but are not limited to:

- Defects and Rework of Products: Time spent correcting defects.
- Overprocessing: Steps in the manufacturing process which do not add product value.
- Overproduction: Producing more products than immediately required. Therefore, storage, handling and inspection costs increase.

Through various techniques, eliminating or mitigating NVA tasks can improve effectiveness, lower expenses, and increase productivity.

At SUTC, testing products is essential to ensure the best quality. However, although crucial, it is an **Overprocess** as it does not add value to the product, thus is an NVA task.

One of the products, **"Product A",** an Electronic Circuit Board (single-board computer or microcontroller) for consumer use, requires testing to ensure it performs correctly after manufacture. The testing process is carried out by human operators who test every product by ensuring component continuity and running software through the product, ensuring it performs its functions correctly.

As testing of Product A is an NVA task performed by human operators, it requires money and additional resources. Furthermore, it is susceptible to human error, whereby human mistakes can occur, which may further lead to Defects and the Rework of products, thus creating additional NVA tasks.

1.2. Purpose of the Project

1.2.1. Project Aim

The project aims to ensure NVA task mitigation for Product A by designing and developing an Automated System Solution to meet the design specification for product testing. Specifications such as cycle time, quality, cost, and safety requirements must be considered and fully stated within section 1.3.

1.2.2. Project Objectives

To ensure the project aim is achieved, thus, feasibility, the following objectives must be completed:

1. Design an Automated Machine utilising Computer Aided Design (CAD) Software, ensuring the machine meets the design specification.

2. Develop the Automated Machine by creating Engineering Drawings to required Geometric Tolerances for ease of manufacture.
3. Build and Program the Automated Machine ensuring the automated movement logic meets specifications whilst providing user-friendly operator interaction.
4. Commission an Automated Machine, ensuring integration with the previous production process.

1.2.3. Project Benefits

Human operators are essential in manufacturing processes and play vital roles in many situations. Human operators are better than automation in many aspects, such as **Creativity** and **Problem Solving**, whereby creative thinking and problem-solving skills help find new and innovative solutions to challenges (Mallon, 2022).

Furthermore, human operators are better at **Adaptability**, whereby changes in situations are quickly undertaken, allowing them to handle unpredictable events, thus, are more suited to the maintenance and repair of equipment and machinery, allowing them to identify and solve many issues (Mallon, 2022).

However, when completing mundane jobs, humans become complacent, leading to mistakes and additional NVA tasks due to rework and repair. Additionally, a lack of enthusiasm develops, reducing effectiveness and productivity because of unsatisfactory job roles and poor compensation (*Benefits of Robots,* 2023).

Automation, however, is better for processes with **Consistency** and **Accuracy** requirements, as it performs tasks with consistent speeds and accuracy, thus, reducing NVA rework tasks by mitigating human error. Therefore, as testing of Product A is repetitive, automation can be utilised to prevent or minimise human error (*Benefits of Robots,* 2023).

Automation can **Increase Efficiency** as it does not require breaks or experience fatigue, thus, processing indefinitely. Conversely, automation requires maintenance, although predictive maintenance can be planned to reduce inefficiencies. Automation is **Repeatable**, performing the same task with consistent precision, done at **Higher Speeds** than humans, whilst maintaining **Consistent Quality**. All of which **Reduce Process Costs** (*Benefits of Robots,* 2023).

Therefore, **Automating** the **Testing** of **Product A**, which is repetitive, low-skill and low-stimulating, can aid in NVA task mitigation, allowing operators to be retrained for more complex, stimulating tasks requiring Creativity and Problem-Solving skills, whereby

Adaptability is required, such as machine maintenance roles. Automation reduces manufacturing costs, providing a Return on Investment (ROI) and increased process efficiency while improving the operators' job satisfaction by providing better compensation and higher-skilled and stimulating roles.

The adoption of automation for Product A Testing, mitigating the NVA tasks may benefit the UK and its regional economy since it may result in the development of higher-skilled jobs, decreased manufacturing costs, and enhanced competitiveness, all of which could increase the **Gross Domestic Product (GDP)** of the nation.

1.3. Project Specification and Constraints

This section outlines the Project Design Brief, Design specification, Constraints and Project Timeline.

It can be noted as **Product A** is an Electronic Circuit Board; it will be referred to as a **Board** or **Product** interchangeably throughout the report.

1.3.1. Design Brief, Specification and Constraints

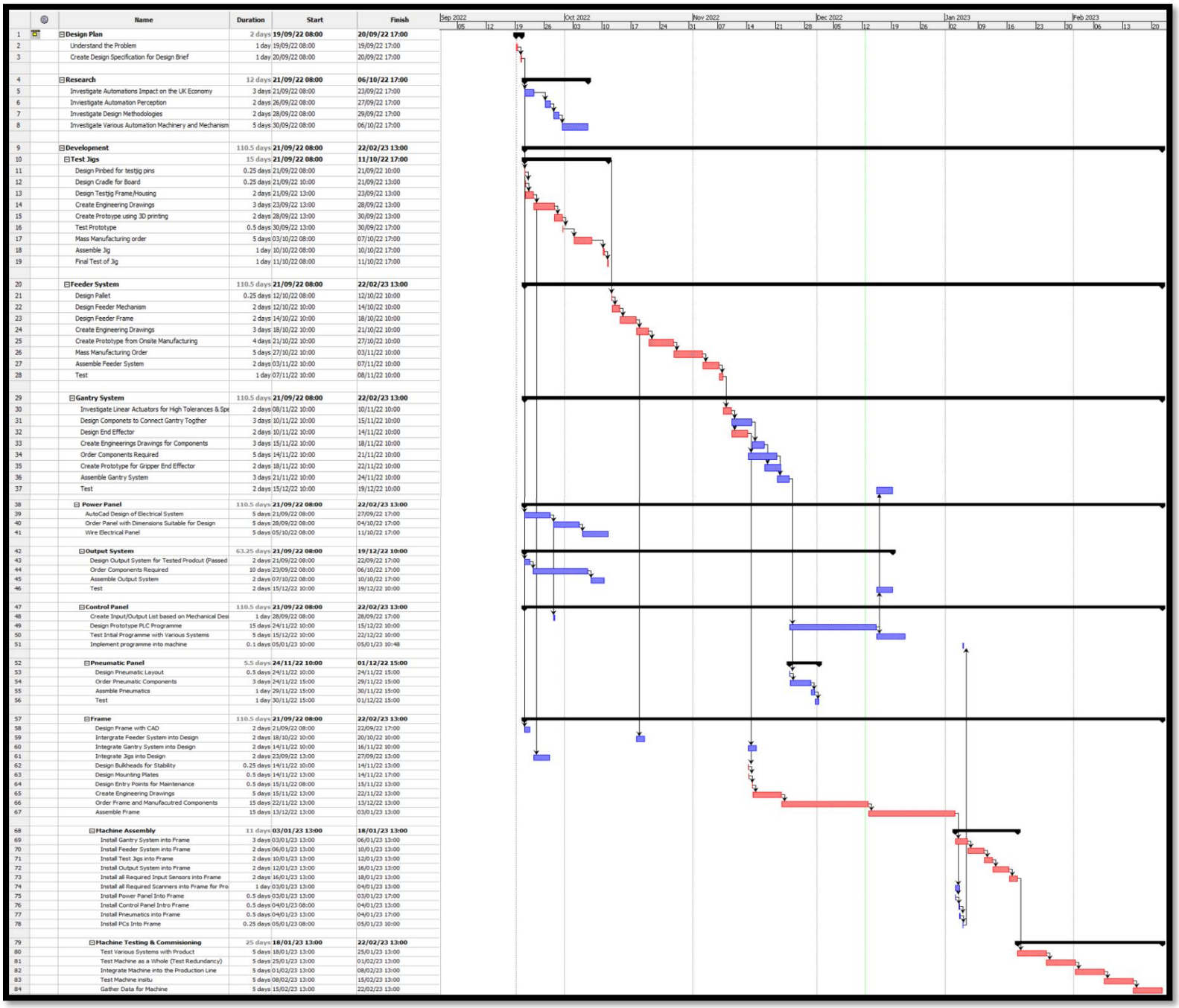
A Design Brief (See Appendix One) offers an overview of the solution requirements to guarantee that the project's goal is satisfied whilst stating the design constraints. This results in a Design Specification (See Appendix Two) outlining the specifications for the machine in great detail.

1.3.2. Timing Plan

A timing plan with predetermined deadlines for task completion is utilised to keep the project on track and guarantee timely completion. The timing plan makes it possible to assign particular tasks to departments and engineers and achieve deadlines.

To take advantage of opportunities and satisfy rising product demand (see Design Brief in Appendix One), the project's completion date of February 22, 2023, has been selected.

The project's overall time is shown on a Gantt chart (Figure 1, with a more in-depth version in Appendix Ten), which uses Critical Path Analysis (CPA) to determine if activities may be completed concurrently or whether they need prerequisites. The project's initial design plan is shown in the Gantt Chart with its final implementation date, with a projected completion time of slightly over five months.



	Name	Duration	Start	Finish
1	**Design Plan**	2 days	**19/09/22 08:00**	**20/09/22 17:00**
2	Understand the Problem	1 day	19/09/22 08:00	19/09/22 17:00
3	Create Design Specification for Design Brief	1 day	20/09/22 08:00	20/09/22 17:00
4	**Research**	12 days	**21/09/22 08:00**	**06/10/22 17:00**
5	Investigate Automations Impact on the UK Economy	3 days	21/09/22 08:00	23/09/22 17:00
6	Investigate Automation Perception	2 days	26/09/22 08:00	27/09/22 17:00
7	Investigate Design Methodologies	2 days	28/09/22 08:00	29/09/22 17:00
8	Investigate Various Automation Machinery and Mechanism	5 days	30/09/22 08:00	06/10/22 17:00
9	**Development**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
10	**Test Jigs**	15 days	**21/09/22 08:00**	**11/10/22 17:00**
11	Design Pinbed for testjig pins	0.25 days	21/09/22 08:00	21/09/22 10:00
12	Design Cradle for Board	0.25 days	21/09/22 10:00	21/09/22 13:00
13	Design Testjig Frame/Housing	2 days	21/09/22 13:00	23/09/22 13:00
14	Create Engineering Drawings	3 days	23/09/22 13:00	28/09/22 13:00
15	Create Prototype using 3D printing	2 days	28/09/22 13:00	30/09/22 13:00
16	Test Prototype	0.5 days	30/09/22 13:00	30/09/22 17:00
17	Mass Manufacturing order	5 days	03/10/22 08:00	07/10/22 17:00
18	Assemble Jig	1 day	10/10/22 08:00	10/10/22 17:00
19	Final Test of Jig	1 day	11/10/22 08:00	11/10/22 17:00
20	**Feeder System**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
21	Design Pallet	0.25 days	12/10/22 08:00	12/10/22 10:00
22	Design Feeder Mechanism	2 days	12/10/22 10:00	14/10/22 10:00
23	Design Feeder Frame	2 days	14/10/22 10:00	18/10/22 10:00
24	Create Engineering Drawings	3 days	18/10/22 10:00	21/10/22 10:00
25	Create Prototype from Onsite Manufacturing	4 days	21/10/22 10:00	27/10/22 10:00
26	Mass Manufacturing Order	5 days	27/10/22 10:00	03/11/22 10:00
27	Assemble Feeder System	2 days	03/11/22 10:00	07/11/22 10:00
28	Test	1 day	07/11/22 10:00	08/11/22 10:00
29	**Gantry System**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
30	Investigate Linear Actuators for High Tolerances & Spe	2 days	08/11/22 10:00	10/11/22 10:00
31	Design Componets to Connect Gantry Togther	3 days	10/11/22 10:00	15/11/22 10:00
32	Design End Effector	2 days	10/11/22 10:00	14/11/22 10:00
33	Create Engineerings Drawings for Components	3 days	15/11/22 10:00	18/11/22 10:00
34	Order Components Required	5 days	14/11/22 10:00	21/11/22 10:00
35	Create Prototype for Gripper End Effector	2 days	18/11/22 10:00	22/11/22 10:00
36	Assemble Gantry System	3 days	21/11/22 10:00	24/11/22 10:00
37	Test	2 days	15/12/22 10:00	19/12/22 10:00
38	**Power Panel**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
39	AutoCad Design of Electrical System	5 days	21/09/22 08:00	27/09/22 17:00
40	Order Panel with Dimensions Suitable for Design	5 days	28/09/22 08:00	04/10/22 17:00
41	Wire Electrical Panel	5 days	05/10/22 08:00	11/10/22 17:00
42	**Output System**	63.25 days	**21/09/22 08:00**	**19/12/22 10:00**
43	Design Output System for Tested Prodcut (Passed	2 days	21/09/22 08:00	22/09/22 17:00
44	Order Components Required	10 days	23/09/22 08:00	06/10/22 17:00
45	Assemble Output System	2 days	07/10/22 08:00	10/10/22 17:00
46	Test	2 days	15/12/22 10:00	19/12/22 10:00
47	**Control Panel**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
48	Create Input/Output List based on Mechanical Desi	1 day	28/09/22 08:00	28/09/22 17:00
49	Design Prototype PLC Programme	15 days	24/11/22 10:00	15/12/22 10:00
50	Test Intial Programme with Various Systems	5 days	15/12/22 10:00	22/12/22 10:00
51	Implement programme into machine	0.1 days	05/01/23 10:00	05/01/23 10:48
52	**Pneumatic Panel**	5.5 days	**24/11/22 10:00**	**01/12/22 15:00**
53	Design Pneumatic Layout	0.5 days	24/11/22 10:00	24/11/22 15:00
54	Order Pneumatic Components	3 days	24/11/22 15:00	29/11/22 15:00
55	Assmble Pneumatics	1 day	29/11/22 15:00	30/11/22 15:00
56	Test	1 day	30/11/22 15:00	01/12/22 15:00
57	**Frame**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
58	Design Frame with CAD	2 days	21/09/22 08:00	22/09/22 17:00
59	Intergrate Feeder System into Design	2 days	18/10/22 10:00	20/10/22 10:00
60	Integrate Gantry System into Design	2 days	14/11/22 10:00	16/11/22 10:00
61	Integrate Jigs into Design	2 days	23/09/22 13:00	27/09/22 13:00
62	Design Bulkheads for Stability	0.25 days	14/11/22 10:00	14/11/22 13:00
63	Design Mounting Plates	0.5 days	14/11/22 13:00	14/11/22 17:00
64	Design Entry Points for Maintenance	0.5 days	15/11/22 08:00	15/11/22 13:00
65	Create Engineering Drawings	5 days	15/11/22 13:00	22/11/22 13:00
66	Order Frame and Manufacutred Components	15 days	22/11/22 13:00	13/12/22 13:00
67	Assemble Frame	15 days	13/12/22 13:00	03/01/23 13:00
68	**Machine Assembly**	11 days	**03/01/23 13:00**	**18/01/23 13:00**
69	Install Gantry System into Frame	3 days	03/01/23 13:00	06/01/23 13:00
70	Install Feeder System into Frame	2 days	06/01/23 13:00	10/01/23 13:00
71	Install Test Jigs into Frame	2 days	10/01/23 13:00	12/01/23 13:00
72	Install Output System into Frame	2 days	12/01/23 13:00	16/01/23 13:00
73	Install all Required Input Sensors into Frame	2 days	16/01/23 13:00	18/01/23 13:00
74	Install all Required Scanners into Frame for Pro	1 day	03/01/23 13:00	04/01/23 13:00
75	Install Power Panel Into Frame	0.5 days	03/01/23 13:00	03/01/23 17:00
76	Install Control Panel Intro Frame	0.5 days	04/01/23 08:00	04/01/23 13:00
77	Install Pneumatics into Frame	0.5 days	04/01/23 13:00	04/01/23 17:00
78	Install PCs Into Frame	0.25 days	05/01/23 08:00	05/01/23 10:00
79	**Machine Testing & Commisioning**	25 days	**18/01/23 13:00**	**22/02/23 13:00**
80	Test Various Systems with Product	5 days	18/01/23 13:00	25/01/23 13:00
81	Test Machine as a Whole (Test Redundancy)	5 days	25/01/23 13:00	01/02/23 13:00
82	Integrate Machine into the Production Line	5 days	01/02/23 13:00	08/02/23 13:00
83	Test Machine insitu	5 days	08/02/23 13:00	15/02/23 13:00
84	Gather Data for Machine	5 days	15/02/23 13:00	22/02/23 13:00

Figure 1. Gantt Chart and CPA

Chapter Two -
Literature Review

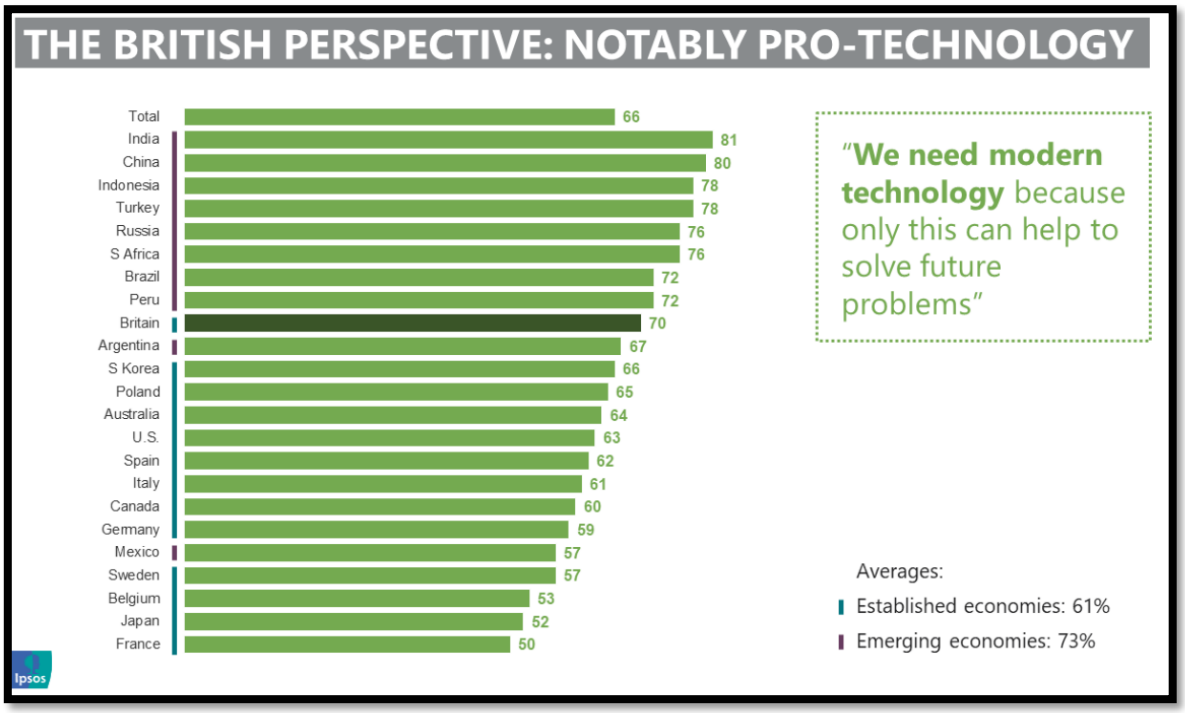
2.1. Automation

Automation is the use of technology to perform tasks without human intervention, such as robots, computers, and control systems. It can be used for complex or repetitive tasks to increase efficiency, reduce errors, and improve safety while reducing costs.

Robotics, Computer Numerical Control (CNC) machinery, Programmable Logic Controllers (PLCs), sensors, actuators and material handling systems may all be used in manufacturing, integrated to create a smooth, effective automated production process (*Automation Systems*, 2023).

2.1.1. Public Perception of Automation

Current literature indicates mixed reviews around automation perception. According to Kleinman *et al.* (2019, p.3), Britons are highly optimistic about innovation, with 70% believing it will solve future problems, higher than the global average of 66% shown in Graph 1.



Graph 1. British Technology Perceptive (Kleinman et al. 2019)

Furthermore, Kleinman *et al*. (2019, pp.3-4) state Britons are pro-technology when it directly benefits them, such as a new smartphone or online shopping.

Conversely, it is further stated by Kleinman *et al*. (2019, pp.3-4) the British public is concerned about the potential loss of their jobs due to automation, with Jones (2022) stating that a third of workers believe their jobs are at risk.

According to Jones (2022), workers in lower-paying, lower-skilled jobs are more likely to be unprepared for automation since they do not think their jobs would be automated. Interestingly, workers in occupations where automation is less likely are more concerned, thus, more prepared as a result.

This may lead to higher negativity around automation within lower-skilled jobs due to the uncertainty and surprise when jobs are automated. Holzer (2022) states that lower-skilled workers will compete with machines. However, those who adapt to the change will enjoy higher compensation. Therefore, automation may benefit not only employers but also workers. Kleinman *et al.* (2019, p.5) support these statements stating that preparation is vital for new job prospects with increased productivity, although changing perception is challenging.

Automation highlights the need for preparation by outlining the potential employment implications and emphasising the necessity for retraining and upskilling.

Conversely, there are positive perceptions around automation within UK manufacturing. According to findings from an annual survey of engineers in the UK manufacturing sector in an Article from the **Institution of Mechanical Engineers (IMechE)**, innovation continues to be the primary focus of business investment despite challenges posed by Brexit, COVID-19, and political and economic unrest.

There is also a positive correlation between innovation and spending on hiring highly skilled workers for automation. The survey also discovers a rising focus on environmental sustainability and lowering carbon emissions. The report shows a favourable trend towards automation in the industry, despite implementation problems (*Automation in manufacturing: A UK perspective,* 2022).

2.1.2. Automation’s Impact on the Economy

The UK economy has been significantly impacted by manufacturing automation in terms of its contribution to economic growth and its effect on employment. Productivity and efficiency gains are the two main advantages of factory automation. Automated manufacturing techniques usually increase productivity and lower production costs because they are faster and more accurate than humans. This enhanced productivity can help firms' ability to compete in a global market and boost economic growth (Westrom, 2022).

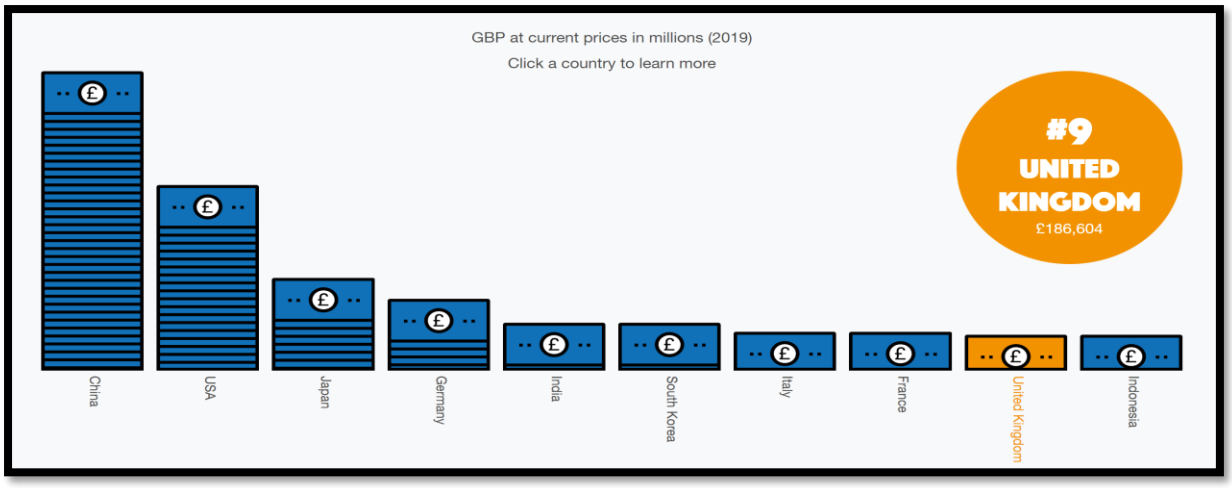
Manufacturing automation can result in new technological advancements, job growth, and improved efficiency. For instance, new businesses like industrial automation have emerged due to the development of automation technology like robotics and machine learning, which creates opportunities for highly qualified employees (Zhang *et al*., 2015, pp.3-22).

Manyika *et al.* (2019) support these statements; however, states automation leads to possible job displacement, explaining automated manufacturing processes have the potential to replace workers who were engaged in manual labour, resulting in job losses and alterations in the skills required in the industry. Conversely, although worldwide job loss due to automation may be inevitable, these create opportunities for jobs requiring new skills relating to Science, Technology, Engineering, and Mathematics (STEM).

A **UK Parliament** report on UK automation highlights its potential to increase productivity and economic growth; however, it also mentions job risks. As a result, the research recommends retraining and reskilling to ensure employability, which aligns with Holzer's (2022) assertion regarding the need for preparedness. It is noted that adopting ethical automation techniques, as well as greater dissemination of the advantages of automation, is crucial (*Automation and the future of work*, 2019).

The UK government has taken steps to support the development of automation technology, such as the Made Smarter Initiative, which helps small and medium-sized enterprises implement new production technologies, such as automation, through funding and support (*UK Digital Manufacturing Advice & Innovation*, 2023).

According to Make UK (2022), in the article “UK remains in the top ten of largest manufacturing countries”, the UK is the ninth largest manufacturing nation in the world as of 2016 – 2019, as shown in Graph 2. Manufacturing by Country (2022) supports these claims into the year 2022, stating the UK contributes 1.8% to the global manufacturing economy.



Graph 2. UK Global Manufacturing Market Position (UK remains in the top ten of largest manufacturing countries, 2022)

GDP measures the size and health of a country's economy. Clark (2022) states the UK has a GDP of 2.2 trillion British Pounds, as of 2021, with a global GDP share of 2.1%, placing the UK ninth in GDP shares globally (*United Kingdom's share of global GDP*, 2021).

The UK contributes 1.8% to global manufacturing, also placing them ninth for their share in Manufacturing contributions globally. The manufacturing sector accounts for 9.8% of the total UK economic output as of 2021, accounting for 8.1% of all jobs in the UK in July-September 2022 (*Manufacturing by country*, 2022).

The McKinsey Global Institute's 2017 paper, "A Future That Works: Automation, Employment, and Productivity," emphasises how automation may boost manufacturing output while reducing costs and increasing product quality, contributing to economic growth.

Automation can create new job opportunities within STEM fields whilst making it feasible to produce larger quantities of product, meeting shifting consumer requirements, thus, opening up new markets.

The article also emphasises the need for legislation and initiatives to lessen adverse effects on employees and communities that may not profit equitably to ensure equitable sharing of gains from automation (*A future that works: Automation, Employment and Productivity*, 2017).

A PwC report suggests that adopting automation and Artificial Intelligence (AI) in the UK industrial sector might raise output by as much as 10% over baseline levels by 2030. The article asserts that employment losses brought on by automation could be partially offset by creating new ones (*Will robots really steal our jobs? - An international analysis of the potential long-term impact of automation*, 2018, pp.17-35).

The McKinsey Global Institute further state that automation has positive potential for economic benefits, from labour cost savings, performance and productivity increases, and increased safety and product quality (*A future that works: Automation, Employment and Productivity*, 2017, p.10).

In its study paper "Robotics and Automation: A New Perspective," the Manufacturing Technology Centre (MTC) emphasizes the significance of the manufacturing industry, which accounts for more than half of the UK's exports. Robotics and automation have recently made significant technological advances, essential for increasing productivity and sustainability to address issues such as Net Zero. The UK, however, falls behind other countries in adopting new technologies.

The article's conclusions state that robotics and automation are essential for boosting manufacturing productivity in the UK since they may significantly impact the entire nation's economy. Additionally, employing automation and robotics can help UK businesses maintain their competitiveness in the international market, which can spur economic growth (*Robotics and Automation: A New Perspective*, 2022).

Therefore, the literature implies that the UK can continue its impact on global manufacturing by embracing automation, although the effects of automation on job losses and productivity gains are unpredictable. More actions are required to maintain the UK's competitiveness and fully reap the benefits of automation. It's essential for long-term economic growth to find solutions to problems.

2.2. Engineering Design

Engineering design integrates mathematics, physics and its subfields, production technology, material science, machine elements, industrial engineering management, and cost accounting (Wang *et al*., 2006, p.257).

In support of this, Webster (2015) defines engineering design as a set of decision-making processes used to decide the form an object should take to perform its required functions, as well as a systematic and intelligent process of creating and evaluating specifications that meet stated goals and limitations.

According to Smith (2000, p.105), the process of creating systems, parts, or protocols that successfully address a need is known as engineering design. Engineering design utilises mathematics, engineering principles, and fundamental sciences whilst using decision-making and iterative stages to transform resources into solutions that best fulfil essential functions.

Thus, according to the consensus, an object's form is determined by its function and necessary objective, and Engineering design involves formulating, generating, analysing, and evaluating (Webster, 2015).

2.2.1. Engineering Design Process

Various design categories (product, software, structural/architectural, mechanical) demand multiple procedures and approaches for effective project outcomes.

Engineers use steps in the engineering design process to solve problems by designing, creating, and testing products that adhere to specifications. Figure 2 highlights various aspects of engineering design while contrasting the engineering design method with the scientific method, whilst Figure 3 highlights the processes around engineering design (Lasser, 2023).

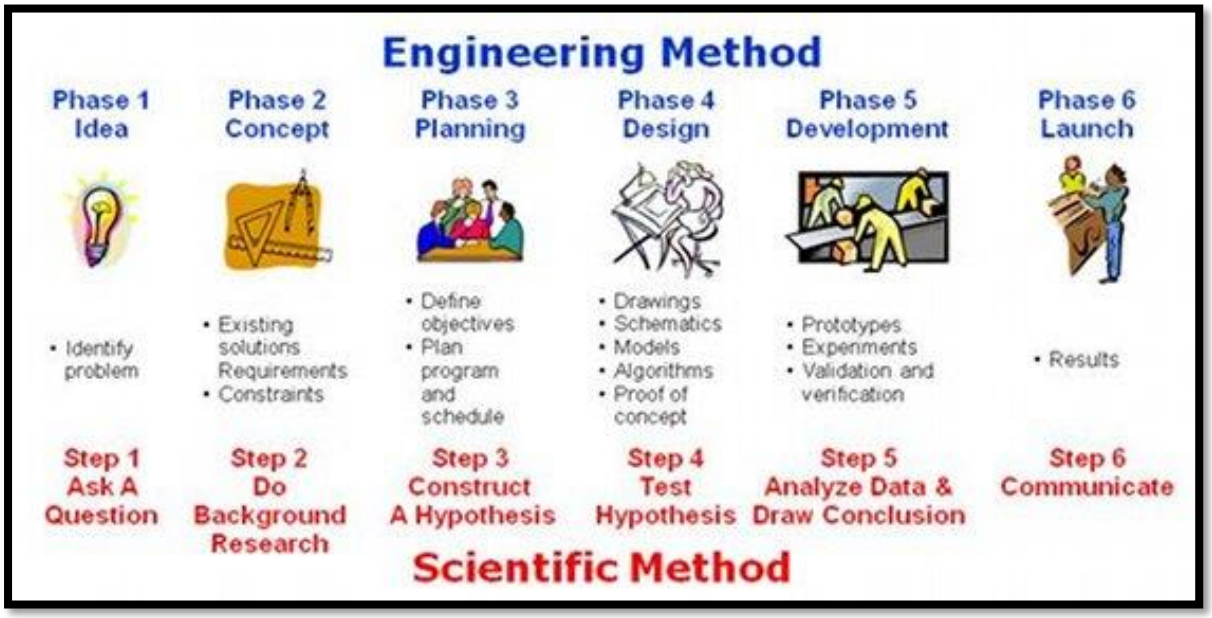


Figure 2. Engineering Method Vs Scientific Method (Lasser, 2023)

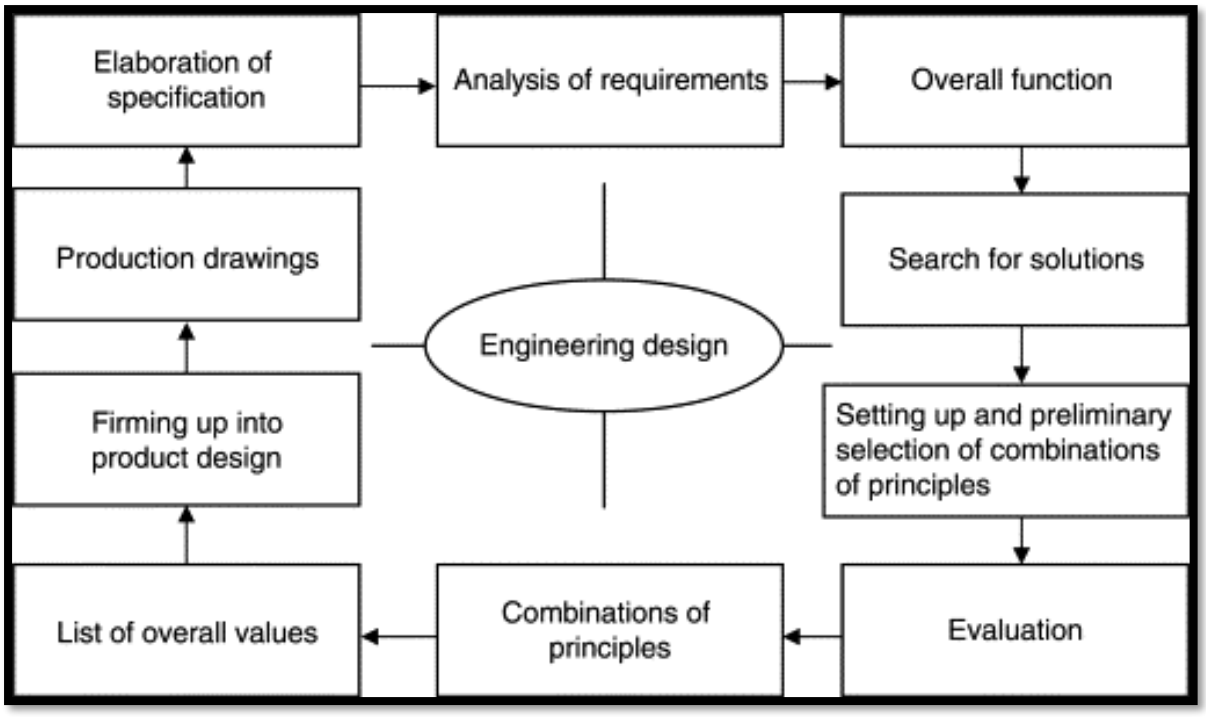


Figure 3. Engineering Design Process (Wang, R. et al. 2006)

Software, electrical, and mechanical design are all included in the scope of automation engineering. Mechanical design is heavily utilised in bespoke machine design. Mechanical design is utilised to create automated manufacturing solutions using engineering physics, mathematics, and material science. These designs must consider electrical power, software control, dependability, maintenance, cost, and quality while adhering to deadlines and specifications (Fitzgerald & Wilson, 2022).

Yu Siang (2022) proposes a Five-Stage Design process, as depicted in Figure 4, which is an iterative approach that follows a linear path but can be used as a loop for redesigning prototypes based on testing and requirements.

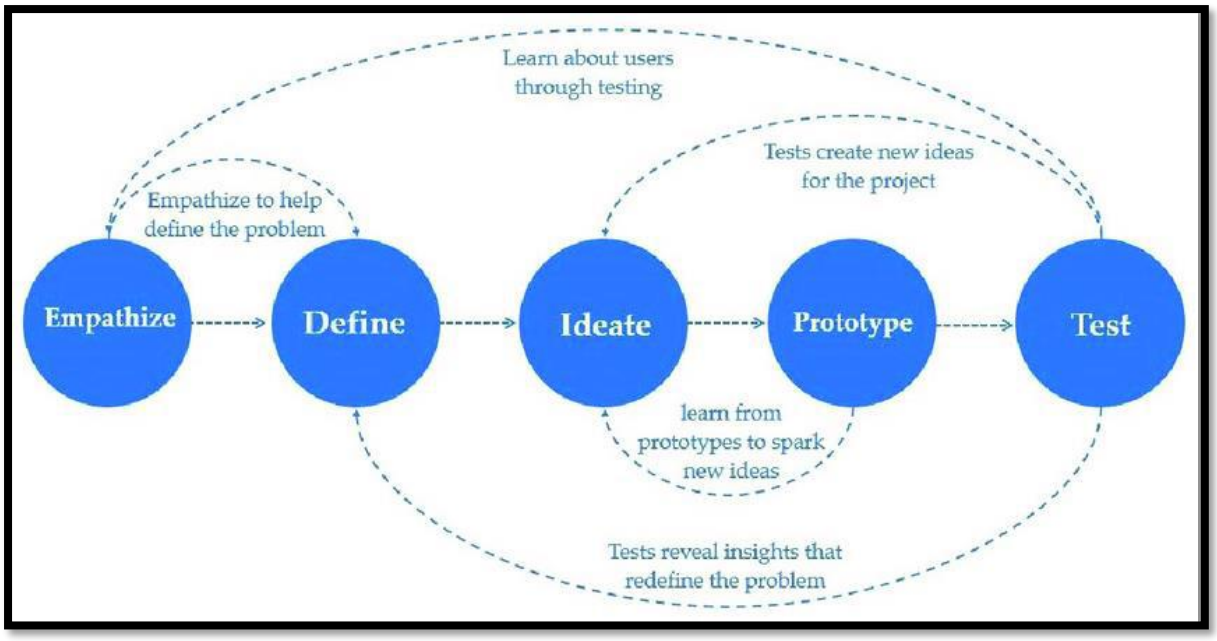


Figure 4. Five-Stage Design Process (Yu Siang, 2022)

Alternatively, due to their similarities, the various process methods can be intertwined whilst implementing additional steps with an iterative approach. Furthermore, process improvement techniques, such as the Define, Measure, Analyse, Improve and Control (DMAIC) Six Sigma Process, can be utilised, as shown in Figure 5.

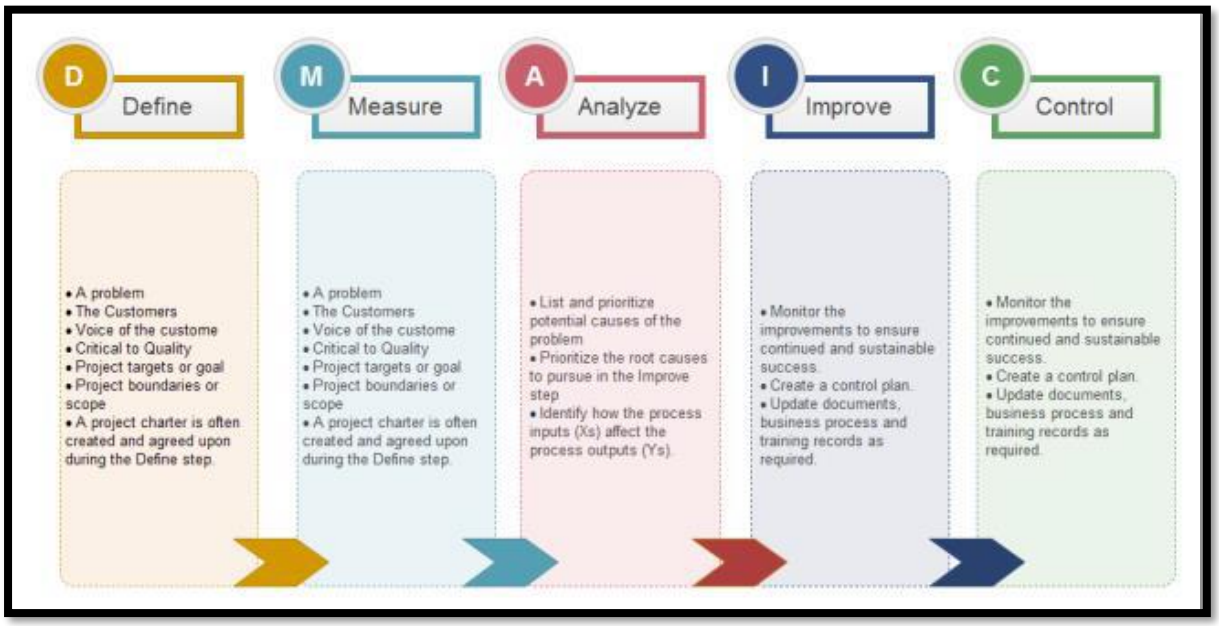


Figure 5. DMAIC Six Sigma Process (Six Sigma DMAIC 5-step process, 2018)

This method is used to improve processes, so even though it isn't used in the early design stages, it can be used for any process design. For instance, it can be used to understand a

manual process before automating it. As a result, it can be thought of as a process that is used concurrently in the background.

2.2.2. Design Methods

Designing is a complex process that compels organisations to strive for optimal outcomes. Beyond the process' sequential steps, the design's efficiency is paramount. This is where various design methodologies, such as Design for X (DFX), highlighted by McGill University (2022), are required. These methodologies guide designers and engineers to create products or systems that align with specific objectives.

The "X" in DFX can stand for several focal areas, including but not limited to:

- **Design for Manufacturing (DFM):** Designing products to reduce manufacturing costs, enhance quality, and boost production efficiency by minimising and standardising parts, creating modular designs, designing multifunctional components, and reducing fasteners (Velling, 2021).

- **Design for Assembly (DFA):** Designing items for easier assembly with fewer mistakes, utilising techniques such as Poka-Yoke (mistake proofing) and modular designs, ensuring not only a more straightforward assembly process but also less complicated maintenance requirements (Velling, 2021).

- **Design for Reliability (DFR):** Designing for reliability includes features like component redundancy, safety considerations, and stress testing to ensure that a product can operate dependably throughout its intended lifetime. Preventive maintenance can also be carried out, including simple maintenance and operational steps before total failure (Velling, 2021).

- **Design for Safety (DFS):** The process of designing items to guarantee user or operator safety and reduce the danger of harm or damage. This can include Hazard Analysis, Ergonomic Design, Durability, and Design Safety Features (*Design for Safety: Design Strategies to generate safe systems*, 2021).

Multiple design techniques can be utilised singly or in combination for a project. ADEPT Engineering (2023) propose an approach to problem-solving for engineers that can use design techniques at each level, similar to the Five-Stage Design Process. Figure 6 illustrates this, with the different phases and design methodologies that can be used to achieve these tasks,

some of which can be utilised more frequently than others (*Product Design Engineering Methods* 2023).

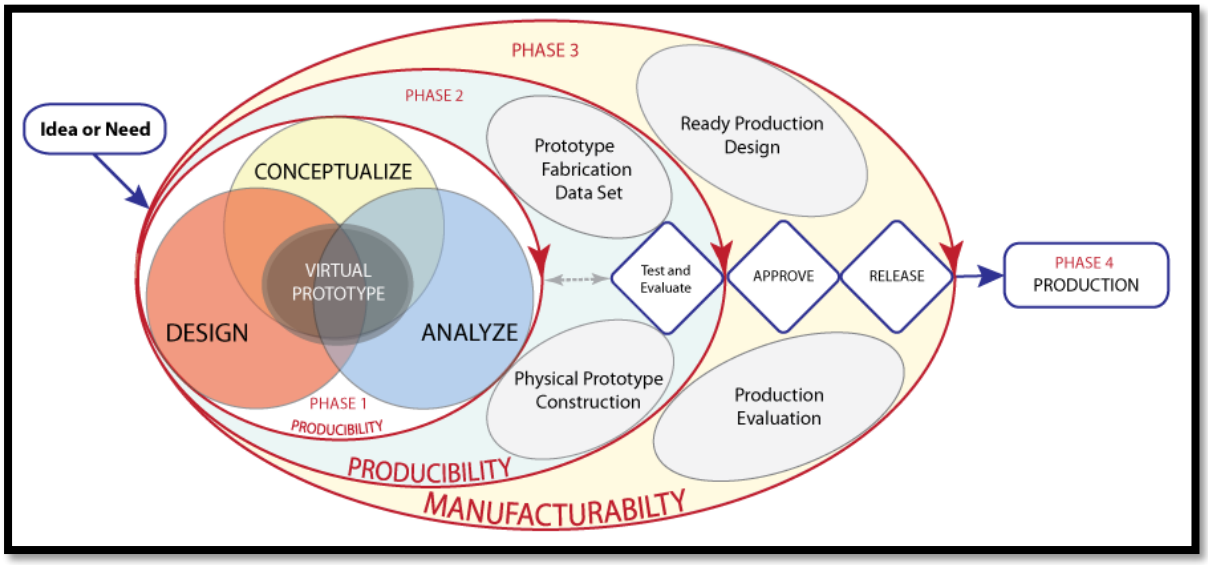


Figure 6. Design Methodology Phases (Product Design Engineering Method, 2023).

Therefore, the design processes and methods can be intertwined to produce various process phases to achieve successful results.

Chapter Three -
Design & Development

The project's aim is achieved using a systematic methodology, similar to the Five-Stage Design Process, to ensure the design adheres to the project's objectives and design requirements. This strategy breaks down each objective to guarantee the project's aim is accomplished. The approach is as follows:

1. **Requirement Gathering**: Involves defining functional requirements to meet the overall design specification.

2. **Conceptional Design**: Solidworks, CAD software, is utilised to develop a visual representation of an idea for the systems or products to convey the main characteristics and functionality of the concept.

3. **Design Review:** A team of professionals in relevant fields, such as engineering, manufacturing, and quality assurance, assess design proposals for viability and potential problems. The evaluation procedure is comprehensive and cooperative.

4. **Detailed Design**: After the design concept has been approved, a detailed design is created using Solidworks, including all necessary calculations, engineering drawings, and specifications.

5. **Prototype Development:** A functional prototype is created and tested to confirm the design and determine any required adjustments.

6. **Production/Integrated Design:** A final production design is created based on the validated prototype. This includes detailed engineering, manufacturing, and quality assurance plans.

DFM and DFA methods are utilised, using a modular design approach, dividing the system into subsystems. This offers several advantages, including individualised treatment of each subsystem for a simpler adherence to the design specification, ease of maintenance, manufacturing, assembly, and machine redundancy.

Before integration into the more extensive system, each subsystem design adheres to the design process mentioned whilst fulfilling the design specification requirements. As a result, the machine design is divided as follows:

- **Product Testing:** This facilitates product testing within the system.

- **Pick and Placement:** The product must be automatically placed into and out of the testing area within the system whilst conforming to the specification.

- **Input System:** The product needs to be delivered into the system.

- **Output System:** The product must be transported out of the system after test completion and sorted into failed and passed products, ready for rework or manual packing.

- **Machine Frame:** This integrates all the subsystems and must adhere to the specification.

Considerations have been made for safety and design standards, with adherence to the Provision and Use of Work Equipment Regulations (PUWER) and relevant ISO standards to promote safety, quality, and efficiency. ISO standards applicable to bespoke manufacturing equipment and automation machines may vary, with some listed in Appendix Three. While not all standards need to be legally followed, they aid in ensuring compliance with PUWER and can be used for guidance.

Although the systematic methodology is followed throughout the project, due to the report size limitation, only an overview of each system and its features can be provided; thus, various concepts, prototypes, design descriptions, design methods and all ISO adherences are not feasible to describe in full detail. Furthermore, the selection of several specific methods is rooted in the empirical decision-making practices within SUTC, with numerous designs being conceived and refined based on empirical knowledge.

3.1. Product Testing Design

Product A, shown in Figure 7, requires connection to its' connection strips (highlighted with red circles) to conduct testing. The software program for testing this product is already designed by the Test Engineering Team at SUTC.

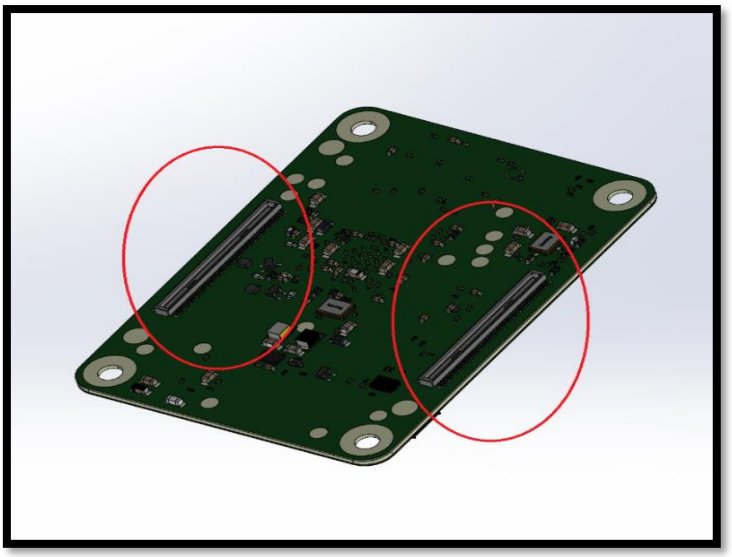


Figure 7. Product "A" Connectors

Test Engineering within SUTC has designed Printed Circuit Boards (PCBs) for the testing procedure. A Master Control Board (MCB) (Figure 8) serves as an interface for the software and network. A Sacrificial Interface Board (SIB) (Figure 9) sits between the MCB, and Product A, acting as an interface board, handling the load from the MCB and designed to be replaceable within designated cycles.

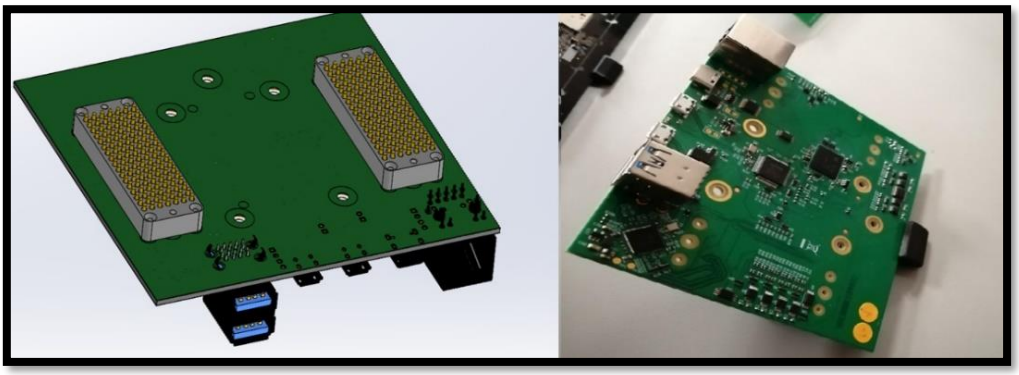


Figure 8. MCB

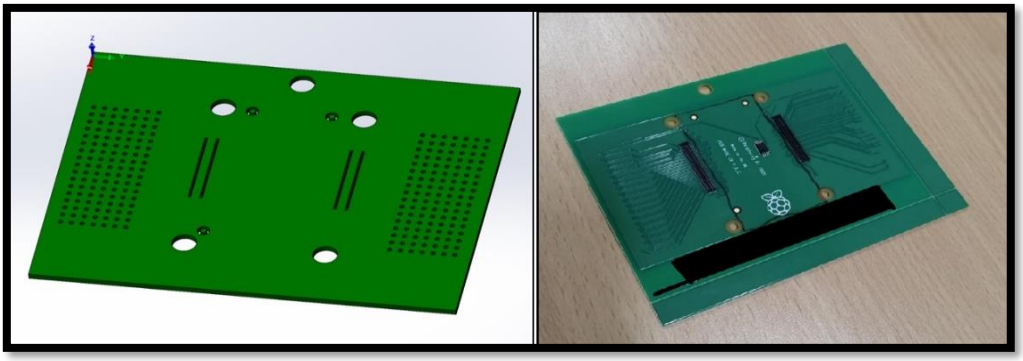


Figure 9. SIB

Mechanical assembly is required for these PCBs allowing for product testing. One method is to use stand-offs which is a low-cost option; however, as it's open to its surroundings, it increases failure potential due to dirty board conditions and operator-caused short-circuits on the MCB.

These disadvantages have led to an alternative approach: designing a component known as a **Pinbed**, which allows the PCBs to be mounted mechanically. It is manufactured from G10/FR-4, a composite material of glass fabric and electrical-grade epoxy resin.

The material is chosen due to its non-conductive, high mechanical strength, and good dimension stability properties whilst conforming to BS-EN-ISO-9001: Quality Management standards (*Garolite G10 FR4 machining services: G10 Material Sheets,* 2023).

Figure 10 shows the Pinbed design and PCB assembly. The MCB is mounted to the underside with the SIB topside, which allows Product A to connect and disconnect through the connection strips.

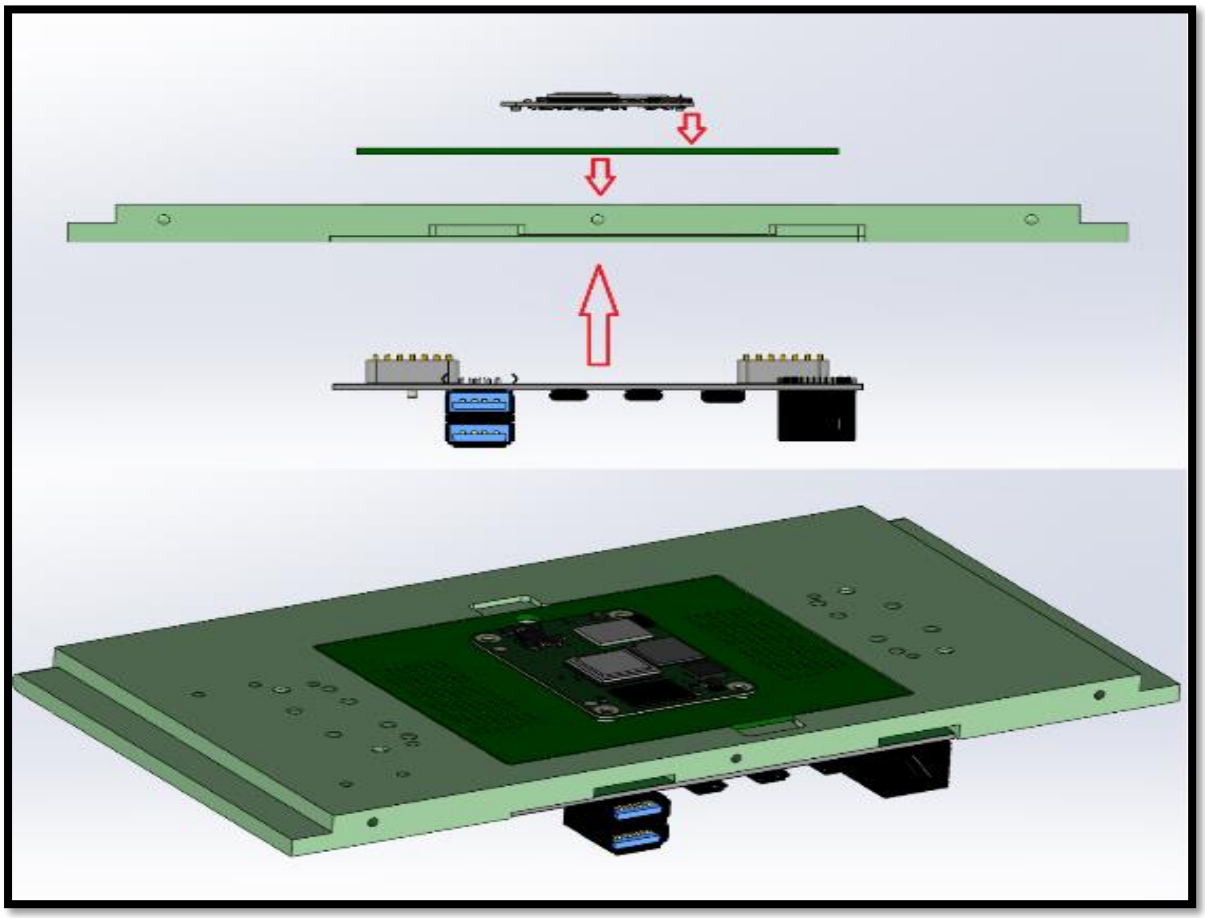


Figure 10. Pinbed Design & Product Assembly

The MCB is mounted with screws, which Pugh (1990, p.137) suggests standardising with British Standards Institution (BSI) screws to increase design efficiency and conform to DFA methods.

To conform to the design specification in Appendix Two (Section 5.0.), the SIB requires cycle replacement; thus, quick-release clamps are used. Holes in the SIB are designed to align with the holes in Product A, allowing tooling (location) posts fastened to the Pinbed to align Product A onto the SIB accurately. Post chamfers allow for the $\pm 0.05mm$ connection tolerance shown in Appendix Two to increase to $\pm 0.25mm$. Furthermore, an additional post prevents incorrect orientation of the SIB (Poka-Yoke), conforming to DFA.

The Pinbed requires a frame to house all electrical and electronic components, including an ethernet hub to connect to the network and a Raspberry Pi to run the software through the MCB. Figure 11 shows the complete design known as the **"Test Jig".**

The Pinbed slides into this aluminium frame connected to a baseplate for stability. The Pinbed is fastened to side supports with aluminium sheets, known as the front and back plates which include cut-outs for the internal electronic components used for external connections. The design thus allows for easy assembly and maintenance. Aluminium is chosen due to its high strength-to-weight ratio, non-corrosive properties, and highly conductive properties, ensuring electrical earthing capabilities.

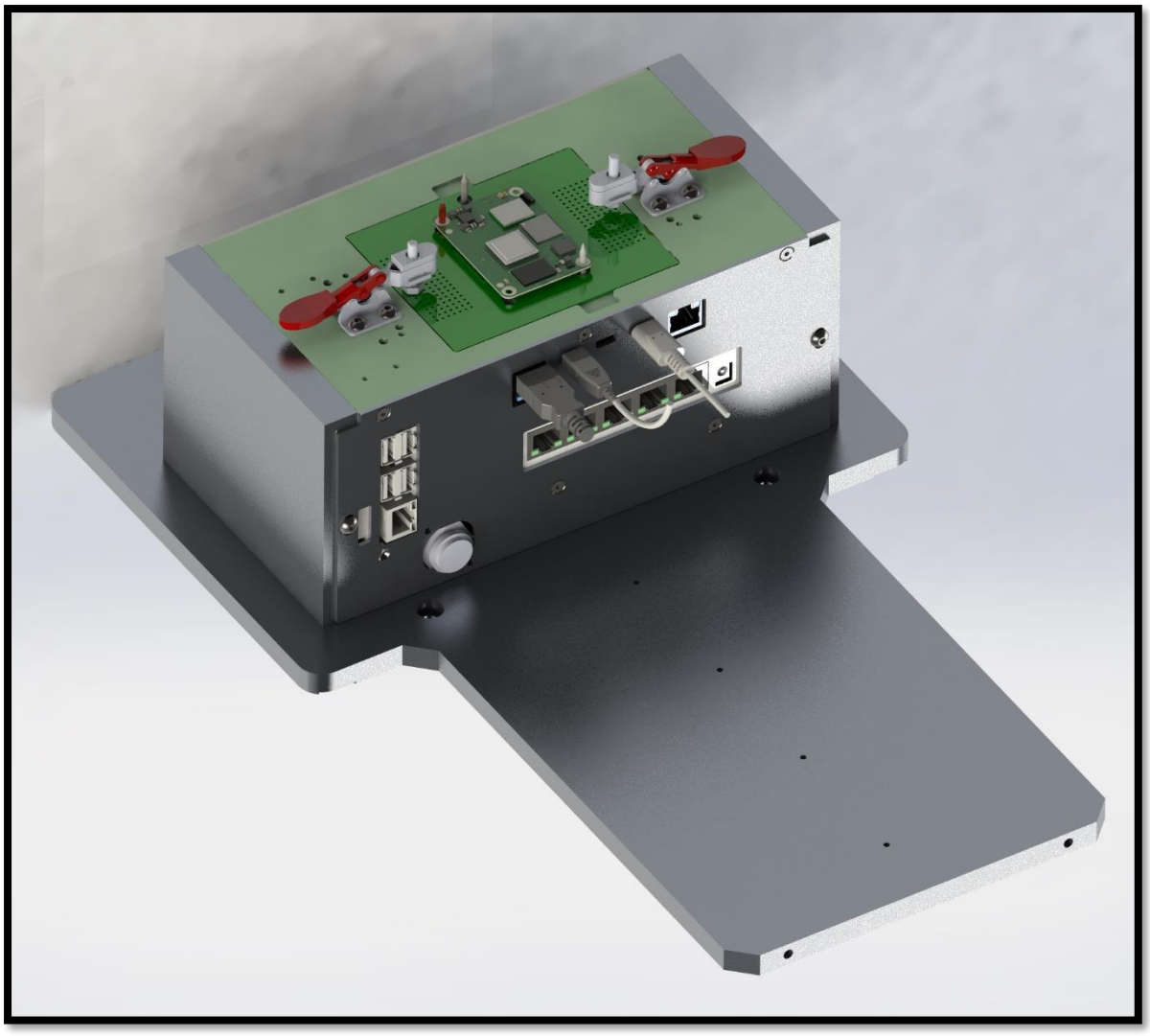


Figure 11. Test Jig Design

The Test Jig is designed to be integrated into the automation machine; however, due to its strong mechanical stability can be used as a standalone if required.

The number of Test Jigs required is calculated in Appendix Four and is based on the solution given for the pick and placement method in section 3.2, which is further discussed later in the report.

3.2. Pick and Place

It must be possible to pick and place Product A into and out of the Test Jig. This needs to adhere to the design requirements and guarantee an accuracy of $\pm 0.25mm$ to ensure connectivity between Product A and the Test Jig. The method must also conform to size requirements set out in the design specification.

Other requirements are not predetermined based on a minimum but are given importance ratings described later. For example, speed requirements have no minimum due to the speed of the solution chosen being used to determine the number of Test Jigs required to produce the required output, which also determines the spacing between the Test Jigs; thus, the faster the solution, the better, however, it is not a predetermined value.

3.2.1. Robotic Solutions

Collaborative robots, or Cobots, have force limits to protect humans and the product. They can operate around operators as they stop when a set force is exceeded, meeting safety standards and aiding in damage protection. Some Cobots also have proximity sensors and operate at slower speeds when humans are nearby. Cobots have a reduced need for guarding and safety risks, making them easier to maintain while meeting safety specifications. They can also operate on the specified power supply (*What is Collaborative Robot (Cobot)?*, 2023).

Cobots are slower than Industrial Robots, but because of their comparable prices and lack of guarding requirements, they are a more affordable option whilst reducing any safety risks.

Figure 12 shows an ABB Yumi, and Figure 13 shows a Universal Robot (UR), potential solutions widely used at SUTC.



Figure 12. ABB Yumi Cobot (ABB's collaborative robot -Yumi, 2023)

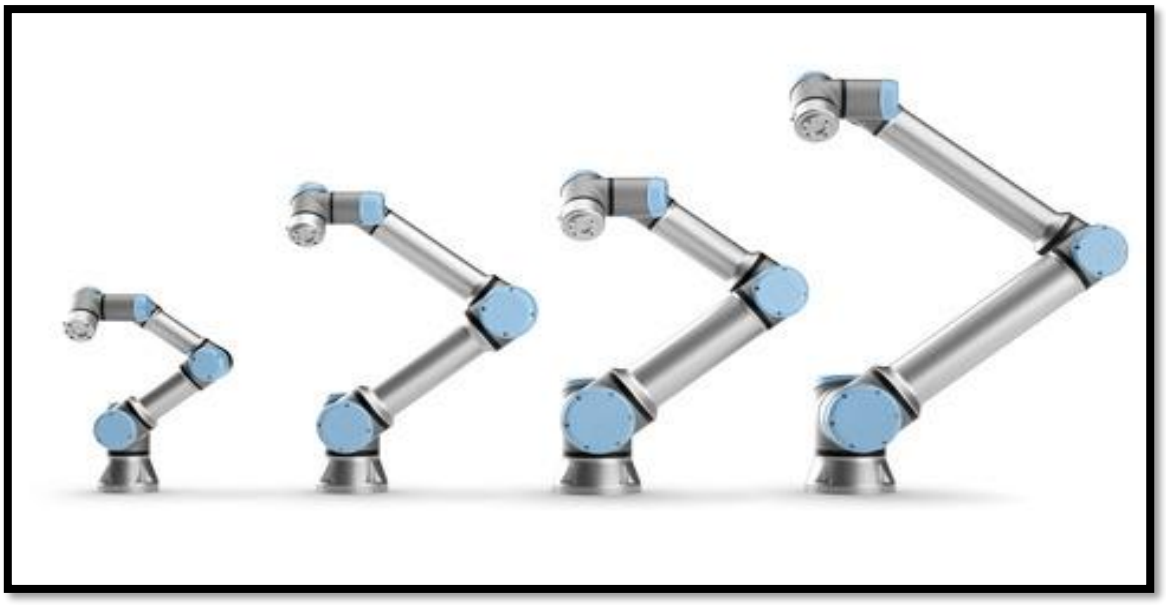


*Figure 13. UR Models (*Collaborative robots from UR: Start your automation journey, *2023)*

The Yumi robot has high collaboration, can lift up to 500g, and stops with even a light touch. For safety, it adjusts its sensitivity based on mass and acceleration. Although it costs between £35,000-£48,000 and has a repeatability of $\pm 0.02mm$, programming with RAPID script software can be difficult. The robot's speed is approximately $1.5m/s$ (ABB, 2023).

The **UR Cobot** comes in various payload capacities, with the lowest capable of lifting 3kg and moving at high speeds. It's less collaborative than the Yumi and needs additional safety programming, such as reducing acceleration below $200\ mm/s^2$. The 5kg version can move up to $1m/s$. The controller is separate, reducing its footprint. UR has a repeatability of $\pm 0.1mm$. It has a user-friendly programming language and pendant and can operate on the specified power supply, costing between £30,000-£38,000 (*UR5 technical specifications item no. 110105 - Universal robots*, 2023).

Prices can vary depending on the retailer. Additionally, some industries, such as SUTC, may be quoted a price based on the retailer's decision. One site, “Unchained Robotics,” states UR is approximately £26,000, and the ABB Yumi is approximately £46,000 (*Cobots,* 2023).

3.2.2. Gantry Systems

A Gantry system, shown in Figure 14, is also known as a Cartesian system in many industries. Typically, the names are interchangeable, with the Gantry system typically being a larger Cartesian system. However, at SUTC, Gantry is used as the terminology due to its purpose and arrangement. Furthermore, it may also be categorised under robotic systems, although

within this report is separated into its own category due to its dissimilarities with the other robotic systems.

A Gantry System employs electrical or fluid-controlled actuators and a Programmable Logic Controller (PLC) to operate in X, Y, and Z directions, and occasionally an R direction which is a rotation about the horizontal plane (*What are gantry robots,* 2023).

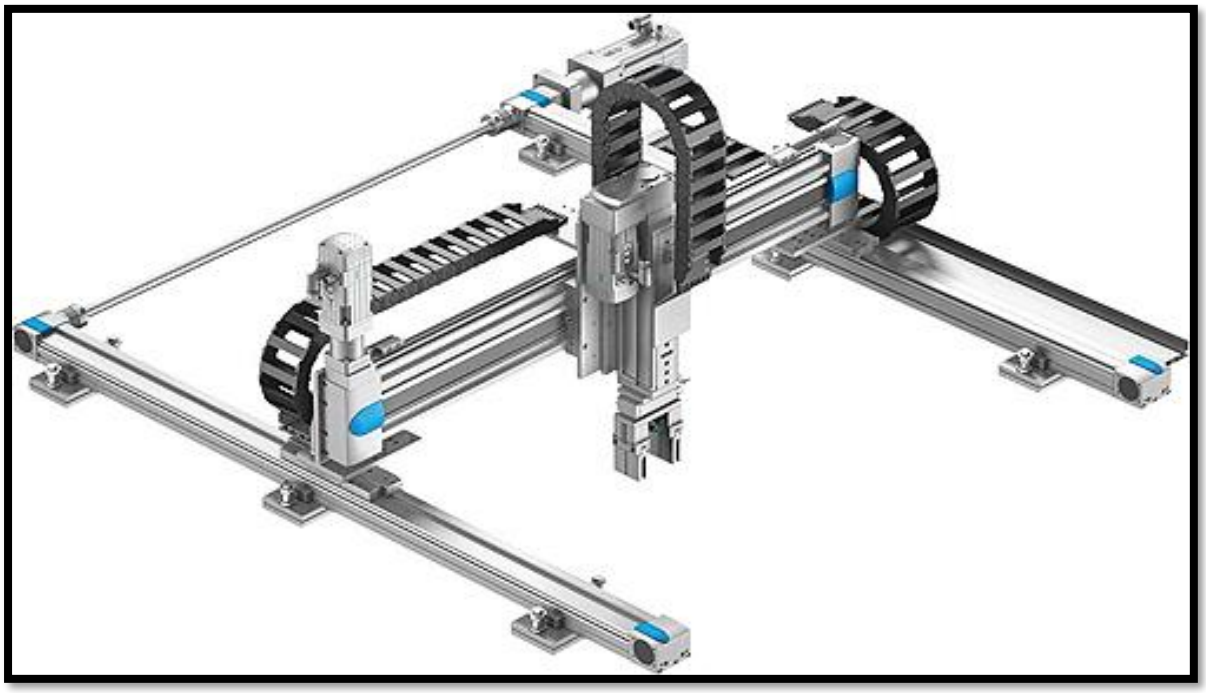


Figure 14. Gantry System (Tertünte & Endrijaitis, 2014)

Using ladder logic makes it simple to program specialised systems such as a Cartesian (Gantry) system using PLCs; however, compliance with ISO requirements necessitates acceptable torque levels on electrical actuators and pressure monitoring with fluid actuators. Additional safety precautions, such as guarding and interlock systems, may be necessary if the actuator torque or pressures cannot be modified.

Sintered Metal Corporation (SMC) have high-precision actuators achieving $\pm 0.001mm$ repeatability for the Y and X axis. However, choosing an actuator for precision may impact other aspects, such as speed and maximum lengths. Construction of a Gantry system depends on many factors; however, it typically costs between £6,000-£8,000 within SUTC, and depending on the actuators selected, some are capable of speeds surpassing $1m/s$. Therefore, speed and precision must be carefully considered in comparison to one another (*Products,* 2023).

3.2.3. Chosen Method

Decision analysis is used to determine the best method. Table 1 shows a scoring table used to generate the scores for the decision analysis table.

Table 1. Design Analysis Scoring

Criteria	Weight	Excellent	Good	Fair	Poor	Very Poor
Cost (£)	0.15	≤ 10000	≤ 15000	≤ 20000	≤ 25000	> 25000
Modifiability	0.10	High	Medium	Low	N/A	N/A
Speed (m/s)	0.10	≥ 1.5	≥ 1.0	≥ 0.5	≥0.25	<0.25
Accuracy (mm)	0.20	≤ 0.02	≤ 0.05	≤ 0.1	≤ 0.25	> 0.5
Safety	0.15	High	Medium	Low	N/A	N/A
Reach (m)	0.10	≥ 4.5	≥ 2.0	≥ 1.0	< 1.0	N/A
Integrability	0.10	High	Medium	Low	N/A	N/A
Payload (kg)	0.10	≥6	≥4	≥2	≥1	≤0.5

Each criterion is assigned a weight, with a total weight of 1, which determines its significance. For each category of criteria, scores of 1 to 5 are assigned on a scoring chart, except for Modifiability, Safety, and Integrability, which have a High-to-Low scale.

To determine the overall score for each design solution, the scores are multiplied by the weights and then added. This is done for each potential solution, as shown in Table 2.

The values are chosen considering the design specification. For example, a more extensive reach (range) is desirable to cover a larger area, with lower costs being desirable to conform to the budget. The specification for these systems is taken from the relevant documentation from the references mentioned previously.

Table 2. Pick and Place Decision Analysis

Design Solutions	Cost (£)	Modifiability	Speed (m/s)	Accuracy (mm)	Safety	Reach (m)	Integrability	Payload (kg)	Total Score
UR Cobot	26,000	Low	1.0	±0.1	Medium	0.850	Medium	5	3.05
ABB Yumi Cobot	46,000	Low	1.5	±0.02	High	0.559	Medium	0.5	3.25
Cartesian/ Gantry System	6,000	High	0.5	±0.08	Low	1.2	High	10	3.9

It can be seen the Gantry system has the highest score. Due to the modular design, it has high modifiability, allowing easy maintenance and part replacement, which can be stored at SUTC. It can be easily integrated using a PLC similar to most automation machines, with many interfaces. It is also the lowest cost and has similar accuracies to the Cobots.

Although due to the high accuracy, the speeds are limited. Furthermore, safety is lower and, thus, requires guarding. However, components meet Conformité Européene (CE) and UK Conformity Assessed (UKCA) regulations, but components must be integrated, forming further regulation requirements discussed later.

It can be mentioned mass (system weight) is not mentioned; however, although this is a design specification requirement, the machine can be designed around these weights to reduce the mass if required, such as Gantry components or other subsystem components being designed differently to reduce overall mass.

3.2.4. Gantry Design

Therefore, the Gantry method has been chosen as the Pick and Placement Subsystem Solution due to the design analysis. Two concepts have been designed, both meeting the specification.

Design one, shown in Figure 15, utilises a single Gantry system over a large area. The area required is based on the number of Test Jigs required, discussed later.

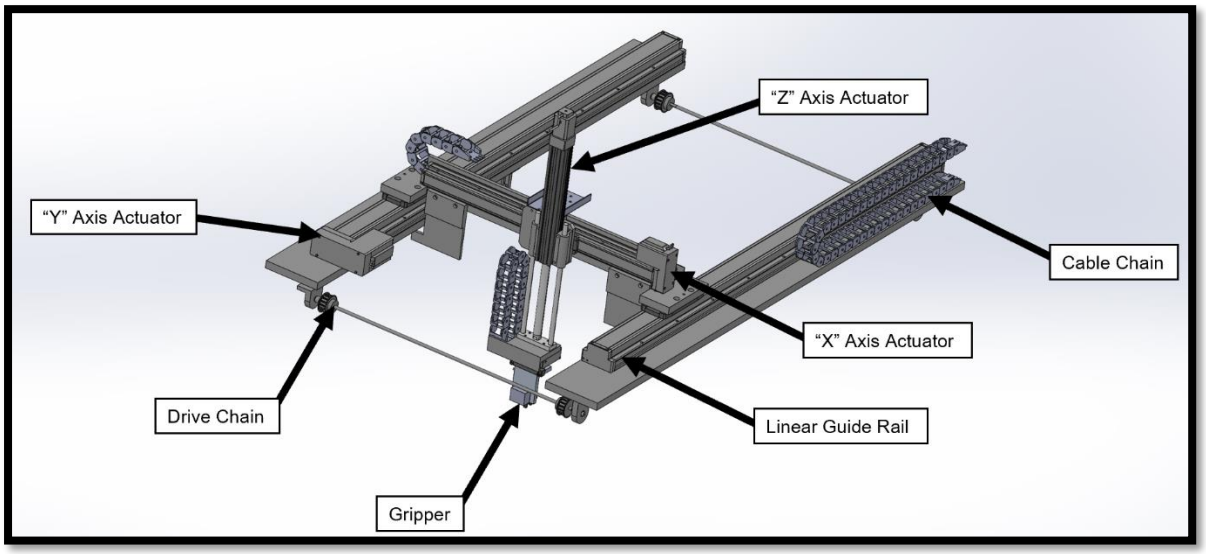


Figure 15. Gantry System (Concept One)

Design One uses a single Y-axis actuator connected to a linear rail by a support plate with the X-axis actuator attached. An electric motor drives the Y-axis actuator to move the X-axis support plate while pushing the linear guide rail, ensuring consistent X-axis support.

Due to the significant distance, drive chains connect both sides of the Gantry by toothed rollers connected to the actuator as flection may occur between the Y-axis actuator and guide rail. The Z-axis actuator attaches to the X-axis actuator support plate and allows for movement in the Z-axis. At the same time, a Gripper is connected to this actuator for part grabbing. Cable chains house pneumatics and electrical cables and move with the linear actuators.

Design Two uses a double Gantry system to cover the same area, as shown in Figure 16. It utilises the same methods as Design One but without needing a drive chain since the two Gantry systems cover the same area, resulting in less cumulative movement over the X-axis direction. This method requires double the components, except for the drive chains, for the same area.

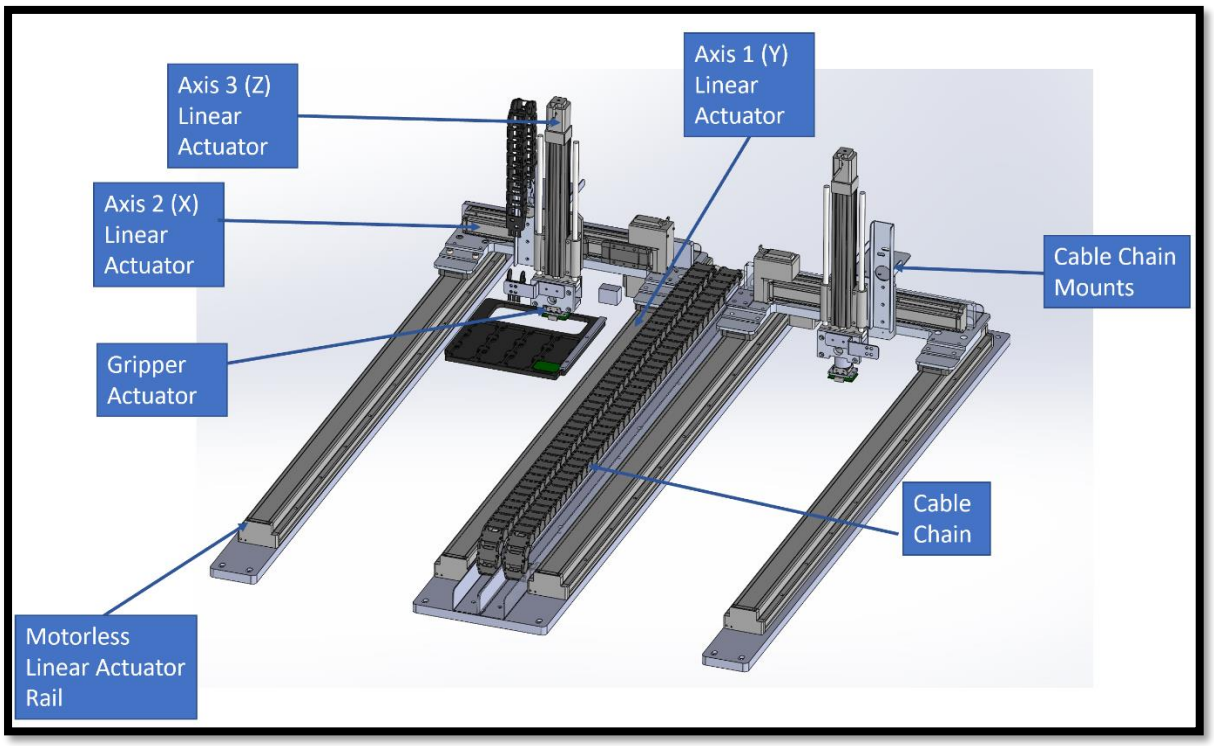


Figure 16. Gantry System (Concept Two)

Findings show that Design One fails the low complexity criteria of section 5.0 in Appendix Two and perhaps the performance requirements because potential alignment problems outweigh the lower cost of using fewer components as slight alignment issues accumulate over a distance. Furthermore, more maintenance is required with the additional drive chain.

Design Two is less complex with increased efficiency due to fewer area coverage requirements. It also decreases downtime with built-in redundancy because the failure of one Gantry only reduces output by half as the other Gantry acts as a standalone and continues to operate.

Figure 17 shows an example quote gathered for the actuators and drivers required for the double Gantry system design.

QUOTE REF QCP 20 - GF4326 (B)

Part Number	Item	Quantity	Unit Price	Disc %	Nett ea	Line Total
JXC927	3 Axis Ethernet IP controller.	2	£1,391.25	25	£1,043.44	£2,086.88
JXC-MA1	Controller setting software	1	£40.18	25	£30.14	£30.14
LEFG40-S-1200	Size 40, 1200mm stroke guide unit	2	£623.84	25	£467.88	£935.76
LEFSH25LB-300-R8	Size 25, electric actuator, 300mm stroke, 6mm lead complete with 8m cable	1	£1,098.10	25	£823.58	£823.58
LEFSH25RB-300-R8	Size 25 electric actuator, 300mm stroke, 6mm lead screw, complete with 8m cable	1	£1,098.10	25	£823.58	£823.58
LEFSH40LA-1200-R5	Size 40 electric actuator, 1200mm stroke,20mm lead, complete with 5m cable	1	£1,802.85	25	£1,352.14	£1,352.14
LEFSH40RA-1200-R5	Size 40 electric actuator, 1200mm stroke, 20mm lead screw, complete with 5m cable	1	£1,802.85	25	£1,352.14	£1,352.14
LEYG25LDC-200-R8	Size 25 electric actuator, 200mm stroke, 3mm lead screw, complete with 8m actuator cable	2	£978.51	25	£733.88	£1,467.76

Figure 17. Gantry System Component Cost Example

A 1200mm stroke actuator is used for the “Y” direction. A 300m stroke actuator is used for the “X” direction, and a 200mm stroke actuator is used for the “Z” direction.

The left- and right-hand Gantry has identical Z-axis actuators, with the Y and X-axis actuators having mirrored positioned motors for each the left- and right-hand side.

Due to the accuracy requirements of $\pm 0.25mm$, actuators with an accuracy of $\pm 0.08mm$ have been chosen as the alternatives did not meet specifications. This limits the speed of each actuator to $500\ mm/s$. The actuator speeds and configuration determine the number of Test Jigs required for a given output, discussed later. For the given number of Test Jigs, a 1200mm actuator is used on each side, the longest available for purchase for the given tolerances and speed requirements. The 300mm actuator comfortably meets the X-direction requirements for the Test Jig sizes, and the 200mm comfortably meets the Z-axis direction requirements.

The Gripper design for grabbing Product A is shown in Figure 18. This uses a pneumatic actuator with 3D-printed Gripper Tips. A tooling (location) post is added to ensure correct alignment with Product A, mitigating alignment issues when placing the product into the Test Jig. Prototype examples are shown in Figures 19 and 20.

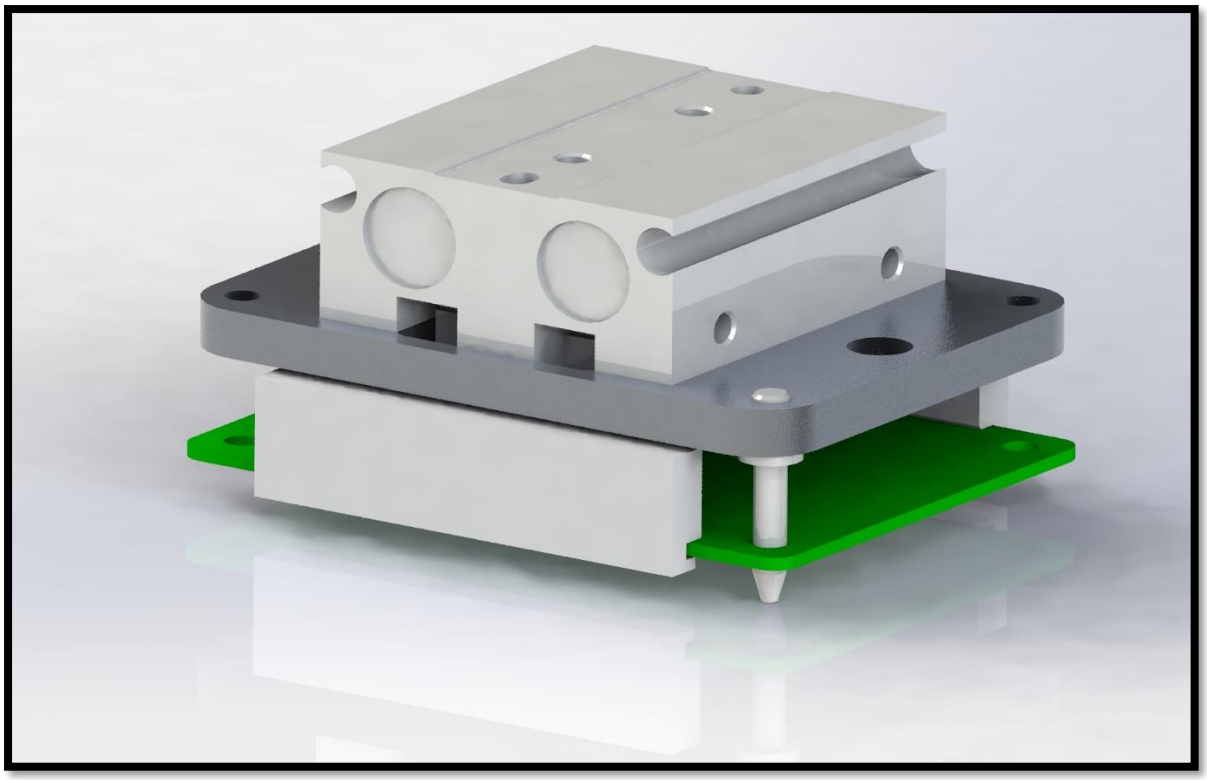


Figure 18. End-Effector Design

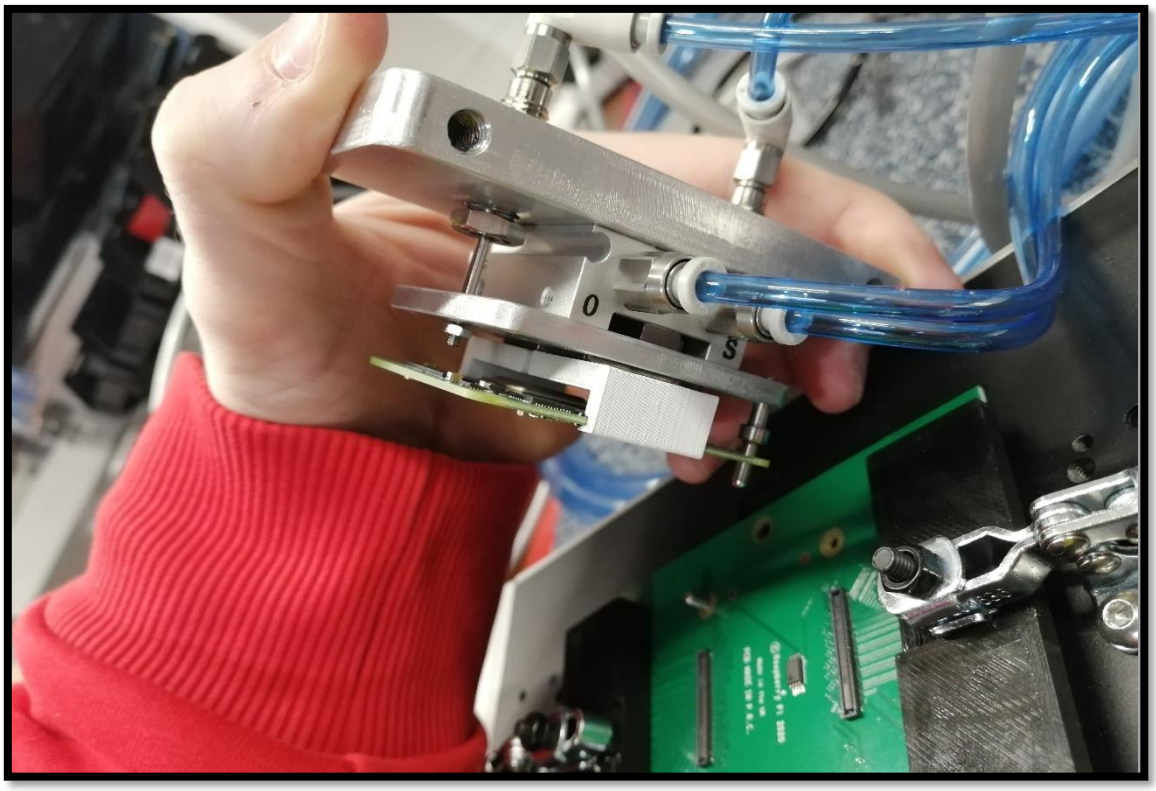


Figure 19. End-Effector Prototype Testing

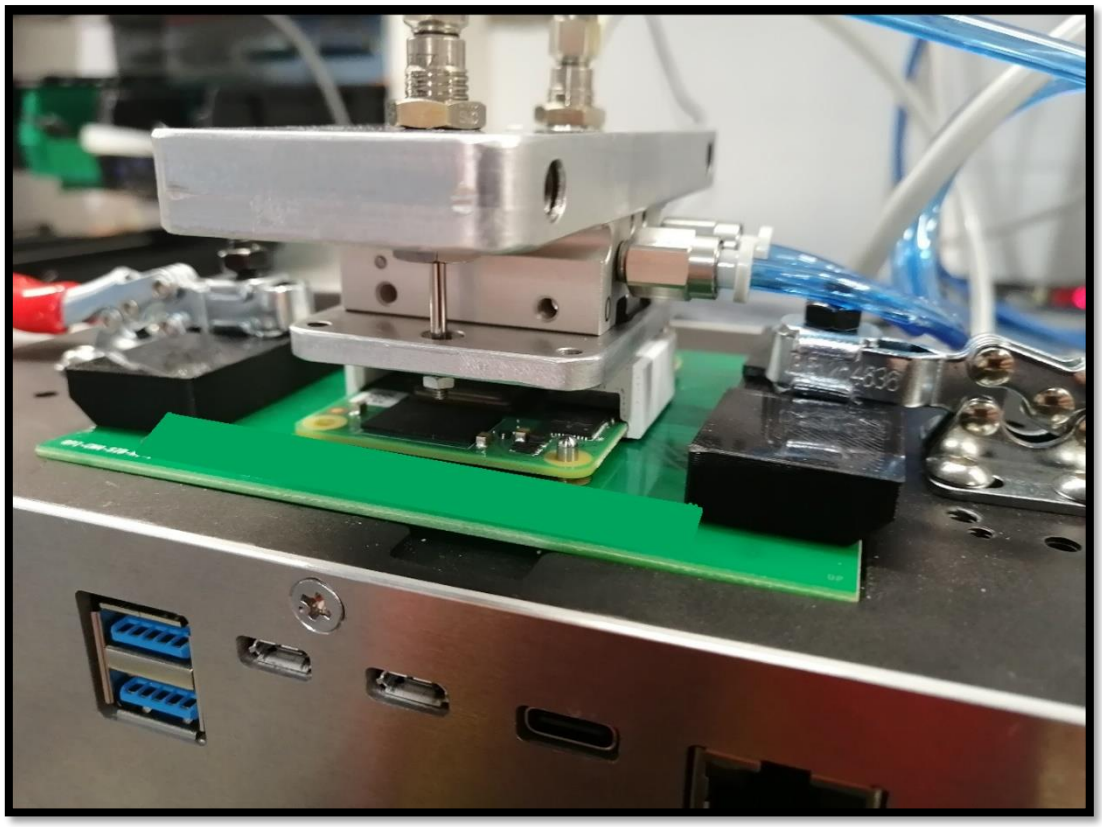


Figure 20. End-Effector Prototype Placement Testing

Furthermore, mass (weight) simulations of the Gantry system's components are shown in Figures 21 and 22. Geometry optimisation is generated, reducing material in non-structural areas. This increases Gantry performance (acceleration and deceleration increase) whilst improving overall mass compliance.

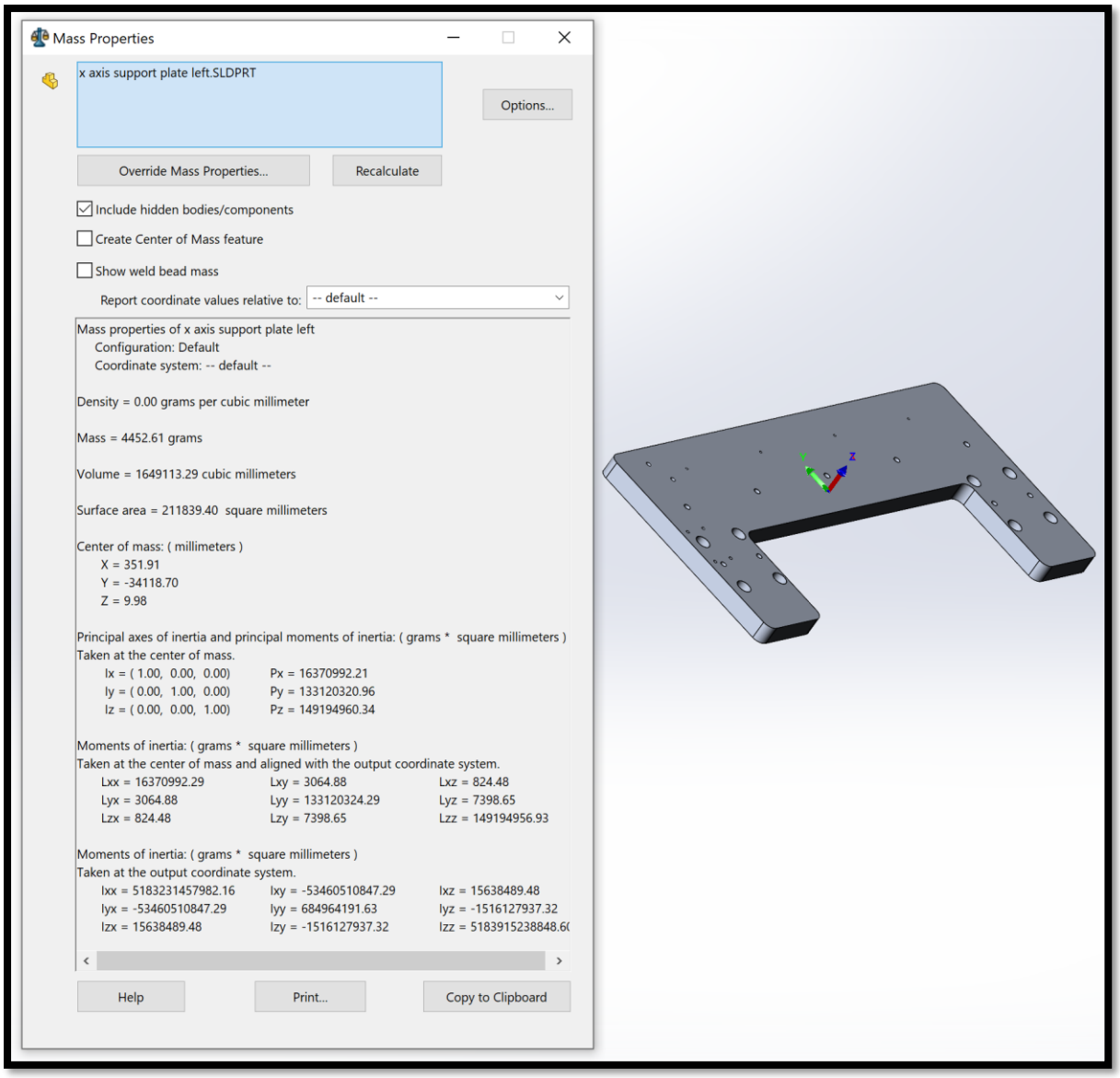


Figure 21. Actuator Support Mass Simulation

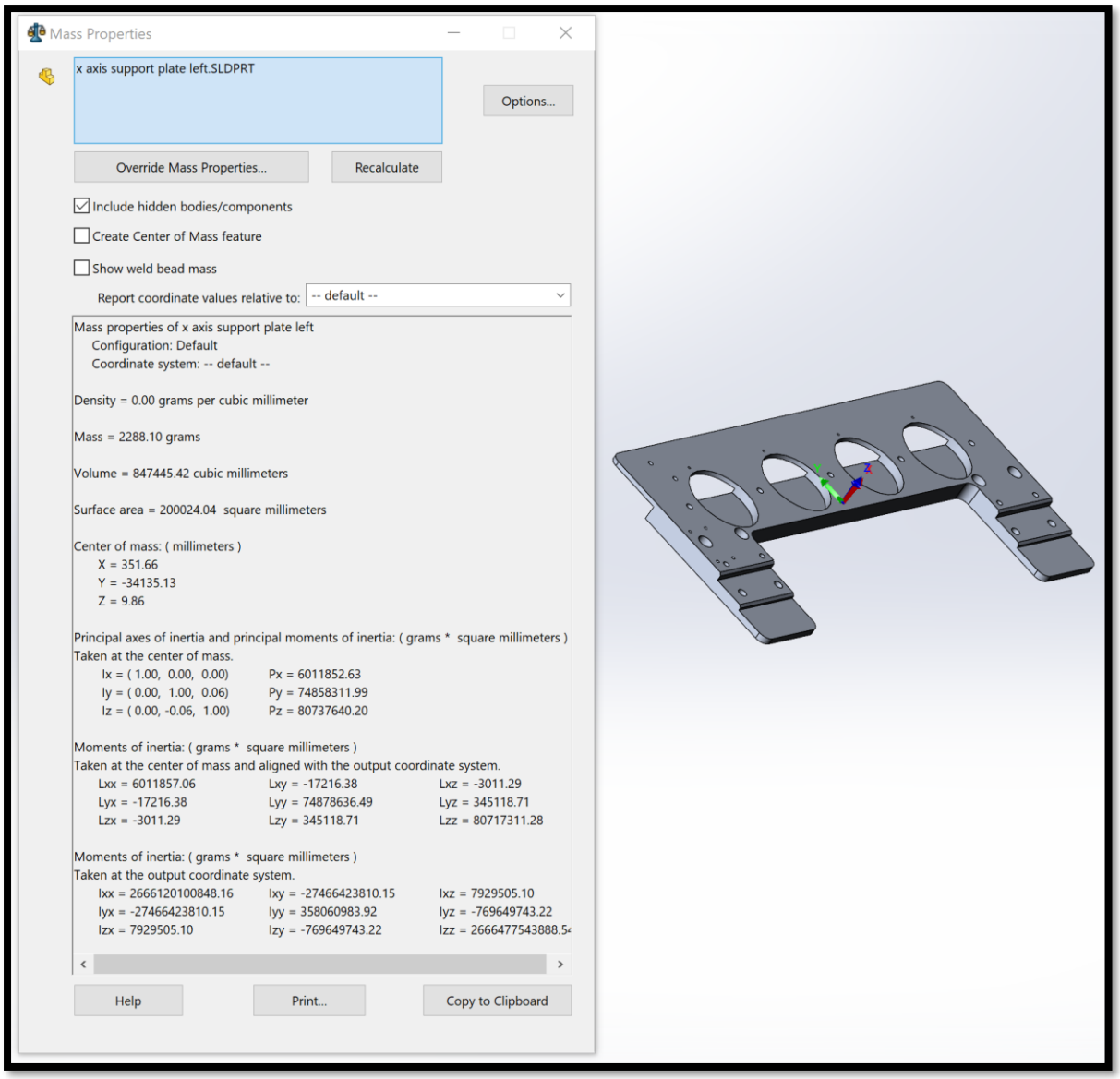


Figure 22. Optimised Actuator Support Mass Simulation

By removing unnecessary material from low-load areas, the mass has been reduced from 4.5kg to 2.3kg while maintaining the centre of mass due to symmetrical reduction, thus, preventing Gantry motion change.

Although the project consistently considers DFX features, only a few examples are given due to report size limitations, such as the Gripper tip considering DFA whereby a location post is added to the tip design, ensuring precise assembly alignment with the pneumatic Gripper actuator (see Figure 23).

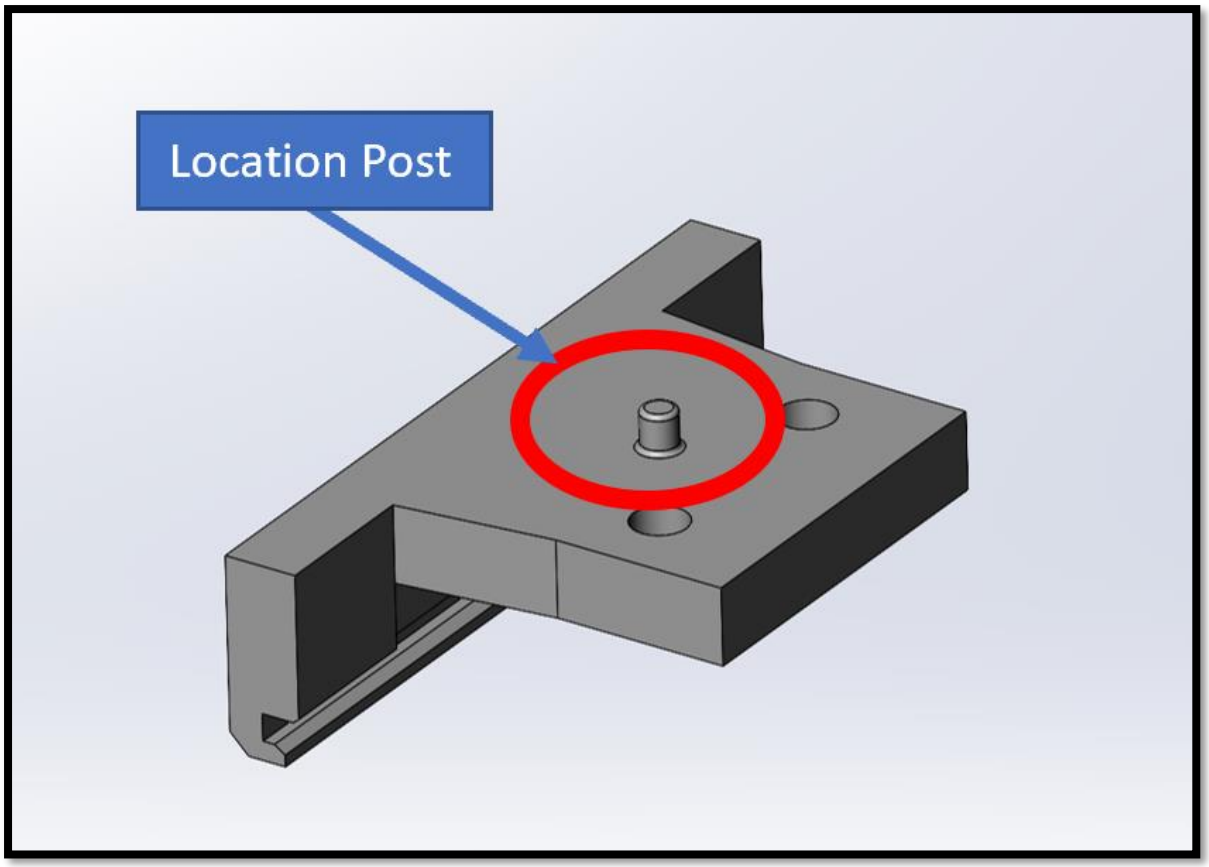


Figure 23. Gripper Tip Design

3.3. Input System

The machine needs an input system to insert Product A accurately and prevent alignment issues with the Gantry system, ensuring the product is placed within the permissible tolerances of $\pm 0.25mm$.

While an accumulating Conveyor system is viable, a pragmatic design analysis reveals that it lacks the required precision. Therefore, a Feeder System is developed (see Figure 24) as a subsystem for the machine's input, following design methods discussed in the literature review.

Product A is manufactured as a 12-panel; thus, a pallet is designed to house 12 electronic boards and manufactured from Durostone (composite material) due to its electrical insulation, dimensional stability, and low thermal expansion coefficient, ensuring static discharge protection and accurate product placement tolerances (*Durostone® CR permits higher loads and more compact transformer designs* 2023).

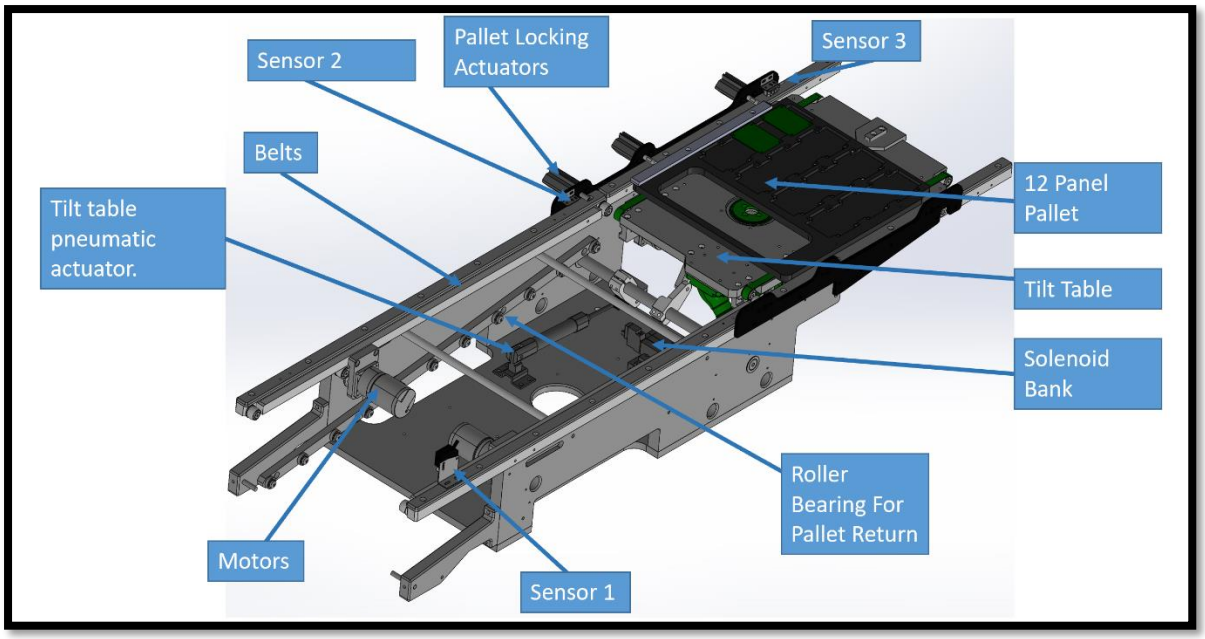


Figure 24. Feeder System Design

The system holds three pallets (36 electronic boards) and two empty pallets in the return area. The design is manufactured from Aluminium due to its strength-to-weight ratio. The housing of the systems contains many mechanisms.

Firstly, two motors operate two separate belts on the input side in both directions. Placing a 12-panel pallet on the belt triggers sensor 1, activating the motors to move the pallet to sensor 2, which is stopped with a pneumatic actuator. If sensor 3 is empty, the actuator unlocks, and additional motors drive another belt on the tilt table, moving the pallet until the pallet triggers sensor 3. Additional actuators lock the pallet into position for accuracy.

The locking actuators release when the Gantry empties the pallet, which then tilts the table, whereby motors reverse the belt, driving the pallet onto roller bearings and to the empty pallet area at the input.

3.4. Output System

Chosen due to low-cost and low accuracy requirements, two Conveyor Systems are used for the output systems: one for failed product to be returned to the operator for retesting/rework (Figure 25), another thinner Conveyor (Figure 26) to ensure product alignment, sending it to the manual packing area.

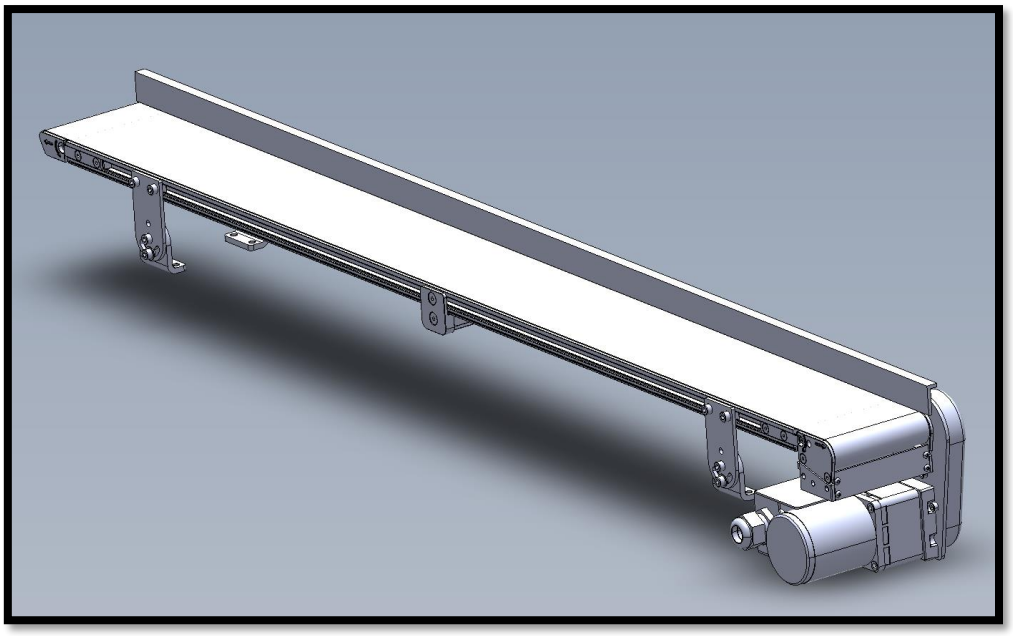


Figure 25. Failed Product Output Conveyor

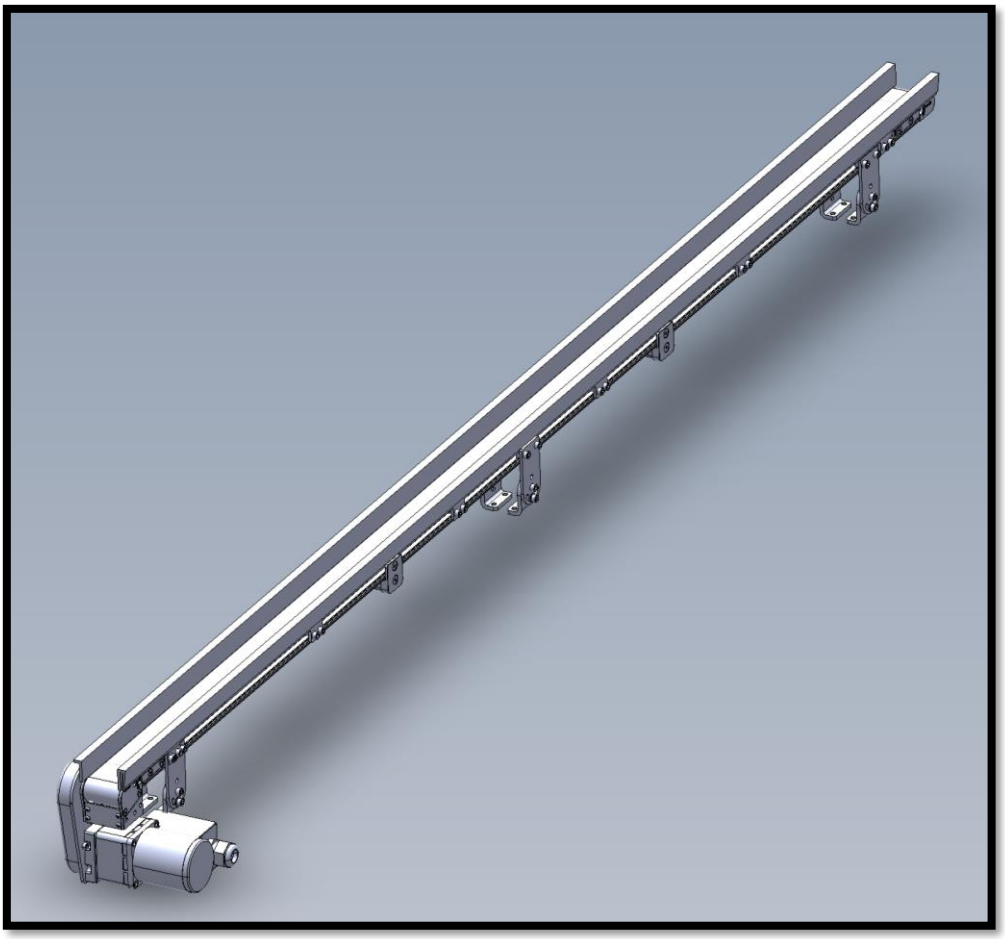


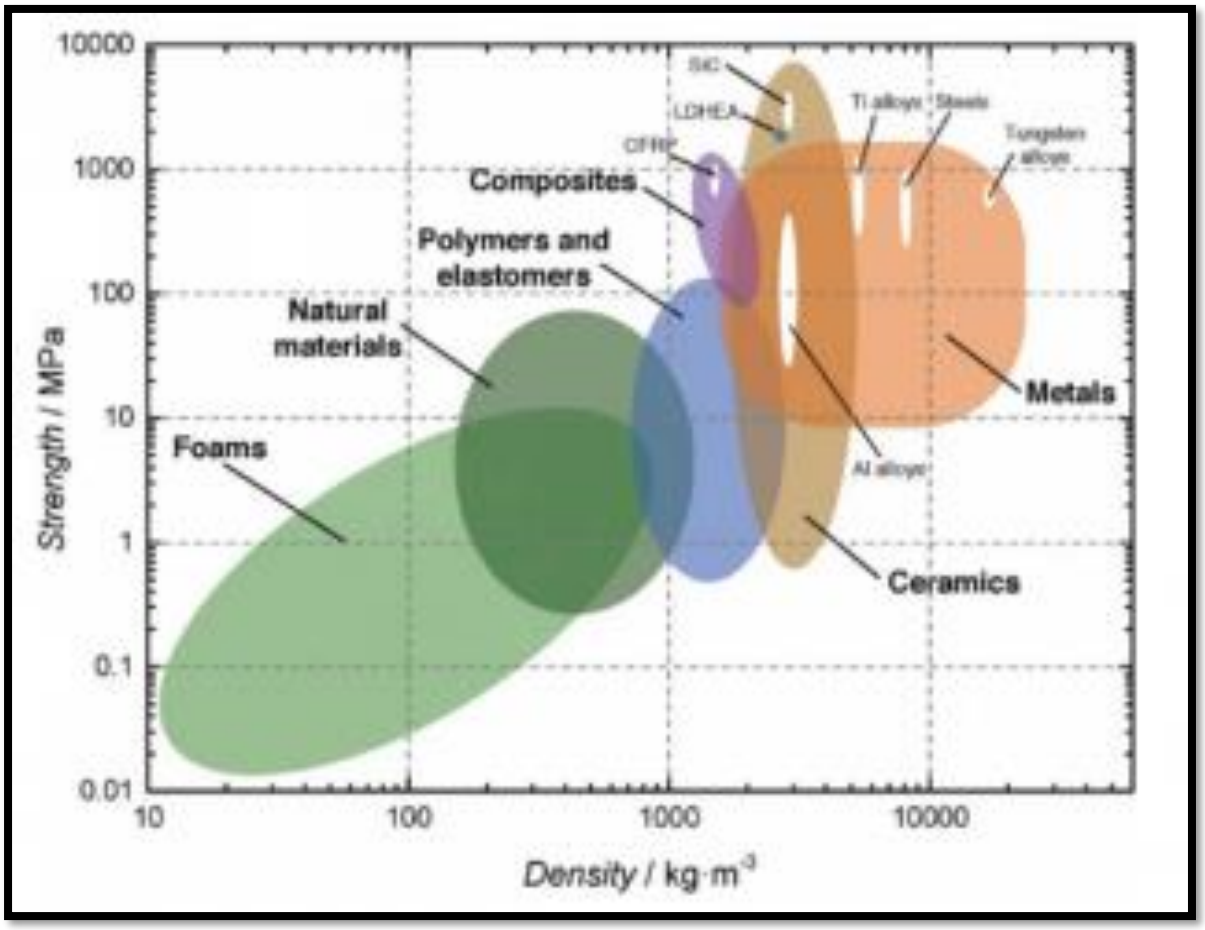
Figure 26. Passed Product Output Conveyor

3.5. Machine Frame

A Machine Frame must be designed to house the subsystems. Steel and Aluminium are compared based on their strength-to-weight ratio and thermal and electrical conductivity properties.

Aluminium is found to be a better choice due to its higher strength-to-weight ratio, as Graph 3 shows. Furthermore, it has good thermal dissipative properties preventing thermal expansion, which could reduce Gantry accuracy, and good electrical conductivity, ensuring safety standards regarding machine earthing. Additionally, aluminium is resistant to corrosion, ensuring dependability and longevity, thus, complying with design requirements (*Steel vs aluminum – comparison and main differences*, 2022).

Aluminium extrusion is used in numerous automation equipment because of its geometry's suitability for high strength and simple mounting applications. As seen in Figure 27, 45mm by 45mm and 90mm by 45mm are utilised.



Graph 3. Strength to Density Merit Function (Crew, 2014)

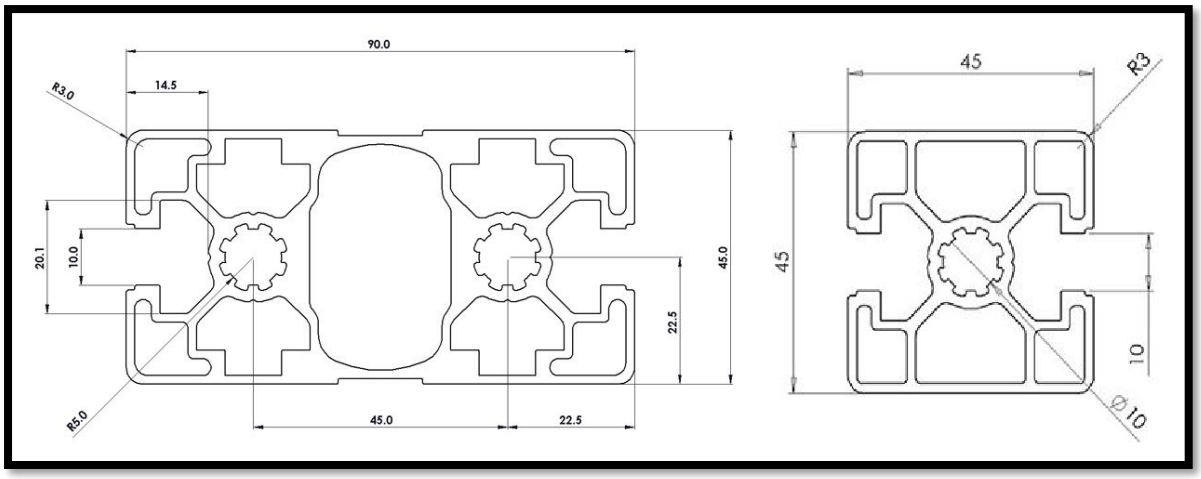


*Figure 27. 45 x 45 and 45 x 90 Extrusion Profile (*45 x 45 2N aluminium profile, *2023)*

The frame is designed around all subsystems explained in section 3.6. It is generated using Solidworks weldment features that extrude profile sketches to conform to the dimensional requirements of the design specification and accommodate all subsystems. The entire frame design is shown in Figure 28.

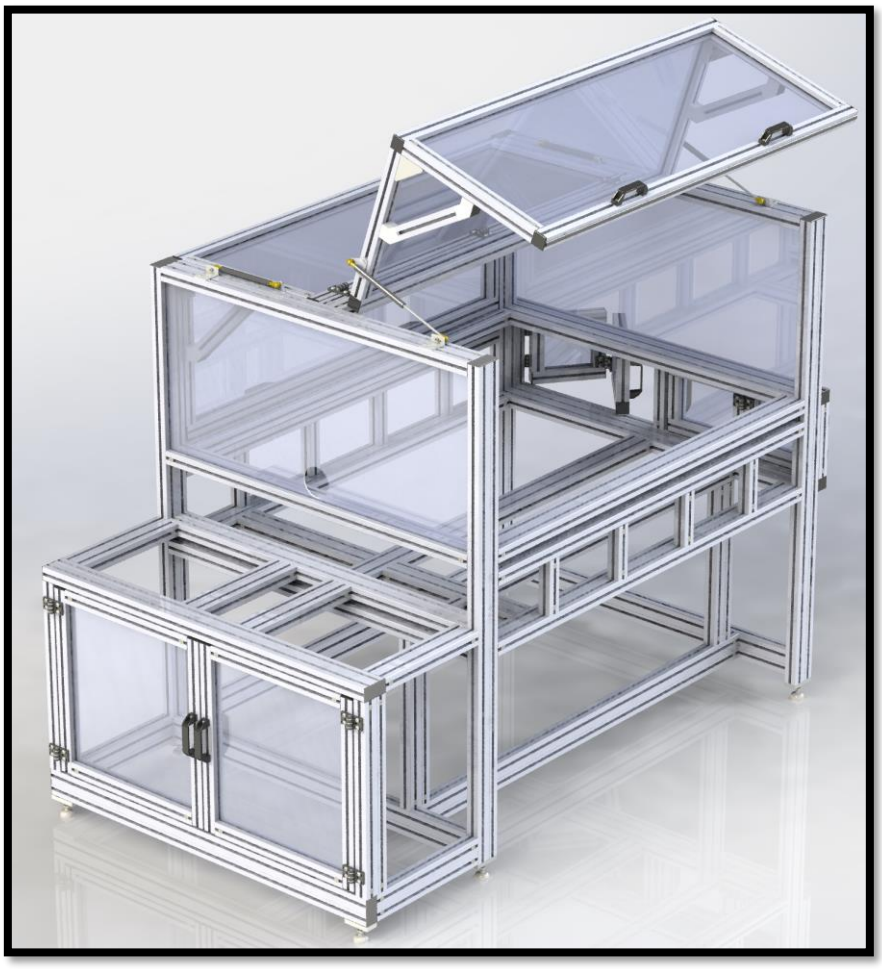


Figure 28. Machine Frame Design

Polycarbonate has been added within the frame to protect the inside from outside influence whilst ensuring safety from the inside contents to operators. Doors have been added to provide easy access for maintenance.

3.6. Integrated Automation Machine

With all the subsystems designed, integration is required to ensure each system works together as a single unit whilst maintaining its' separation when needed for redundancy.

3.6.1. Test Jigs Integration

Calculations shown in Appendix Four are completed to fulfil product demand requirements, indicating 6 Test Jigs are required. The layout of these within the machine is shown in Figure 29. The entire operation and sequencing of these Test Jigs within the machine are stated in Appendix Five.

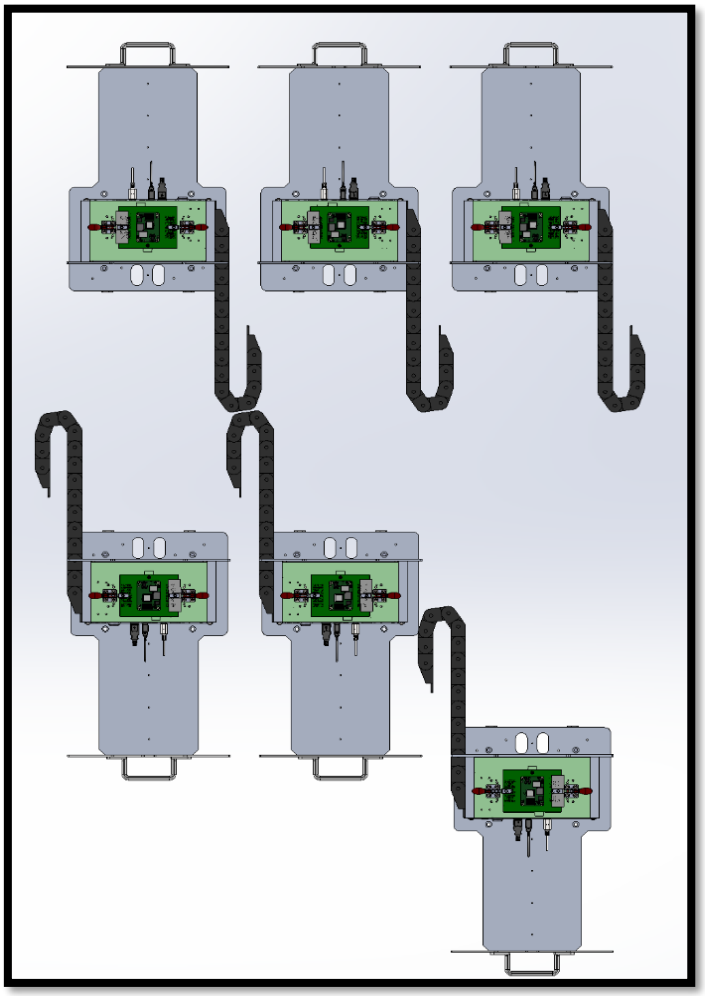


Figure 29. Test Jig Layout

The system requires Test Jig access for maintenance and SIB replacement to conform to the design specification. The Test Jigs are mounted on linear rails, which are mounted to an aluminium baseplate, as Figure 30 shows. This allows for the movement of the Jigs, acting as a drawer system. Rollers, as Figure 31 shows, ensure movement stability.

As shown in Figure 31, sensors mounted to the machine's main baseplate under the Jigs communicate the position of the Jigs to the PLC, which activates a locking mechanism (pneumatic actuator) shown in Figure 32, to prevent Jig movement until unlocked with a control screen, which prevents collisions with the Gantry if trying to move the Jig.

Furthermore, aluminium safety plates are mounted to the front and rear of the Jig, blocking openings when Jigs are locked in the retracted or extended position. Moreover, the Gantry enters a rest mode when the Jigs are in transit between the two positions, minimising safety risks.

This setup provides redundancy, allowing the machine to continue running with the remaining Jigs during SIB replacement or Jig maintenance.

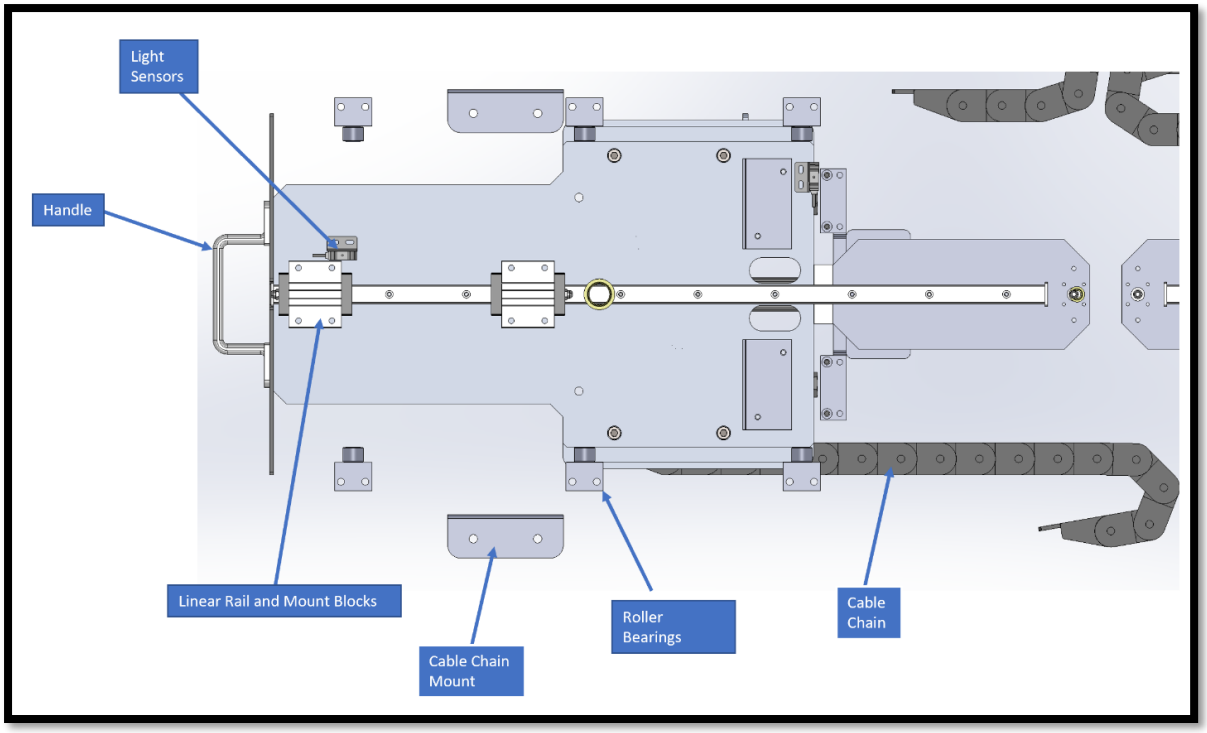


Figure 30. Test Jig Mechanisms

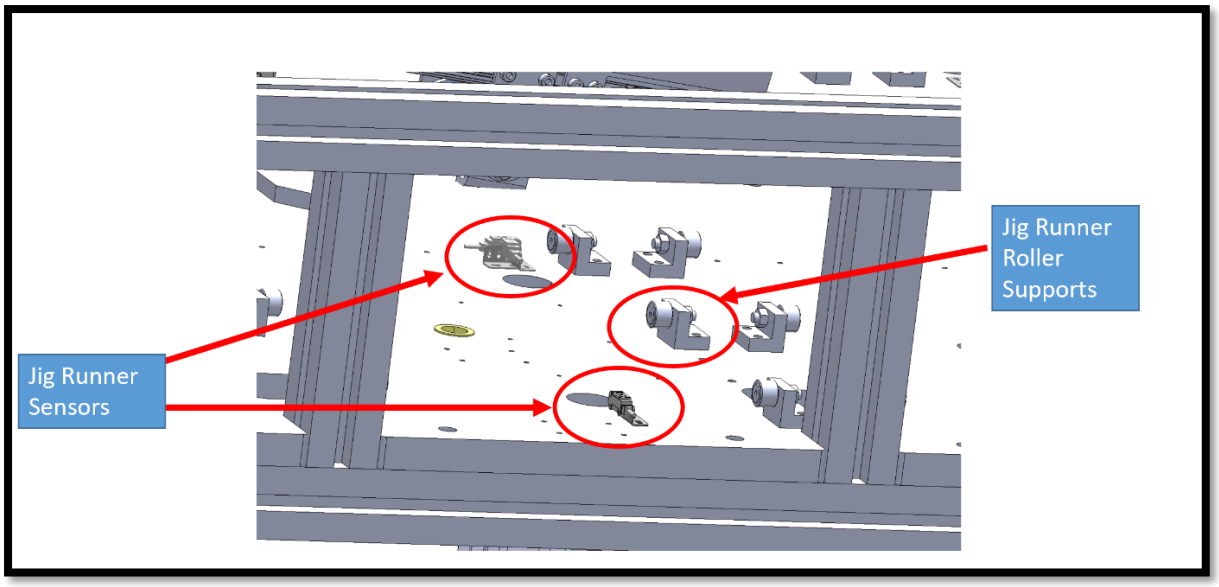


Figure 31. Test Jig Support Rollers & Sensors

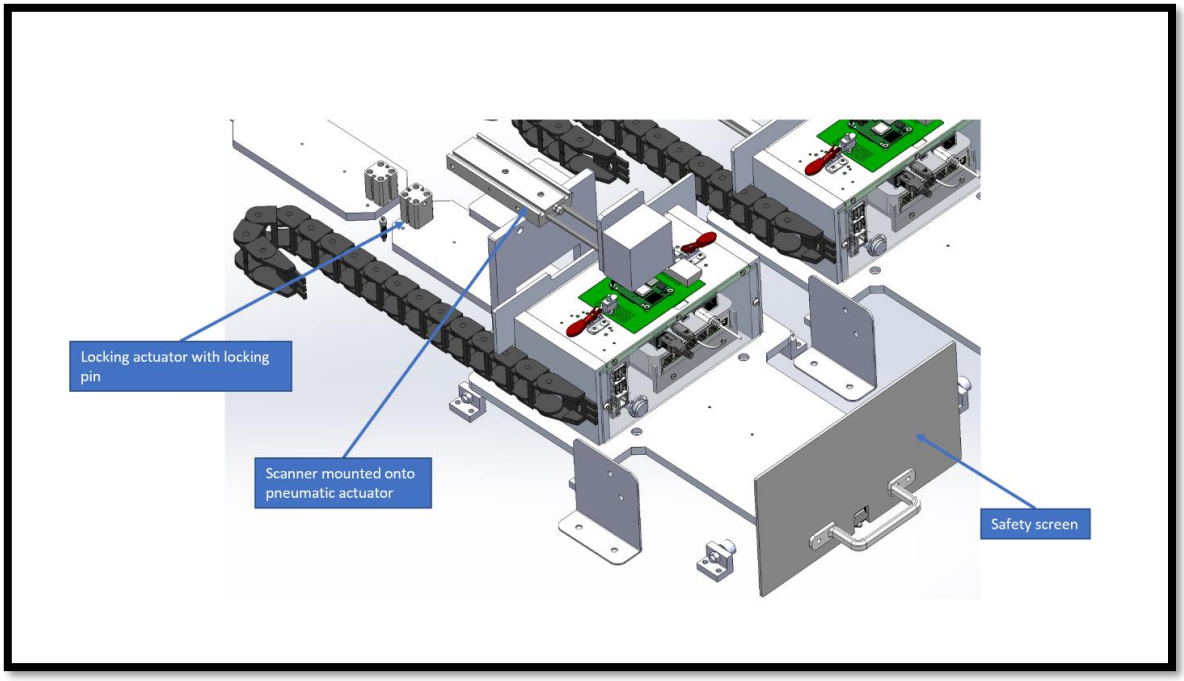


Figure 32. Additional Test Jig System Design

Additionally, a scanner located on a PLC-operated pneumatic actuator extends to scan the product when required to identify the product and begin Product A testing. This reduces machine inefficiencies as every Jig has its own scanner.

Furthermore, the Test Jigs are connected by cabling to small computers within the machine, within PC panels containing all the software, whilst connected to the factory network. These cables run through cable chains to prevent damage and allow quick and easy maintenance.

The cable chain also houses the sensor cables and pneumatic tubes. The entire Test Jig integration is shown in Figure 33.

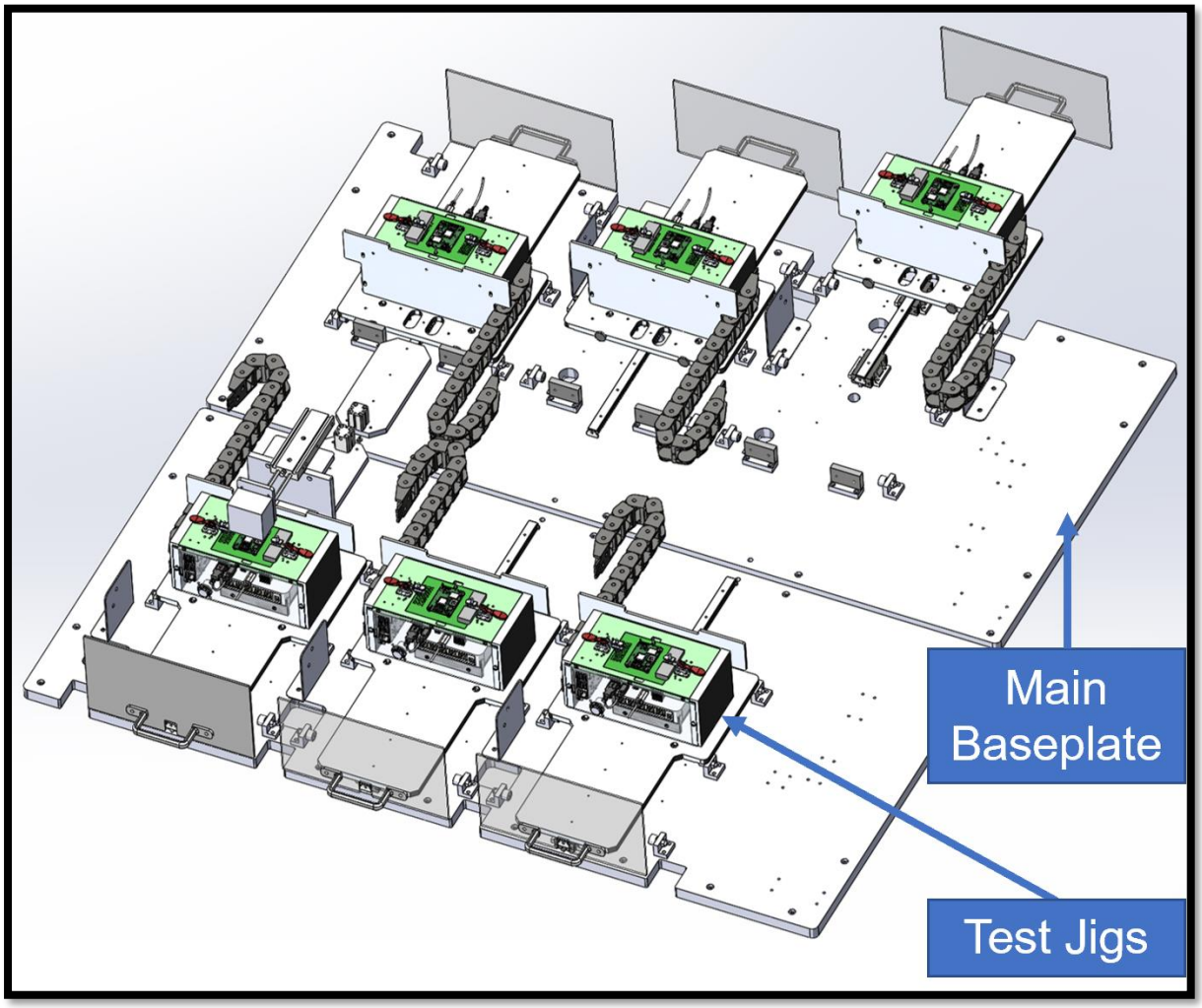


Figure 33. Test Jigs on Main Machine Mounting Plate

3.6.2. Gantry System Integration

The Gantry system, mounted on aluminium plates above the Test Jigs within the frame, uses robotic cabling to prevent failure. Electrical cables and pneumatic tubing run through cable chains for actuator movement. Solenoids control the pneumatic Gripper actuators, while driver units manage electrical linear actuators. Both connect to a PLC in a separate control panel. Figures 34 and 35 show Gantry system integration.

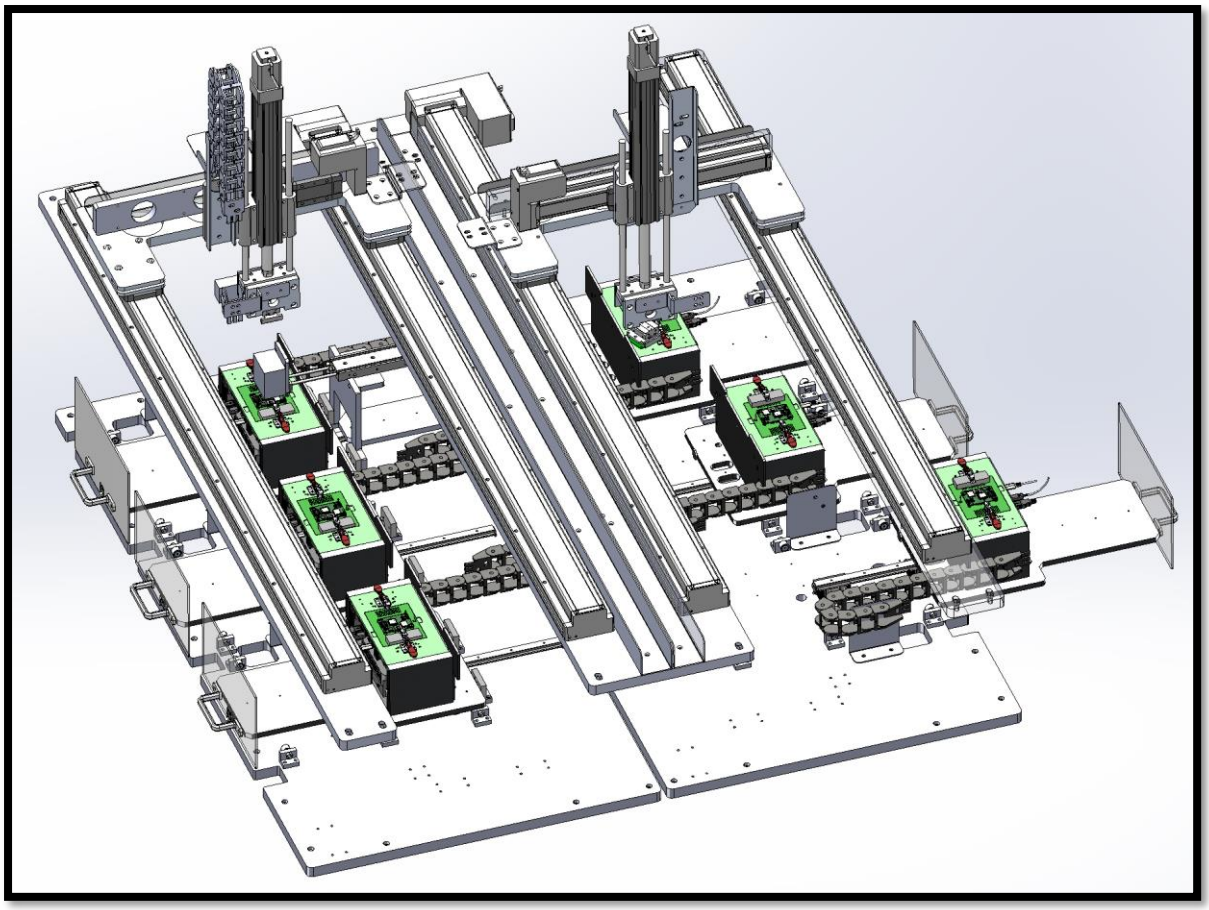


Figure 34. Gantry System on Mounting Plates

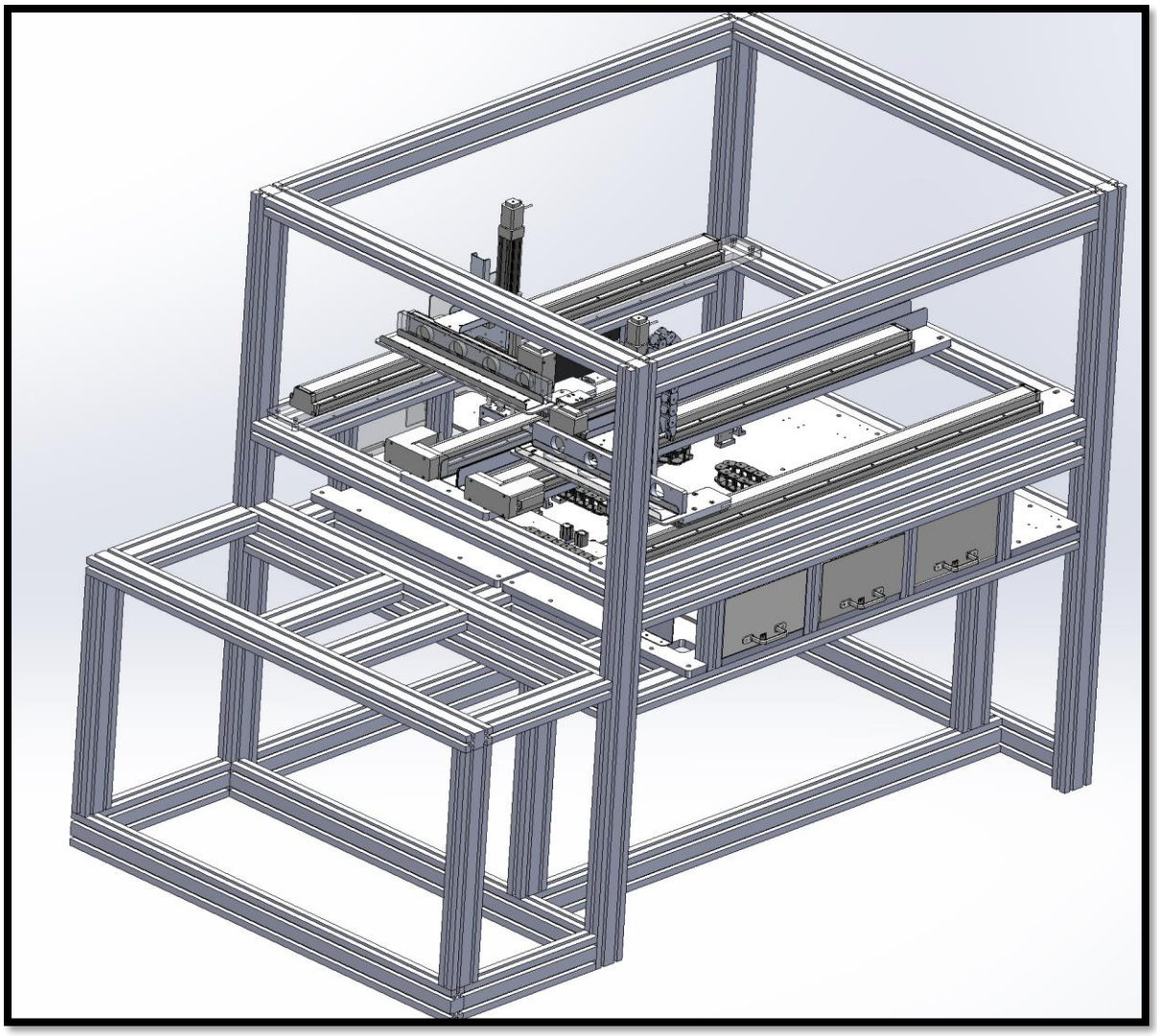


Figure 35. Gantry System within the Machine

3.6.3. Feeder System Integration

The Feeder system meets ergonomic and functional requirements considering the design specifications. It is designed to be height-appropriate for the operator and accessible for the Gantry. The frame includes a designated area and an aluminium mounting plate for the Feeder system, as shown in Figure 36.

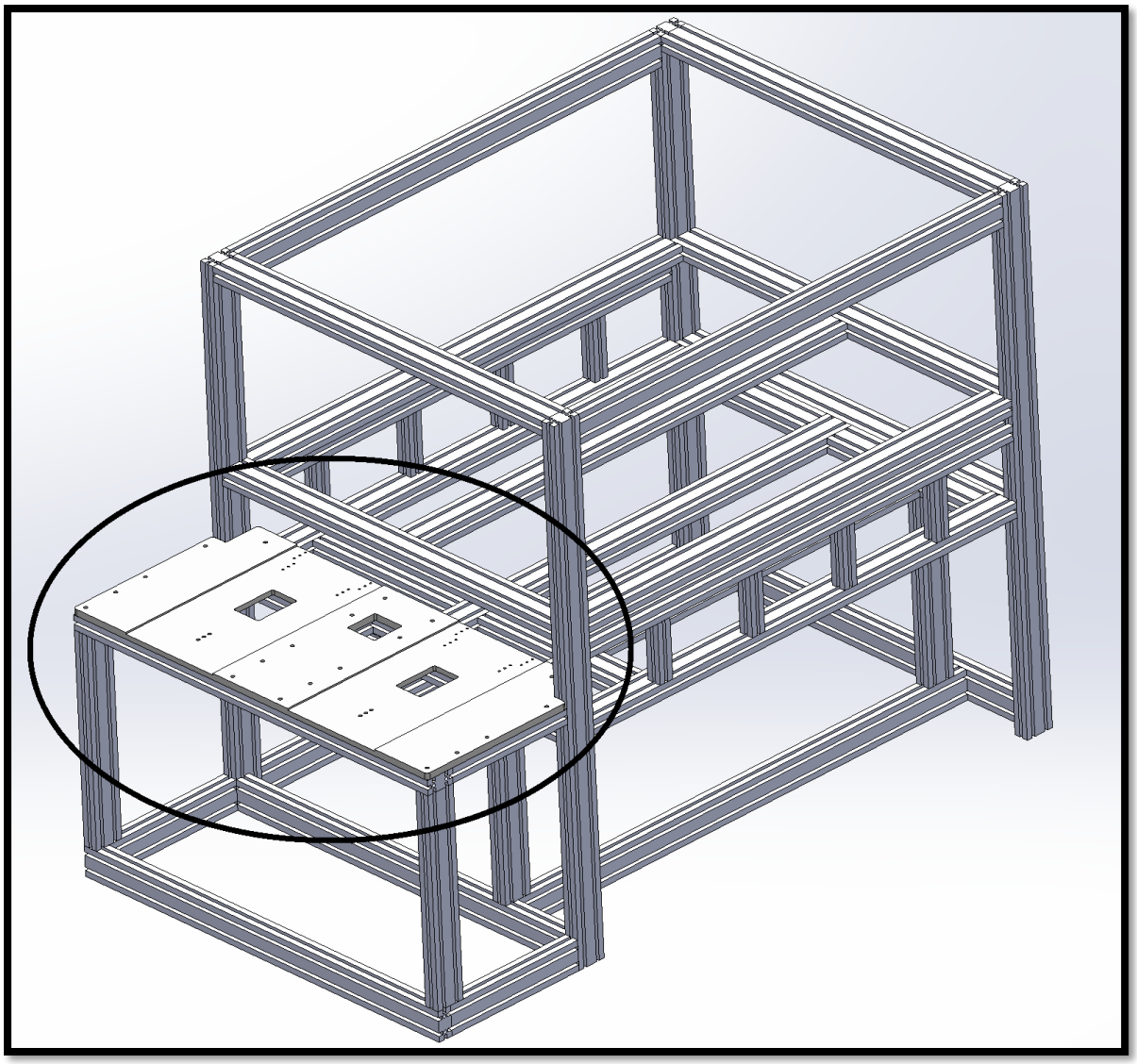


Figure 36. Feeder System Mounting Plate

Large square cut-outs in the frame accommodate cabling and pneumatics, while small holes serve as mounting points for the Feeder system, standardised BSI screws and dowel posts. Additional holes permit adjustments if needed. Figure 37 illustrates two Feeder systems within the frame, which increase efficiency and redundancy for the double Gantry, as each can act individually for the given Gantry system.

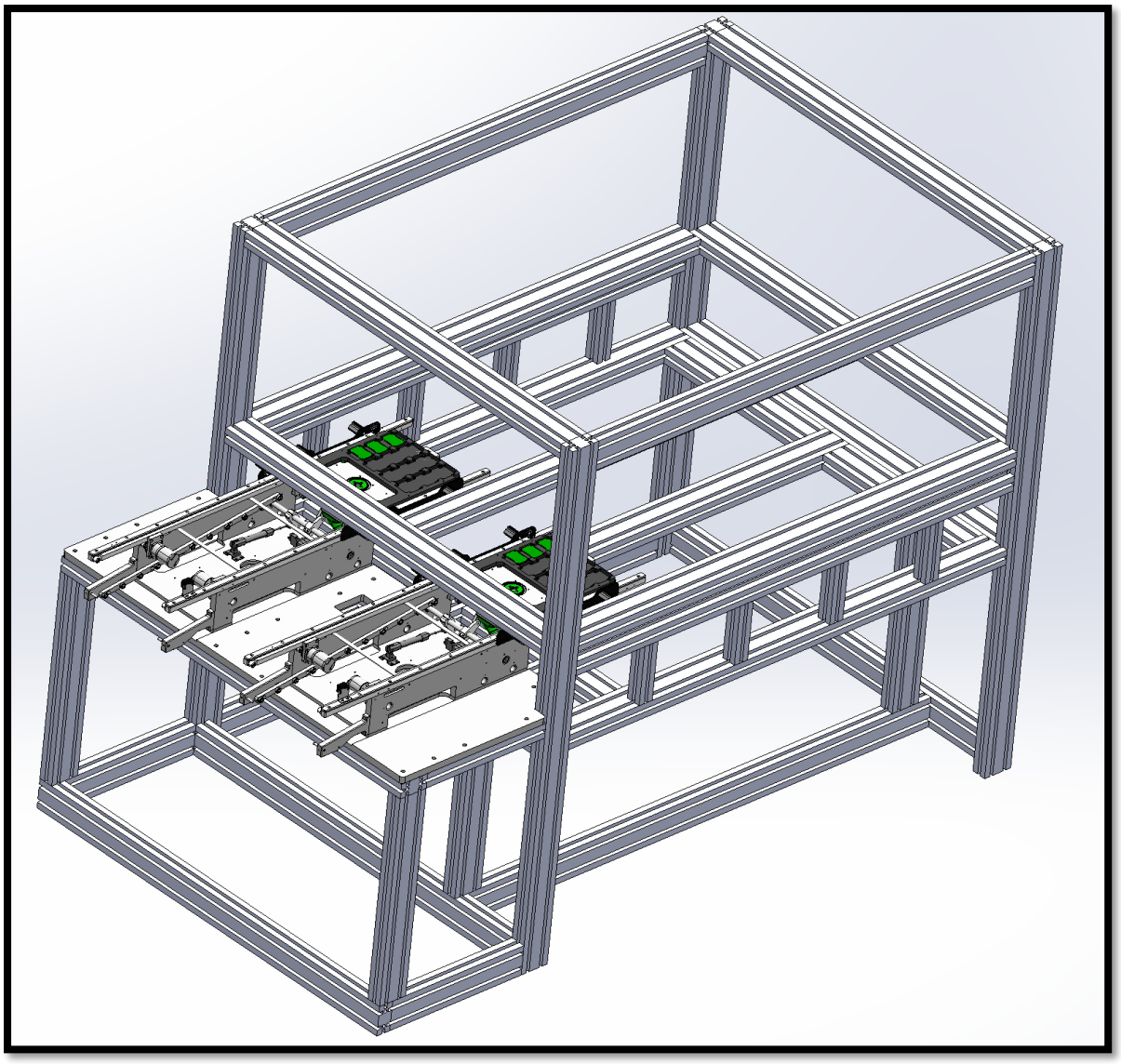


Figure 37. Feeder Systems Machine Integration

3.6.4. Output System Integration

The Conveyor systems are fastened to the machine's main baseplate having predetermined tapped holes, utilising standardised BSI screws and bolts. They are mounted at the machine's rear to separate tested and untested products, as Figures 38 and 39 show.

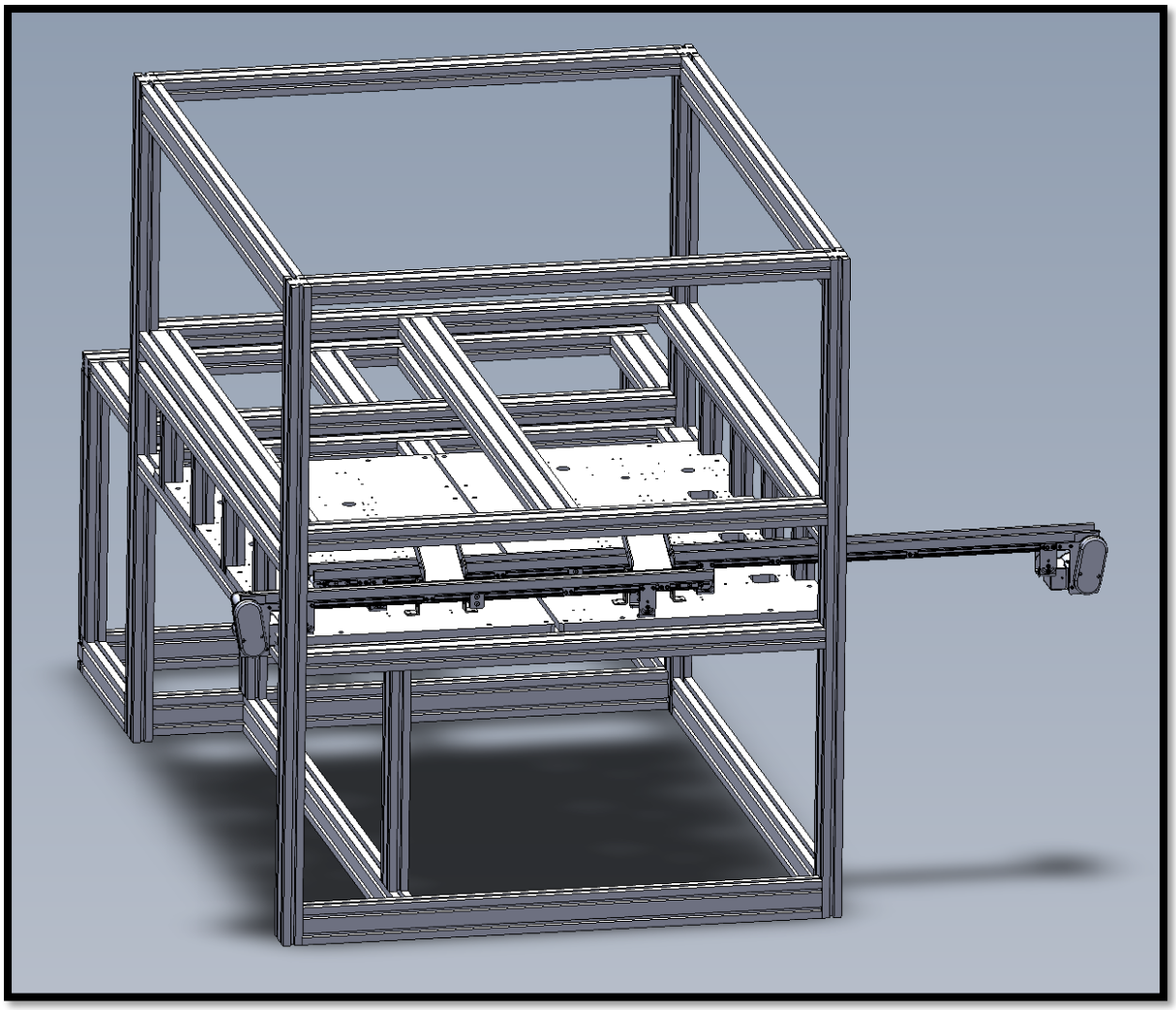


Figure 38. Passed Conveyor Integration (Longer Conveyor)

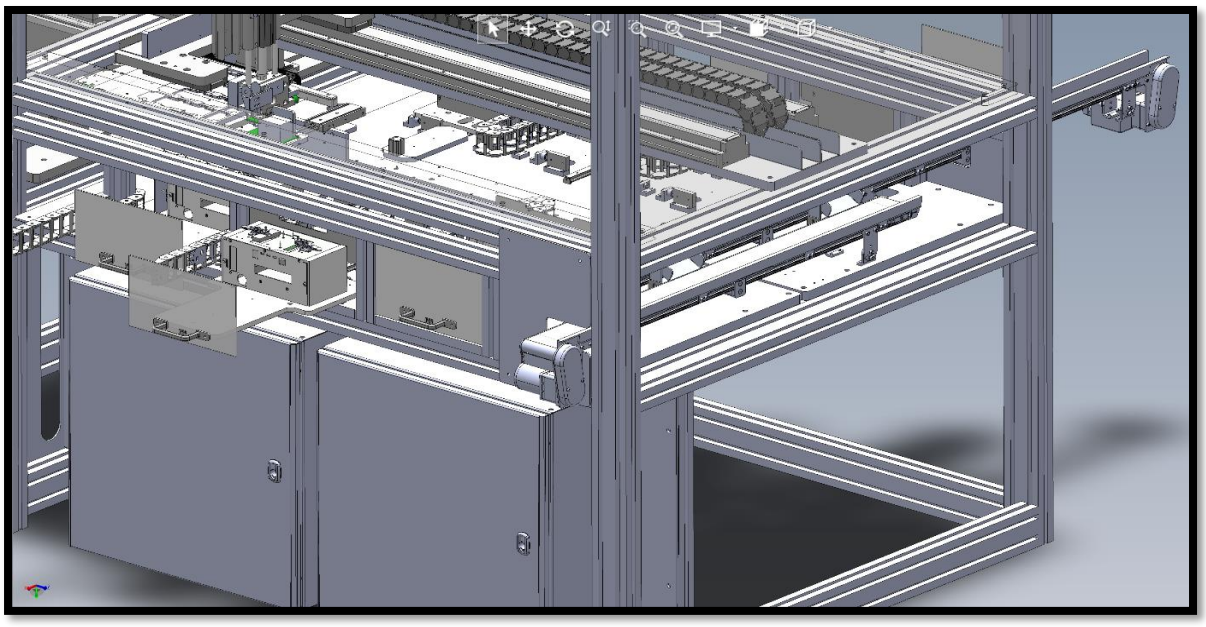


Figure 39. Failed Conveyor Integration (Shorter Conveyor)

A long narrow conveyor transports approved products, ensuring alignment, to the packing area, while a shorter, wider conveyor handles failed boards separately to prevent confusion.

The narrow conveyor is within the reach limitations of the Gantry; however, the wider conveyor is not; thus, Chutes, shown in Figure 40, address the reach limitations of the Gantry system imposed by speed and accuracy requirements. These are suitable for a failed product but not an approved product, as they may lead to the failure of a passed product.

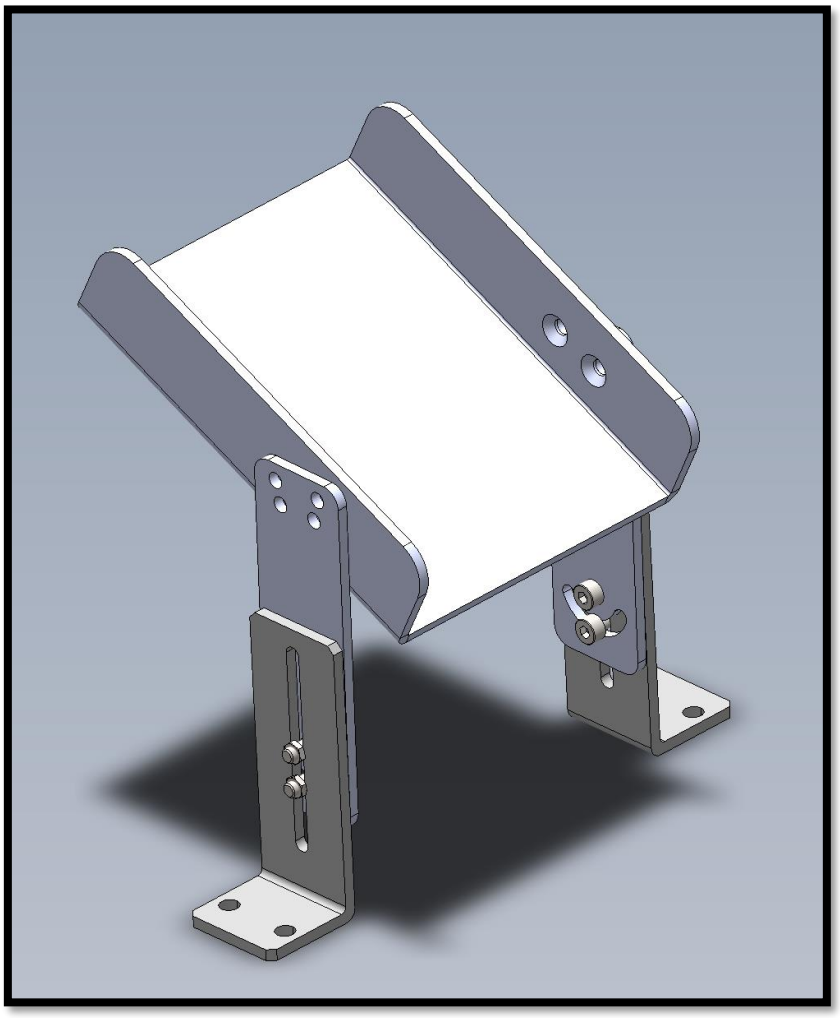


Figure 40. Failed Conveyor Chutes

3.6.5. Full Integration

The final machine design shown in Figure 41, which automates Product A Testing, comprises subsystems, including a pneumatics control area beneath the Feeder systems and electrical panels for power and control under the main baseplate.

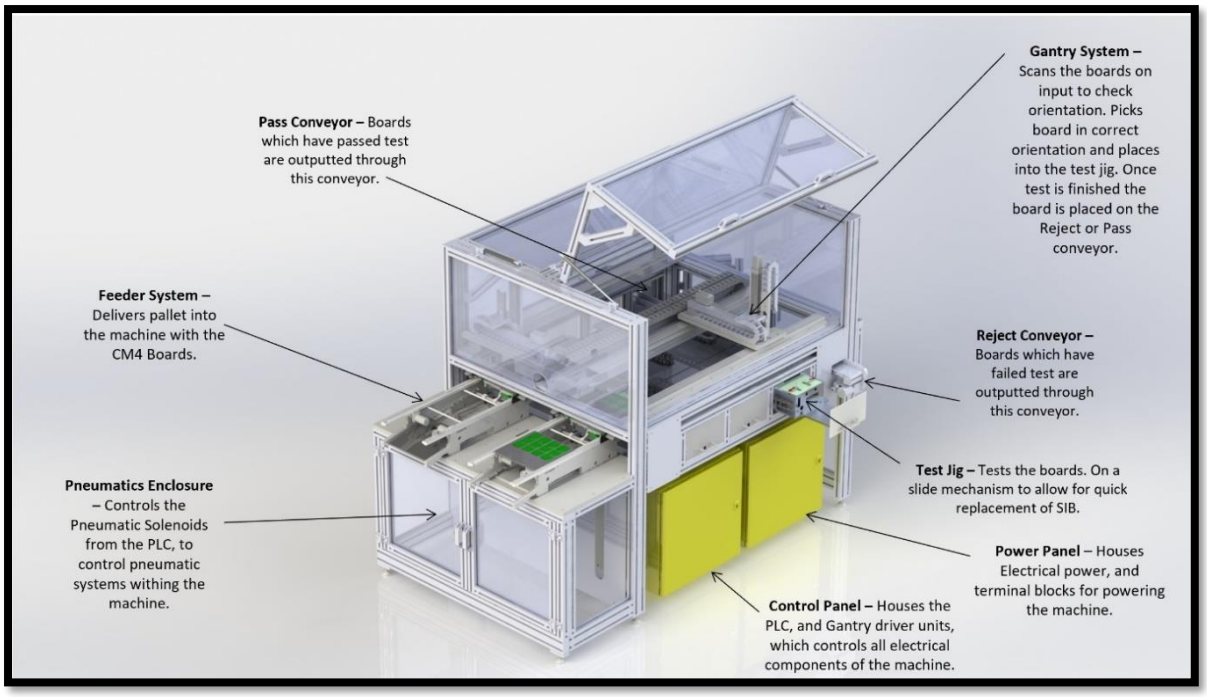


Figure 41. Full Machine Design

For a detailed description of machine operation and sequencing, see Appendix Five. The machine is controlled via a PLC using Omron ladder logic, while Test Jig programs are managed by internal computers beneath the Jigs, connected to the factory network. Human Machine Interface screens control various machine operations.

Additionally, for reference, a complete machine CAD concept for the unchosen single Gantry system machine design is shown in Appendix Nine.

3.7. Design Conformity

The project follows processes similar to the Five-Stage Design process, including data gathering through a design specification. Subsystems undergo iterative development involving design analysis, simulations, CAD designs, and prototypes. Solutions are evaluated based on the design specification and adherence to DFX principles, such as modularity, assembly efficiency, and ease of maintenance. ISO standards are also considered. A Design Failure Mode and Effects Analysis (DFMEA) identifies further considerations, as shown in Table 3. The fully integrated design is detailed in Appendix Seven, using Appendix Five for an understanding of machine sequencing.

Table 3. Machine DFMEA

Item Function	Potential Failure Mode	Potential Effect on Customer Because of Defect	SEV	Potential Causes	OCC	Current Process Controls	DET	RPN	Actions Recommended	Resp.& Target Date	SEV	OCC	DET	Future RPN
What is the component, function, or feature?	In what ways can the Component, Subsystem or System potentially fail to meet the Design Intent ?	What is the impact on the Key Output Variables (customer requirements) or internal requirements?	How Severe is effect to the customer?	List every conceivable failure and/or failure mechanism for each failure mode	How frequent is cause likely to Occur?	What are the Existing Controls & Procedures (Fail-Safe, Tests, Mathematical calculations) that prevent either the cause or the failure mode	How probable is Detection of cause?	Risk Priority # to rank order concerns	What are the actions for reducing the Occurrence of the cause, or improving Detection? Should have actions on high RPN's or EASY FIXES	Who's Responsible for the recommended action?	Future Severity	Future Occurance	Future Detection	Future RPN
Gripper Tips	Not fully closing or opening	Loss of function	10	Component Wear or Incorrect Assembly	3	Pneumatic Actuator has high amounts of pressure	10	300	Placing Reed Switch Sensors on the gripper system to detect gripper position	Joshua Thorngate	10	3	1	30
Output System	Boards being placed on top of one another on exit for the same gantry system	Damage to product	10	The conveyor system has sensors in the packing area to stop the conveyor when the packing area is full	7	No current controls	10	700	When the sensor is blocked the gantry will enter rest mode	Joshua Thorngate	10	1	10	100
Output System	Boards are placed on top of one another on exit conveyors, whereby the product is outputted from the alternate gantry system	Damage to product	10	Gantry 1 places products on the conveyor and Gantry 2 places products on the same conveyor – Therefore, products coming from the alternative conveyor can have products placed on top	4	No process to prevent product stacking	10	400	Create a diversion solution, which diverts product into additional lanes away from the placement area from the additional gantry system	Joshua Thorngate	10	1	10	100
Test Jig	Product not being placed correctly on the Test Jigs	Damage to product	10	Test Jig not being fully locked into the system	3	Locking mechanism on the Jig when fully inserted - With a high tolerance	5	150	Add reed switches to the locking mechanism to ensure fully locked and add magnets to the back of the jig, ensuring fully closed Jig	Joshua Thorngate	10	1	2	20

Gripper tip position detection is addressed by adding reed switches, allowing the PLC to ensure proper operation, and reducing function loss risks. The output system's potential for product damage is mitigated by programming the Gantry to stop when the packing area is full, lowering the Risk Priority Number (RPN).

The passed product conveyor is widened for efficiency, and diversion lanes are added to prevent product stacking from the alternative Gantry, as programming and stroke length limitations preclude other solutions. The failed product conveyor is repositioned for operator accessibility, enabling manual retesting and reducing the need for walking around the machine, as Figure 42 shows.

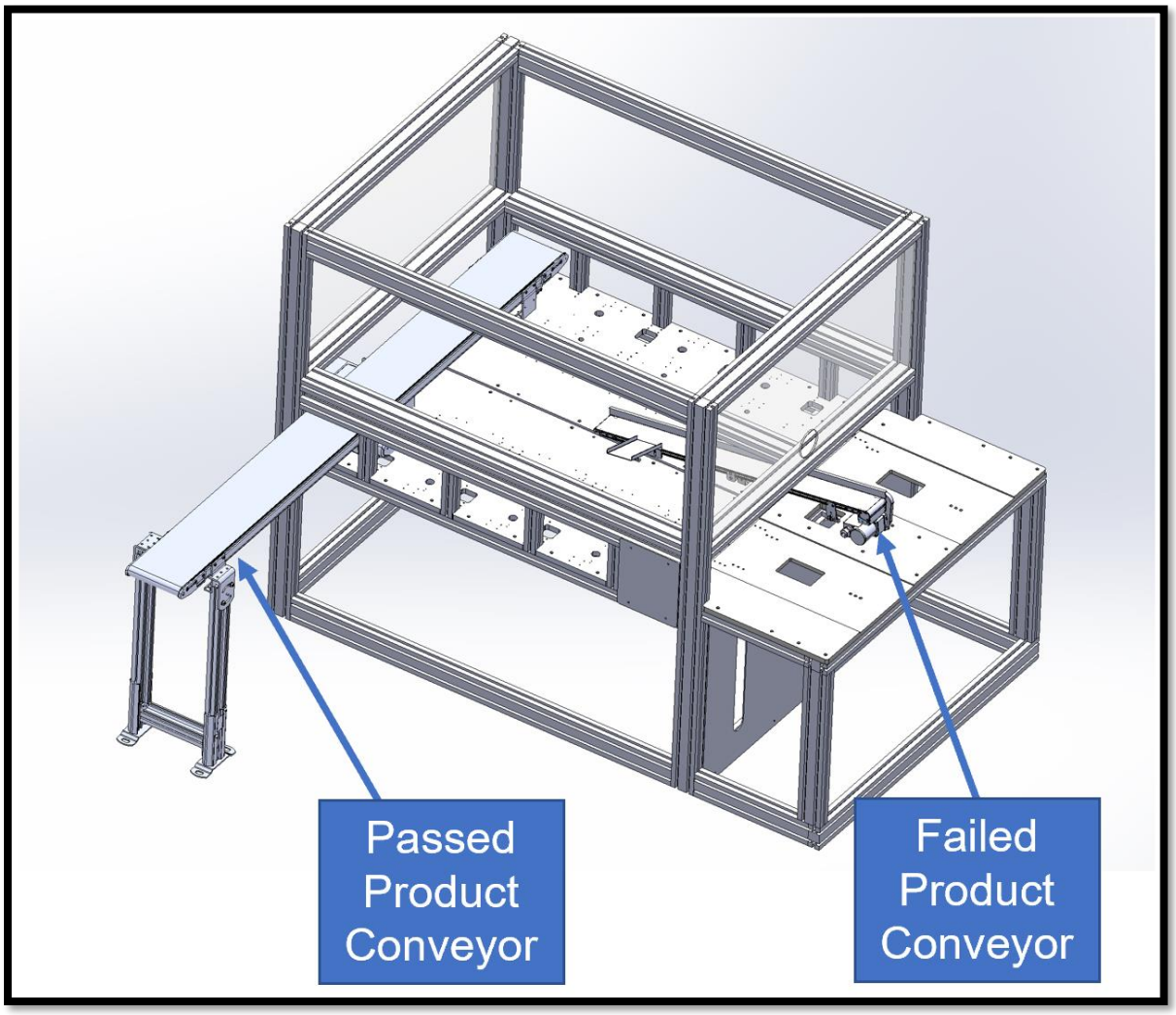


Figure 42. Conveyor Modifications

Furthermore, magnets assembled to the Test Jig rear baseplate (Figure 43) ensure magnetic attraction to steel blocks mounted to the main baseplate. This ensures full Test Jig closure, preventing partial opening within a tolerance “dead zone” of the sensors, meaning they cannot detect tolerances to the placement requirements.

This full Jig closure ensures the locking mechanism (Figure 44) functions correctly, reducing RPN for incorrect product placement and preventing Jig movement during Gantry operation.

Design changes reduce risks, enhancing the likelihood of a successful machine that meets the design specification. Figure 45 displays the final machine and subsystem designs

(conveyors are off-the-shelf systems, thus, not shown as a designed subsystem within Figure 45), with further depictions in Appendix Seven.

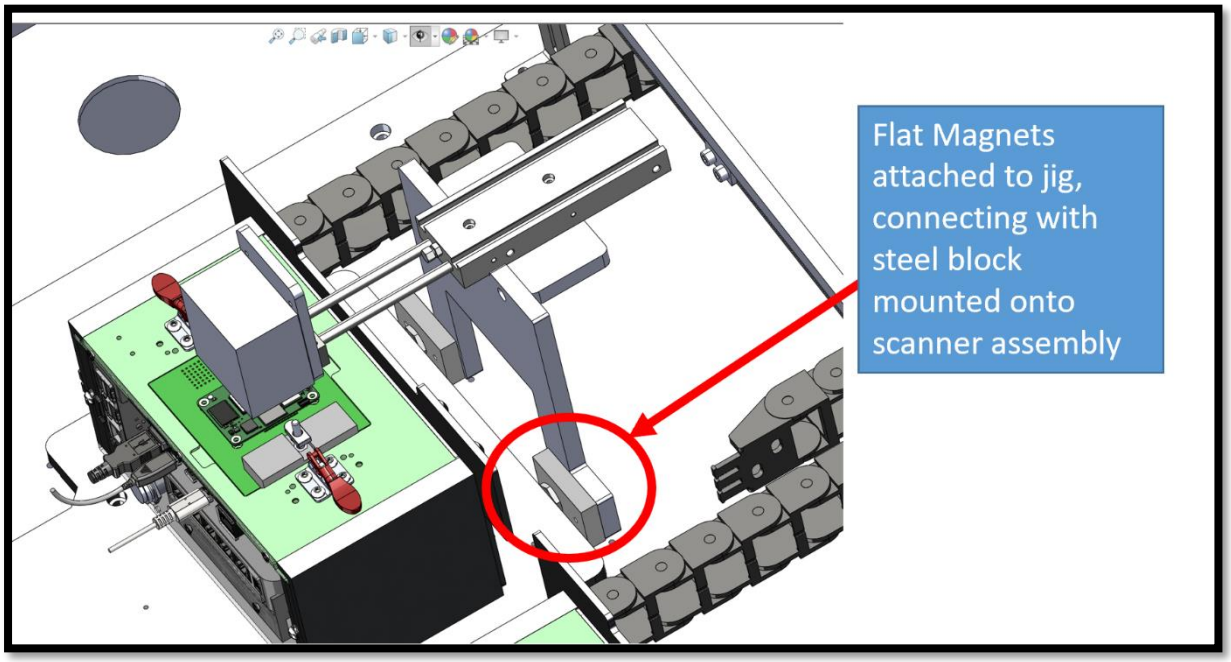


Figure 43. Test Jig Magnetic Location

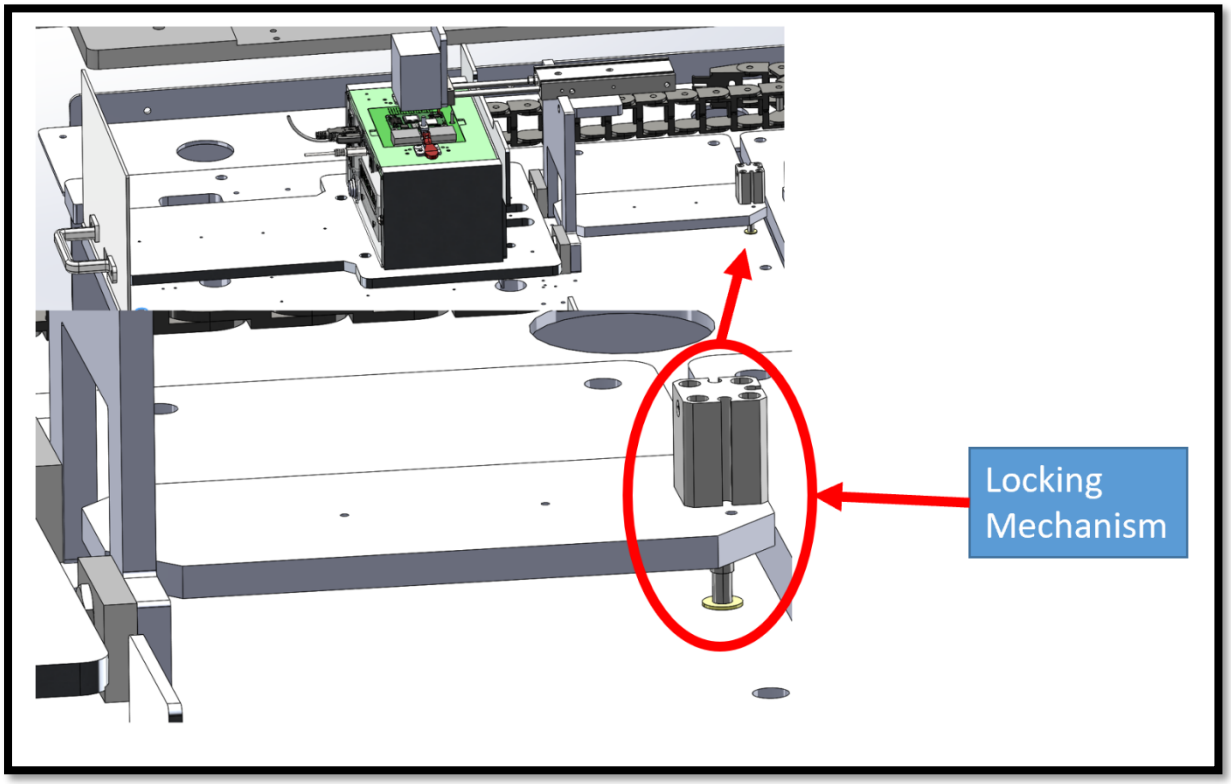


Figure 44. Test Jig Locking Mechanism

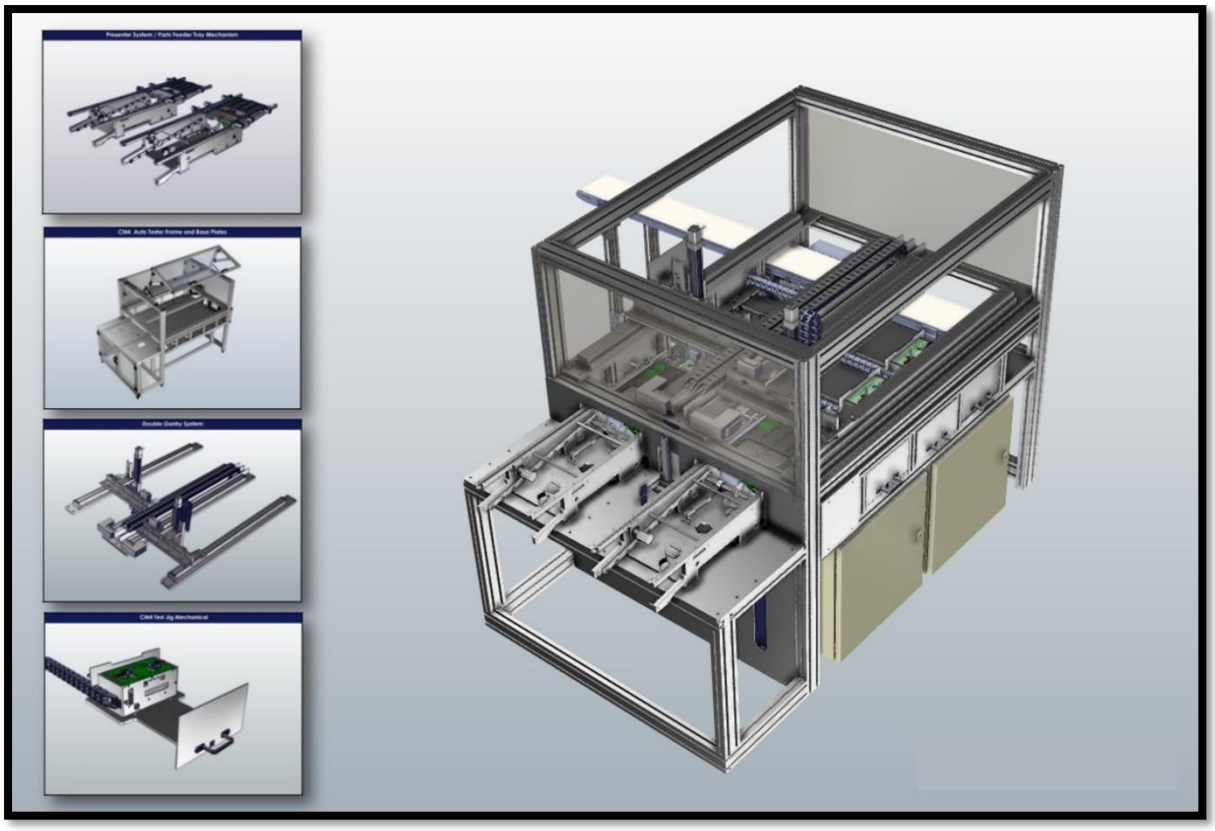


Figure 45. Entire Machine & Subsystem Design

3.8. Engineering Drawings & Manufacturing

Numerous engineering drawings and procedures are followed for machine manufacturing, adhering to British Standard (**BS) 8888:2020 – BSI** when necessary. Geometric tolerances are applied as needed, while components are designed with tolerances in mind. Tooling posts, dowels, and slots provide easy adjustments, reducing manufacturing costs.

Numerous engineering drawings and manufacturing methods are employed for the machine. This section offers a preview of these. Each subsystem has multiple components, making a full description impractical; instead, examples illustrate manufacturing methods, materials, and drawings. Various techniques and methods convey component requirements, from engineering drawings to CAD files.

Table 4 presents a breakdown of Test Jig manufacturing, providing an example of how different methods and materials are used for each component.

Table 4. Test Jig Manufacturing Methods

Subsystem	Component	Material	Manufacturing Method
Test Jig	Pinbed	G10	CNC
Test Jig	Side Support Left	Aluminium	CNC
Test Jig	Side Support Right	Aluminium	CNC
Test Jig	Baseplate	Aluminium	CNC
Test Jig	Front Plate	Aluminium	Laser Cutting
Test Jig	Rear Plate	Aluminium	Laser Cutting
Test Jig	Force Reaction Block	Aluminium	CNC
Test Jig	Ethernet Port Holder	PLA (polylactic acid)	3D Printing
Test Jig	Clamp Blocks	PLA (polylactic acid)	3D Printing

3.8.1. CNC Manufacturing

CNC machining, a subtractive manufacturing technique, uses computerised machine tools to create custom-designed parts by chipping away material based on programming codes (*CNC Machining 101: Get to know CNC Machining Basics*, 2022).

ProtoLabs is a prominent manufacturer that enables CAD model uploads to their online software, which analyses components, material choices, and tolerances without the need for engineering drawings. This streamlines the process, saving time and resources.

Figure 46 displays examples of Test Jig parts uploaded to the software, illustrating materials, manufacturing methods, tolerances, and surface finishes.

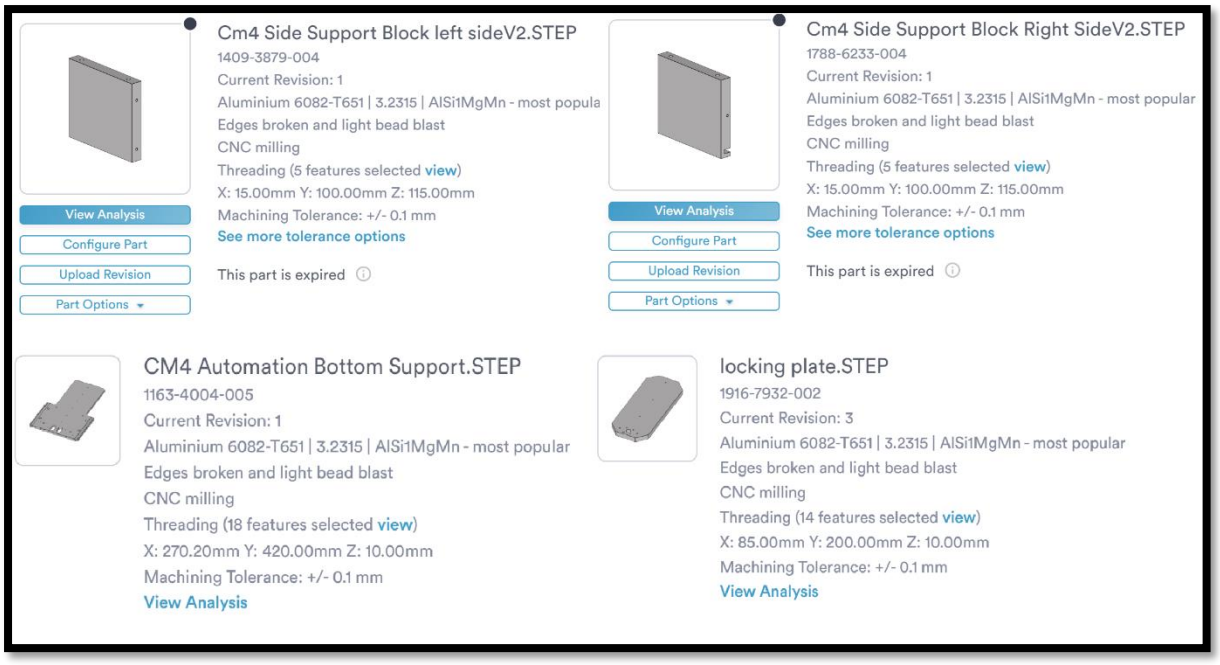


Figure 46. ProtoLabs Manufacturing Quoting Software

ProtoLabs is employed for various machined components, such as the Gantry system mounting plates. Figure 47 demonstrates the X-axis support plate's manufacturing process and typical cost. "Economy Manufacturing" components can be chosen with longer lead times as long as they conform to the project timeline, helping reduce the machine's total cost to meet the budget.

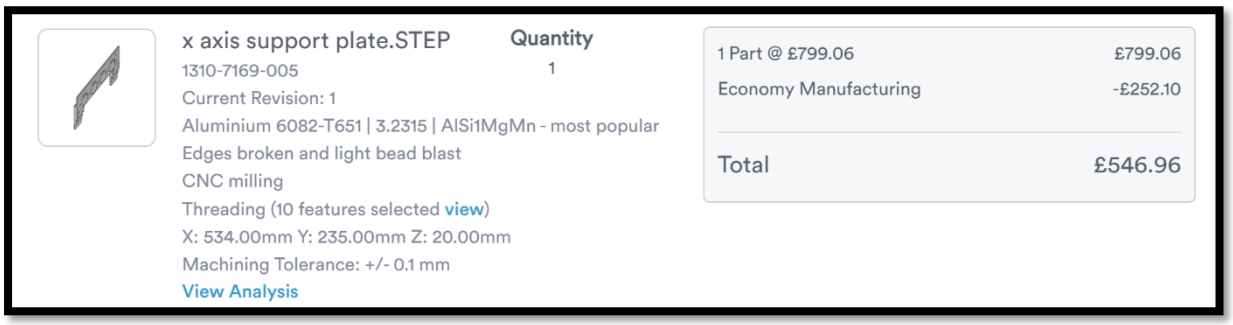


Figure 47. ProtoLabs Economy Manufacturing Example

CNC machining can also use engineering drawings to program the CNC machine when required. Figures 48 and 49 show engineering drawing examples of the machine's main baseplate.

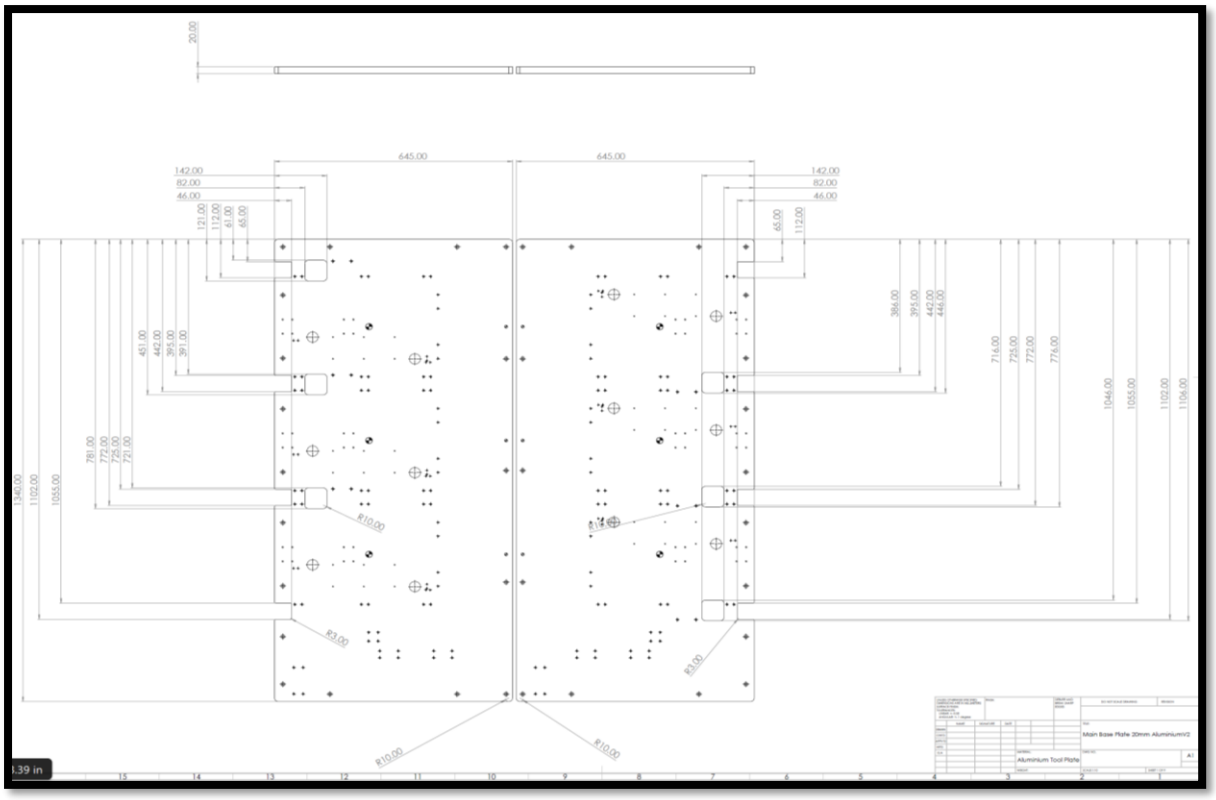


Figure 48. Main Baseplate Engineering Drawing One

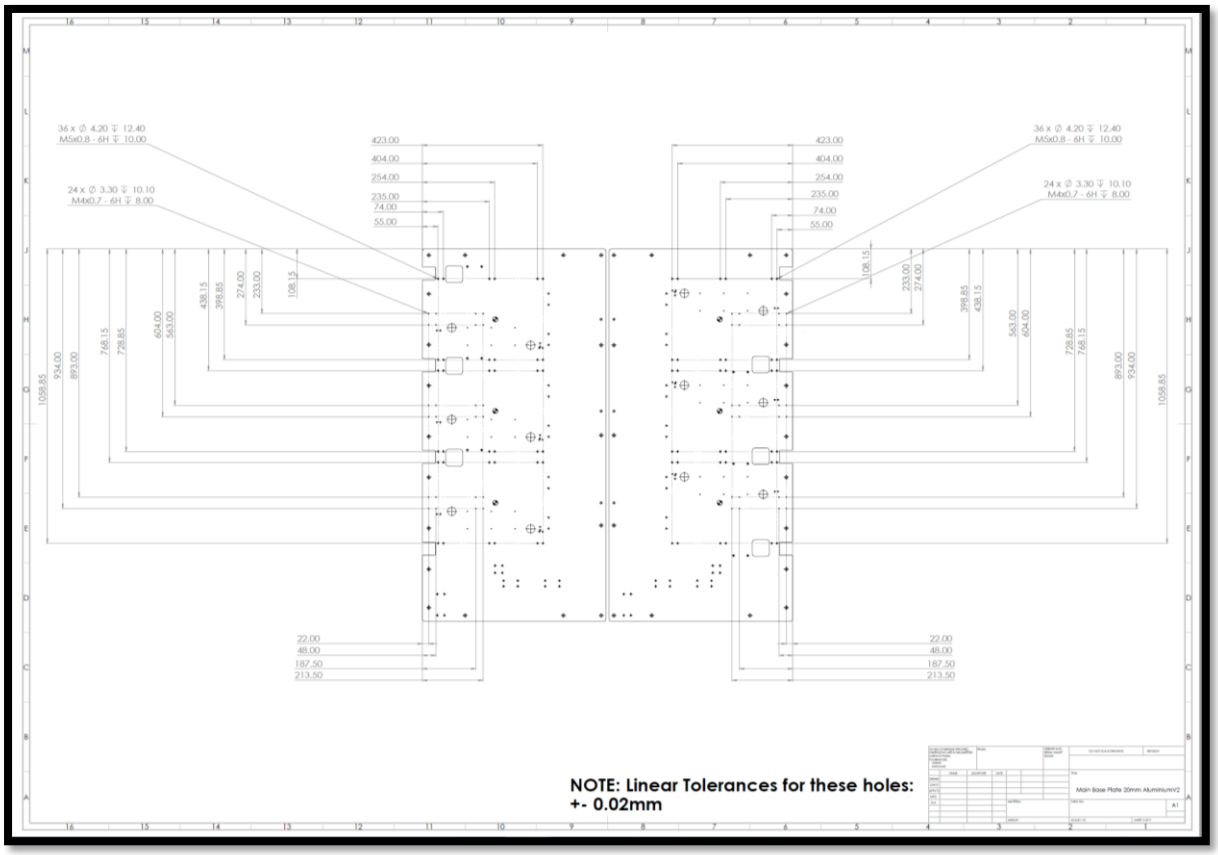


Figure 49. Main Baseplate Engineering Drawing Two

Figures 48 and 49 show two of nine pages for the main baseplate, highlighting its complexity as the primary mounting point and support for the entire machine. Some pages specify tolerances as $\pm 0.05mm$ linear and $\pm 1°$ angular unless otherwise stated. Geometric tolerances and projection indication aren't needed due to the drawing's simplicity.

Many machine components are manufactured using CNC processes, especially when made from aluminium thicker than 4mm. DFM considerations are considered for CNC methods; most components are designed with features created from the same plane, minimising the need for component readjustment in the CNC machine, thus reducing costs.

Furthermore, SUTC has their own CNC; thus, although ProtoLabs have been described, most components are completed within SUTC, thus, further reducing costs.

3.8.2. Laser Cutting

Laser cutting is employed within this project for aluminium sheets less than 4mm thick in various areas of the machine. Laser cutting processes use powerful laser beams controlled by a computer to cut or engrave materials such as metal, plastic, wood, fabric, and acrylic, producing intricate designs with clean edges. It offers advantages over conventional cutting techniques and minimises waste, making it popular in manufacturing, sign-making, jewellery-making, art, and design (*Laser cutting: How it works,* 2023).

Laser cutting is favoured for sheet metal due to its speed, simplicity, and cost-effectiveness. Figures 50 and 51 compare Laser Cutting and CNC machining quotes for Test Jig Front Panel Plates, highlighting the notable price difference.



DRAGON LASER LTD

Heol Ffaldau, Brackla Industrial Estate, Bridgend, CF31 2AJ
Tel: 01656 664130 E Mail: enquiries@dragonlaser.co.uk
www.dragonlaser.co.uk
Company Number: 3091591 Vat Number: 682686291

QUOTATION

SONY EUROPE B.V.
SONY UK TECHNOLOGY CENTRE
PENCOED TECHNOLOGY PARK
PENCOED
BRIDGEND
CF35 5HZ

Quotation Ref: **58558**
Quotation Date: **03/02/2023**
Customer Contact:
Account Ref: **SONY01**

Thank you for your recent enquiry, we now have great pleasure in confirming our quotation price.
We trust the following is of interest and look forward to your further instructions.

QTY	DESCRIPTION	UNIT COST	NET COST
10.00	2mm 5251 Alu Profile as Front Panel Plate V3.Step	6.750	67.50
1.00	Laser cut only	0.000	0.00
0.00	Lead time 7-10 days, ex works	0.000	0.00

Figure 50. Laser Cutting Quote Example



Figure 51. CNC Machining Quote Example

Laser cutting requires minimal engineering drawing input and is used in many areas of the machine, from cover plates for safety to bulkheads for securing power and control cabinets while enhancing structural stability. The quick and efficient process makes it an ideal manufacturing choice for various machine components. Figure 52 shows some examples of the machine's bulkheads.

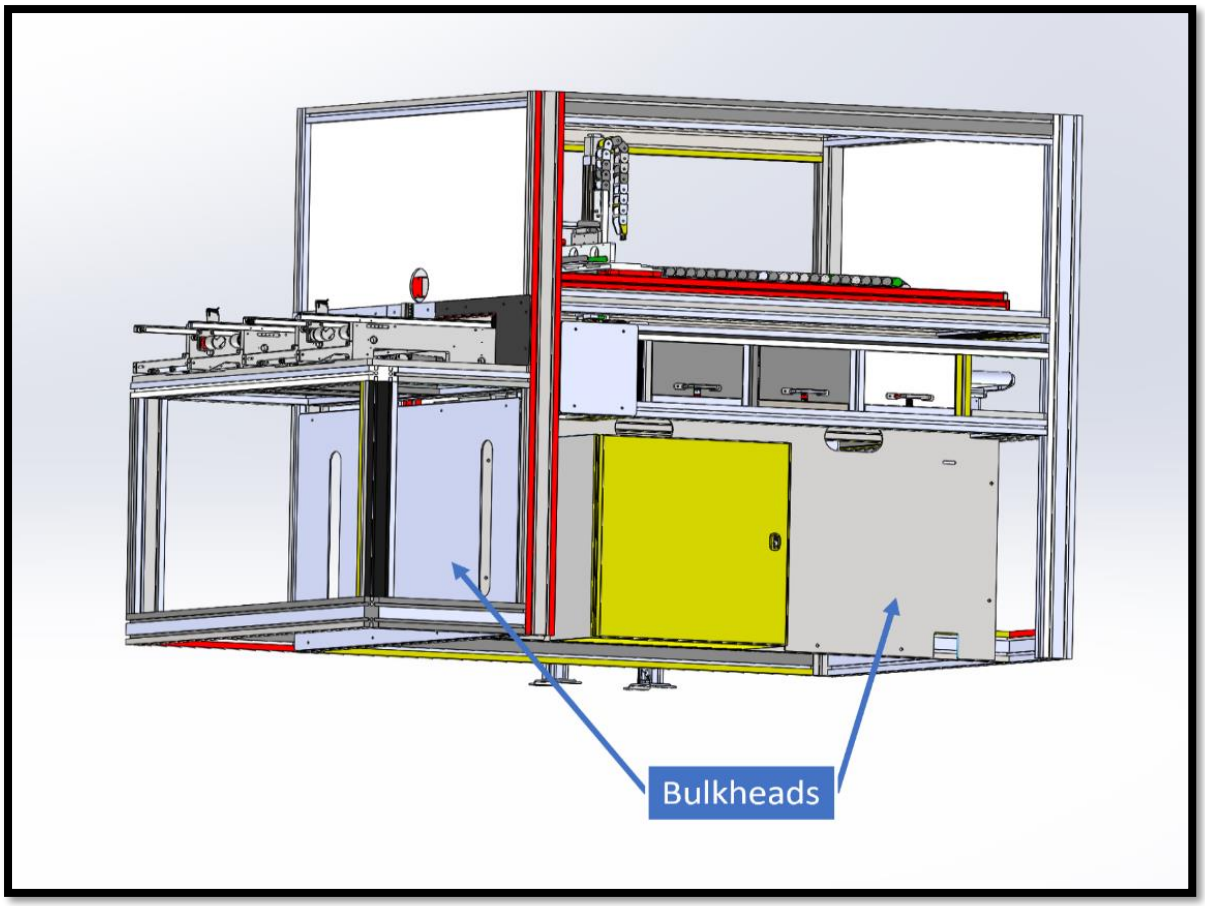


Figure 52. Machine Bulkheads

DXF (Drawing Exchange Format) files are a type of CAD file format used to share and exchange 2D and 3D design data between software programs. Commonly employed in manufacturing, engineering, and architecture, DXF files facilitate design data creation, distribution, and updating (*Learn about DXF files,* 2023).

The company “Dragon Laser” has been utilised for manufacturing sheet metal components, including those requiring bending, such as supports for the machine’s cable chains. Figure 53 displays an example of an engineering drawing of the Chute made from sheet aluminium, while Figure 54 shows the DXF file used to create the laser cutting program.

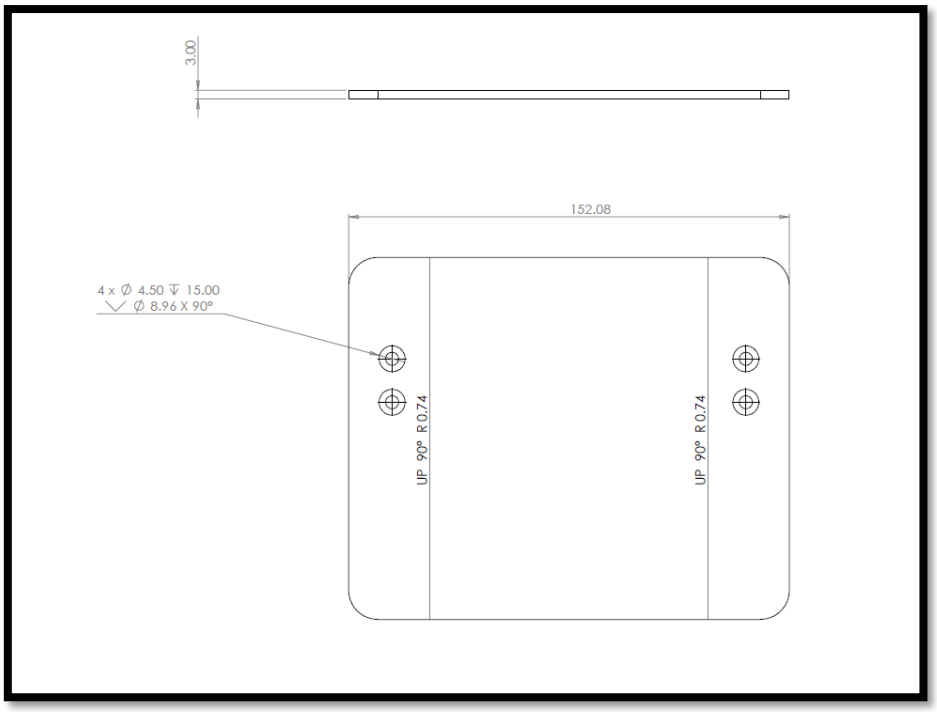


Figure 53. Laser Cutting & Bending Engineering Drawing for the Conveyor Chute

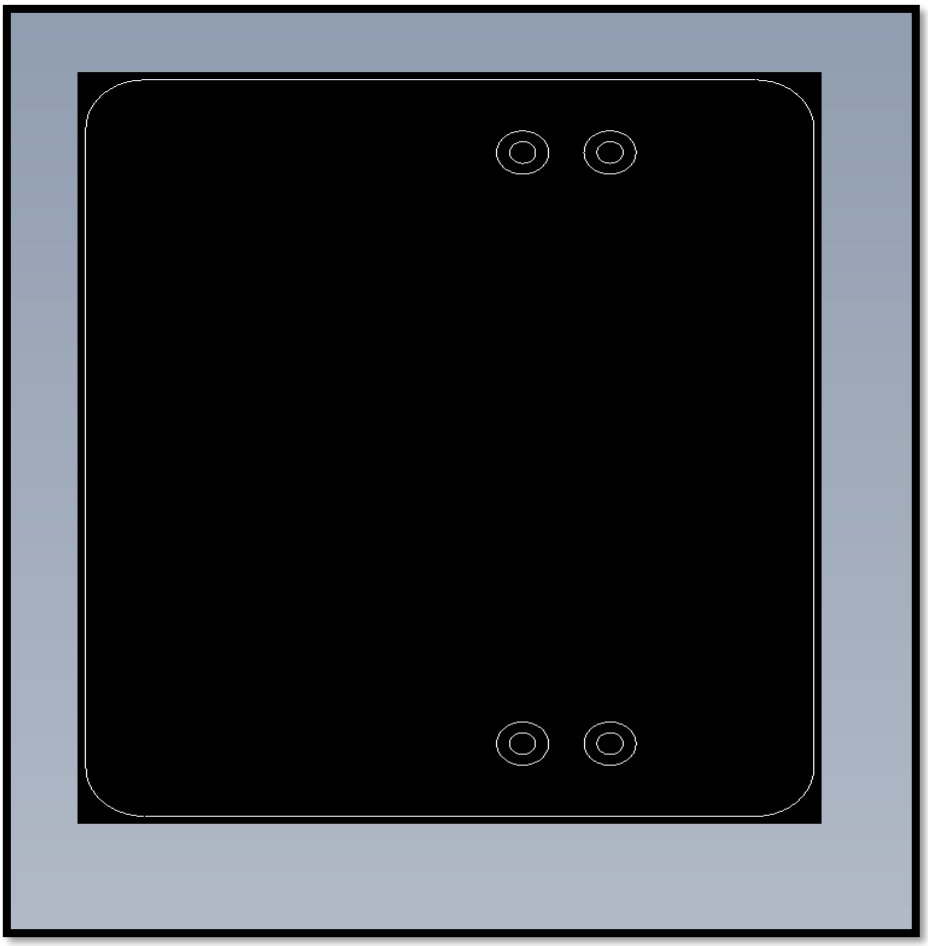


Figure 54. Chute DFX Example

3.8.3. 3D Printing

3D printing has been employed throughout the design and development process, not only for prototyping but also for various permanent components.

Using a digital design file, 3D printing builds objects in three dimensions, one layer at a time. There are three fundamental 3D printing techniques, Fused Deposition Modelling (FDM), Stereolithography (SLA), or Selective Laser Sintering (SLS).

To start the process, specialised software is used to melt and extrude plastic filament (FDM method), cure liquid resin (SLA method), and sinter powdered material (SLS method). Due to its advantages, which include the capacity to create complex geometries and reduce waste, 3D printing is widely used in a variety of sectors, including manufacturing, product design, architecture, medicine, dentistry, and education (*What is 3D printing? - technology definition and types,* 2023).

Various components, such as the Gripper Tips used on the Gripper system, are produced using FDM 3D printing. 3D printing offers several advantages, such as using a soft material such as plastic that does not damage Product A, conforming to the specification requirements.

Polylactic Acid (PLA) is the chosen material, as testing indicates no PCB damage, meets accuracy requirements, and is biodegradable, sourced from renewable resources such as sugarcane or corn starch. It's novice-friendly, has minimal warping, and is easy to print. Converting CAD to Stereolithography (STL) files and using 3D printing software enables additive manufacturing of the desired design, as depicted in Figure 55.

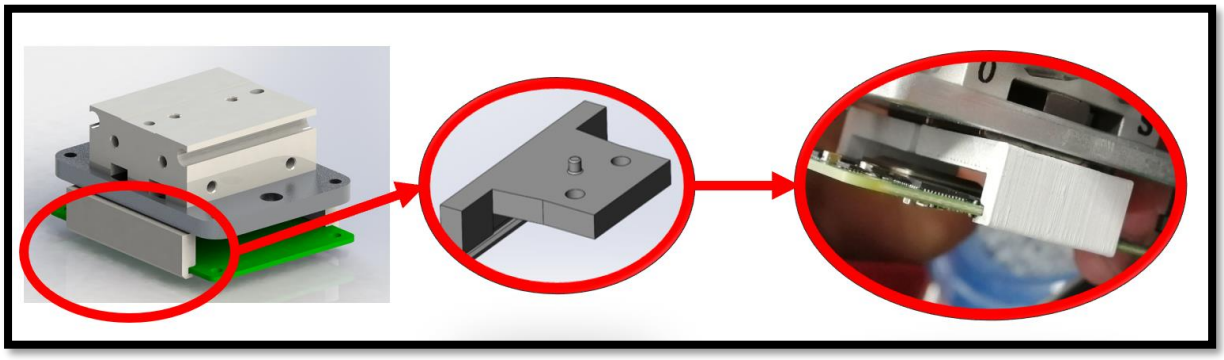


Figure 55. CAD to 3D Print

3.8.4. Off-The-Shelf & Pre-Fabrication

The machine combines manufactured and off-the-shelf parts with a prefabricated aluminium frame built by a manufacturer (KJN) using a Standard for the Exchange of Product Data (STEP) file, reducing time and cost. Standard parts such as electrical components, Test Jig

tooling posts, clamps, actuators and so on are purchased, simplifying integration. This "off-the-shelf" approach reduces development costs and time, ensuring the project stays on schedule and within budget.

These stocked components adhere to quality and safety standards such as CE and UKCA marking. CE signifies compliance with European Union health, safety, and environmental protection standards. UKCA is used in the UK as a replacement for CE marking after the country left the EU (*UKCA marking information,* 2023).

Purchasing stocked components helps meet ISO standards and regulations such as PUWER; however, integrating them into a machine means the entire system must be examined as a whole. Purchasing individual components that meet regulations provides added reassurance. An engineering drawing for the electrical components of the control panel is shown in Figure 56, with a Bill of Materials (BOM) created for ease of component ordering before assembly. Figure 57 also displays this for the power panel, while Figure 58 shows an example of a pneumatics layout.

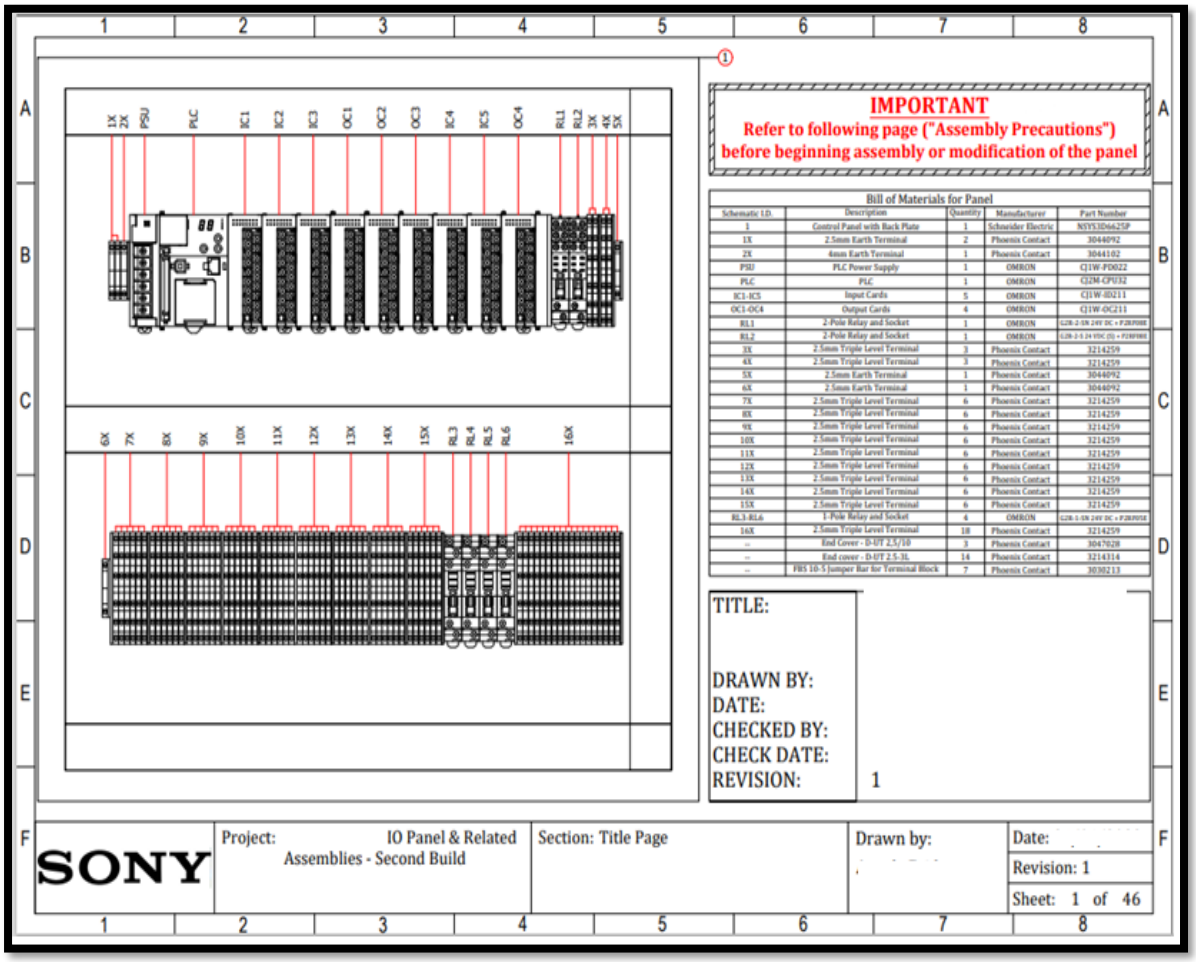


Figure 56. Control Panel Engineering Drawing & BOM

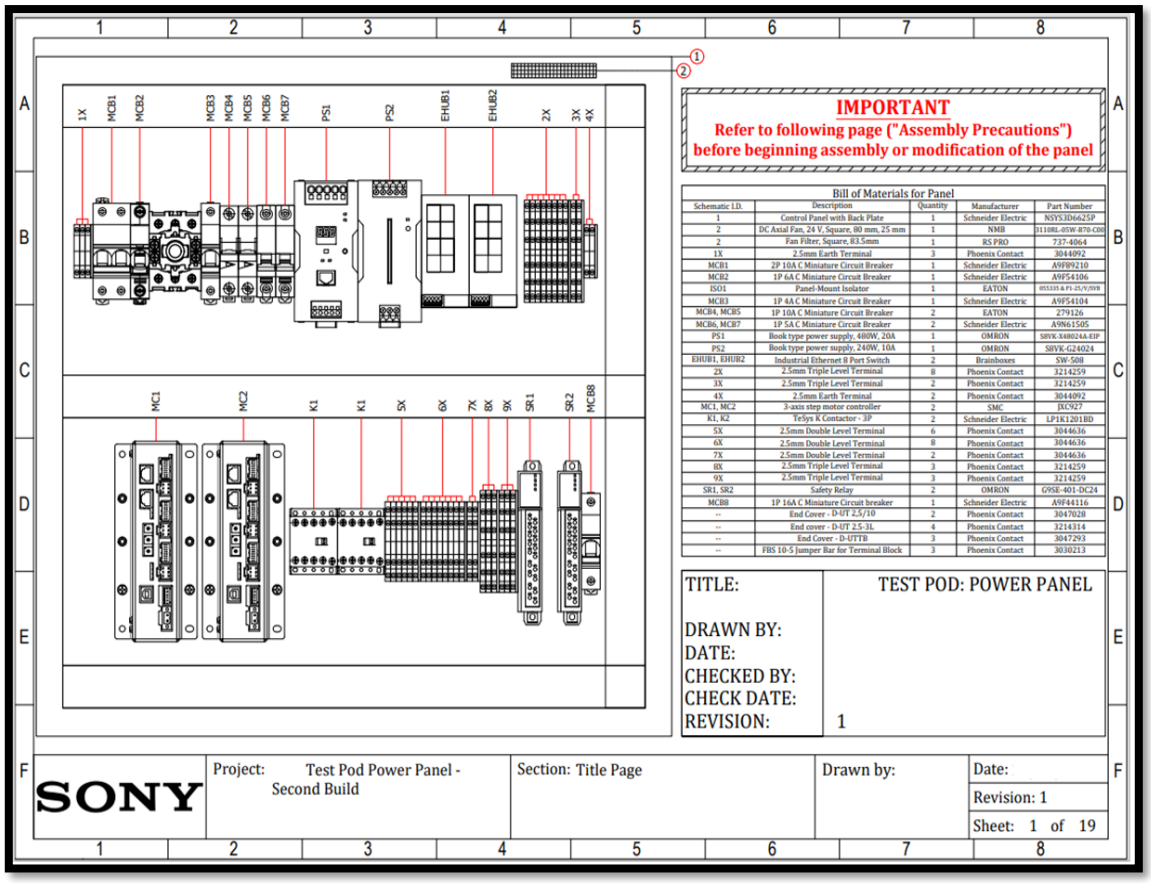


Figure 57. Power Panel Engineering Drawing & BOM

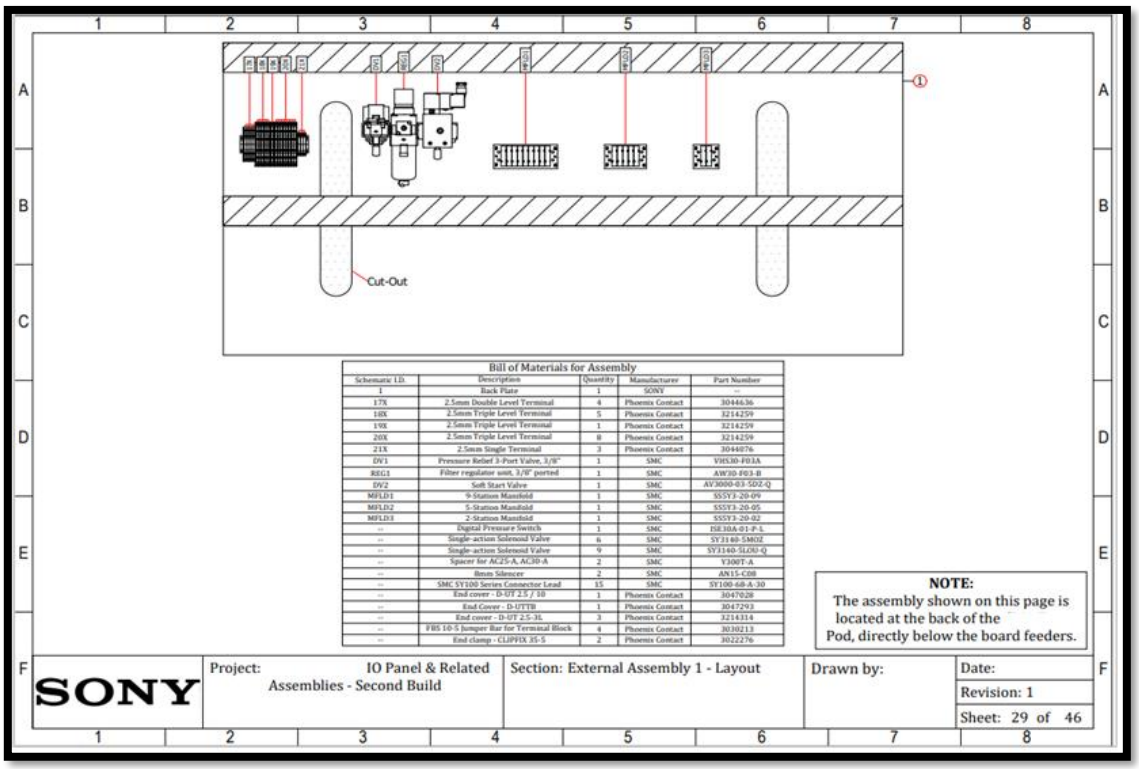
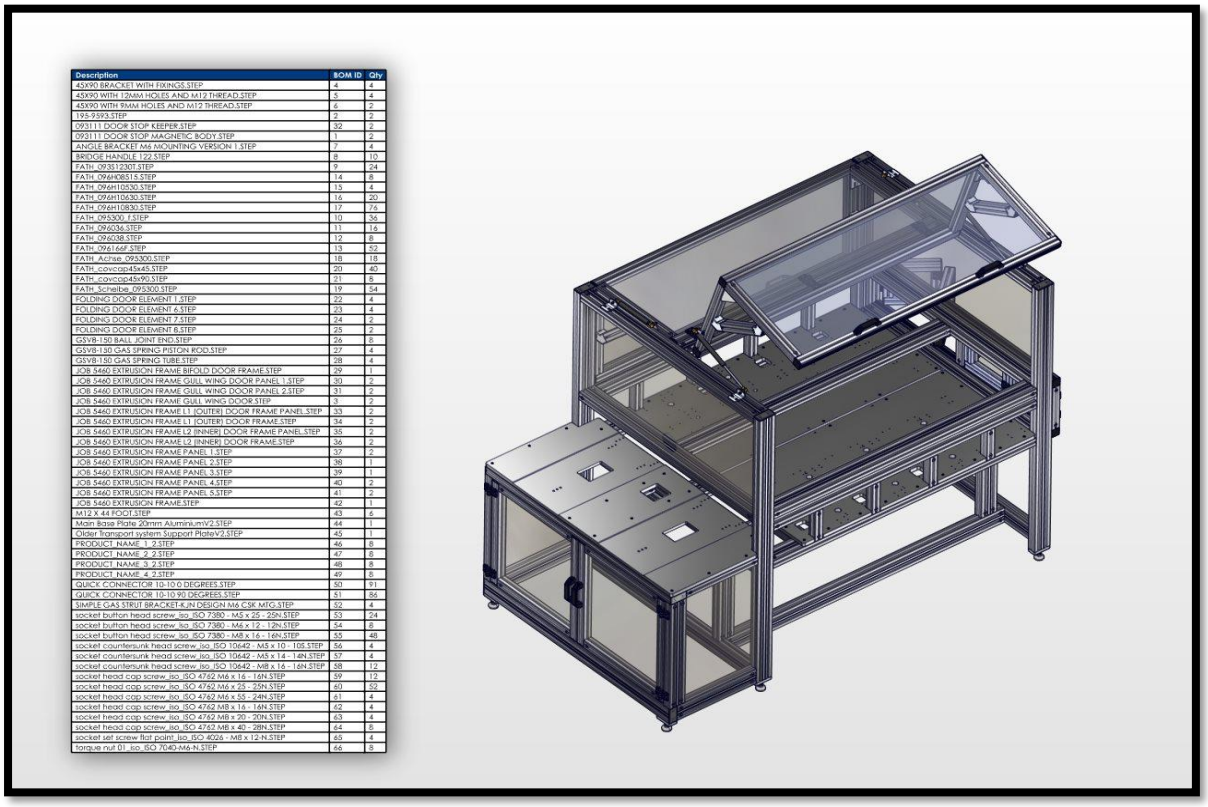


Figure 58. Pneumatics Engineering Drawing & BOM

Figure 59 displays the frame design with a BOM for manufacturing, which includes the main baseplates and an empty frame ready for component attachment.



Description	BOM ID	Qty
45X90 BRACKET WITH FIXINGS.STEP	4	4
45X90 WITH 12MM HOLES AND M12 THREAD.STEP	5	4
45X90 WITH 9MM HOLES AND M12 THREAD.STEP	6	2
195-9593.STEP	2	2
093111 DOOR STOP KEEPER.STEP	32	2
093111 DOOR STOP MAGNETIC BODY.STEP	1	2
ANGLE BRACKET M6 MOUNTING VERSION 1.STEP	7	4
BRIDGE HANDLE 122.STEP	8	10
FATH_093512307.STEP	9	24
FATH_096H08515.STEP	14	8
FATH_096H10530.STEP	15	4
FATH_096H10630.STEP	16	20
FATH_096H10830.STEP	17	76
FATH_095300_1.STEP	10	36
FATH_096036.STEP	11	16
FATH_096038.STEP	12	8
FATH_096166F.STEP	13	52
FATH_Achse_095300.STEP	18	18
FATH_covcap45x45.STEP	20	40
FATH_covcap45x90.STEP	21	8
FATH_Scheibe_095300.STEP	19	54
FOLDING DOOR ELEMENT 1.STEP	22	4
FOLDING DOOR ELEMENT 4.STEP	23	4
FOLDING DOOR ELEMENT 7.STEP	24	2
FOLDING DOOR ELEMENT 8.STEP	25	2
GSVB-150 BALL JOINT END.STEP	26	8
GSVB-150 GAS SPRING PISTON ROD.STEP	27	4
GSVB-150 GAS SPRING TUBE.STEP	28	4
JOB 5460 EXTRUSION FRAME BIFOLD DOOR FRAME.STEP	29	1
JOB 5460 EXTRUSION FRAME GULL WING DOOR PANEL 1.STEP	30	2
JOB 5460 EXTRUSION FRAME GULL WING DOOR PANEL 2.STEP	31	2
JOB 5460 EXTRUSION FRAME GULL WING DOOR.STEP	3	2
JOB 5460 EXTRUSION FRAME L1 (OUTER) DOOR FRAME PANEL.STEP	33	2
JOB 5460 EXTRUSION FRAME L1 (OUTER) DOOR FRAME.STEP	34	2
JOB 5460 EXTRUSION FRAME L2 (INNER) DOOR FRAME PANEL.STEP	35	2
JOB 5460 EXTRUSION FRAME L2 (INNER) DOOR FRAME.STEP	36	2
JOB 5460 EXTRUSION FRAME PANEL 1.STEP	37	2
JOB 5460 EXTRUSION FRAME PANEL 2.STEP	38	1
JOB 5460 EXTRUSION FRAME PANEL 3.STEP	39	1
JOB 5460 EXTRUSION FRAME PANEL 4.STEP	40	2
JOB 5460 EXTRUSION FRAME PANEL 5.STEP	41	2
JOB 5460 EXTRUSION FRAME.STEP	42	1
M12 X 44 FOOT.STEP	43	6
Main Base Plate 20mm AluminiumV2.STEP	44	1
Outer Transport system Support PlateV2.STEP	45	1
PRODUCT_NAME 1_2.STEP	46	8
PRODUCT_NAME 2_2.STEP	47	8
PRODUCT_NAME 3_2.STEP	48	8
PRODUCT_NAME 4_2.STEP	49	8
QUICK CONNECTOR 10-10 0 DEGREES.STEP	50	91
QUICK CONNECTOR 10-10 90 DEGREES.STEP	51	86
SIMPLE GAS STRUT BRACKET-4JN DESIGN M6 CSK MTG.STEP	52	4
socket button head screw_iso_ISO 7380 - M5 x 25 - 25N.STEP	53	24
socket button head screw_iso_ISO 7380 - M6 x 12 - 12N.STEP	54	8
socket button head screw_iso_ISO 7380 - M8 x 16 - 16N.STEP	55	48
socket countersunk head screw_iso_ISO 10642 - M5 x 10 - 10S.STEP	56	4
socket countersunk head screw_iso_ISO 10642 - M5 x 14 - 14N.STEP	57	4
socket countersunk head screw_iso_ISO 10642 - M8 x 16 - 16N.STEP	58	12
socket head cap screw_iso_ISO 4762 M6 x 16 - 16N.STEP	59	12
socket head cap screw_iso_ISO 4762 M6 x 25 - 25N.STEP	60	52
socket head cap screw_iso_ISO 4762 M6 x 55 - 24N.STEP	61	4
socket head cap screw_iso_ISO 4762 M8 x 16 - 16N.STEP	62	4
socket head cap screw_iso_ISO 4762 M8 x 20 - 20N.STEP	63	4
socket head cap screw_iso_ISO 4762 M8 x 40 - 28N.STEP	64	8
socket set screw flat point_iso_ISO 4026 - M8 x 12-N.STEP	65	4
torque nut 01_iso_ISO 7040-M6-N.STEP	66	8

Figure 59. Machine Frame BOM Example

Chapter Four -
Assembly & Testing

4.1. Machine Assembly

Once the final design is achieved after all previous development stages, parts are ordered and manufactured on and off-site. Modular designs allow for individual subsystem construction; thus, following the CPA, construction can occur concurrently, ensuring flexible assembly with DFX adherence.

Each subsystem has a BOM for component accountability, with an example in section 4.1.2. Not all BOMs are shown due to the report word limit; thus, additional samples are shown in Appendix Six and Seven. SUTC uses 3D Portable Document Format (PDF) and eDrawing files, software that can interact with the CAD files to understand its construction, reducing resource requirements spent on assembly drawings.

4.1.1. Test Jigs

Utilising the Test Jig BOM, parts ordering and manufacturing can occur. Figures 60 and 61 show the assembly.

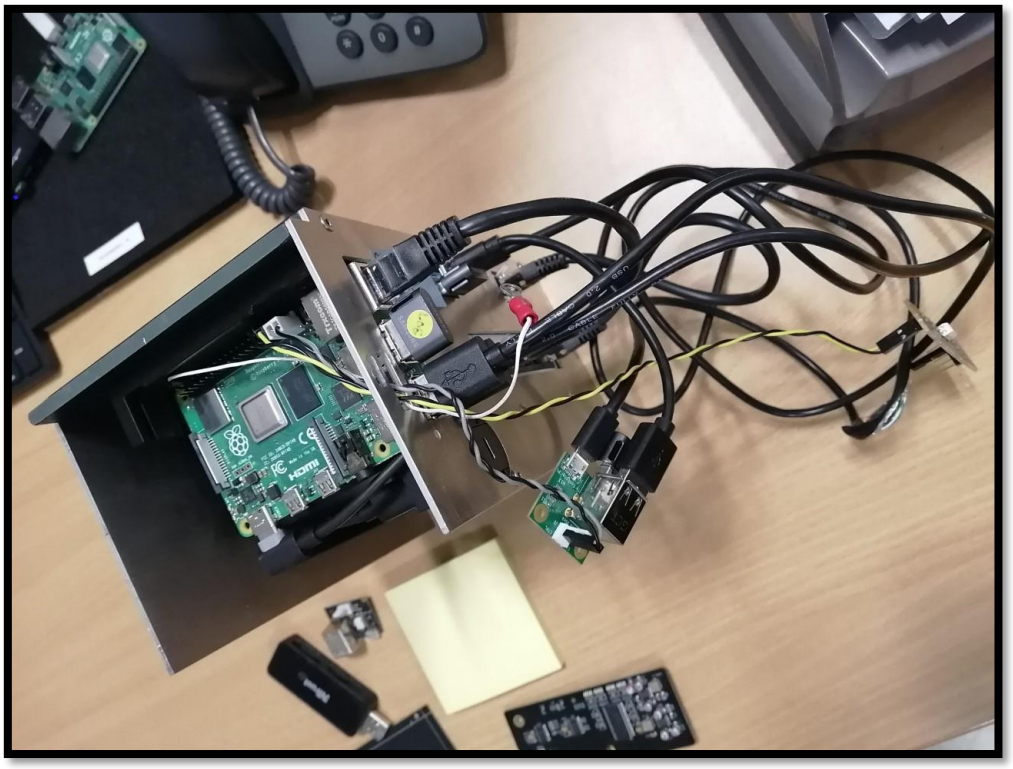


Figure 60. Test Jig Assembly



Figure 61. Test Jig Assembly - Alternative View

4.1.2. Feeder Systems

Two Feeder systems are assembled, one for each Gantry. Figure 62 shows the Feeder system CAD and BOM, illustrating data available for assembly and component accountability. Figures 63 to 65 show assembly examples, indicating how they are built as separate subsystems. This involves many mechanical, pneumatic, and electrical assemblies which control the system.

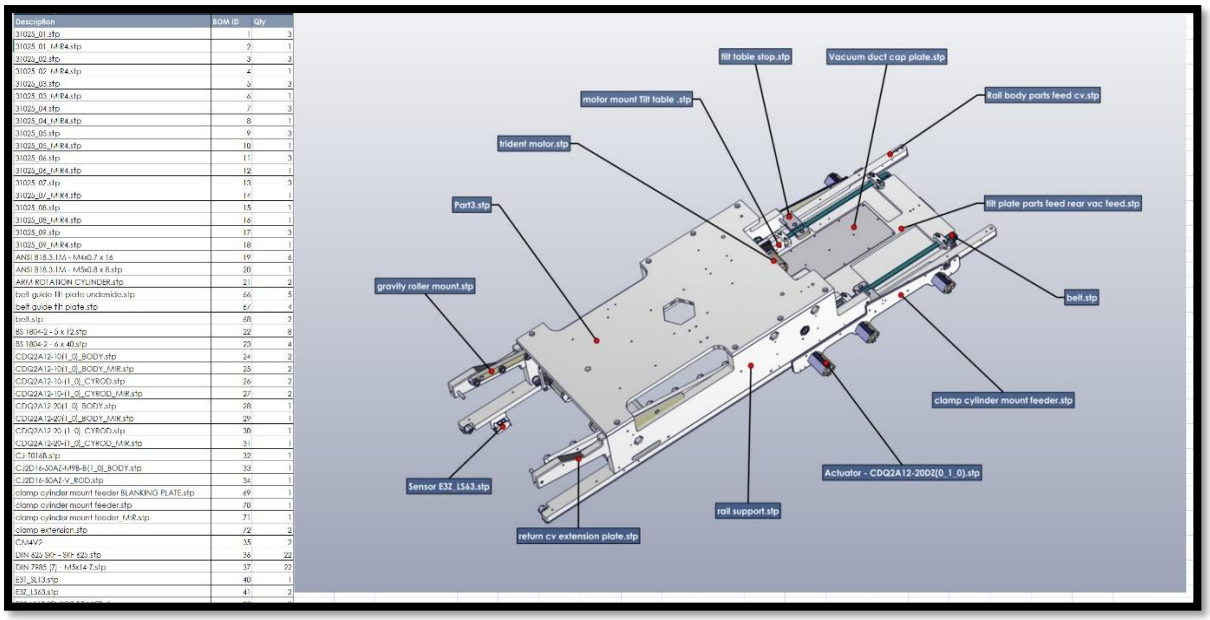


Figure 62. Feeder System CAD & BOM Example

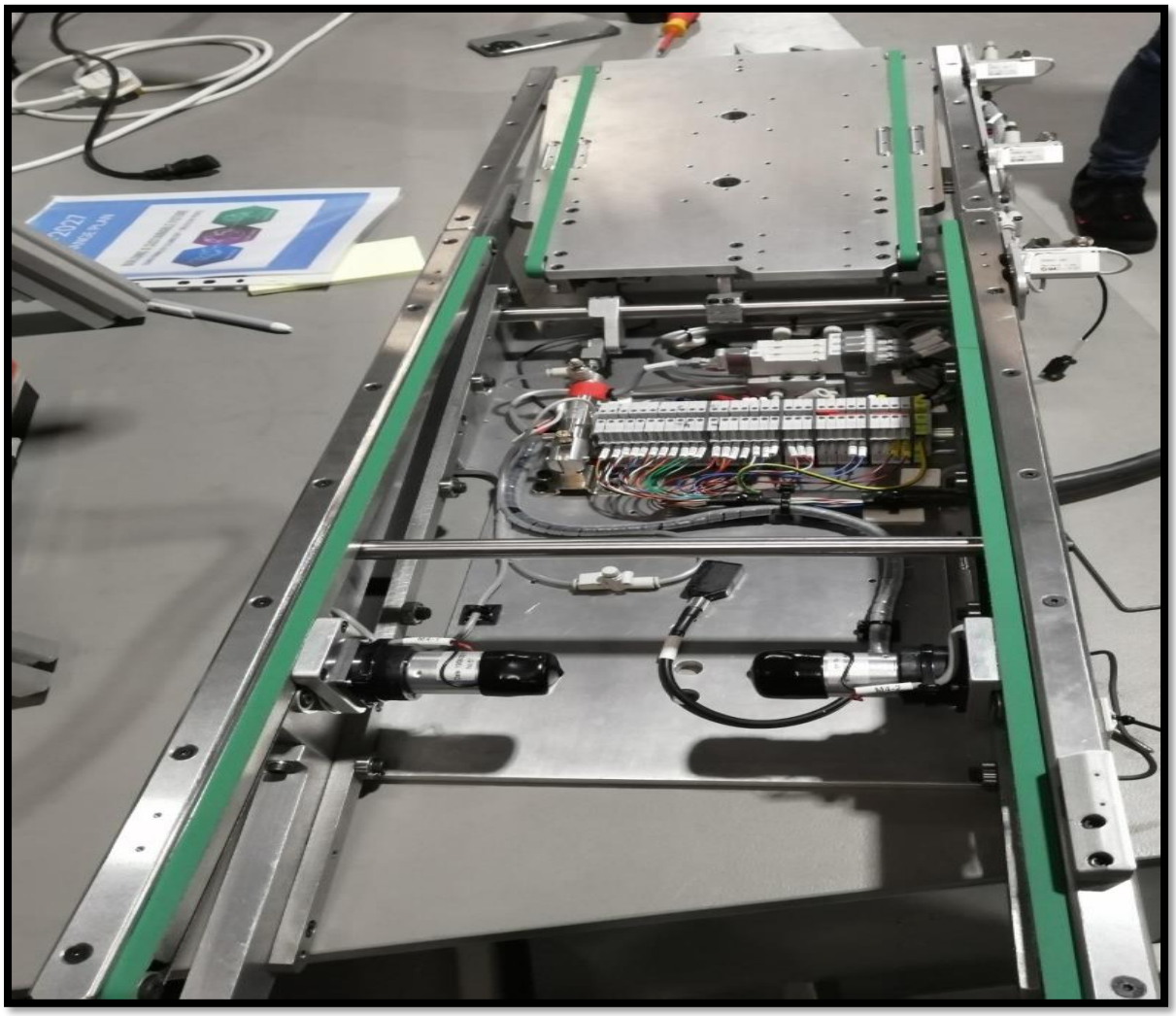


Figure 63. Feeder System Assembly

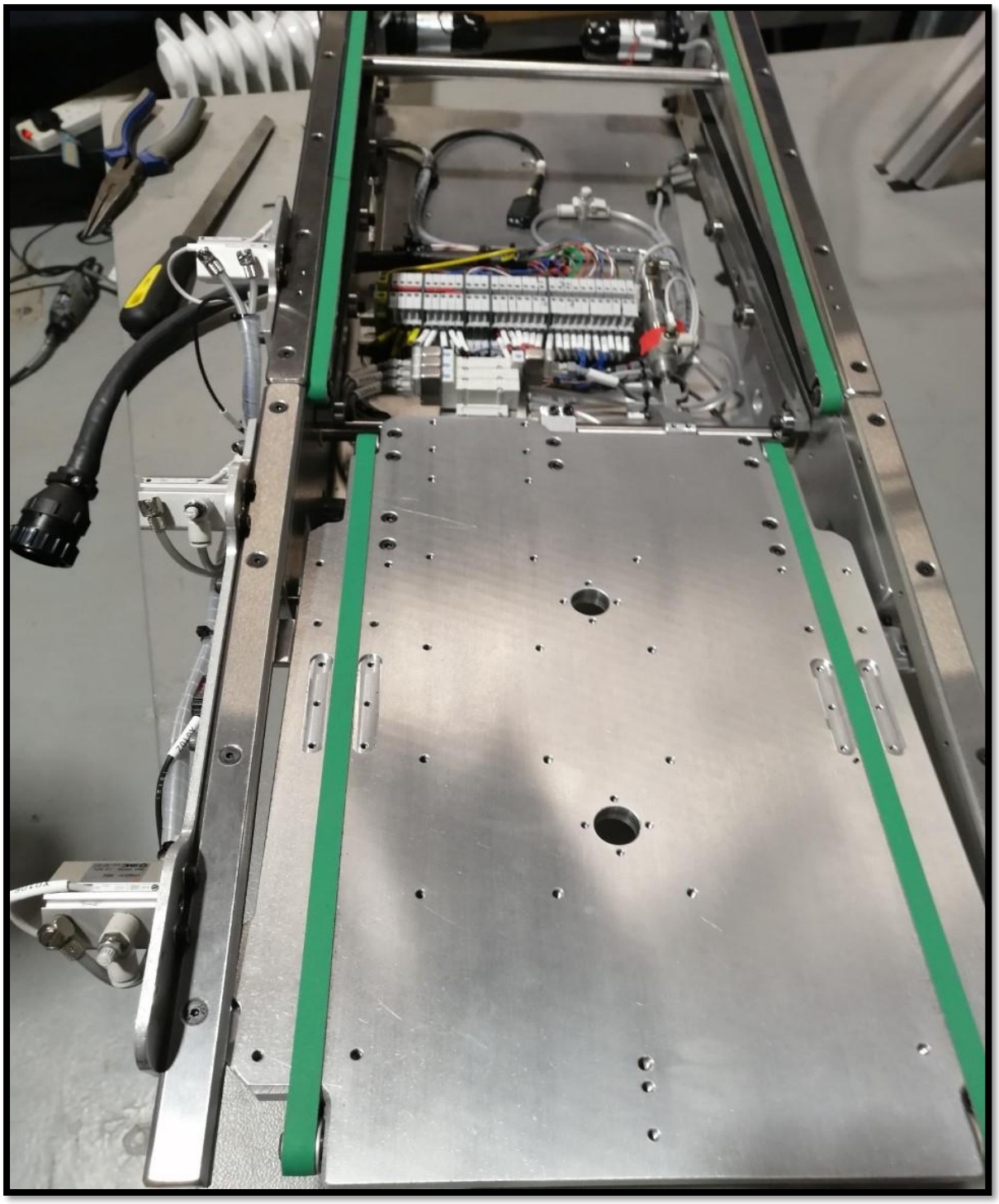


Figure 64. Feeder System Assembly - Alternative View

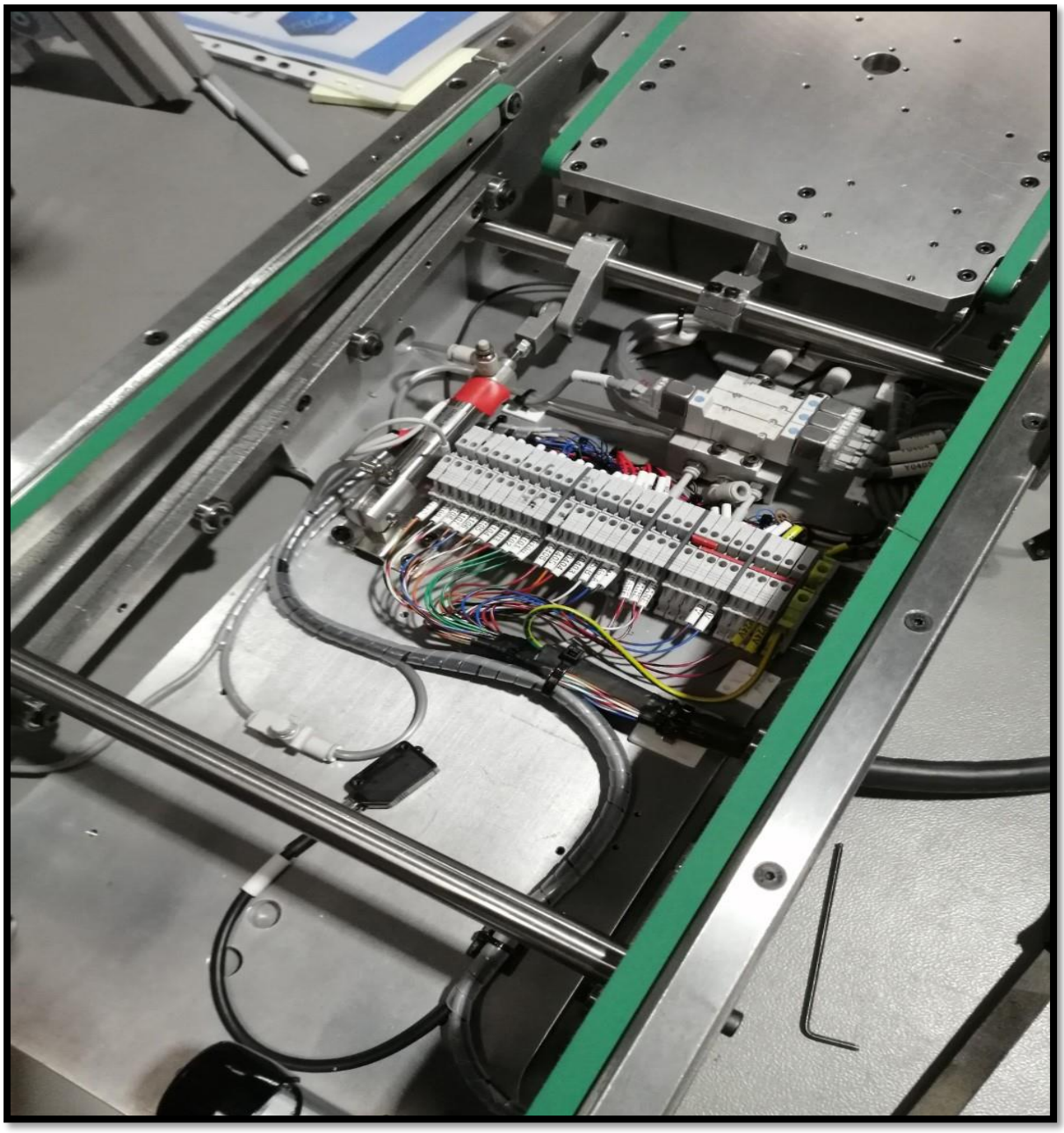


Figure 65. Feeder System Electrical and Pneumatic Mounting View

4.1.3. Gantry System

Though mechanically connected by a central mounting plate, the double Gantry system acts separately as left and right-hand systems. It can be assembled as a single unit, and to ensure DFA, actuators have motors placed accordingly (Left-Hand and Right-Hand Mounted). Linear rail mounting plates for the "X" and "Z" axes have mirrored, non-interchangeable components, preventing incorrect assembly.

Figure 66 to 73 shows the assembly of both Gantry systems before being integrated into the machine frame.



Figure 66. Gantry System Assembly (Phase One - Right Side)



Figure 67. Gantry System Manufactured Components



Figure 68. Gantry System Assembly (Phase One - Right Side) - Alternative View

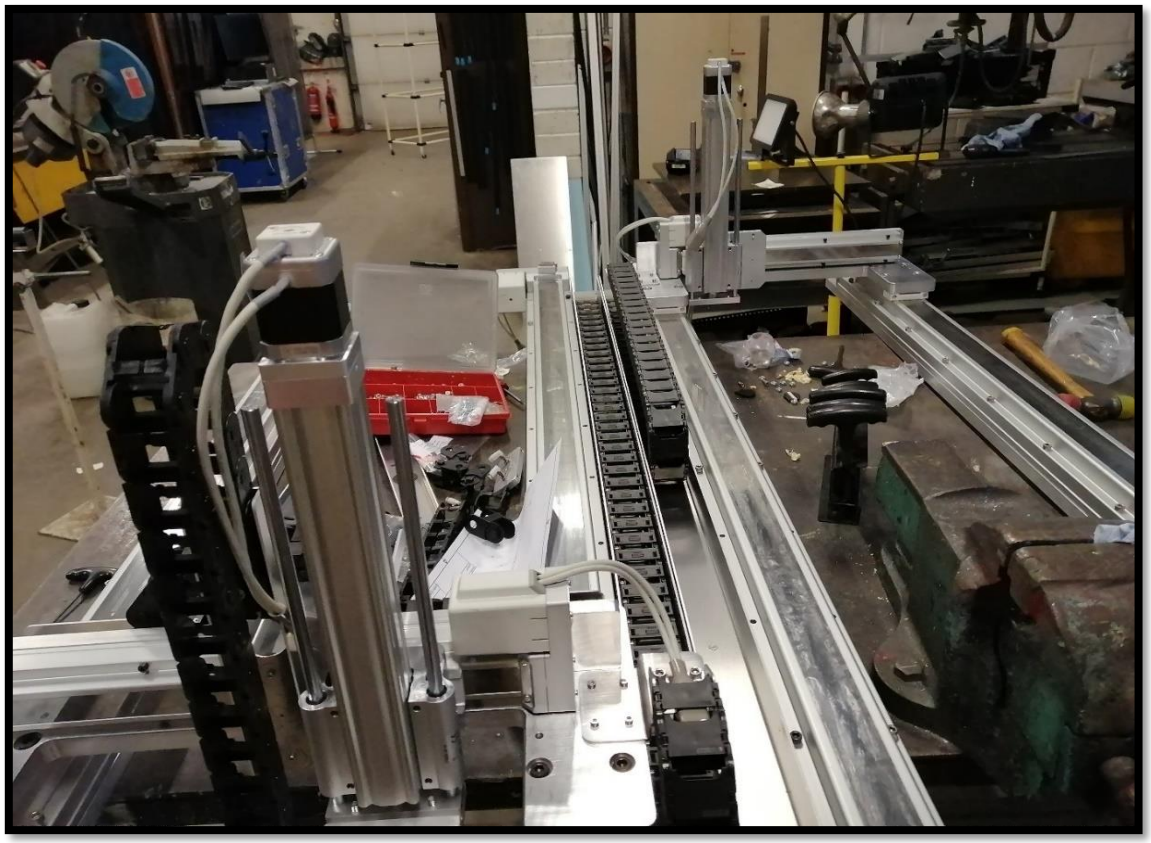


Figure 69. Gantry System Assembly (Phase Two - Left Side)

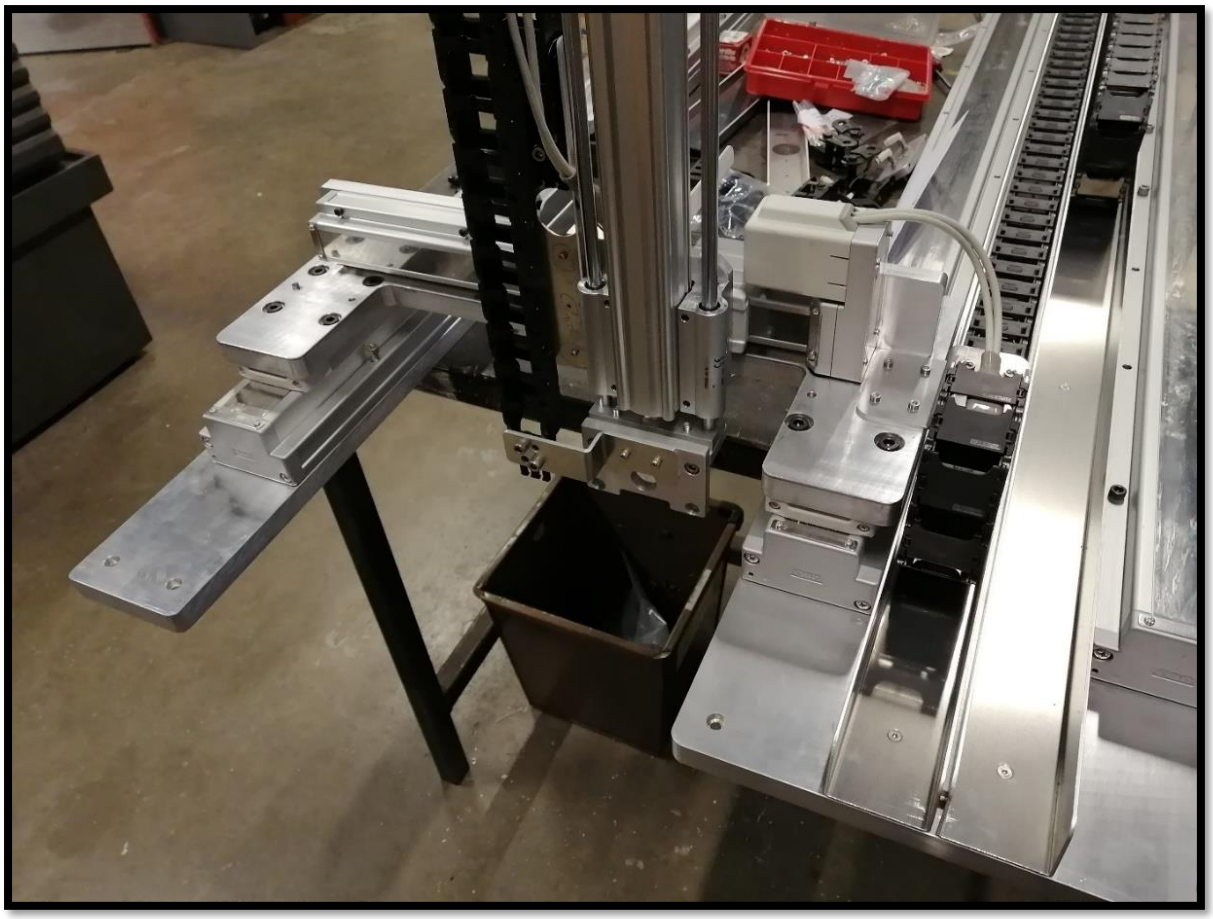


Figure 70. Gantry System Assembly - Z Axis & Gripper View



Figure 71. Gantry System - Completed Mechanical Assembly



Figure 72. Gantry System - Completed Mechanical Assembly - Alternative View (Front)

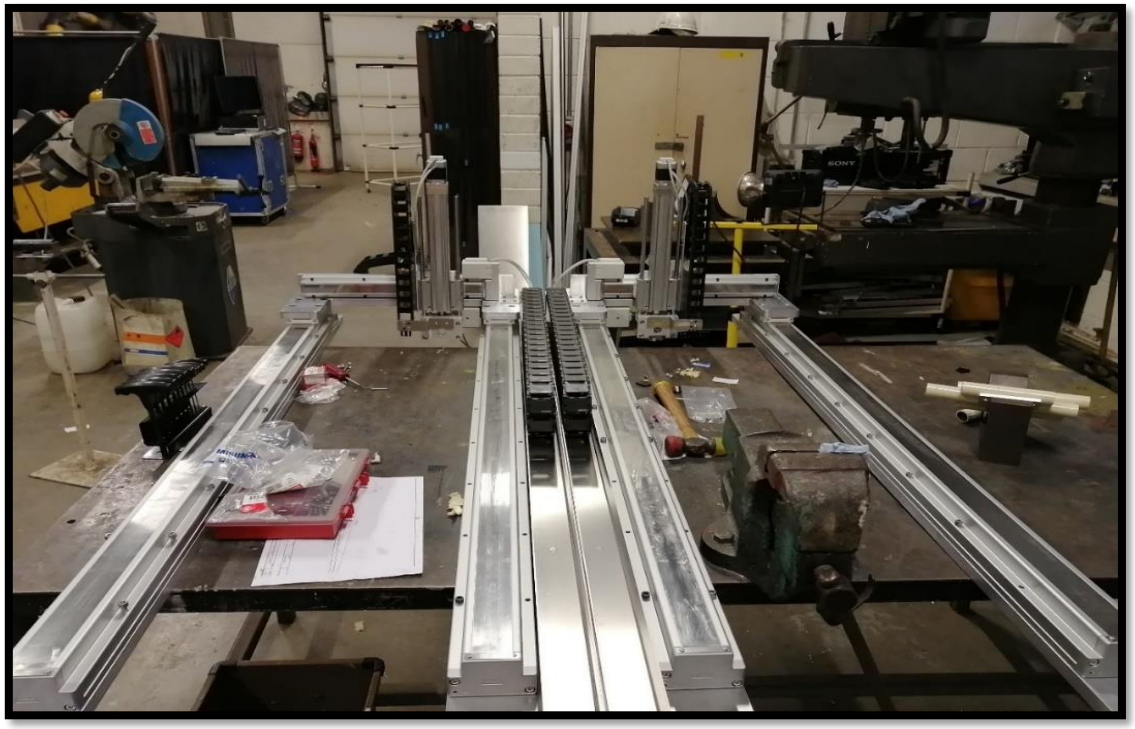


Figure 73. Gantry System - Completed Mechanical Assembly - Alternative View (Rear)

4.1.4. Output

Conveyors are off-the-shelf systems from Dorner Conveyors, simplifying integration and assembly. Tapped mounting holes on the main baseplate enable easy screw-in assembly, and they are powered from the power panel and linked to the control panel.

Figure 74 shows the passed product conveyor, and Figure 75 shows the failed product conveyor. As mentioned previously, sensors are mounted at the end of each conveyor, indicating Product A Board presence.

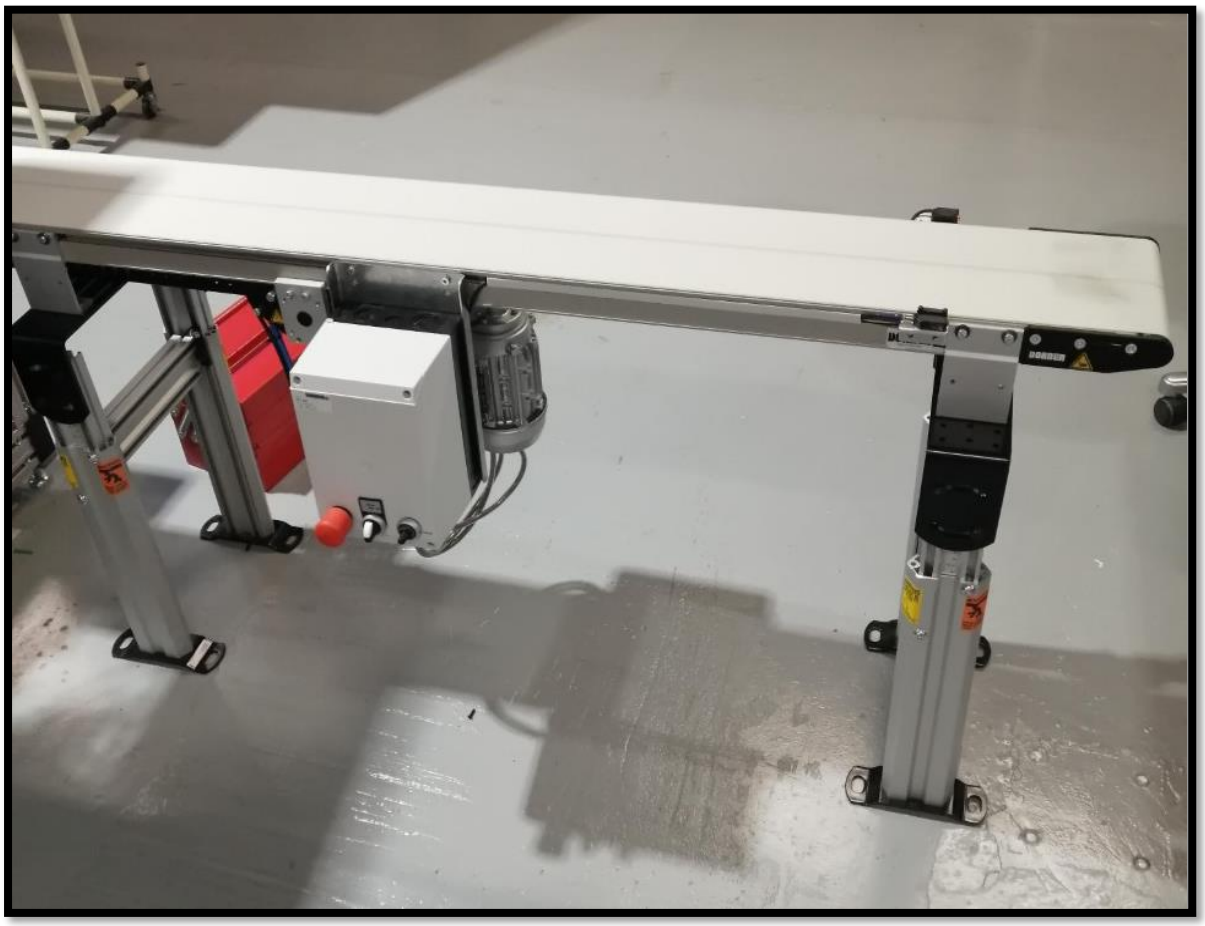


Figure 74. Passed Conveyor Installation

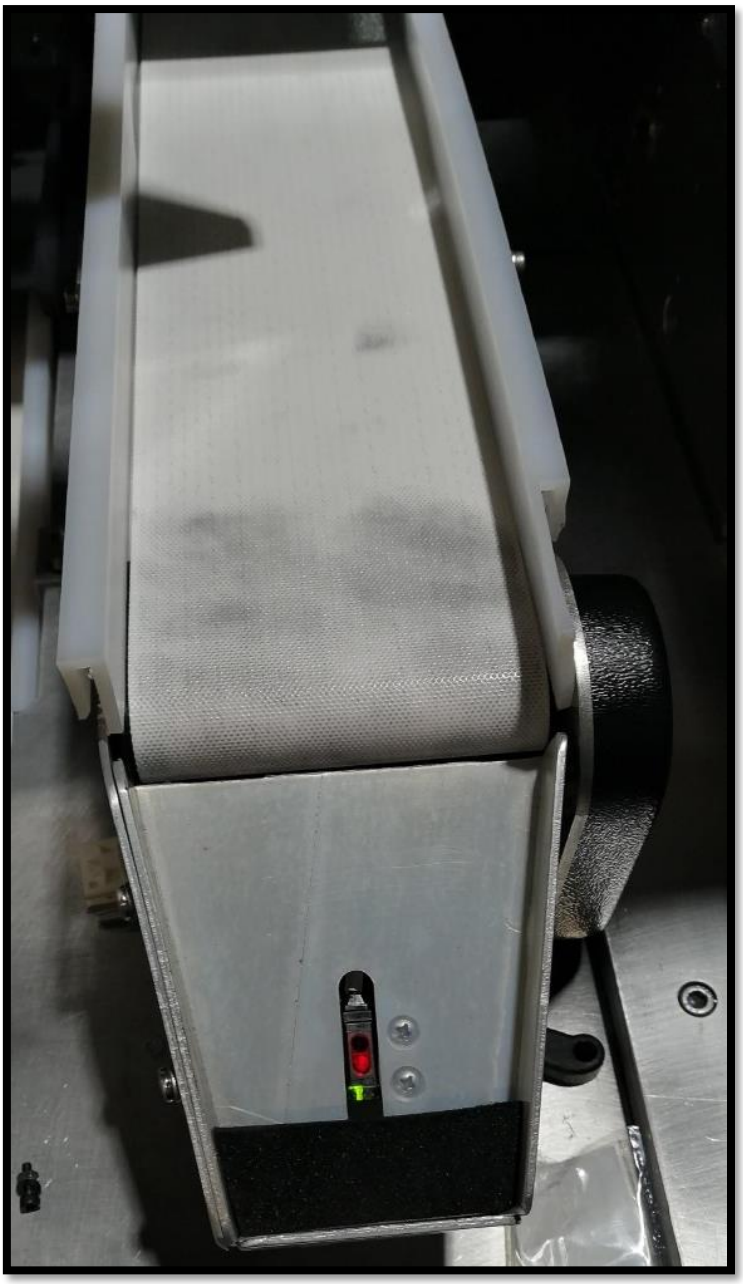


Figure 75. Failed Conveyor Installation

4.1.5. Machine Integration Assembly

The machine integration includes the subsystem designs, electrical panels, Personal Computers (PCs), pneumatics, and cable routing, as Figures 76 to 86 show. A BOM and a 3D CAD model in eDrawing ensure component accountability and easy assembly. Its modular design allows individual subsystem construction, with no sequence required, adhering to DFA and meeting maintenance and redundancy specifications. The entire machine BOM example is in Appendix Six, but only a sample is shown due to report size limitations.

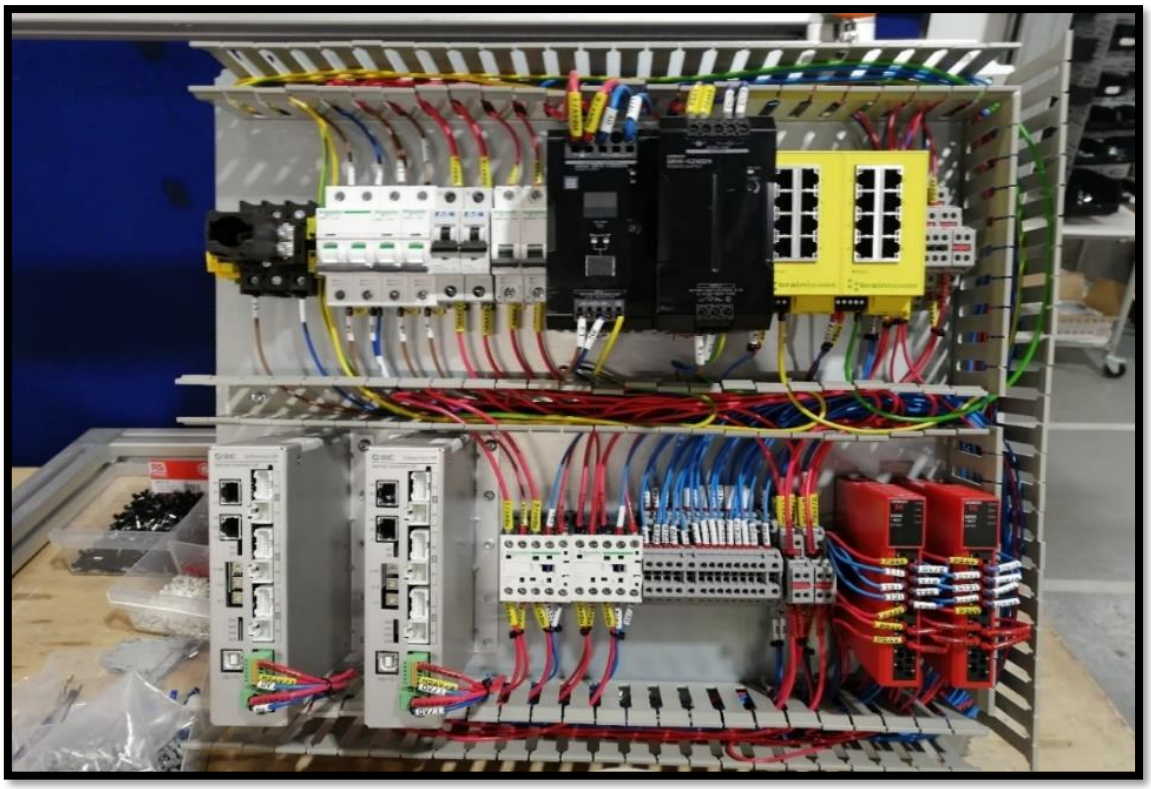


Figure 76. Power Panel Wiring Assembly

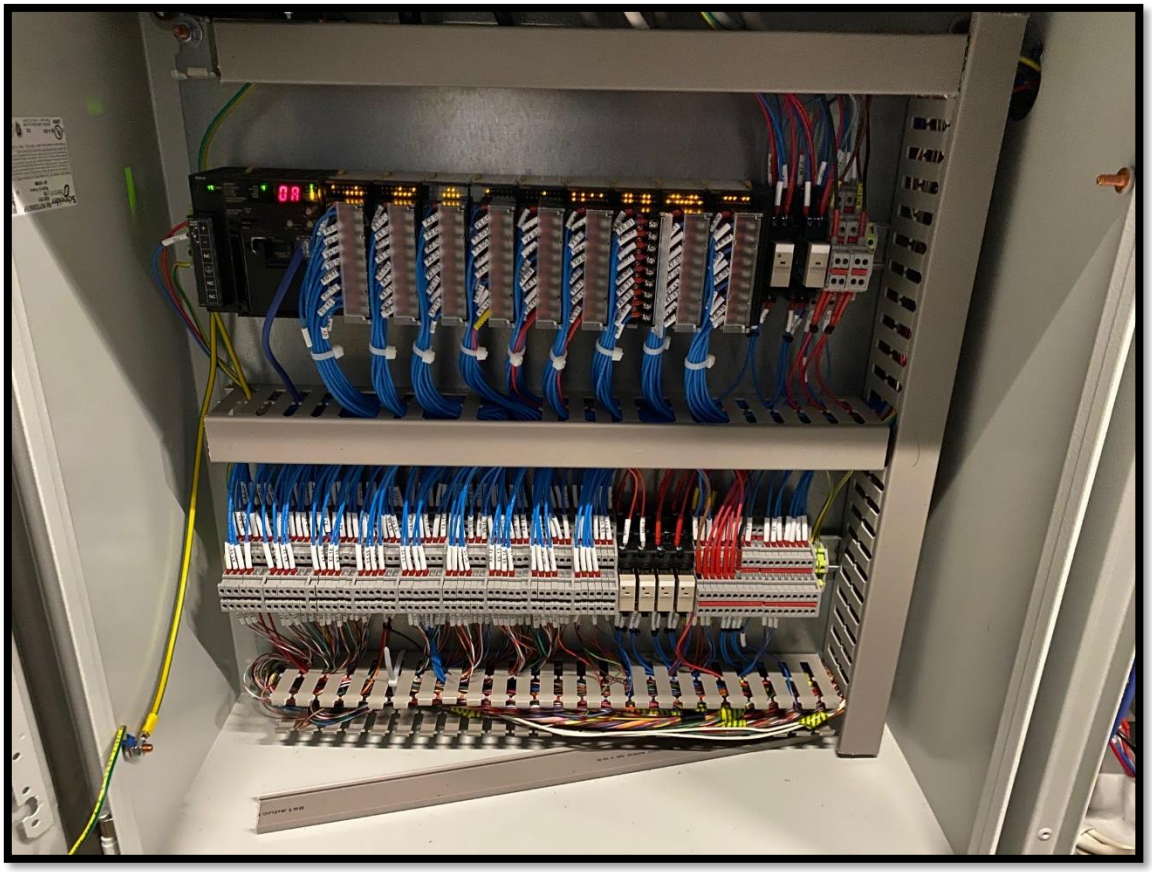


Figure 77. Control Panel Wiring Assembly

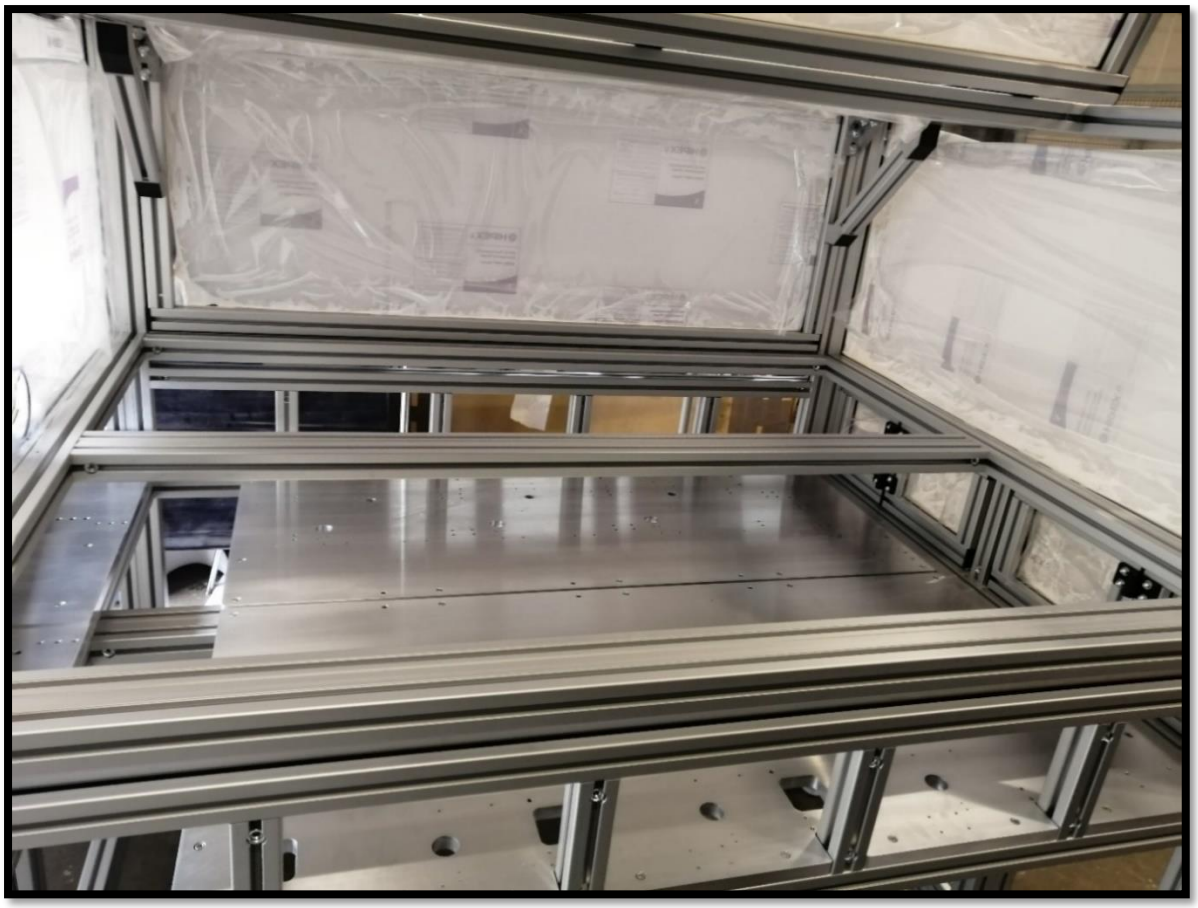


Figure 78. Main Baseplate Installation into Frame



Figure 79. Pre-assembled Frame and Feeder System Baseplate



Figure 80. Feeder System Installation

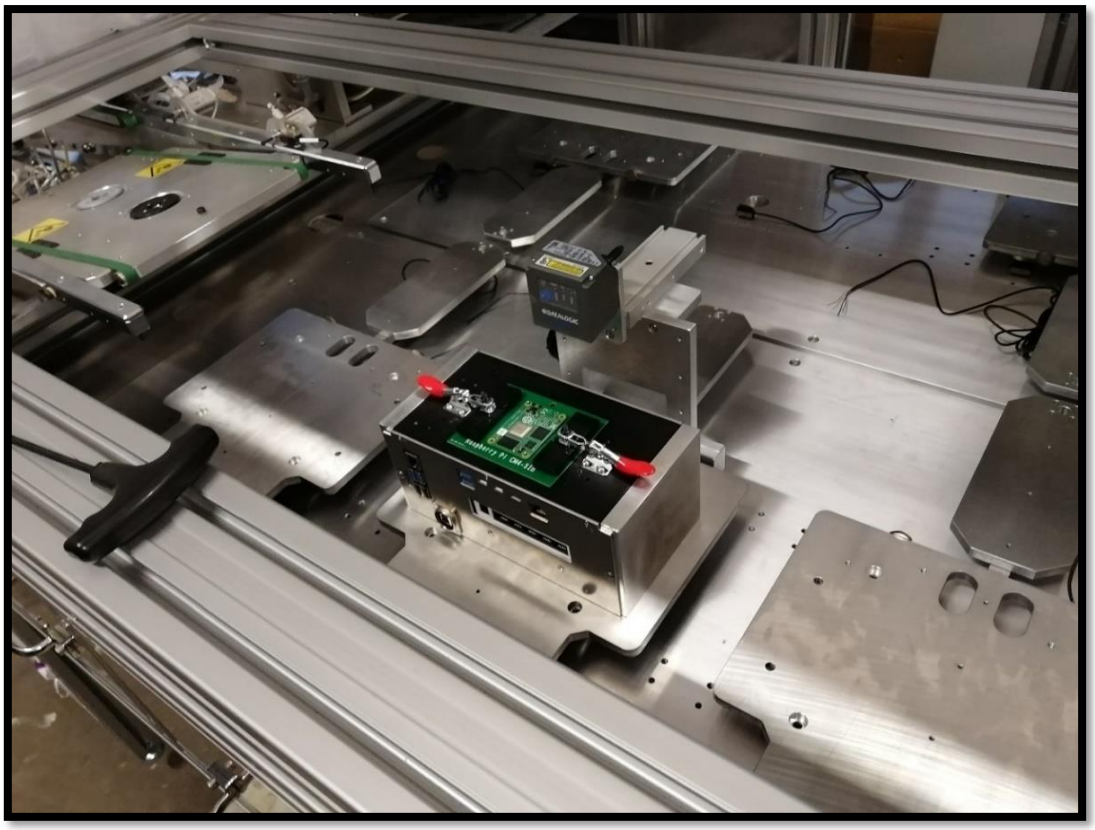


Figure 81. Test Jig Installation

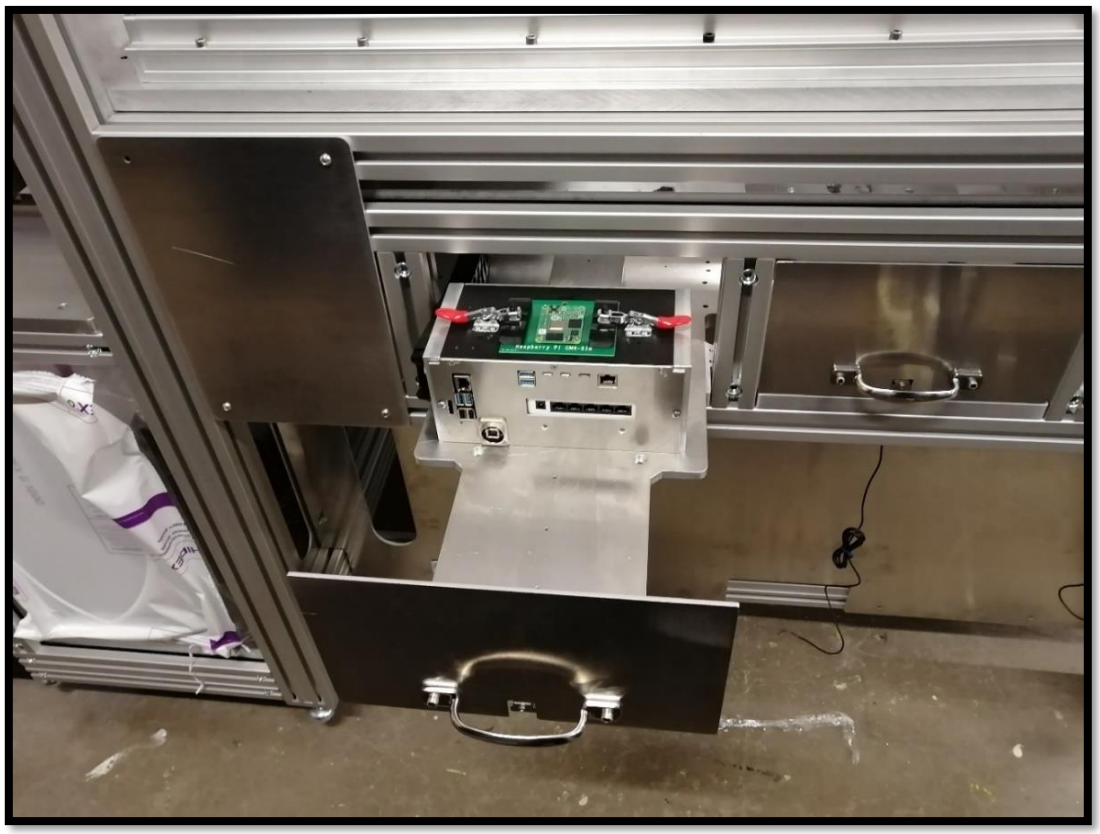


Figure 82. Test Jig Drawer System Test



Figure 83. Test Jig Drawer System Installation (Right Side)



Figure 84. Gantry System Installation

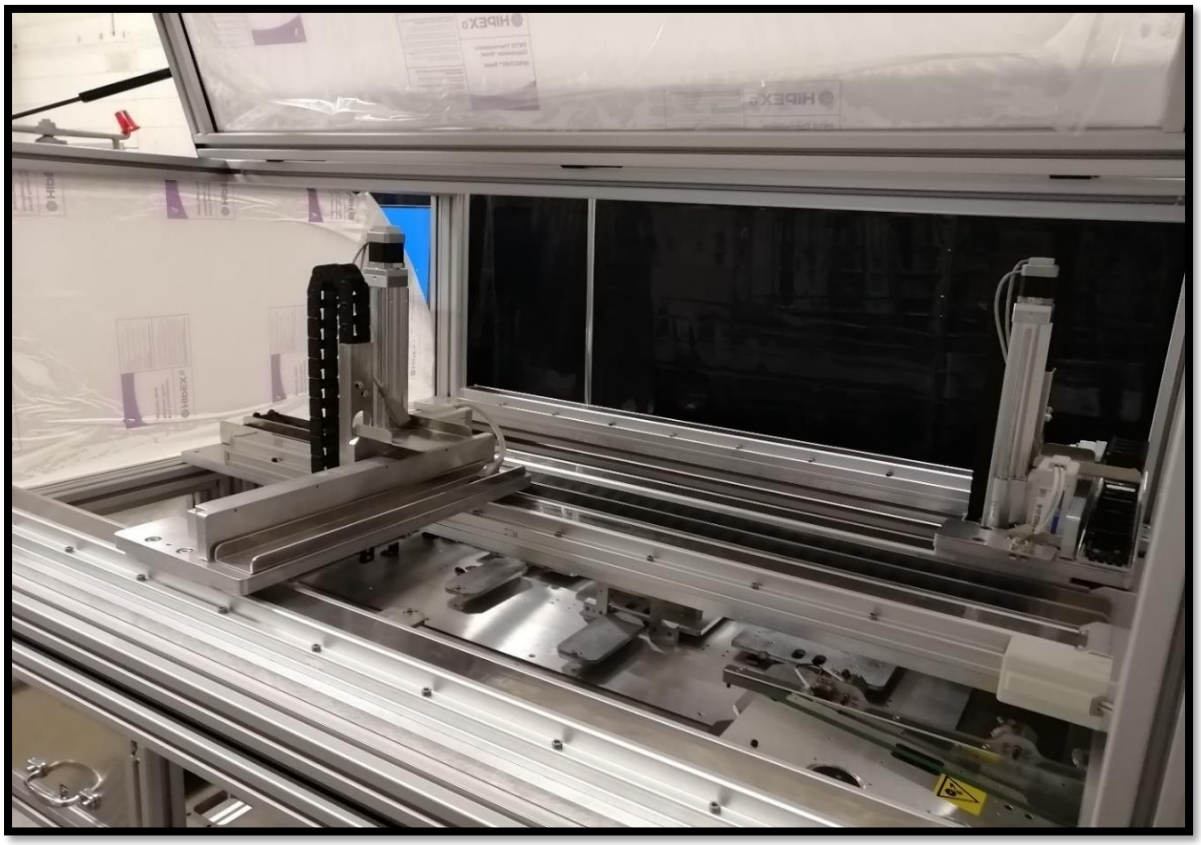


Figure 85. Gantry System Installation - Alternative View



Figure 86. Machine Assembly Overview

In addition to mechanical, pneumatic, and electrical components, the software is included, with an example in Appendix Eight sampling some of the PLC programming, which controls the machine sequence based on the inputs and outputs and programmed logic flow.

The program uses ladder logic, a standard programming method for PLCs in industrial automation. Ladder logic diagrams resemble ladders, with rungs representing PLC commands

and logic expressions connected by vertical lines indicating power sources and control signals. Pictorial symbols represent inputs, outputs, timers, counters, and other logic operations, depicting steps for activities or processes (Romanov, 2022).

4.2. Machine Testing

Testing ensures each subsystem performs its required function. Test Jigs can be used as an example, with the steps as follows:

• **Design Verification:** Ensure compliance with testing requirements and product suitability.

• **Debug:** Debugging of hardware and software components.

• **Calibration:** Calibrate the measuring and control elements.

• **Verification and Validation:** Assess performance against criteria and standards.

• **Testing:** Examine Test Jig performance with diverse product samples.

Each subsystem follows these steps, with the overall machine undergoing an Operational Qualification (testing under various conditions) and a Performance Qualification (long-term performance evaluation) to ensure design specification adherence.

The machine is linked to the local factory network allowing for its primary purpose of Product A testing. Once the machine is started, SUTC Engineers place sample boards (Product A) through the machine's Feeder systems. The output is measured to calculate theoretical weekly output (see Table 5) for the **Performance Qualification**.

Table 5. Initial Machine Testing - Output Results

Machine Variables	Gantry 1 Output	Gantry 2 Output
Time (Min) to Complete 1 Pallet	7.33	7.25
Number of Boards / Pallet	12	12
Board Output / Minute	1.637107776	1.655172414
Minutes / Shift / Day	450	450
Board Output / Shift / Day	736.6984993	744.8275862
Total Board Output / Shift / Day	1481.526086	
Number of Shifts	1	
Number of Days	5	
Total Board Output / Week	7407.630428	

Table 5 reveals that the weekly production rate fails to satisfy demand within a single working shift (7 am to 3 pm, Monday to Friday). Implementing a two-shift pattern (7 am to 3 pm and then 3 pm to 11 pm) is, thus, required.

Machine operation necessitates only half of an operator's time per shift, primarily for feeding Product A. In a two-shift pattern, each operator can thus allocate half their time to other responsibilities. In terms of resources, this results in the equivalent of one full-time operator overseeing the machine split between the two shifts. This satisfies the machine's design objective by mitigating NVA tasks.

However, both operator resources are still allocated against the machine, and theoretical calculations in Appendix Four suggest higher output numbers, warranting analysis using a process Failure Mode and Effects Analysis (FMEA) to determine inefficiencies.

FMEA is conducted after an Operational Qualification confirms the machine's resilience against random events and human error. Discoveries made during this analysis are shown in Table 6.

Table 6. Machine FMEA

Process Step or Variable or Key Input	Potential Failure Mode	Potential Effect on Customer Because of Defect	SEV	Potential Causes	OCC	Current Process Controls	DET	RPN	Actions Recommended	Resp.& Target Date	Actions Taken	SEV	OCC	DET	Future RPN
What is the process step?	In what ways can the Process Step, Variable, or Key Input go wrong? (chance of not meeting requirements)	What is the impact on the Key Output Variables (customer requirements) or internal requirements?	How Severe is the effect to the customer?	What causes the Key Input to go wrong? (How could the failure mode occur?)	How frequent is cause likely to Occur?	What are the existing controls that either prevent the failure mode from occurring or detect it should it occur?	How probable is Detection of cause?	Risk Priority # to rank order concerns	What are the actions for reducing the Occurrence of the cause, or improving Detection? Should have actions on high RPN's or Severity of 9 or 10.	Who's Responsible for the recommended action? What date?	What were the actions implemented? Include completion month/year. (Then recalculate resulting RPN.)	Future Severity	Future Occurance	Future Detection	
Product A insertion into the pallet	Product A placed in the wrong orientation	Reduced machine efficiency and Product not being picked correctly, causing a test failure or damage	10	Human Error	4	Operator Training	10	400	A scanner is placed on the gantry to scan the QR code in a set location. If no QR code is present, the pallet is empty or Product A is in an incorrect orientation, thus, the gantry moves to the next position	Joshua Thorngate - by 20/02/2023	Completed	10	1	1	10
Product A insertion into the pallet	Inconsistency for Product A orientation for each Feeder system (Both require different orientations of the Product)	Scanners will add detection, thus, only efficiency reduces	8	Human Error	6	Operator Training	1	48	A Rotary is to be placed on one of the gantry systems to rotate Product A on one side of the machine, allowing for both feeder systems to have the same process (Product A Orientation)	Joshua Thorngate - by 20/02/2023	Completed	8	1	1	8
Product A insertion into the pallet	Product A not being flush in the pallet	Scanners will add detection, thus, only efficiency reduces	8	Human Error	6	Operator Training	3	144	Chamfers were added to the pallets to ensure Product A sits flush in the pallet	Joshua Thorngate - by 20/02/2023	Completed	8	1	3	24
Gantry movement for Pick and Place	Exessive Travel causes inefficiency	Test Jig Product failures finish the test early, causing the gantry to change its sequence, causing inefficiencies in the program	5	Programming Error	6	Current Programming	5	150	Change the Test Program to create wait points in the middle of the test jigs, ensuring less travel time	Control Engineer - by 20/03/2023	Completed	2	1	5	10

The analysis shows a lack of detection mechanisms for correct product orientation within the pallet. Product A is symmetrical except for its slightly offset connectors; thus, a method to detect human error is necessary. A scanning feature is added to the Gantry to check Product A orientation, using the products' Quick Response (QR) code position, which can mitigate errors and enhance efficiency.

In the FMEA, the additional risks are analysed to incorporate the new scanner feature solution, which increases the detection element of the other potential failure modes within the FMEA.

Furthermore, chamfers are added to pallet pockets to ensure flush board placement. Additionally, the PLC program is reprogrammed to reduce actuator travel time and enhance logical efficiency, such as directing the Gantry to wait centrally after placing Product A on the Jigs for a shorter post-test travel time.

Test Jigs on the machine's left and right sides face opposite directions, necessitating different Product A placement and risking operator confusion. A rotary actuator is added to Gantry 2 to ensure the consistent orientation of Product A for both Feeder systems. Table 7 displays post-modification testing results.

Table 7. Modified Machine-Output Testing Results

Machine Variables	Gantry 1 Output	Gantry 2 Output
Time (Min) to Complete 1 Pallet	4.51	4.52
Number of Boards / Pallet	12	12
Board Output / Minute	2.66075388	2.654867257
Minutes / Shift / Day	450	450
Board Output / Shift / Day	1197.339246	1194.690265
Total Board Output / Shift / Day	2392.029512	
Number of Shifts	1	
Number of Days	5	
Total Board Output / Week	11960.14756	

The project's aim has been achieved. The total weekly output on a single shift now surpasses the specified target, but this assumes perfect product placement and easily readable QR codes. Most improvements stem from reprogramming, while other changes act as contingencies to mitigate failures.

Chapter Five -
Machine Performance & Discussion

5.1. Implementation and Commissioning

The machine's design meets the specification, project objectives, and aims. However, additional standardised requirements such as health and safety are required. SUTC uses the Performance Level (PL) risk assessment, based on the ISO:13849-1 standard, to evaluate machine safety during the design and development phases.

PL risk assessment involves analysing hazards related to a machine or system and determining the necessary safety performance level to reduce risks. Each safety function is assigned a PL based on factors such as injury severity, exposure frequency and duration, and dependability of the safety-related control system.

Quantitative and qualitative techniques are employed in PL calculation, using Mean Time to Dangerous Failure (MTTDF) and Diagnostic Coverage (DC) metrics. The resulting PL level guides the selection of appropriate safety-related control elements, such as safety sensors, relays, and programmable safety controllers.

Figure 87 displays a typical machine's PL, indicating the required safety PL. Systems chosen must be rated accordingly, such as an interlock rated to a "D" level if the PL assessment requires it. PL risk assessment is vital for ensuring device or system security. It helps identify and mitigate potential hazards and guarantees the proper creation and integration of safety-related control systems, meeting the necessary safety performance (Fuchs & Zajicek, 2013, p.101).

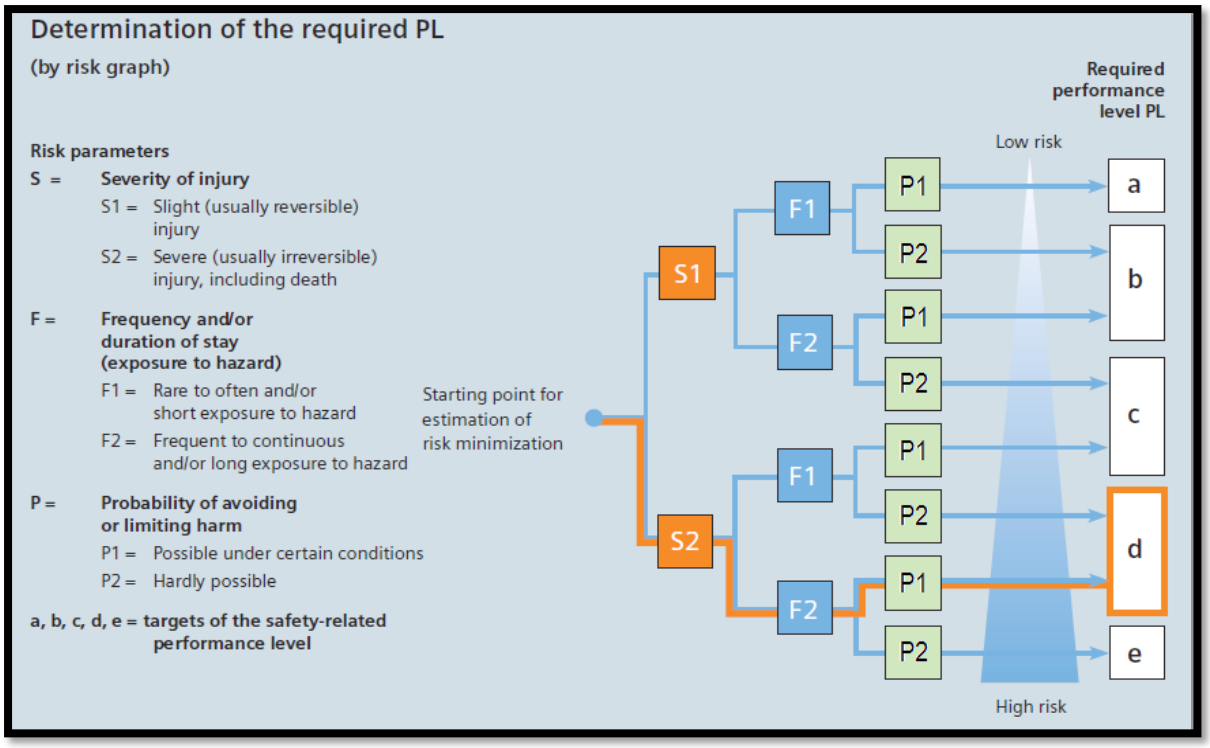


Figure 87. PL Example (Fuchs & Zajicek, 2013)

The machine conforms to safety standards and ISO recommendations by performing PL risk assessment, thus, adhering to PUWER regulations.

Machine integration is implemented into an area allocated by the Industrial Engineering department, with connections to air supply, network, and power supply provided by a Facilities group, enabling full integration into the process.

After machine integration and system setup, the Industrial Engineering and Production Engineering groups conduct an additional risk assessment to ensure compliance with further regulations and PUWER. Although due to the comprehensive PL risk assessment, no extra actions or modifications are necessary. Figures 88 to 93 show the machine integrated into the production process.

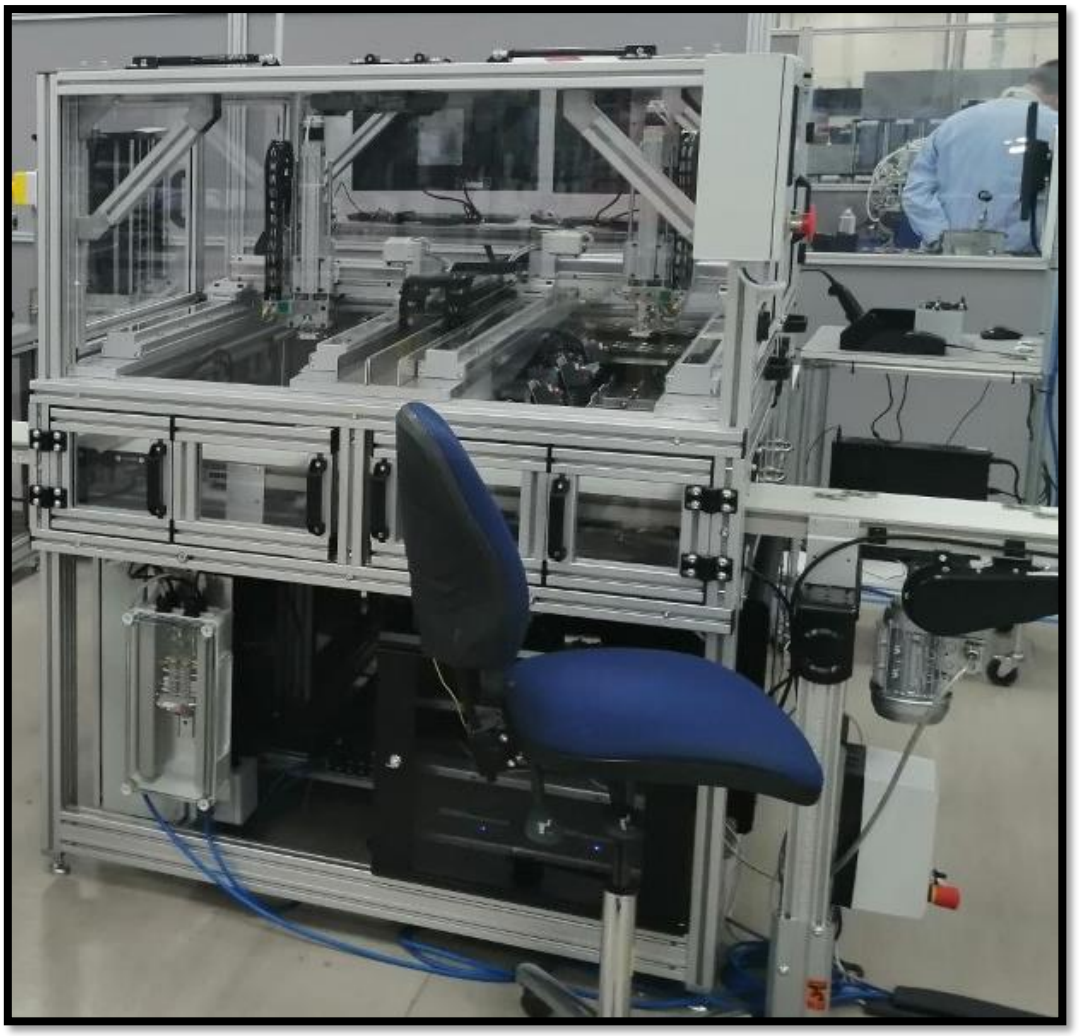


Figure 88. Machine Process Integration



Figure 89. Machine Process Integration - Alternative View



Figure 90. Gantry System – Pallet Picking



Figure 91. Gantry System Placing Product on Test Jigs



Figure 92. Machine Front View – Feeder Systems and Failed Product Conveyor

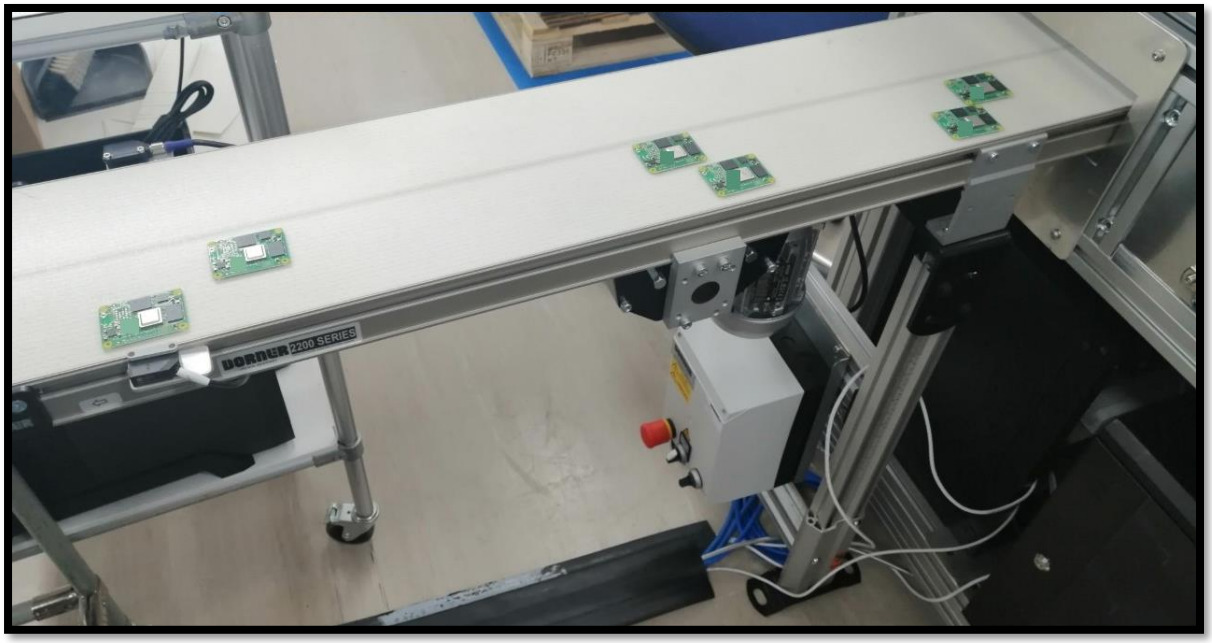


Figure 93. Passed Product Conveyor

5.2. Machine Performance

The machine is required to produce an output of 9,000 boards (Product A) per week, enabling reduced NVA tasks and increased productivity. During initial commissioning, testing and debugging must be performed.

5.2.1. Product Output

Figure 94 displays a dashboard during an early implementation stage, illustrating the machine operating on a day shift from 7 am to 3 pm. The data displayed indicates the total output for that shift for each Test Jig (Head) and the cumulative product output for the entire shift (Total).

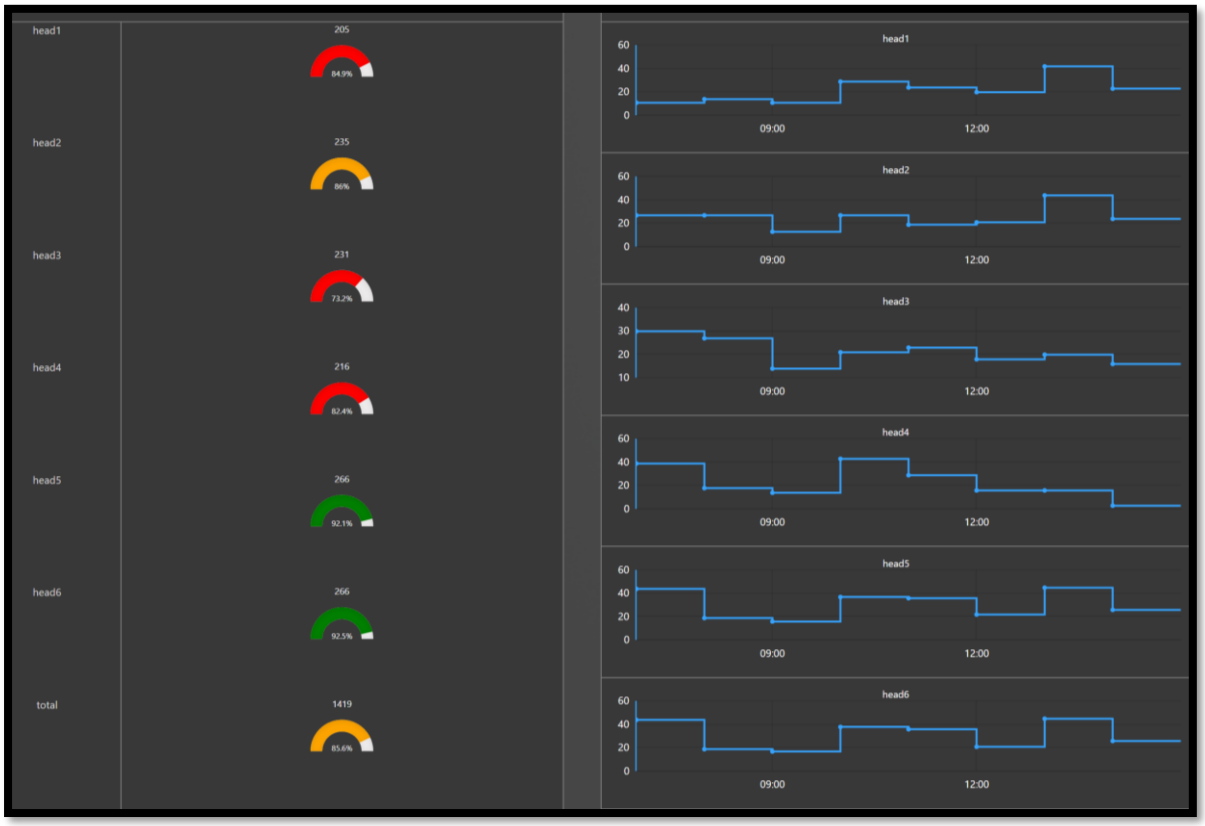


Figure 94. Machine Output Data (Process Integrated)

Figure 94 also displays the percentages for each Test Jig and the total output, representing the First-Time Yield, or the percentage of product A that passed the test on its first attempt. Amber indicators appear when the yield drops below 90%, and red indicators appear below 85%. For example, if ten products were tested and nine passed, and the last one was retested manually and passed, the first-time yield would be 90%. The graph on the right in Figure 94 shows the output through time.

The initial online trial reveals an average first-time yield of 85.6%, with 1,419 boards tested and outputted successfully in a single shift, resulting in approximately 7,095 products passing the test per week. Test Jigs 1 to 3 perform worse than 4 to 6, indicating one of the Gantry systems is underperforming compared to the other.

Figure 95 highlights the reasons for test product failure, with "Boot Check" being the leading cause relating to product placement issues.



5.4%	3.8%	12.6%	0.0%	1.5%	0.4%	A0742262A, 84, BOOT_CHECK,JSON ERROR BUT NO DETAIL
1.0%	0.9%	9.5%	0.0%	0.0%	0.0%	A0742262A, 52, MTB_I2C_TEST,BUS_12_ADDR_48
0.0%	0.0%	0.0%	5.6%	0.0%	0.0%	A0742262A, 82, RPIBOOT_FLASH_EEPROM,USB_OTG_ID_val2
1.5%	1.3%	1.3%	5.1%	0.4%	0.0%	A0742262A, 82, RPIBOOT_FLASH_EEPROM,JSON ERROR BUT NO DETAIL
0.5%	3.8%	0.4%	2.8%	1.9%	1.5%	A0742262A, 62, GPIO_TEST,PIN_6_9
2.4%	0.0%	0.0%	0.0%	0.4%	0.0%	A0742262A, 82, RPIBOOT_FLASH_EEPROM,EXT_RESET_val2
0.5%	0.0%	0.0%	0.0%	0.0%	1.1%	A0742262A, 64, HDMI_PIN_TEST,HDMI_1_TX0
1.0%	0.0%	0.0%	0.9%	0.4%	0.0%	A0742262A, 82, RPIBOOT_FLASH_EEPROM,BT_ON_val2
0.0%	0.0%	0.0%	0.9%	0.0%	0.8%	A0742262A, 74, WIFI_BT_CHECK,JSON ERROR BUT NO DETAIL
0.0%	0.0%	0.9%	0.0%	0.8%	0.8%	A0742262A, 88, STRESS CM4,JSON ERROR BUT NO DETAIL
2.9%	4.3%	2.2%	2.3%	2.6%	3.0%	Other
15.1%	14.0%	26.8%	17.6%	7.9%	7.5%	Summary

Figure 95. Failure Reasons

Repeated tests yield similar results, prompting a Problem Analysis study for the machine using a Cause and Effect (Fish Bone) Diagram (Figure 96) to identify and understand the issues.

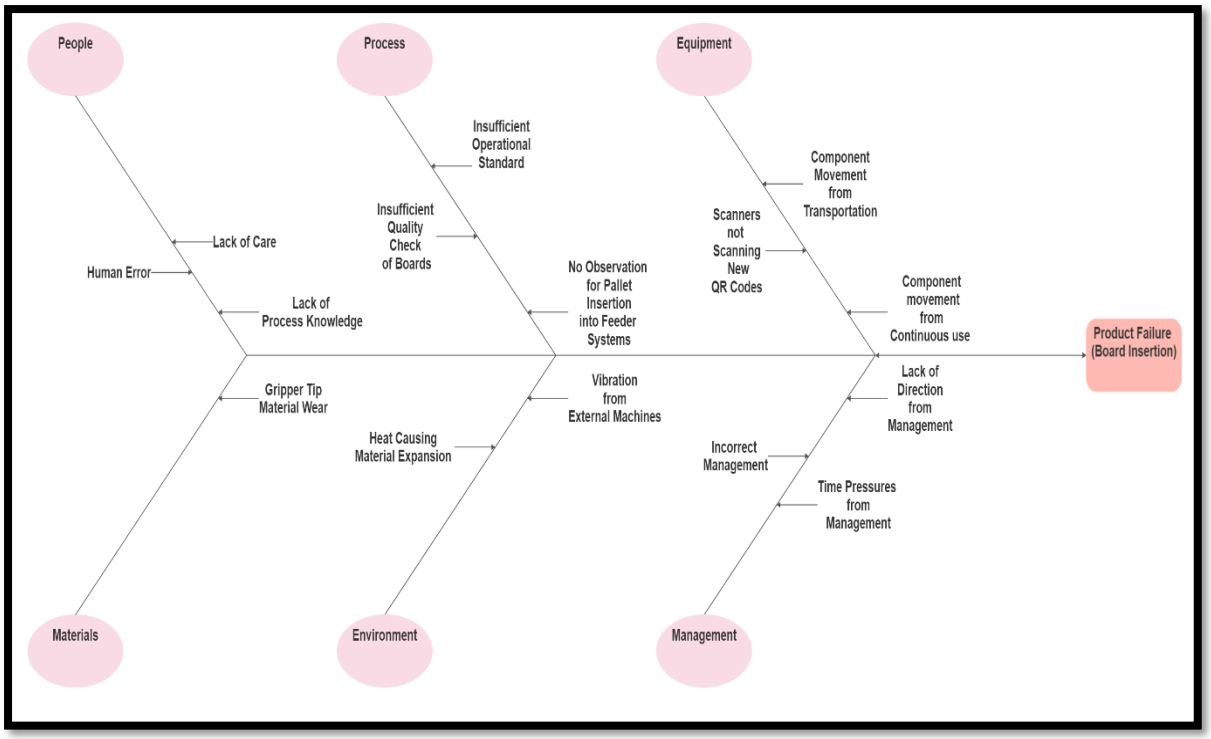


Figure 96. Machine - Cause and Effect Analysis

The analysis reveals multiple causes for incorrect product placement. Notable changes include new operators operating the machine, not the engineers who initially tested it. To address this, comprehensive training is provided to operators and managers. Additionally, Gripper Tips have been switched from PLA to Carbon Fibre Reinforced plastic (CFRP) to minimise wear.

Another cause is the introduction of new QR codes on Product A, transitioning from black and white stickers to etched codes. This change necessitates adjusting the scanners' position on the Gantry to ensure accurate readings.

After implementing these changes, the First-Time Yield significantly improves, with a weekly output of 9,395, as Figure 97 shows.

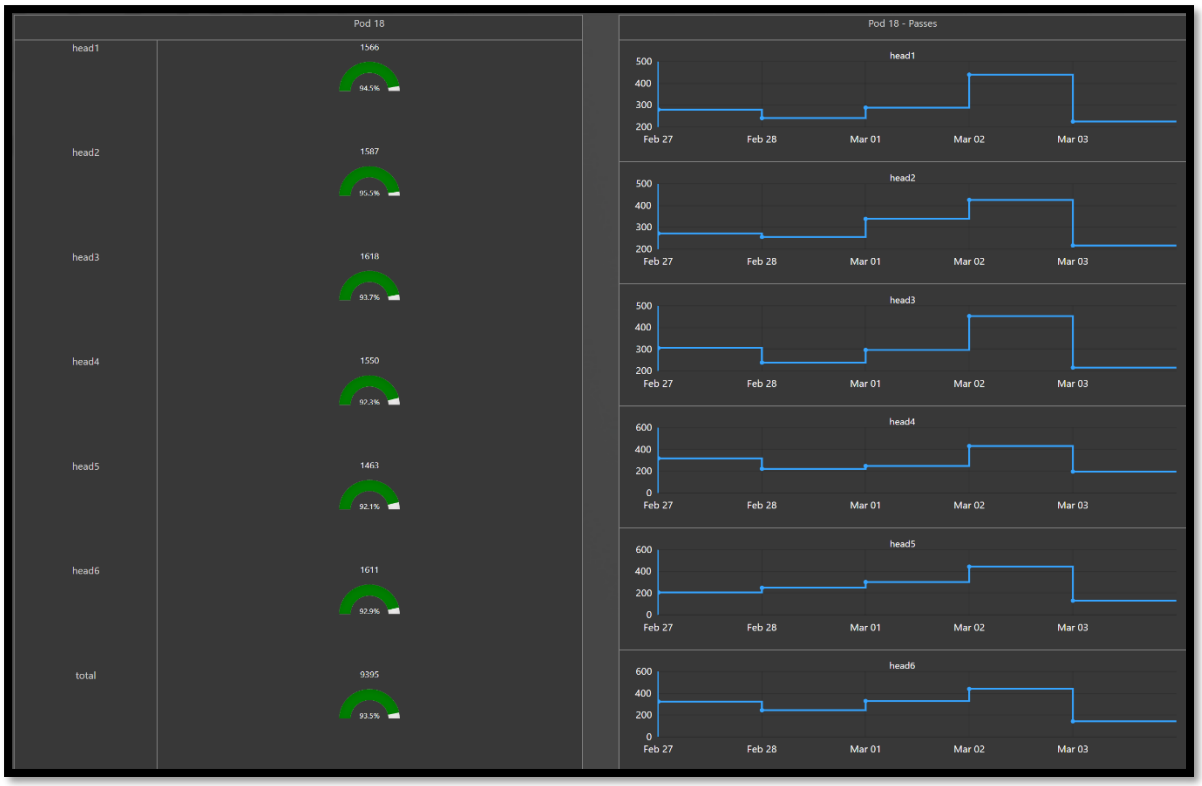


Figure 97. Modified Machine Output Data

5.2.2. Performance

All machines have a set Operational Downtime Efficiency of 85%, factored into calculations that allow for contingencies, with human operators having an Operational Downtime Efficiency of 80%, as Appendix One mentions. The Industrial Engineering Department sets these.

However, Machine Performance and Efficiency are also measured for **"Test Jig Utilisation Time".** When a Test Jig is not being used or is idle with a finished product, **Machine Efficiency** is reduced due to insufficient Gantry pick-and-place speed, leading to underutilised Test Jigs. This is also known as **Motion Inefficiency**. Operators also have this during manual testing, but percentages are out of the project's scope.

The Test Engineering Department's software requires a 50-second testing time per product, serving as an efficiency benchmark. Ideally, at 100% efficiency, the machine would output one board every 50 seconds for every Test Jig. For example, with 100% efficiency, Gantry 1, having three Test Jigs, would output three boards every 50 seconds; however, additional movements and scans before and after testing lower overall Motion Efficiency, thus, Test Jig utilisation time. Table 8 shows calculations for a hypothetical 100% efficient machine.

Table 8. Theoretical Maximum Efficiency

Motion Efficiency	
Pick and Place Time (Seconds)	
Pick from Pallet	0
Board Scan	0
Place in Test Jig	0
Gripper Time and Jig Clearance	0
Sub - Total	**0**
Test Time (Seconds)	
Test Jig Scan	0
Test Time	50
Sub-Total	**50**
Pick and Accept/Reject Time (Seconds)	
Pick from Test Jig	0
Place onto Conveyor	0
Sub-Total	**0**
Total Time Per Jig (Seconds)	50
Total Machine Efficiency (%)	100

With no movement and only test time considered, the total efficiency of Test Jig utilisation (Machine Efficiency or Motion Efficiency) would be 100%. This means the machine could produce one board every 50 seconds for each Test Jig, resulting in the total output displayed in Table 9.

Table 9. Theoretical Maximum Output

	Output Per Week (Maximum)	Machine Efficiency (%)	Actual Output
Gantry 1	8100	100	8100
Gantry 2	8100	100	8100
Total Per Machine	**16200**	**100**	**16200**

With additional pre- and post-test steps, the efficiency is calculated using timings shown in Table 10, obtained from the machine operating within the production process. Table 11 shows the theoretical output based on machine efficiency.

Table 10. Factual Machine Efficiency

Motion Efficiency	
Pick and Place Time (Seconds)	
Pick from Pallet	4
Board Scan	3
Place in Test Jig	4
Gripper Time and Jig Clearance	3
Sub-Total	**14**
Test Time (Seconds)	
Test Jig Scan	2
Test Time	50
Sub-Total	**52**
Pick and Accept/Reject Time (Seconds)	
Pick from Test Jig	4
Place onto Conveyor	4
Sub-Total	**8**
Total Time Per Jig (Seconds)	74
Total Machine Efficiency (%)	67.57

Table 11. Machine Output Estimates Based on Efficiency

	Output Per Week (Maximum)	**Machine Efficiency (%)**	**Actual Output**
Gantry 1	8100	67.57	5472.97
Gantry 2	8100	67.57	5472.97
Total Per Machine	**16200**	**67.57**	**10945.95**

Although machine efficiency is **67.57%,** output requirements in the design specification are met, with a potential of **10,946** tested and outputted products per week. This is slightly different from when initially tested, possibly due to initial testing having perfect conditions, new components, and engineers running the machine.

Additionally, **Operational Downtime Efficiency** must be incorporated into calculations, set at **85%**, which accounts for contingencies such as user interfacing, downtime, maintenance, and actual product failures. Consequently, with 85% of 10,946, the estimated average output is approximately **9,304** boards per week, similar to the recorded results in section 5.2.1.

It can be noted having a double Gantry system results in higher efficiencies compared with a single Gantry system (first design concept) due to reduced movements and steps required per Test Jig.

5.3. Machine Success & Discussion

This section discusses the machine outcome compared to the design brief and specification.

5.3.1. Cost and ROI

The machine meets the design specification requirements by achieving the required weekly output and reducing the need for additional operators. Appendix One outlines the operator requirements and associated costs. The machine requires an operator only for feeding boards, which has minimal time impact. Consequently, only half the operator's time is needed, meaning the operator can also be utilised elsewhere, which further benefits resource allocation.

Due to the vast majority of machine components, a complete cost analysis cannot be shown; however, Table 12 shows an example of some of the components obtained from the machine's BOM whilst showing the total machine cost.

Table 13 shows a simplified version for a clearer understanding with an approximate cost, hence, the slight differences. Therefore, the total cost is approximately £40,000, rounded for easy analysis. This is below the £50,000 budget set within the design specification.

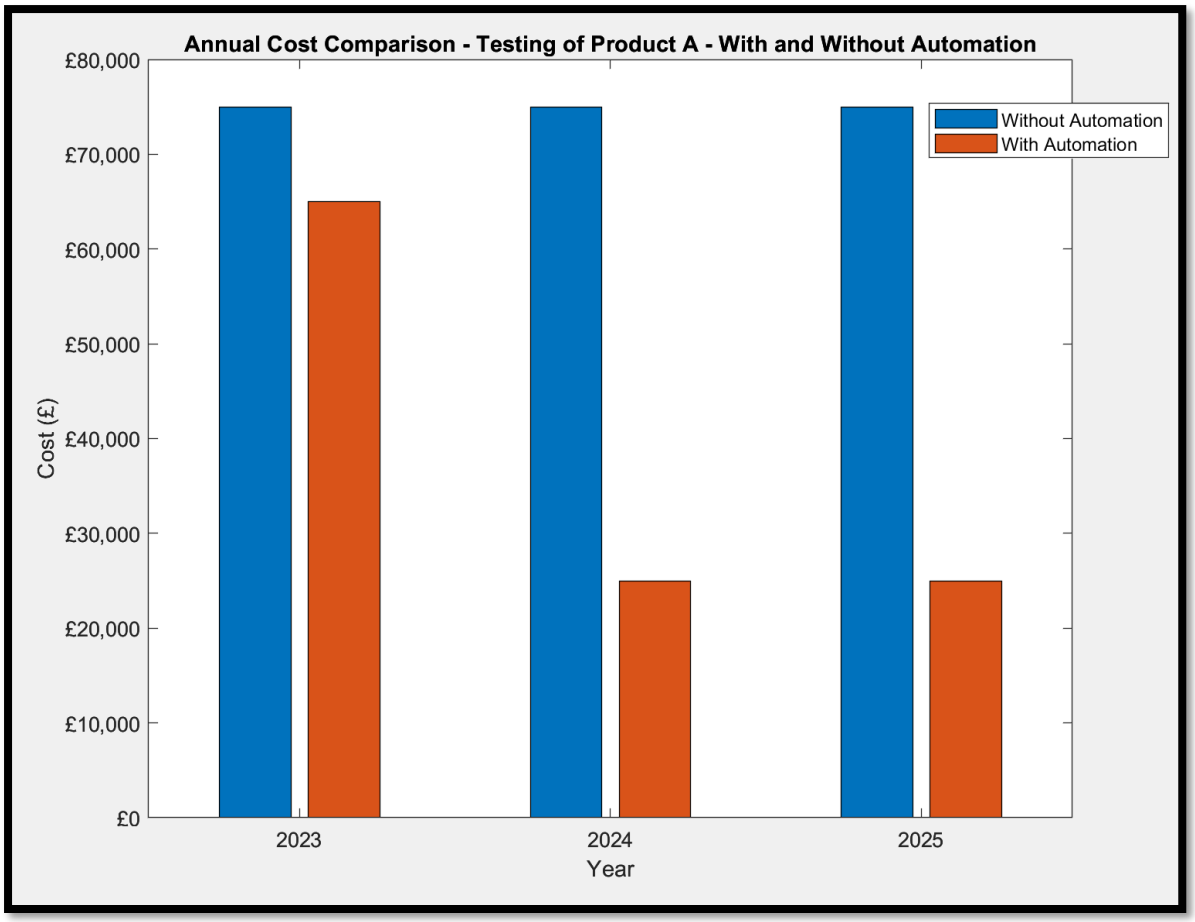
Table 12. Machine Cost Breakdown Example and Total Cost

X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	PLC	(Quote: QCP22-GF5252) - CJ2M-CPU32 - CPU with built-in EtherNet/IP port, 10K steps program, 32K words data memory - FA	1	1.00	1.00	500.00
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatic	AW30-F03-B - Filter regulator unit, 3/8" ported	1	1.00	1.00	30.22
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatic	VHS30-F03A - PRESSURE RELIEF 3 PORT VALVE 3/8"	1	1.00	1.00	17.84
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatic	AN30-03 - SMC AN Resin 1MPa Pneumatic Silencer, Threaded, R 3/8 Male	5	5.00	5.00	31.60
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatic	AV3000-03-5DZ-Q - SMC Pneumatic Soft Start Valve, G 3/8 Female 1 Mpa	1	1.00	1.00	105.27
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatic	AN15-C08 - SMC SY3000 Resin 1MPa Pneumatic Silencer, Tube, 8mm	5	5.00	5.00	15.00
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatic	Y300T-A - Spacer for AC25-A, AC30-A	2	2.00	2.00	6.24
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatic	MSQA3A - Rotary Table	0	2.00	2.00	0.00
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatic	(Quote: QCP21-GF5094) - CDM2B40-25SZ - AIR CYLINDER - FAO: Josh Thorngate	2	2.00	2.00	137.00
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatics	SY100-66-A-30 - 3 m lead for sy solenoid valves	15	15.00	15.00	106.65
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatics	D-A93L - Auto Switch 24vdv	12	12.00	0.00	186.72
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatics	(Quote: QCP21-GF5207) - CDQSB12-10S - Air Cylinder - FAO: Josh Thorngate	6	6.00	6.00	111.48
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatics	SS5Y3-41-15-C6F-Q - 15 station manifold mm push fittings	1	1.00	1.00	81.25
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatics	D-M9PZ - Auto Switch (SM)	4	4.00	4.00	105.84
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatics	SY3140-5LOU-Q - 5/2 solenoid valve 24vdc	15	15.00	15.00	551.10
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatics	CXSM10-75 - Air Cylinder	6	6.00	6.00	895.98
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Pneumatics	MHF2-8D - Low Profile Air Gripper	2	2.00	2.00	589.94
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Sensors	E39-L117 - Mounting bracket for EaT-S' sensor, rear mounting	15	15.00	15.00	50.25
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester	Sensors	E3T-SL232M 2M - Photoelectric sensor, side view, limited to 5 to 30mm, light-ON, PNP, 2m cable (requires m3 screw and brack	15	15.00	15.00	984.90
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Conveyor		XS5F-LM8PVC4S5M - Cable	2	2.00	2.00	12.80
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Conveyor		(Quote: QCP22-GF5364) - E3Z-T86A - Photoelectric Sensor - FAO: Martin Willis	1	1.00	1.00	75.74
X-STK Applied Automation (UK) Limited	21-046/CM4 Link Phase 1 Test	Auto Tester		D-Z73L - Auto-Switch For Cp96 Units	12	12.00	0.00	211.68
							Total Cost (£):	39889.06

Table 13. Simplified Machine Cost Breakdown

Item No.	Component/Part	Quantity	Unit Cost (£)	Total Cost (£)
1	Frame & Mounting Plates	1	2200	2200
2	Feeder System	2	3200	6400
3	Gantry System	2	6000	12000
4	Test Jigs	6	2000	12000
5	Electrical Panel (Power)	1	1000	1000
6	Control Panel (PLC, Drivers)	1	1200	1200
7	Pneumatics	1	1000	1000
8	PCs & Network	1	500	500
9	Pass Conveyor	1	1200	1200
10	Fail Conveyor	1	1000	1000
11	Miscellaneous Components	1	1350	1350
	Total Cost (£)			**39850**

The machine has an ROI within the same financial year, effectively making the machine free for the following years, assuming numbers remain constant. This is because each operator costs approximately £25,000 annually and manually tests approximately 4,320 boards per week. Three operators would be needed to achieve a 9,000-per-week target manually (£75,000 annual cost). Therefore, with an initial investment of £40,000 for the automation machine, the yearly cost is £25,000 due to only one operator required. This is shown in Graph 4; however, this does not consider inflation costs for manual labour.



Graph 4. Compares the Annual Cost of Testing Product A, with and without Automation, for a Single-Shift (One Machine)

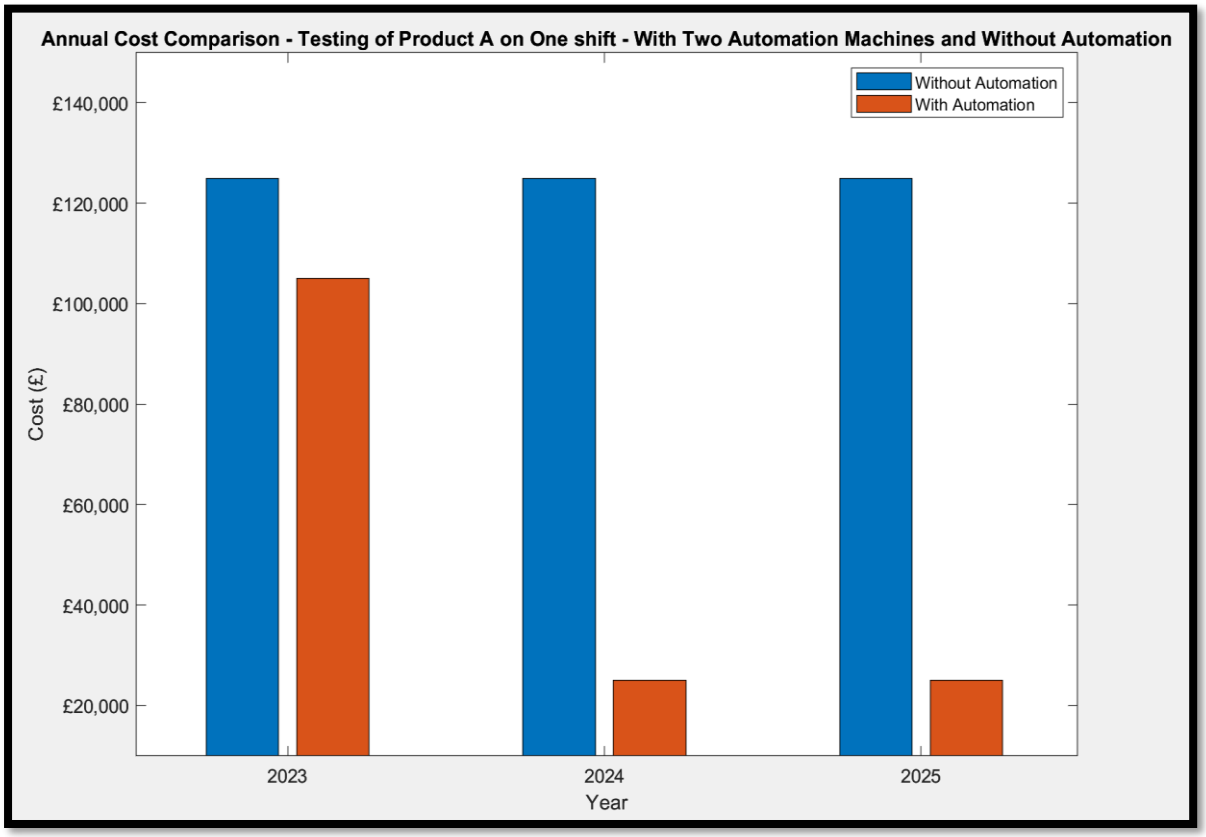
Although additional to this project, thus out of the scope, since starting the project, an increased demand for product A is seen, requiring **18,000** products per week. Therefore, approximately five operators would be needed to produce this target manually, costing £125,000 annually.

One machine can produce approximately **9,304** products per week due to its efficiency. Thus, as shown in Figure 98, two machines have been integrated into the previous process with the original machine, enabling them to produce the required number of products.



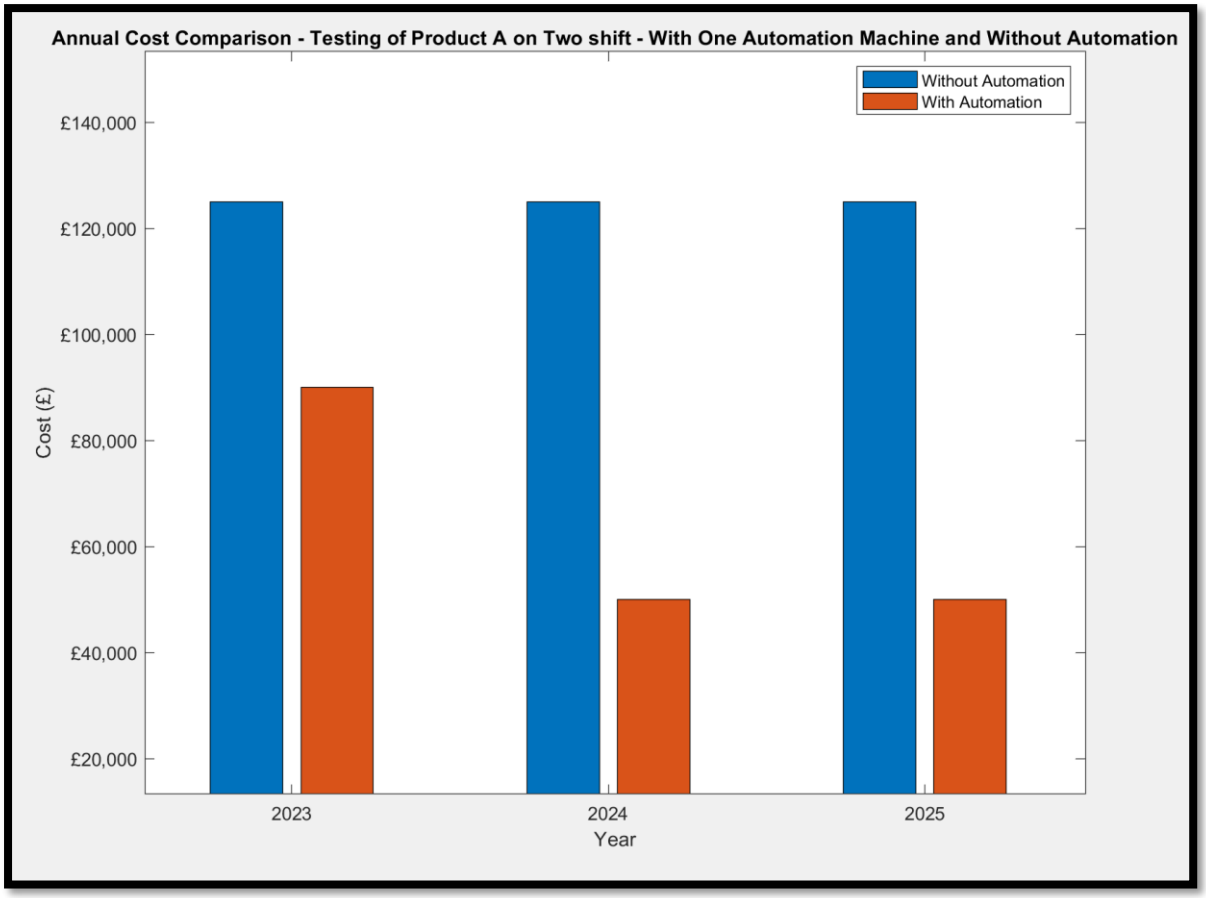
Figure 98. Two integrated machines connected by a throughput conveyor

Therefore, with an **£80,000** initial investment and **£25,000** annually (as one operator can feed both machines due to the low resource requirement mentioned previously), automation achieves the same output as five operators; however, having a first-year saving of £20,000, and year on year saving of £100,000 after that as Graph 5 shows.



Graph 5. Compares Annual Cost of Testing Product A for Increased Product Demand, with and without Automation, for a Single-Shift (Two Machines)

Greater initial savings can be achieved by utilising one machine on a two-shift, as shown in Graph 6, compared with two machines on a single shift (Graph 5); however, even though the operator can utilise half their time elsewhere, the resource cost is allocated for the machine, thus, with one machine on a two-shift, one operator per shift would be required, therefore, costing £50,000 annually, compared with £25,000 annually with two machines, not including shift payment or annual inflation for salaries. Thus, two machines are a better option long term.



Graph 6. Compares the Annual Cost of Testing Product A for Increased Product Demand, with and without Automation, for a Two-Shift (One Machine)

5.3.2. Machine Conformity

Utilising the design brief, the machine meets the project objectives. Section 5.3.1. discusses budget conformity. Table 14 demonstrates how it conforms to the design specification, fulfilling the Design Brief requirements. The machine adheres to size and mass constraints as depicted in Figures 99, 100 and 101.

Table 14. Performance Conformity

Performance	
Specification	**Conformity**
Test and output 9,000 Boards (Product A) per week.	The machine outputs 9,395 boards per week, measured from the production trails, with an average of 9,304 boards per week calculated from the machine's motion timings.
Boards must be transported into and out of the machine.	The machine automatically transports the product into the machine, into the Test Jig, and then out of the machine to its designated area based on its test status.
Boards must be separated between Passed and Failed.	The output systems have two separate Conveyors, onto which a Gantry places the product depending on whether it passes or fails the test. The machine receives data from the network, where the results are uploaded from the Test Jigs.
Boards must not be damaged.	Gripper Tips are made from plastic, ensuring they break under excessive load, whilst the softer material prevents damage to the product.
Boards must be identified for each test.	The scanner at each Test Jig is initiated upon receiving a signal from the Gantry system. It scans the product's QR code to identify it and begin the test.
Boards must be able to be tested within a standard test sequence.	Test Jigs have a test program written by the Test Engineering Group, which is uploaded to the PCs within the machine.
Board loading must be simple for operator use.	Board loading is simple, with board breaking being the same process as the manual test. Furthermore, loading is simple due to the uniform pallet board pocket pattern, with the same orientated boards being placed on both Feeder systems due to the Gantry system rotary actuator. Furthermore, pallet board pocket chamfers allow the boards to be flush, thus, reducing pick errors.
The machine must be able to handle 12 Boards at a time (Board Route Quantity).	Each pallet can hold 12 boards, and each Feeder system can hold three pallets. The machine can, therefore, hold up to 72 boards at a time.
Product A and SIB connectors must have a $\pm 0.05mm$ tolerance for connection.	The Gantry system has a $\pm 0.08mm$ tolerance; however, location pins (tooling posts) on the Test Jigs and Gripper allow tolerances of $\pm 0.25mm$, with the pins having chamfers, ensuring the board is aligned to the $\pm 0.05mm$ tolerance.

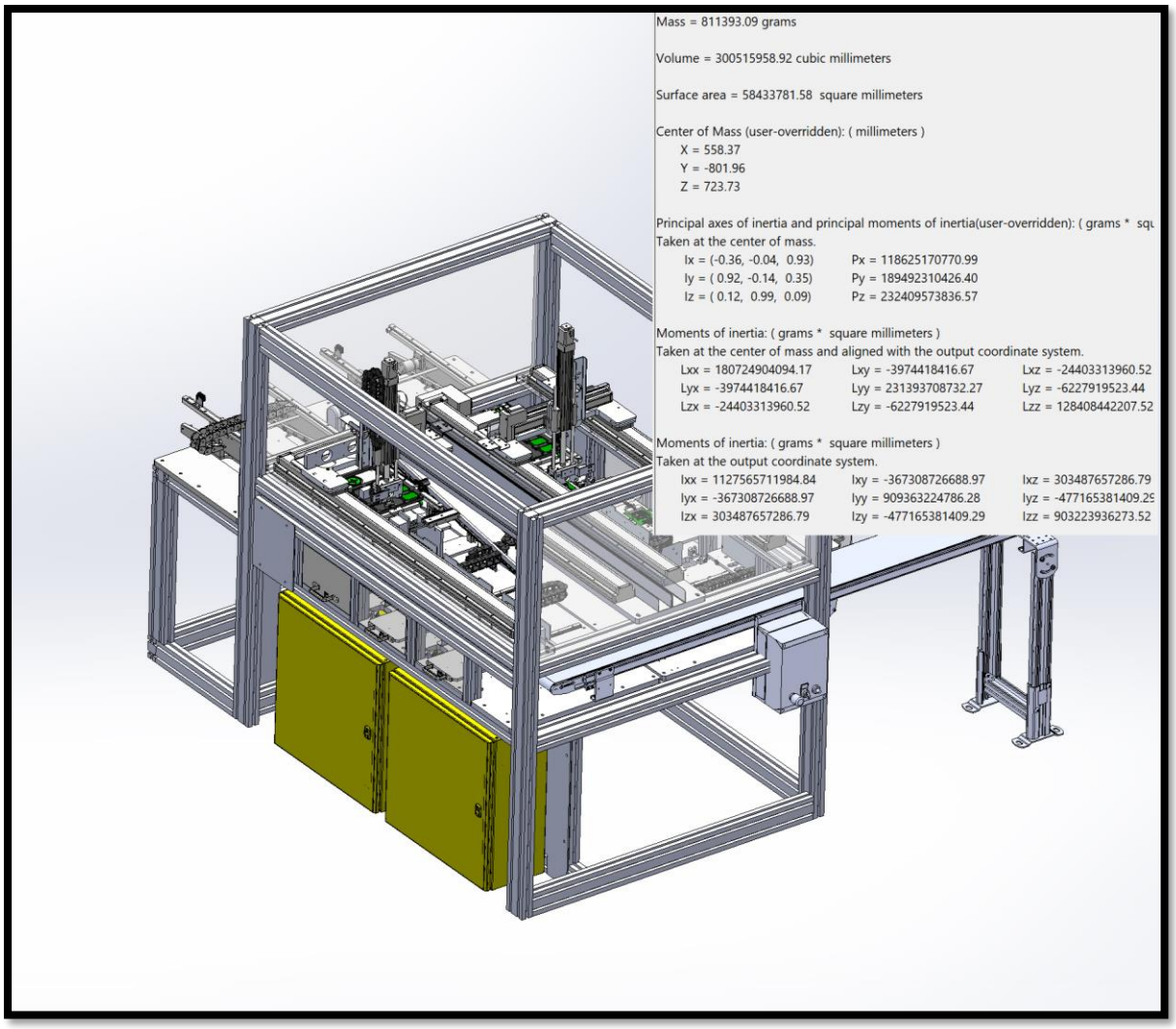


Figure 99. Mass Conformity

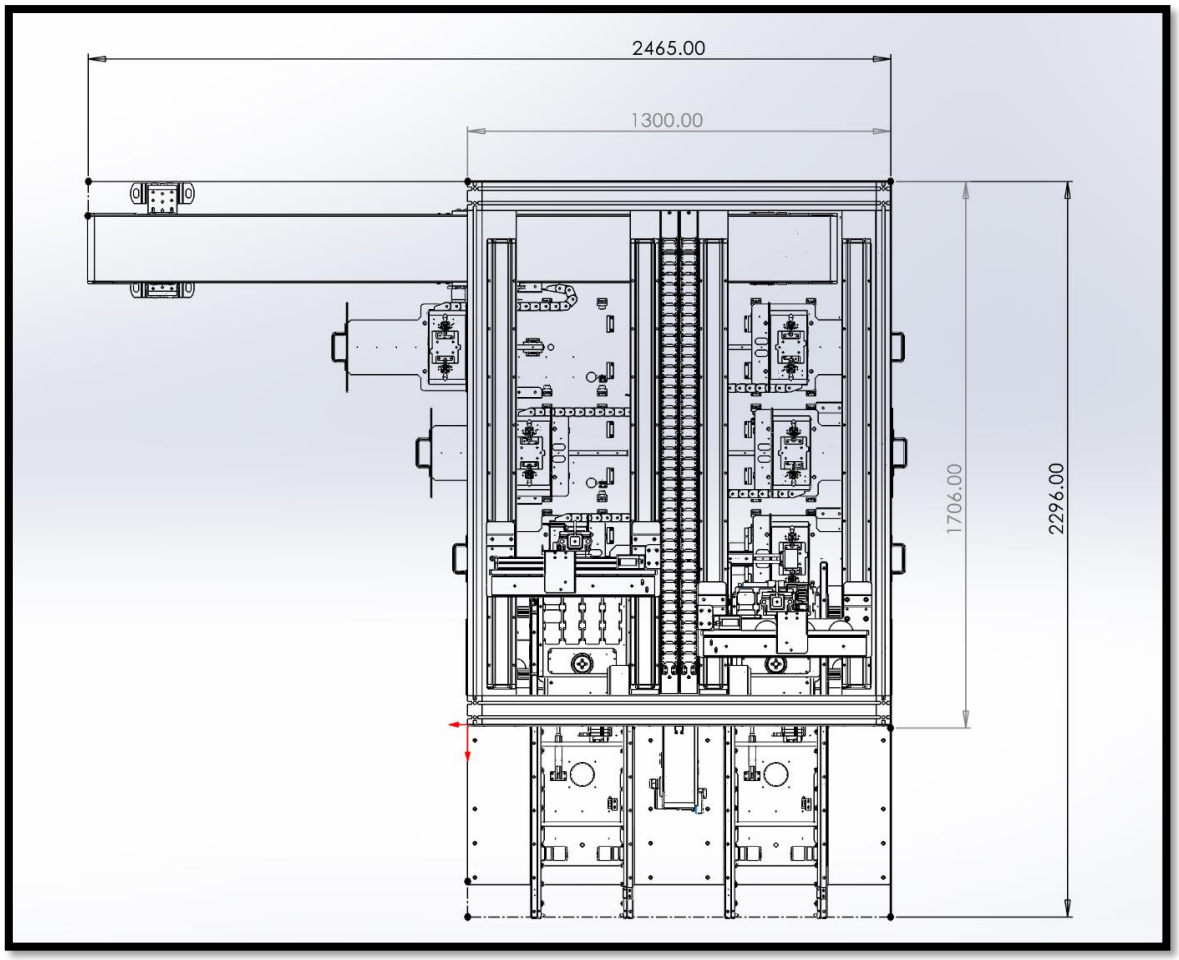


Figure 100. Width & Length Conformity

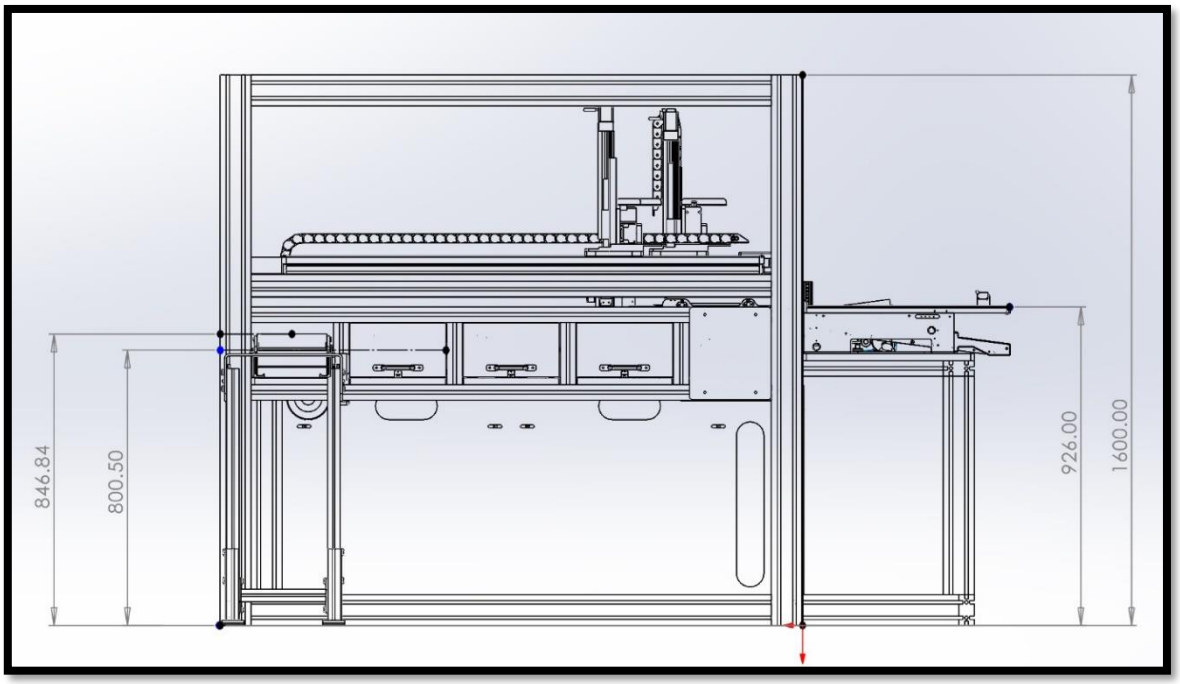


Figure 101. Height Conformities

It also uses standard power and supply, with electrical control and power relying on factory mains, including a maximum of 6 bar air pressure and 230V AC. Table 15 displays the machine's conformity to safety features, while its complete maintenance and lifecycle conformity can be found in Table 16.

Table 15. Machine Safety Conformity

Safety	
Specification	**Conformity**
Provision and Use of Work Equipment Regulations (PUWER) Conformity.	Many safety features allow for PUWER conformity. A PL analysis has led to the machine having interlocks, emergency stops, and guarding to prevent access while operating. Furthermore, all electrical panels have isolation switches, and the pneumatics are regulated to ensure safety pressure. Full machine earthing is carried out with many warning labels attached to the machine to ensure correct operation. As the SIBs require replacement due to lifecycle limits, the Test Jigs are designed on linear rails to ensure quick access for efficient and simplistic maintenance. The sensors provide safety, enabling the machine to lock the Test Jigs into position while the Gantry operates. Human Machine Interface screens allow the Test Jigs to be unlocked when safe, whilst the Gantry is stopped during Test Jigs transit until the Test Jigs are fully extended or retracted, thus, enabling the sensors to trigger the locks once again, therefore, preventing collisions and safety risks.

Table 16. Maintenance and Lifecycle Conformity

Maintenance and Lifecycle	
Specification	**Conformity**
Minimum lifecycle of 11,700 hours.	Due to it being a new bespoke machine, further analysis is required. However, components such as "off-the-shelf" are ensured to have cycles greater than 11,700 hours.
Modular design for easy repair and part replacement.	The machine is designed with various integrated subsystems, allowing easy assembly and maintenance. Conveyors are modular and can be replaced easily. Each Test Jig operates independently, as well as each Feeder system operating independently, with its own Gantry system. All the systems can communicate if a subsystem is taken offline, preventing machine errors whilst continuing process operations.
Easy maintenance access.	The machine is designed with various doors and access points.
SIB replacement and testing equipment maintenance prevent excessive machine downtime.	SIBs are replaced after specified cycles, indicated on a screen. The screen can unlock the Test Jigs individually, and the Test Jigs can slide from the machine, allowing it to continue its operation for the remaining Test Jigs and thus reduce downtime. Furthermore, if the Test Jigs are not fully retracted or extended, the Gantry stops, preventing safety risks and collisions with the Test Jigs. Additionally, downtime is decreased through the redundancy design due to the double Gantry system, preventing total machine downtime, thus, allowing one side to continue operation if required.
Low complexity for easy maintenance.	Simple designs, such as the Gantry systems, are utilised instead of 6-axis Robotic systems. All the subsystems utilise standardised components, such as the Feeder systems using standard motors and electrical and pneumatic components. Furthermore, all subsystems include BSI fasteners for ease of replacement, with all the designs being simplistic, utilising DFA and DFM methods, ensuring ease of manufacture and assembly when required for maintenance. Additionally, off-the-shelf subsystems, such as Conveyor systems, are easily replaceable. All systems have a BOM, which can be utilised for ease of parts replacement with eDrawings and documentation for ease of system understanding.

The measured output and calculated output based on efficiency are similar. However, there are slight differences compared to the calculations in Appendix Four.

An original output time estimate of 66.8 seconds per board per Test Jig is calculated whilst the measured time is approximately 74 seconds, thus, explaining the calculation discrepancy. This may be due to Gantry acceleration, deceleration, additional scanning, and actuator rotaries, which are not initially accounted for. Moreover, if Test Time reduces, the Motion Efficiency will decrease as the Test Jig utilisation time decreases.

5.3.3. Outcome

Therefore, with the machine producing over the maximum required output per week, preventing additional manning, the machine has an annual process saving of approximately £50,000.

During this project, additional requirements are requested, which require an output of 18,000 products per week; although one machine can run on a two-shift, reducing the initial investment, annually, this will cost more, thus, with an additional £40,000 investment, two machines can produce over 18,000 a week with one operator on a single shift, with double the output on a two-shift if required with one operator per shift, thus, £50,000 annually for operator costs.

Therefore, the machine not only conforms to the design specification, thus meeting the Design Brief, but it is also completed under budget and, thus, has an ROI of less than one year. It can be stated that the machine, therefore, the project, is successful.

Machine Efficiency (Motion Efficiency) is **67.57%**; thus, with the additional Operational Downtime Efficiency of 85%, it produces approximately 9,300 weekly. Therefore, although successful, it is very close to the target and would require an additional shift if major maintenance or problems were to occur. Therefore, some future recommendations are discussed in section 6.2.

Chapter Six - Conclusion & Recommendations

6.1. Conclusion

The non-value-added tasks for Product A are successfully decreased due to the outcome of this project. For a 9,000-weekly demand of Product A, the automation system costs £40,000 but saves £50,000 annually after the first year.

With the additional investment of £40,000, an additional machine produces more than 18,000 products per week, saving the company approximately £100,000 annually after the first year compared to a £75,000 annual saving after the first year if one machine on a two-shift was used, with only £15,000 more total investment in the first year (Including operator costs) for two machines, thus, after two years, two machines provide a better return on investment, with the potential to increase output on a two-shift for a further product demand increase.

Consequently, this project promotes business and UK economic growth. Savings enable businesses to cut expenses and compete with nations with lower prices, promoting manufacturing in the UK.

Although some people might be wary of automation, combining design techniques such as Design for Assembly and Modular Designs produces efficient and effective machines. These techniques aid in developing a project that is both cost-effective and regulatory.

By showing the impact of innovation and technology on current operations, this project highlights the value of automation in production and responds to public concerns.

Savings from the project can be used to train and enhance local workers' abilities, which will be necessary for upcoming initiatives. This accomplishment demonstrates how ethical automation benefits both the business and the employees, which may help the UK economy flourish and shape its future.

6.2. Further Design Recommendations

Many recommendations can be made from the design and development of this project. Firstly, Design for Sustainability should be considered. Designing sustainable machines minimises environmental impact, preserves resources, and enhances economic viability. Additionally, eco-conscious clients and investors are attracted to brands with sustainable machines due to positive brand perception. Sustainable design principles can increase equipment lifespan, save money, and reduce waste, contributing to a brighter future.

One sustainable aspect of the machine is its modular design. Modular machines are easier to maintain and repair, increasing longevity and reducing replacement needs. This lowers waste and saves businesses money.

To ensure sustainable designs, future work should also consider the following:

- **Energy Efficiency:** Energy-efficient machines consume less energy and have a smaller carbon footprint, saving money and reducing environmental impact. Standby modes can also be utilised, reducing power consumption when not in use for a specific period of time.

- **Use of Recycled Materials:** Machines designed from recycled materials decrease waste and preserve resources, reducing the need to purchase new raw materials.

- **Recycling-friendly Design:** Machines designed for easy recycling, cut waste and conserve resources, lowering the need for new raw materials elsewhere.

An increase to the machines' 67.57% efficiency can be achieved, which provides more output for a given time whilst also supporting sustainability by reducing energy consumption requirements and increasing the machine's life. Ways to improve machine efficiency for future projects include:

- Scan the entire pallet at the Feeder section instead of a Gantry scan. This can be achieved with a wide-ranged fixed scanner, scanning the whole 12-panel pallet before entering the machine, thus, can be achieved whilst the Gantry is in operation. Utilising calculation methods from section 5.2.2, the efficiency of doing so can increase to approximately **70%**.

- Use a double Gantry in one zone by having one for pre-test pick and place and another for post-test pick and accept/reject within the same footprint. This reduces Motion Inefficiencies as it ensures that a new board is placed immediately after a previous one has been picked. Using methods from section 5.2.2., this can theoretically increase efficiency to approximately **79%**, as movement times are halved.

References

A future that works: Automation, Employment and Productivity (2017) *McKinsey & Company*. McKinsey Global Institute. Available at: https://www.mckinsey.com/featured-insights/digital-disruption/harnessing-automation-for-a-future-that-works (Accessed: February 24, 2023).

ABB (2023) *"YuMi IRB 14000 Dual Arm Collaborative Robot."* Available at: https://search.abb.com/library/Download.aspx?DocumentID=3HAC052982-001&LanguageCode=en&DocumentPartId=&Action=Launch (Accessed: February 19, 2023)

About Us (2023) *Sony Pencoed*. Sony UK Technology Centre. Available at: https://www.sonypencoed.co.uk/about/ (Accessed: February 11, 2023).

Automation and the future of work (2019) House of Commons Business, Energy and Industrial Strategy Committee. UK Parliament.

Automation in manufacturing: A UK perspective (2022) *Innovation remains key for UK manufacturing in Turbulent Times*. Institution of Mechanical Engineers. Available at: https://www.imeche.org/news/news-article/innovation-remains-key-for-uk-manufacturing-in-turbulent-times (Accessed: February 15, 2023).

Automation Systems (2023) *Industrial Quick Search*. Industrial Quick Search. Available at: https://www.iqsdirectory.com/articles/automation-equipment/automation-system.html (Accessed: March 16, 2023).

Benefits of Robots (2023) *RobotWorx*. Available at: https://www.robots.com/articles/benefits-of-robots (Accessed: March 16, 2023).

CNC Machining 101: Get to know CNC Machining Basics (2022) *rapiddirect*. Available at: https://www.rapiddirect.com/blog/cnc-machining-basics/ (Accessed: March 4, 2023).

Cobots (2023) *Unchained Robotics*. Available at: https://unchainedrobotics.de/en/category/robot/cobot (Accessed: April 8, 2023).

Design for safety: Design strategies to generate safe systems (2021) *Leedeo*. Available at: https://www.leedeo.es/l/design-safety-strategies/ (Accessed: February 25, 2023).

Design methods (2022) *Engineering Design*. Available at: https://www.mcgill.ca/engineeringdesign/step-step-design-process/design-methods (Accessed: December 4, 2022).

Durostone® CR permits higher loads and more compact transformer designs (2023) *News Detail | Röchling EN*. Röchling. Available at:

https://www.roechling.com/newsroom/detail/durostoner-cr-s-permits-higher-loads-and-more-compact-transformer-designs#:~:text=Durostone%C2%AE%20CR%20is%20characterised,pressboard%20and%20laminated%20densified%20wood. (Accessed: March 22, 2023).

Fitzgerald, D. and Wilson, C. (2022) *What is an automation engineer and what do they do?*, *GetReskilled*. Available at: https://www.getreskilled.com/what-is-an-automation-engineer/ (Accessed: March 17, 2023).

Fuchs, Pavel & Zajicek, Jaroslav. (2013). *Safety integrity level (SIL) versus full quantitative risk value*. Eksploatacja i Niezawodnosc - Maintenance and Reliability. 15. P.101. Available at: https://www.researchgate.net/figure/The-risk-elements-evaluation-and-PL-requirements-determination-according-to-ISO-13849-1_fig1_291295542 (Accessed: February 23, 2023).

Garolite G10 FR4 machining services: G10 Material Sheets (2023) *AmericanMicroIndustries*. Available at: https://www.americanmicroinc.com/electrical-insulator-materials/g10-fr4/#:~:text=G10%2FFR4%20has%20the%20best,water%20absorption%20and%20dissipation%20factors. (Accessed: March 19, 2023).

Holzer, H.J. (2022) *Understanding the impact of automation on workers, jobs, and wages*, *Brookings*. Brookings. Available at: https://www.brookings.edu/blog/up-front/2022/01/19/understanding-the-impact-of-automation-on-workers-jobs-and-wages/#:~:text=Automation%2C%20jobs%2C%20and%20wages&text=Workers%20who%20can%20work%20with,the%20creation%20of%20new%20jobs. (Accessed: November 26, 2022).

Jones, E.-L. (2022) *A third of workers think their jobs are at risk from automation*, *FE News*. Available at: https://www.fenews.co.uk/work-leadership/a-third-of-workers-think-their-jobs-are-at-risk-from-automation/ (Accessed: November 26, 2022).

Kleinman, M. *et al.* (2019) “Innovation and public attitudes in Britain: Challenges for policy-makers,” *Responding to the fourth industrial revolution*, pp. 1–12.

Kumar, P. (2019) *Value Added and Non-Value Added Activities in Lean*, *AIG*. Available at: https://www.advanceinnovationgroup.com/blog/value-added-and-non-value-added-activities-in-lean/ (Accessed: April 8, 2023).

Laser cutting: How it works (2023) *Trotec Laser* . Available at: https://www.troteclaser.com/en-gb/learn-support/faqs/how-to-laser-cut (Accessed: March 26, 2023).

Lasser, R. (2023) *Engineering method*, *Electrical and Computer Engineering Design Handbook*. Available at: https://sites.tufts.edu/eeseniordesignhandbook/2013/engineering-method/ (Accessed: March 17, 2023).

Learn about DXF files (2023) *Adobe* . Available at: https://www.adobe.com/creativecloud/file-types/image/vector/dxf-file.html (Accessed: March 26, 2023).

Mallon, S. (2022) *7 Jobs Humans Can Do Better Than Robots And AI*, *SmartData Collective*. Available at: https://www.smartdatacollective.com/7-jobs-humans-can-do-better-than-robots-and-ai/ (Accessed: March 16, 2023).

Manufacturing by Country (2022) *World Population Review*. Available at: https://worldpopulationreview.com/country-rankings/manufacturing-by-country (Accessed: November 27, 2022).

Manyika, J. *et al.* (2019) *Jobs Lost, jobs gained: What the future of work will mean for jobs, skills, and wages*, *McKinsey & Company*. Available at: https://www.mckinsey.com/featured-insights/future-of-work/jobs-lost-jobs-gained-what-the-future-of-work-will-mean-for-jobs-skills-and-wages (Accessed: February 23, 2023).

Product Design Engineering Method (2023) *Adept Engineering*. Available at: https://adeptengineering.com/engineering-method-2/ (Accessed: February 25, 2023).

Products (2023) *SMC*. Available at: https://www.smc.eu/en-eu/products (Accessed: March 20, 2023).

Pugh, S., 1990. *Total design*. 1st ed. Essex: Addison-Wesley, pp.136-141.

Robotics and Automation: A New Perspective (2022) *MTC - Manufacturing Technology Centre* MTC - Manufacturing Technology Centre. Available at: https://the-mtc.org/media/vevauetq/automation-and-robotics-research-paper-a4-pages.pdf (Accessed: February 24, 2023).

Romanov, V. (2022) *PLC programming: How to read ladder logic*, *SolisPLC*. Available at: https://www.solisplc.com/tutorials/how-to-read-ladder-logic (Accessed: March 8, 2023).

Smith, K.A. (2000) “Engineering Design: A Project-Based Introduction,” *Journal of engineering education*, 89, p. 105.

UK Digital Manufacturing Advice & Innovation (2023) *Made Smarter*. Available at: https://www.madesmarter.uk/ (Accessed: February 23, 2023).

UK remains in the top ten of largest manufacturing countries (2022) Make UK. Available at: https://www.makeuk.org/insights/publications/uk-manufacturing-the-facts--2022#/world-rankings (Accessed: November 27, 2022).

UKCA marking information (2023) *Conformance*. Available at: https://www.conformance.co.uk/ukca/ukca-mark-information-advice (Accessed: March 26, 2023).

UR5 technical specifications item no. 110105 - Universal robots (2023) *universal-robots*. universal-robots. Available at: https://www.universal-robots.com/media/50588/ur5_en.pdf (Accessed: February 19, 2023).

Velling, A. (2021) *Design for X (DFX): 10 approaches of DFX explained*, *Fractory*. Available at: https://fractory.com/design-for-x-dfx/ (Accessed: February 25, 2023).

Wang, R. *et al.* (2006) "Database for biomechanical engineering design," in *Biomechanical engineering of textiles and clothing*. Cambridge: Woodhead Pub., p. 257.

Webster, K. (2015) EPT 221 Engineering Design [PowerPoint presentation] *Introduction to Engineering Design.* Available at: https://slideplayer.com/slide/7569860/ (Accessed: November 20, 2022).

Westrom, D. (2022) *The growing use of automation in manufacturing*, *The Growing Use of Automation in Manufacturing*. MachineMetrics. Available at: https://www.machinemetrics.com/blog/automation-in-manufacturing (Accessed: February 23, 2023).

What are gantry robots? (2023) *RobotWorx*. Available at: https://www.robots.com/faq/what-are-gantry-robots (Accessed: February 19, 2023).

What are printed circuit boards made of? (2022) *ABL Circuits*. Available at: https://www.ablcircuits.co.uk/blog/what-are-printed-circuit-boards-made-of/ (Accessed: March 5, 2023).

What is 3D printing? - technology definition and types (2023) *TWI Global* . Available at: https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing (Accessed: March 26, 2023).

What is Collaborative Robot (Cobot)? (2023) *Techopedia.com*. Available at: https://www.techopedia.com/definition/14298/collaborative-robot-cobot (Accessed: February 19, 2023).

Will robots really steal our jobs? - An international analysis of the potential long term impact of automation (2018) *PwC*. PwC. Available at: https://www.pwc.com/hu/hu/kiadvanyok/assets/pdf/impact_of_automation_on_jobs.pdf (Accessed: February 24, 2023).

Yu Siang, T., n.d. *What Is Design Thinking?*. [online] The Interaction Design Foundation. Available at: <https://www.interaction-design.org/literature/topics/design-thinking> [Accessed 15 March 2020].

Zhang, Y., Fan, G. and Whalley, J. (2015) “Economic cycles in ancient China,” *NATIONAL BUREAU OF ECONOMIC RESEARCH*, pp. 3–22. Available at: https://doi.org/10.3386/w21672 (Accessed: February 23, 2023).

Figure References

Figure 2 - Lasser, R. (2023) *Engineering method*, *Electrical and Computer Engineering Design Handbook*. Available at: https://sites.tufts.edu/eeseniordesignhandbook/2013/engineering-method/ (Accessed: March 17, 2023).

Figure 3 - Wang, R. *et al.* (2006) "Database for biomechanical engineering design," in *Biomechanical engineering of textiles and clothing*. Cambridge: Woodhead Pub.

Figure 4 - Yu Siang, T., (2023). *Proposed Five-Stage Design Thinking Model: A Non-Linear Process. Research Gate.* Available at: <https://www.researchgate.net/figure/Proposed-five-stage-design-thinking-model-A-non-linear-process-Teo-Yu-Siang-and-the_fig1_335625850> (Accessed: March 17, 2023).

Figure 5 - *Continuously Improving Manufacturing. (2018*) *Six Sigma DMAIC 5-Step Process*. Available at: <https://leanmanufacturing.online/six-sigma-dmaic-5-step-process/> (Accessed: March 17, 2023).

Figure 6 - *Product Design Engineering Method* (2023) *Adept Engineering*. Available at: https://adeptengineering.com/engineering-method-2/ (Accessed: February 25, 2023).

Products (2023) *SMC*. Available at: https://www.smc.eu/en-eu/products (Accessed: March 20, 2023).

Figure 12 - *ABB's collaborative robot -yumi* (2023) *Robotics*. ABB. Available at: https://new.abb.com/products/robotics/industrial-robots/irb-14000-yumi (Accessed: April 15, 2023).

Figure 13 - *Collaborative robots from UR: Start your automation journey* (2023) *Universal Robots*. Available at: https://www.universal-robots.com/products/ (Accessed: April 15, 2023).

Figure 14 - Tertünte , J. and Endrijaitis, L. (2014) *Switching from robot systems to Cartesian Handling Systems*, *Linear Motion Tips*. Available at: https://www.linearmotiontips.com/switching-robot-systems-cartesian-handling-systems (Accessed: April 15, 2023).

Figure 27 - *45 x 45 2N aluminium profile* (2023) *KJN Aluminium Profile*. Available at: https://www.aluminium-profile.co.uk/45x45l-2n-aluminium-profile-kjn992403 (Accessed: April 15, 2023).

Figure 87 - Fuchs, Pavel & Zajicek, Jaroslav. (2013). *Safety integrity level (SIL) versus full quantitative risk value*. Eksploatacja i Niezawodnosc - Maintenance and Reliability. Available

at: https://www.researchgate.net/figure/The-risk-elements-evaluation-and-PL-requirements-determination-according-to-ISO-13849-1_fig1_291295542 (Accessed: February 23, 2023).

Graph References

Graph 1 - Kleinman, M. *et al.* (2019) “Innovation and public attitudes in Britain: Challenges for policy-makers,” *Responding to the fourth industrial revolution.*

Graph 2 - *UK remains in the top ten of largest manufacturing countries* (2022) Make UK. Available at: https://www.makeuk.org/insights/publications/uk-manufacturing-the-facts--2022#/world-rankings (Accessed: November 27, 2022).

Graph 3 - Crew, B. (2014) *New Metal Alloy has the highest strength-to-weight ratio of any metal*, *ScienceAlert*. Available at: https://www.sciencealert.com/new-metal-alloy-has-highest-strength-to-weight-ratio-of-any-metal (Accessed: April 15, 2023).

Appendix One – Design Brief

Product “A” is a small Electronic Circuit Board (single-board computer or microcontroller) for consumer use, which has dimensions of $55mm\ length \times 40mm\ width \times 4.7mm\ thickness$. A machine must be able to fully automate the testing of the product, increasing the output per operator, which mitigates the NVA tasks by producing more boards per week per operator.

Currently, one operator has three testing stations where product testing occurs. Prior to this, the boards are stacked in hoppers holding multiple 12-panel boards. Therefore, the operator first breaks the 12-panel, placing the 12 separated products in a waiting area.

Connectors are then attached to counter-part connectors on the product to be tested, located underside, slightly offset from the centre. The board is then scanned to begin the test, which takes 50 seconds. Once the test is finished, the board is taken from the test area and placed in a packing area. The entire process can take approximately 75 seconds per board, per station per operator. Therefore, this can produce around 0.8 boards every minute for every station. Thus, with three stations, 2.4 boards per minute.

This equates to approximately 5,400 boards per operator, week, and shift (37.5 hours per shift). However, due to human error, retest work, and additional circumstances such as talking or toilet breaks, an 80% calculation is factored in, known as Operation Downtime Efficiency; thus, an operator can produce approximately 4,320 boards per week.

The production output, however, is increasing with a requirement of 9,000 boards per week from March 2023; thus, to achieve this, more operators are required, therefore, requiring three operators to achieve this target, as increasing the number of stations per operator can cause more human error, thus, more operators are needed. The cost of one operator is approximately £25,000 annually.

Therefore, to achieve 9,000 a week maximum, three operators will be required in total, as only having two operators produce a slight shortfall from the target. Therefore, an automated machine must be able to test and output 9,000 boards per week whilst reducing operator resources. The project budget has been set for £50,000.

The machine must last for at least three years. The machine must be safe around operators and user-friendly. The area the machine is being placed into has a footprint area of approximately 5m by 5m. The tested boards must be transported to a rework area if they fail testing and sent to the packing area if they pass.

Appendix Two – Design Specification

A design specification is generated from the design brief. However, some points in the specification are not taken from the brief and added due to Sony UK Technology Centre Design standards, such as Power Supply, maximum heights of machine for door height clearances, safety standards, maximum weights for transportation, and lifecycle, based on a two-shift pattern operating over three years. Furthermore, additional details are obtained from within the company for this specification.

Therefore, the design specification is as follows:

1.0. Performance

1.1. Test and output 9,000 Boards per week
1.2. Boards must be transported into and out of the machine
1.3. Boards must be separated between Passed and Failed
1.4. Boards must not be damaged
1.5. Boards must be identified for each test
1.6. Boards must be able to be tested within a standard test sequence
1.7. Board loading must be simple for operator use
1.8. The machine must be able to handle 12 Boards at a time (Board Route Quantity)
1.9. Product A and SIB connectors must have a $\pm$0.05mm tolerance for connection

2.0. Size and Weight

2.1. Maximum Dimension: 4,500mm (Width)
2.2. Maximum Dimension: 4,500mm (Depth)
2.3. Maximum Dimension: 1,981mm (Height)
2.4. Maximum Weight: 1,000kg
2.5. Optimal Board Input Station Height: 900mm $(\pm 150\mathrm{mm})$

3.0. Power and Supply

3.1. Operate with the factory air supply of 6 bar (87.0226 PSI)
3.2. Operate with factory power supply (230V AC)

4.0. Safety

4.1. Conform to the Provision and Use of Work Equipment Regulations (PUWER)

5.0. Maintenance and Lifecycle

5.1. Minimum lifecycle of 11,700 hours (Three years on a two-shift)
5.2. Modular design for easy repair and part replacement
5.3. Easy maintenance access

5.4. SIB replacement and testing equipment maintenance prevent excessive machine downtime

5.5. Low complexity for easy maintenance

6.0. Budget and Cost

6.1. Return on Investment within one year (£50,000 budget)

Appendix Three – ISO Standards

Note: New standards may have superseded some of these standards.

ISO Standards	Description
BS EN ISO 12100:2010	Safety of machinery - General principles for design - Risk assessment and risk reduction
BS EN ISO 13849-1:2015	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design
ISO 13850:2015	Safety of machinery - Emergency stop - Principles for design
ISO 14119:2013	Safety of machinery - Interlocking devices associated with guards - Principles for design and selection
ISO 16092-1:2017	Machine tools - Safety - Machining centres - Part 1: Safety requirements for machine tools
ISO 20607:2019	Safety of machinery - Instruction handbook - General drafting principles and detailed requirements
BS EN ISO 14121-1:2007	Safety of machinery. Risk assessment. Principles
BS EN 614-1:2006	Safety of machinery. Ergonomic design principles. Part 1: Terminology and general principles
BS EN 953:1997	Safety of machinery. Guards. General requirements for the design and construction of fixed and movable guards
BS EN 999:1998	Safety of machinery. The positioning of protective equipment in respect of approach speeds of parts of the human body
BS EN 1037:1995	Safety of machinery. Prevention of unexpected start-up
BS EN 60204-1:2018	Safety of machinery. Electrical equipment of machines. General requirements

Standards (2021) *ISO*. Available at: https://www.iso.org/standards.html (Accessed: 12 January 2023).

Appendix Four – Output Requirements

To calculate the output of the machine and, thus, the number of Test Jigs required per Gantry (Cartesian) system, the following variables are needed:

- Test Cycle Time (Test Jig Time) – 50 Seconds
- Maximum Actuator Speeds – 500mm/s
- Maximum "Y-Axis" Distance – 1.2m
- Maximum "X-Axis" Distance – 300mm
- Maximum "Z-Axis" Distance – 200mm

Therefore, these variables can be used to determine the time it takes for the Gantry system to Pick and Place Product A from the input onto the Test Jigs and then to the output.

Maximum distances are used for a safety factor, although actual times may differ due to programming and sequencing. For example, some Test Jigs will be closer to the input, while others will be closer to the output. Therefore, utilising worst-case distances ensures discrepancies are offset. Using this method allows for a worst-case scenario time, determining Product A output per minute, thus, determining the number of Test Jigs required to meet production demands.

Picking products from the front of the machine and placing them at the rear of the machine will accumulate a distance within the horizontal plane of 2.4m in the "Y" direction for pre-test placement, with an additional 2.4m with post-test output placement and 600mm in the "X" direction for pre-test placement with an additional 600mm for post-test placement (Double actuator lengths).

Although cartesian systems can move both actuators simultaneously; thus, only the longest distance will be utilised; therefore, the following equation will be used:

$$T_y = d_y / v_y$$

$$T_y = 4.8 / 0.5$$

$$\boldsymbol{T_y = 9.6s}$$

Whereby:

$$T_y = Time\ in\ the\ Y\ direction\ [Seconds]$$

$$d_y = Y\ Direction\ Distance\ [Metres]$$

$$v_y = Y\ Axis\ actuator\ Speed\ [m/s]$$

The Z-Axis has a 200mm stroke, which will require a total accumulated movement per board of 1.6m (400mm for the pre-test pick, 400mm for the placement, 400mm for the post-test pick, and 400mm for the output placement. This could be run simultaneously with the other actuators, which may cause placement issues; thus, assuming the horizontal plate actuators are stationary, this actuator will travel a total distance of 1.6m. Therefore, utilising the following equation:

$$T_z = d_z / v_z$$

$$T_z = 1.6 / 0.5$$

$$\boldsymbol{T_z = 3.2s}$$

Whereby:

$$T_z = Time\ in\ the\ Z\ direction\ [Seconds]$$

$$d_z = Z\ Direction\ Distance\ [Metres]$$

$$v_z = Z\ Axis\ actuator\ Speed\ [m/s]$$

The Gripper stroke distance is minimal, only taking approximately 0.5 seconds to operate fully per stroke; thus, with four operations per board for picking, placing, and sorting, this would mean a 2-second additional time,

Each Test Jig also has a scan to initiate the test, which may take up to 2 seconds; therefore, a calculation for total time for a product per Test Jig can be calculated:

$$T_t = T_j + T_y + T_z + T_s + T_g$$

$$T_t = 50 + 9.6 + 3.2 + 2 + 2$$

$$\boldsymbol{T_t = 66.8s}$$

Whereby:

$$T_t = Total\ Time\ [Seconds]$$

$$T_s = Scan\ Time\ [Seconds]$$

$$T_g = Gripper\ Time\ [Seconds]$$

$$T_j = Test\ Jig\ Time\ [Seconds]$$

Therefore, to calculate the boards per minute per Test Jig:

$$B_m = 60 / T_t$$

$$B_m = 60/66.8$$

$$\boldsymbol{B_m = 0.898\ (Three\ Decimal\ Places)}$$

Therefore with 0.898 Boards Per Minute (B_m), one can calculate how many products are produced per week, per shift (37.5 hours) with one Test Jig Per Gantry.

$$Output = \ 0.898 \cdot 60 \cdot 37.5$$

$$\therefore Ouput = 2020.5$$

Therefore, with two Gantry Systems within the machine:

$$Ouput = 2020.5 \cdot 2$$

$$\boldsymbol{\therefore Ouput = 4041}$$

This is with one Test Jig per Gantry system; thus, as two Gantry systems are used, the output shown is for two Test Jigs.

Therefore, the number of Test Jigs can be calculated based on the output per minute per Test Jig. Again, this does not account for line balancing and sequencing methods. Therefore, to ensure 9,000 boards are achieved within 37.5 hours, calculations using the B_m are used as follows:

$$N_j = 9000/37.5/60/0.898$$

$$\boldsymbol{N_j = 4.45\ (Two\ Decimal\ Place)}$$

Whereby:

$$N_j = Number\ of\ Jigs$$

Therefore, utilising B_m, the total number of Test Jigs required is 5 Test Jigs. However, every Test Jig which is added per Gantry reduces the machine's efficiency due to the Gantry becoming the bottleneck when the test is finished, as the movement inefficiencies may increase Test Jig waiting time; thus, the reason for a double Gantry system is to reduce **Motion Inefficiency**, thus, increasing machine efficiency. Additionally, **Operational Downtime Efficiency** accounts for various factors, such as maintenance, a set standard at Sony UK Technology Centre of 85%. Therefore, to account for this, allowing for contingencies:

$$B_m = 0.898 \cdot 0.85$$

$$\boldsymbol{\therefore B_m = 0.76\ (Two\ Decimal\ Places)}$$

$$\therefore N_j = 9000/37.5/60/0.76$$

$$\boldsymbol{N_j = 5.26\ (Two\ Decimal\ Places)}$$

Therefore, a total of 6 Test Jigs are required. As this ensures it accounts for Operational Downtime Efficiency and rounding done in the calculations, thus, allowing for redundancy to ensure 9,000 boards can be tested per week; therefore, 3 Test Jigs per Gantry system are required.

Appendix Five – Machine Operation

This appendix explains the machine and its operation and maintenance. The figures in this section show the documents taken from Sony UK Technology Centre, used not only for the operation, thus for the Production team, but also maintenance used by the Production Engineering team. Furthermore, as the following documents are taken from Sony UK Technology Centre, errors may be shown, although they are kept for authenticity.

Appendix 5.1. Machine Overview

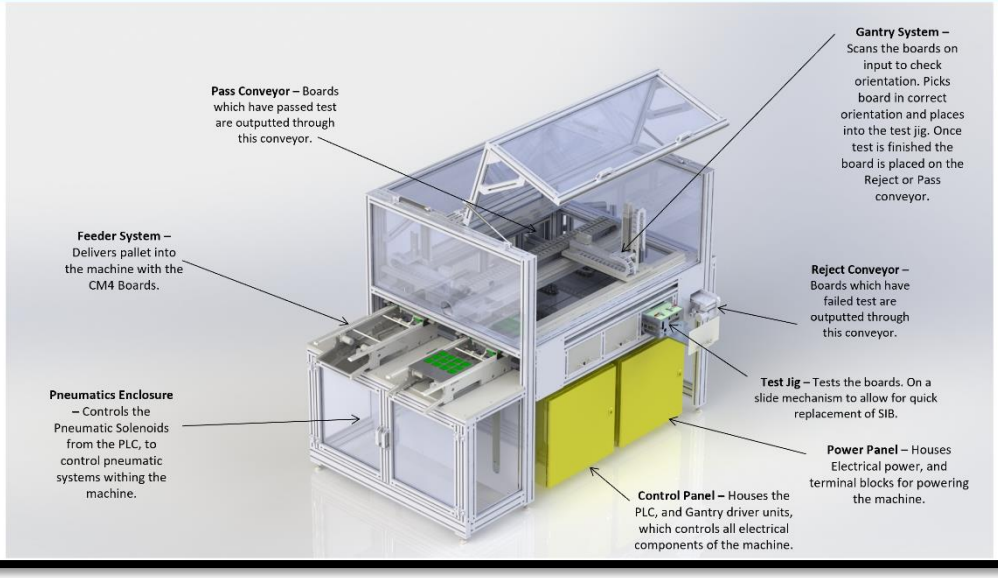
1.0. Product "A" Machine Overview

The Automation Machine must ONLY be used for its' intended purpose. Using or modifying the machine in anyway without the consent of the Equipment Development/Engineering team may result in machine failure, health and safety concerns or product damage.

The machine is utilised for the automation of testing the product. Each side can be treated as its' own machine, although safety features ensure both sides are treated as one.
The sequence of events are as follows:

- Boards are placed into the pallet in the correct orientation (Shown on the next slide).
- Once all 12 boards are loaded into the pallet, the pallet is placed onto the presenter system, of which a sensor moves the pallet into a waiting position.
- If the machine is empty (No pallet at the end of the presenter system the motors drive the belt, ensuring the pallet moves to the end whereby it is then locked with an actuator into position.
- Once in position and sensor is made, a signal is sent to the gantry system to let the gantry know it is ready for use.
- The gantry will then proceed to Scan the board ensuring the correct orientation.
- Once a scan is achieved, the gantry will pick the board and place into one of the text jigs.
- Once test has finished the gantry will check the network to determine whether the board is a pass of fail
- The gantry will then place the board onto the pass conveyor or onto the reject conveyor.
- This cycle will be repeated until the machine is depleted of pallets/ boards.

1.1. Product "A" Automation Machine Overview (Visual)

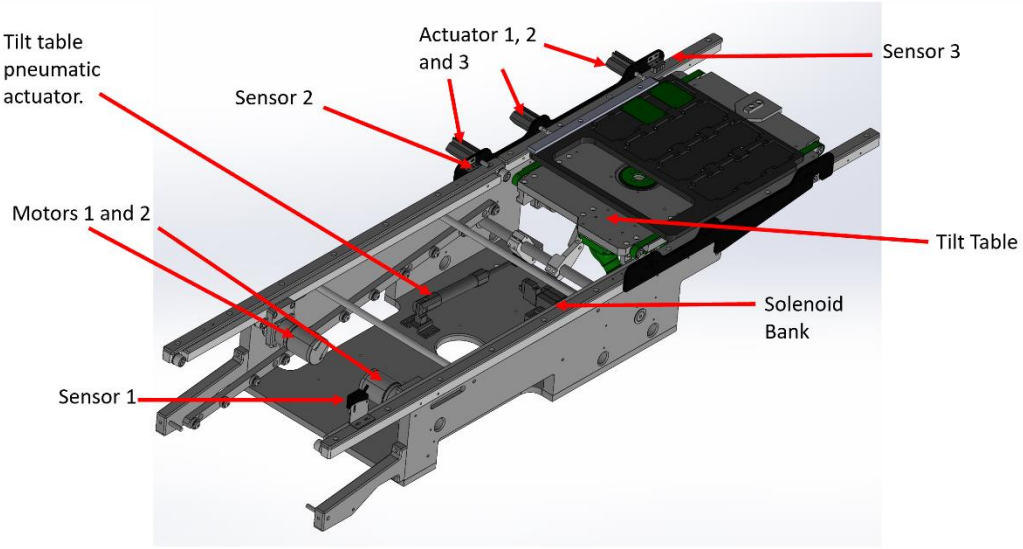


1.2. Presenter System - Operation and Considerations

As one can see from the image on the next page. The presenter system consists of motors which drive a belt. These motors act in both directions. As the pallet is placed onto the belt – sensor 1 is made. This will drive motor 1 and 2, driving belts 1 and 2 moving the pallet to sensor 2 where it is met with an actuator stop from actuator 1. If sensor 3 is empty (no pallet in the pick area) the actuator will retract and the all the mothers will drive the pallet to a stop on the pick area. Once sensor 3 is activated, actuator 1 will lock behind, and actuators 2 and 3 will lock the pallet into position.

Once the pick sequence has been completed, actuator 2 and 3 will unlock and the tilt table will tilt. motors 3 and 4 will activate in the reverse direction driving the pallet to the empty pallet area. This process is cycled.

1.2.1. Presenter system



1.3. Gantry System – Operation and Considerations

The machine contains two gantry systems which can be thought of separately.

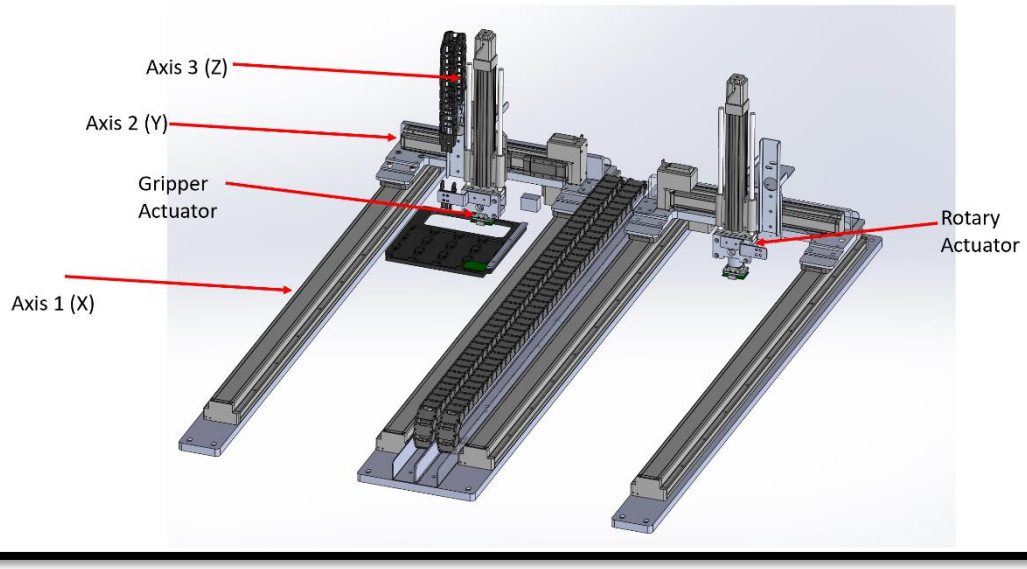
Each gantry consists of a 1200mm actuator [**Axis 1** (X Axis)], a 300mm actuator [**Axis 2** (Y Axis)], and a 250mm actuator [**Axis 3** (Z Axis)].

Each gantry also has a pneumatic gripper actuator which is utilised with tips to pick and place the boards. They further have a scanner to ensure the correct orientation of the boards before picking.

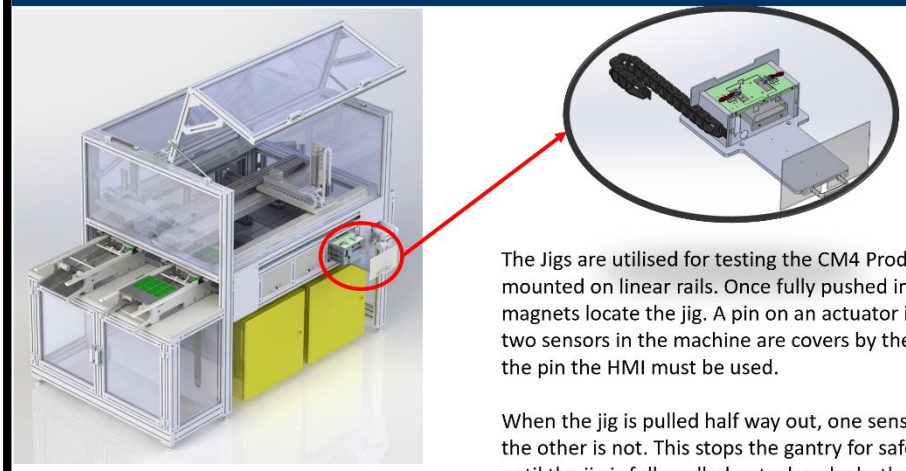
The left gantry system contains a rotary actuator to turn the board to place them on the jigs in the correct orientation.

Each gantry system have their pneumatic tube, scanner cable and reed switch cable routed through the E – chains, with the reed switches having their own terminal blocks on the y axis e chain mounting plate.

1.3.1 Gantry System



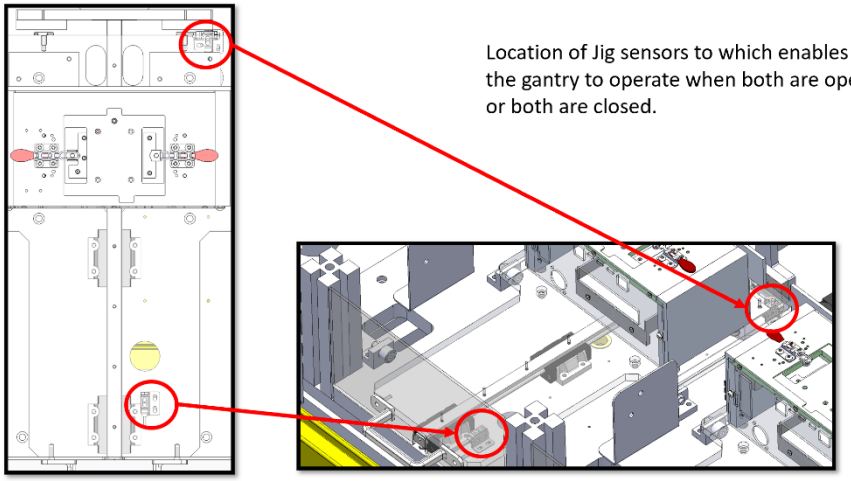
1.4. Jigs – Operation and Considerations



The Jigs are utilised for testing the CM4 Product. They are mounted on linear rails. Once fully pushed into the machine, magnets locate the jig. A pin on an actuator is activated when two sensors in the machine are covers by the jig. To release the pin the HMI must be used.

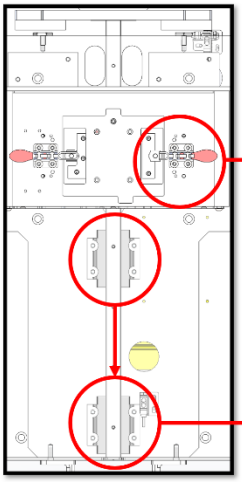
When the jig is pulled half way out, one sensor is made and the other is not. This stops the gantry for safety purposes until the jig is fully pulled out whereby both sensors are not made, thus, locking the pin into the machine whereby the HMI must be used again to push the jig into the machine.

1.4.1. Jig Sensors



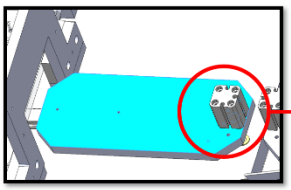
Location of Jig sensors to which enables the gantry to operate when both are open or both are closed.

1.4.2. Test Jigs

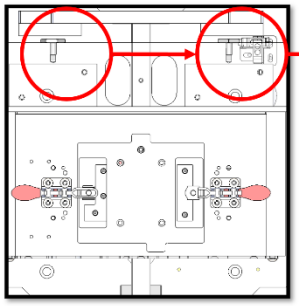


Jig Clamps and force blocks

Linear rails and carriages

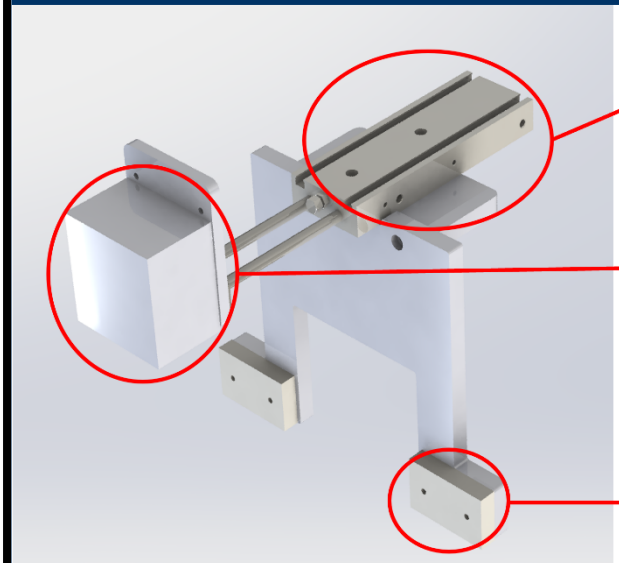


Actuator Lock and Pin which prevents accidental opening of the jig



Magnets and Steel Block or Steel screws which allows for accurate placement of jig into the machine and prevent movement.

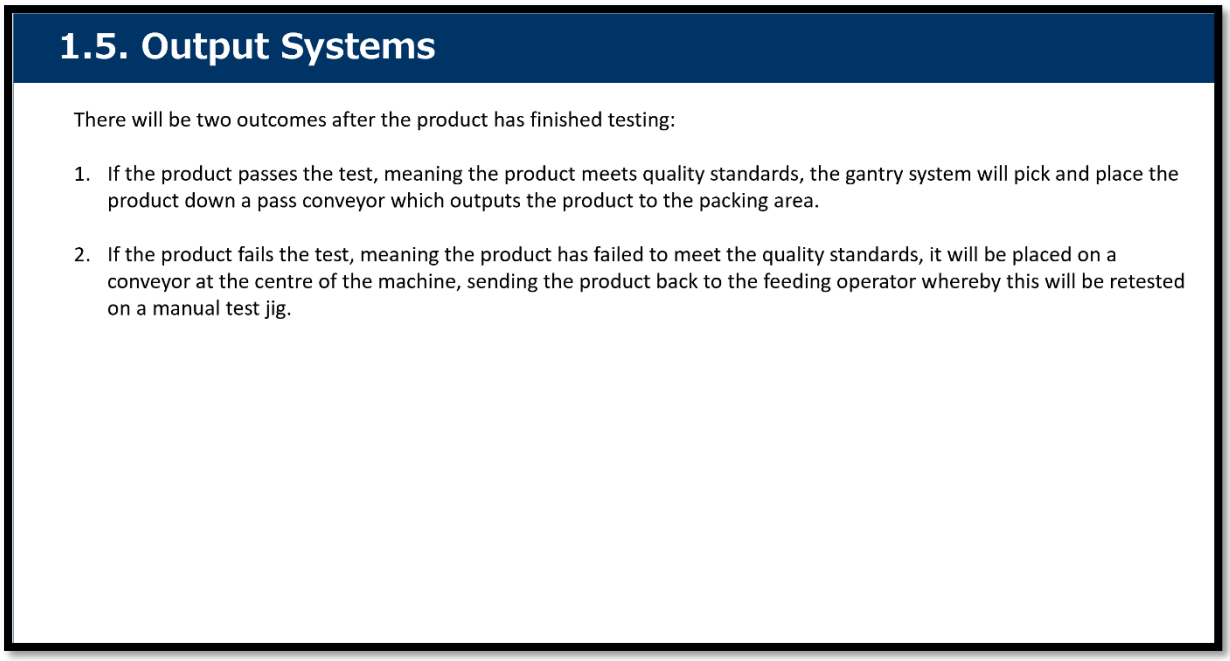
1.4.3. Jig Scanner



Pneumatic Actuator to extend scanner when required to allow for scanning of the product

Scanner to scan boards to identify the product and begin test

Steel Block for magnetic alignment with magnets on the jig



1.5. Output Systems

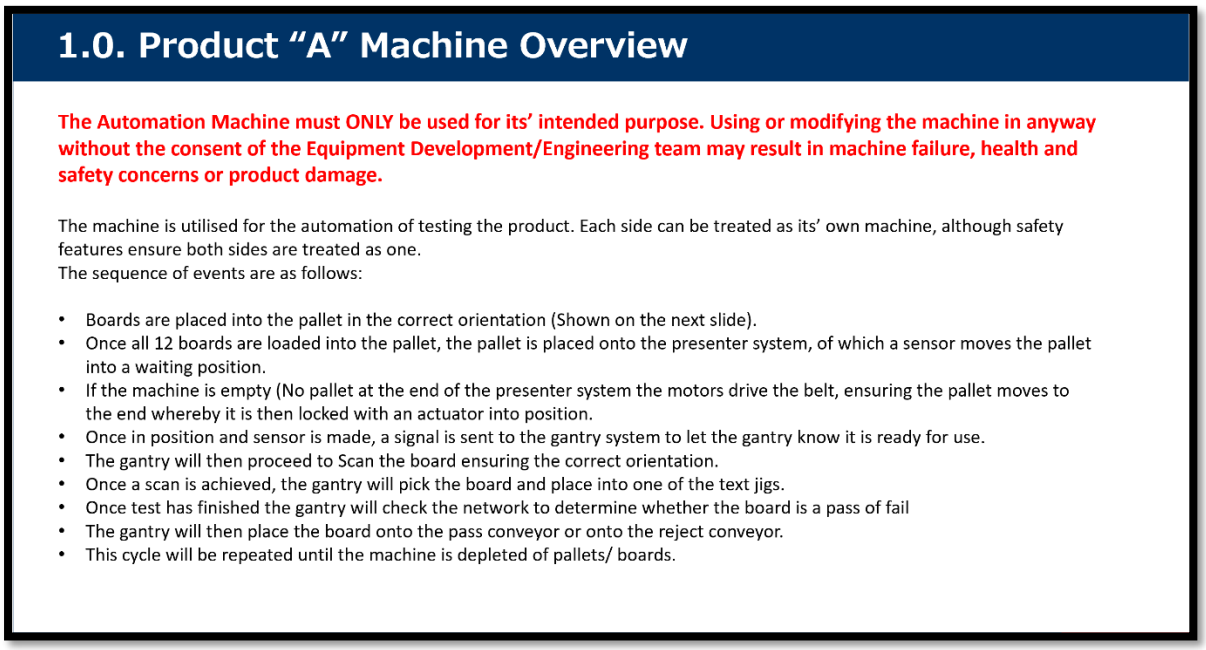
There will be two outcomes after the product has finished testing:

1. If the product passes the test, meaning the product meets quality standards, the gantry system will pick and place the product down a pass conveyor which outputs the product to the packing area.

2. If the product fails the test, meaning the product has failed to meet the quality standards, it will be placed on a conveyor at the centre of the machine, sending the product back to the feeding operator whereby this will be retested on a manual test jig.

Appendix 5.2. Machine Operation and Control

This section outlines the operational standard for the operator to control the machine, with supporting documents for technicians to operate the Human Machine Interface screens for the maintenance and operation of the machine.



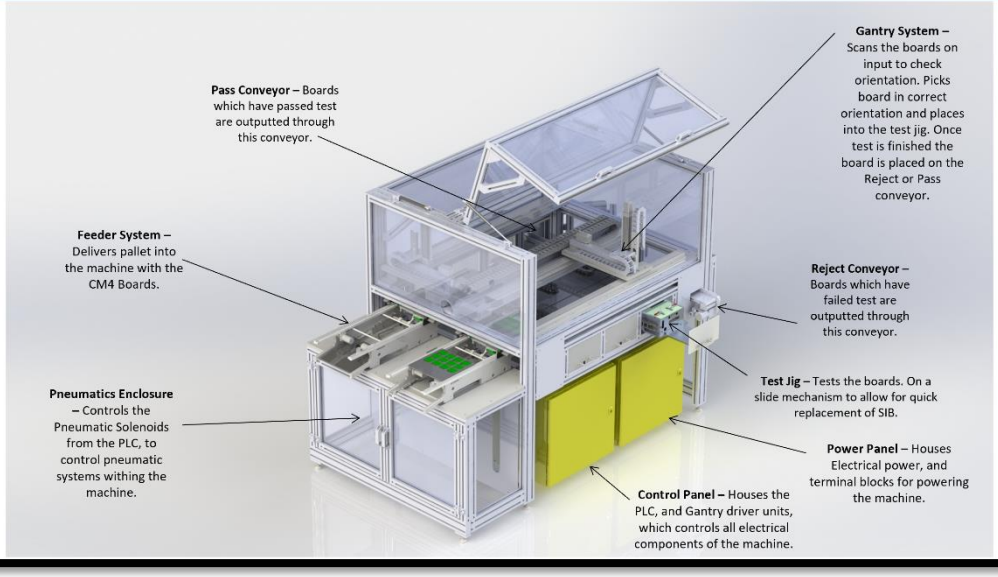
1.0. Product "A" Machine Overview

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- Once all 12 boards are loaded into the pallet, the pallet is placed onto the presenter system, of which a sensor moves the pallet into a waiting position.
- If the machine is empty (No pallet at the end of the presenter system the motors drive the belt, ensuring the pallet moves to the end whereby it is then locked with an actuator into position.
- Once in position and sensor is made, a signal is sent to the gantry system to let the gantry know it is ready for use.
- The gantry will then proceed to Scan the board ensuring the correct orientation.
- Once a scan is achieved, the gantry will pick the board and place into one of the text jigs.
- Once test has finished the gantry will check the network to determine whether the board is a pass of fail
- The gantry will then place the board onto the pass conveyor or onto the reject conveyor.
- This cycle will be repeated until the machine is depleted of pallets/ boards.

1.1. Product "A" Automation Machine Overview (Visual)



1.2 Machine Operation – Loading

1. Break boards into individual product and place into the pallet provided. The product should be placed into the pallet with the QR code at the bottom-right corner. The pallet should have the handle at the bottom, therefore, having the arrows indicating the direction it is placed into the machine.
2. Whilst breaking up a panel, ensure the 'board-breaking' equipment provided is used and use the plate with foam to ensure less stress is placed on the boards.
3. **Note**: Ensure each board is flush in the pocket, if this does not occur, the machine will not be able to pick the product correctly. On occasion the boards have excess fibreglass material. Remove this before inserting into the pallet.
4. Once the pallet has been fully loaded, place onto the conveyor in the direction of the arrows, ensuring the boards remain flush. The sensor will pull the boards into the machine.
5. Once a pallet has been fully used by the machine, it will release at the bottom of the feeder.
6. Multiple pallets can be loaded into the system whilst the machine is in use to reduce waiting time.
7. Repeat the process as required.

1.3 Machine Operation – Tested Boards

If the product passes the test, meaning the product meets quality standards, the gantry system will pick and place the product down a pass conveyor which outputs the product to the packing area.

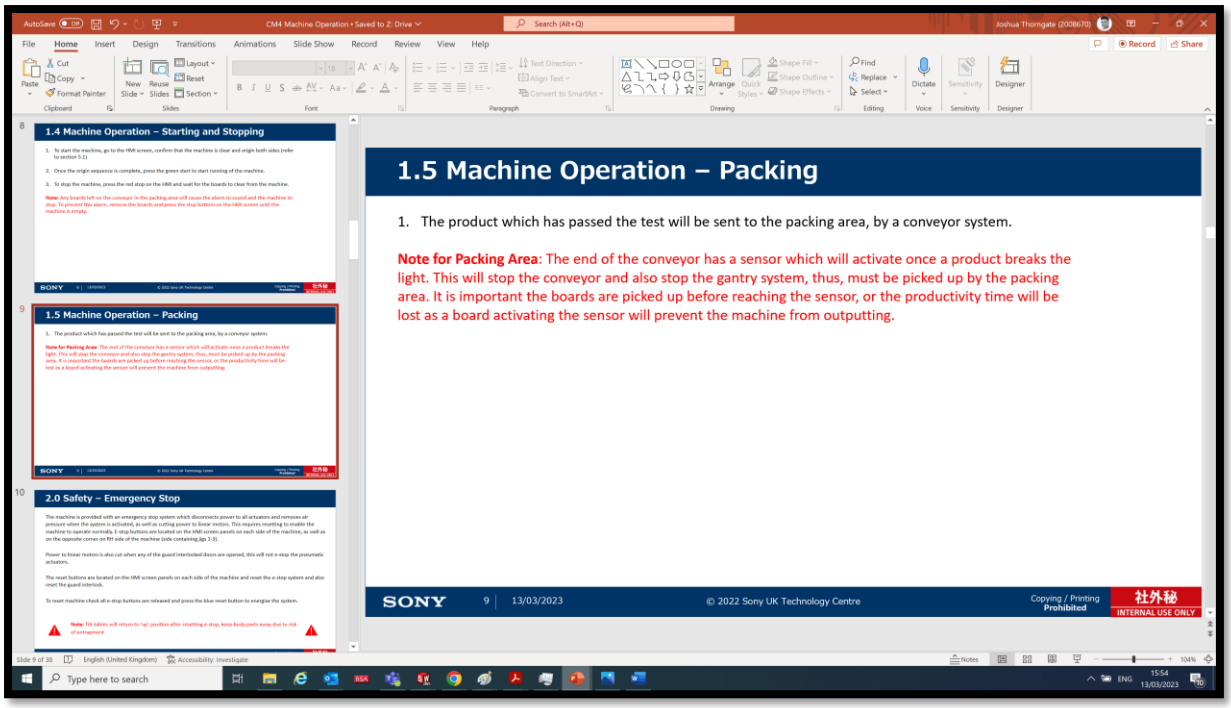
If the product fails the test, meaning the product has failed to meet the quality standards, it will be placed on a conveyor at the centre of the machine, sending the product back to the feeding operator whereby this will be retested on a manual test jig.

Place the rejected boards on a manual test. If it has passed, give the board to the packing area. If it fails again, place aside with receipt.

All dropped boards must be inspected by QC.

1.4 Machine Operation – Starting and Stopping

1. To start the machine, go to the HMI screen, confirm that the machine is clear and origin both sides (refer to section 5.1)
2. Once the origin sequence is complete, press the green start to start running of the machine.
3. To stop the machine, press the red stop on the HMI and wait for the boards to clear from the machine.
4. **Note:** Any boards left on the conveyor in the packing area will cause the alarm to sound and the machine to stop. To prevent this alarm, remove the boards and press the stop bottom on the HMI screen until the machine is empty.



2.0 Safety – Emergency Stop

The machine is provided with an emergency stop system which disconnects power to all actuators and removes air pressure when the system is activated, as well as cutting power to linear motors. This requires resetting to enable the machine to operate normally. E-stop buttons are located on the HMI screen panels on each side of the machine, as well as on the opposite corner on RH side of the machine (side containing jigs 1-3).

Power to linear motors is also cut when any of the guard interlocked doors are opened, this will not e-stop the pneumatic actuators.

The reset buttons are located on the HMI screen panels on each side of the machine and reset the e-stop system and also reset the guard interlock.

To reset machine check all e-stop buttons are released and press the blue reset button to energise the system.

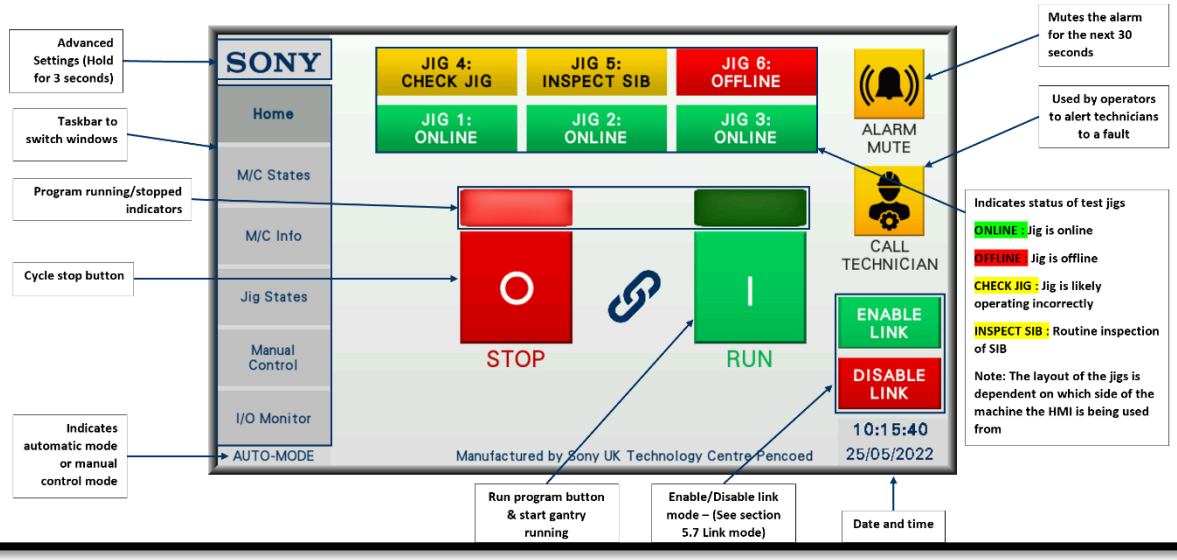
Note: Tilt-tables will return to ‘up’ position after resetting e-stop, keep body parts away due to risk of entrapment

3.0 HMI Screens - Characteristics

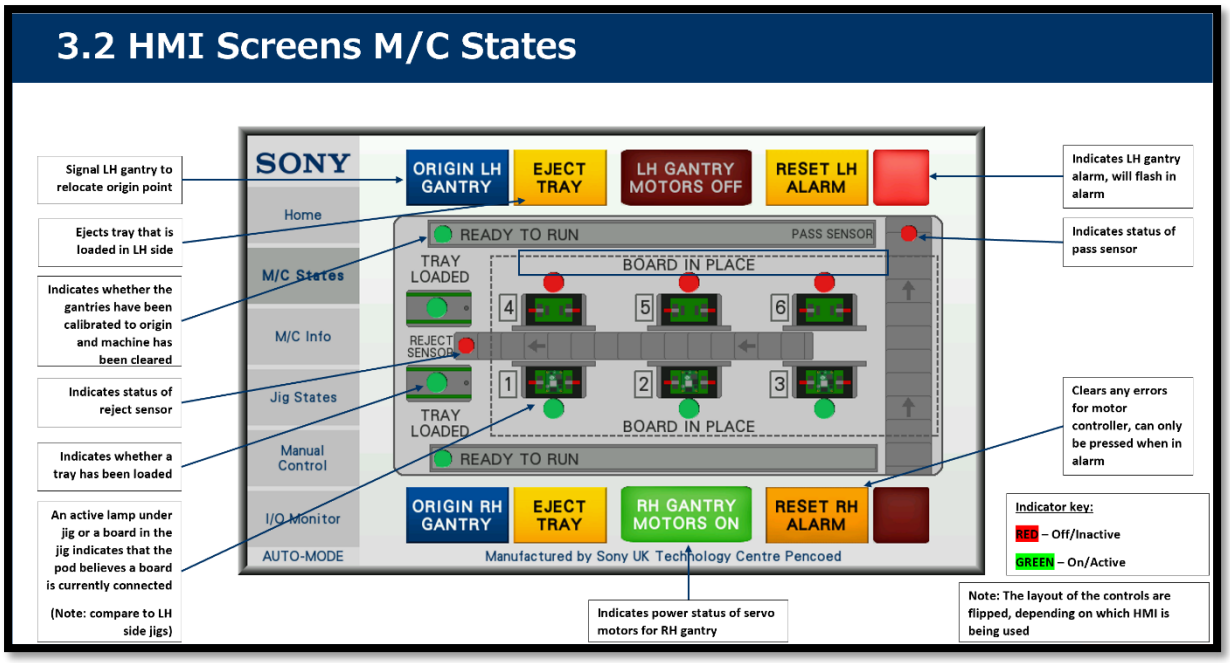
Specifications

Model: OMRON NB7W-TW01B
Display size: 7 inch
Display resolution (H × V): 800 x 480 pixels
Number of colours: 65,536
Backlight: LED
Backlight lifetime: 50,000 hours of operating time at the normal temperature (25°C)
Touch panel: Analog resistive membrane type, resolution 1024 × 1024
Touch panel lifetime: 1 million touch operations
Dimensions in mm (H × W × D): 148 × 202 × 46
Line voltage: 20.4 to 27.6 VDC (24 VDC −15 to 15%)
Power consumption: 11 W
Battery lifetime: 5 years (at 25°C)
Enclosure rating (front side): IP65 (Dust proof and drip proof only from the front of the panel)
Obtained standards: EC Directives, KC, cUL508
Noise immunity: Compliant with IEC61000-4-4, 2 KV (Power cable)
Ambient operating temperature: 0 to 50°C
Ambient operating humidity: 10% to 90% RH (Without condensation)

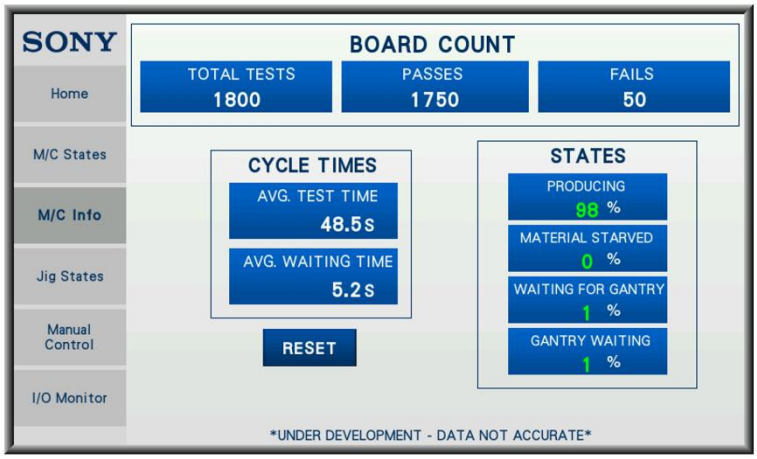
3.1 HMI Screens - Home



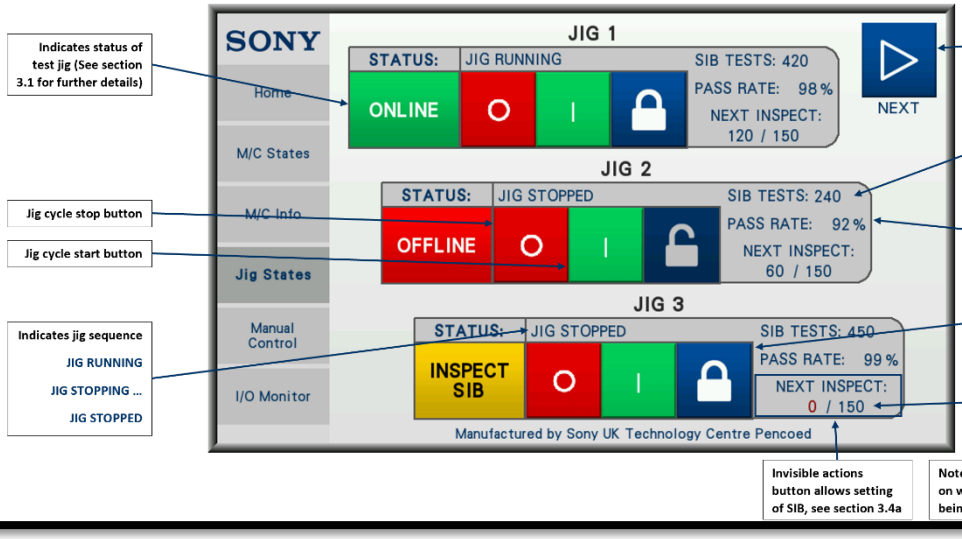
3.2 HMI Screens M/C States



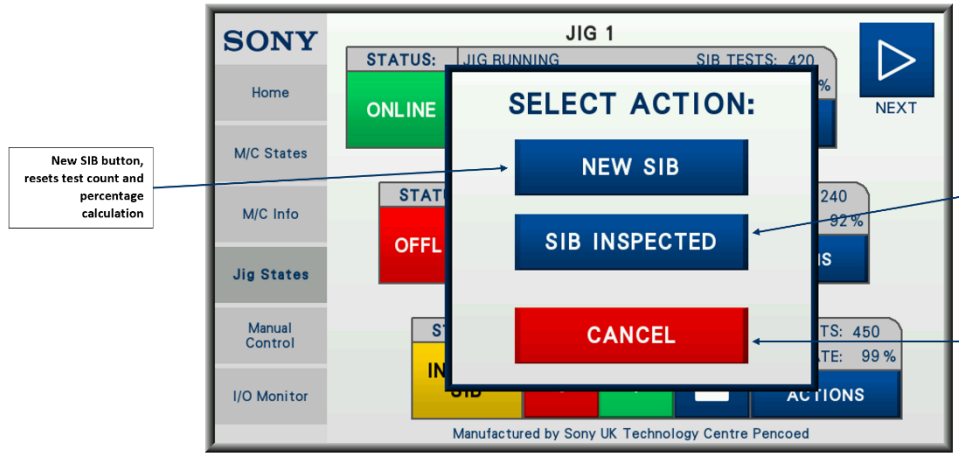
3.3 HMI Screens - M/C Info



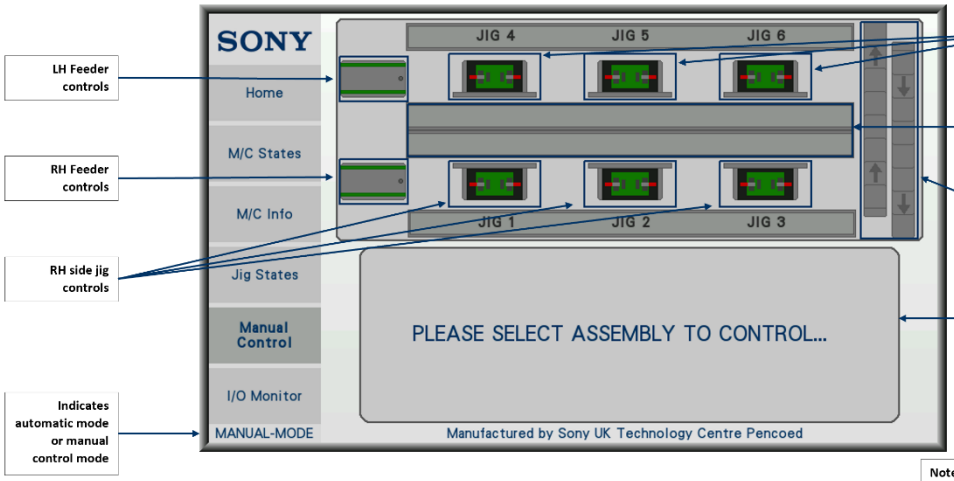
3.4 HMI Screens - Jig States



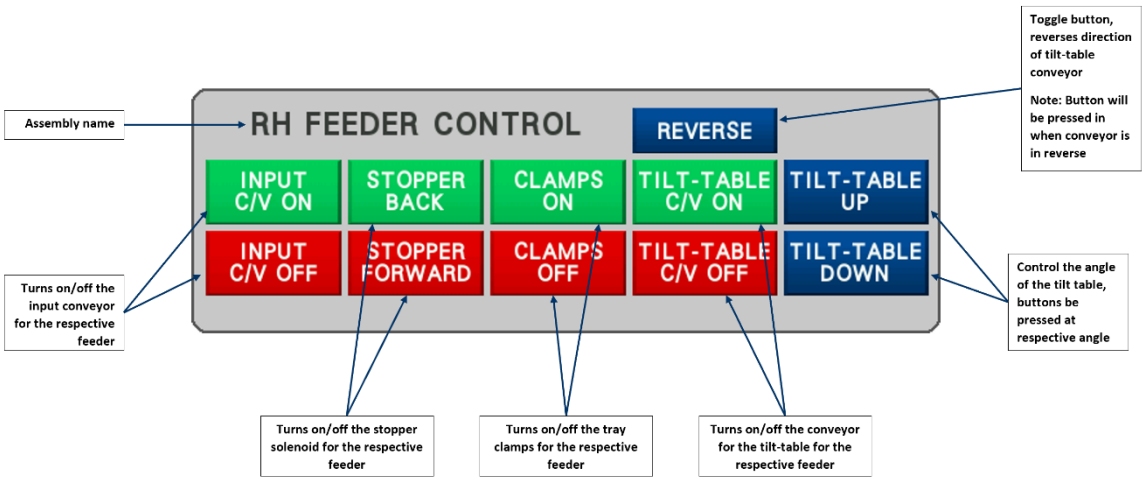
3.4a HMI Screens - Actions Menu



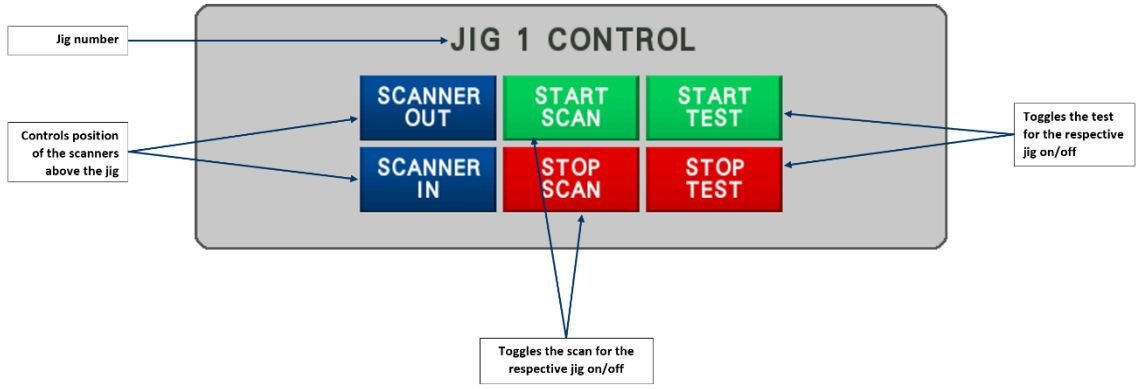
3.5 HMI Screens - Manual Control



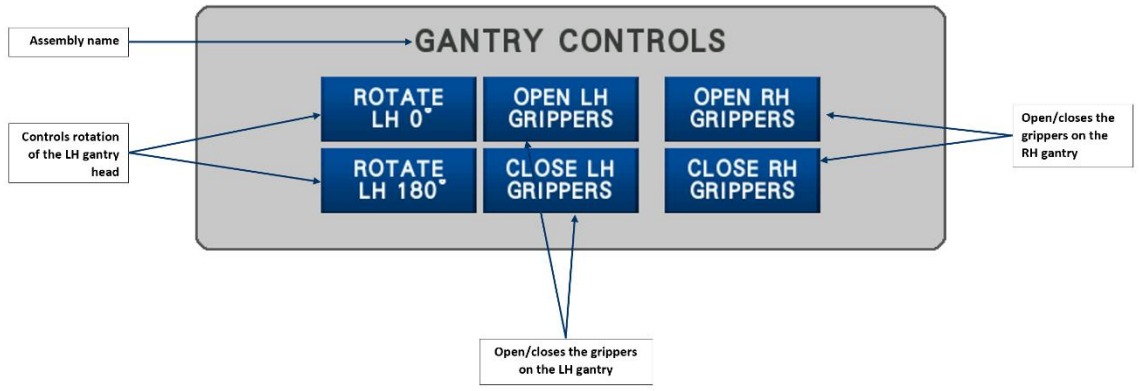
3.5a HMI Screens – Feeder Controls



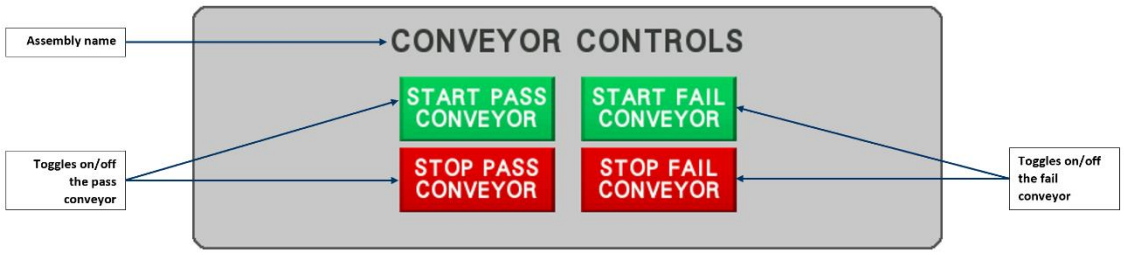
3.5b HMI Screens – Jig Controls



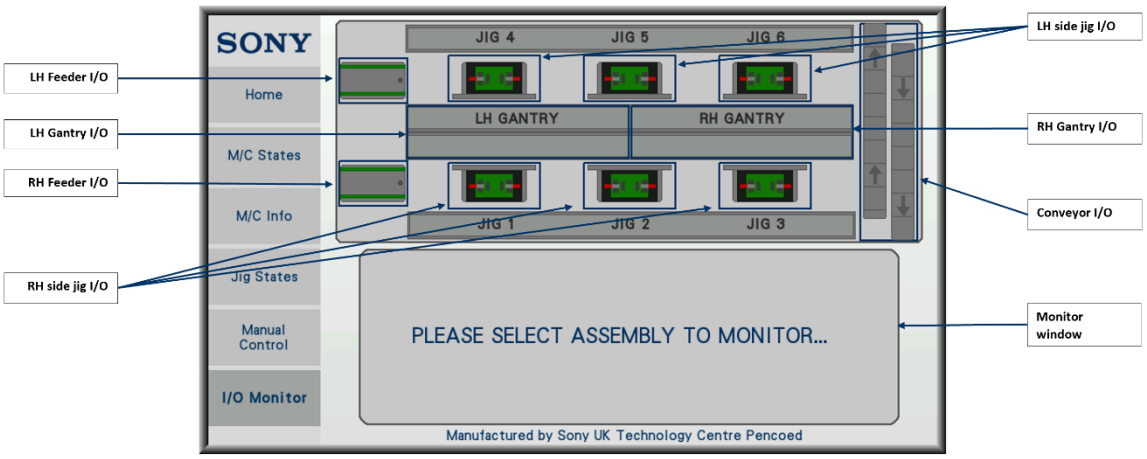
3.5c HMI Screens - Gantry Controls



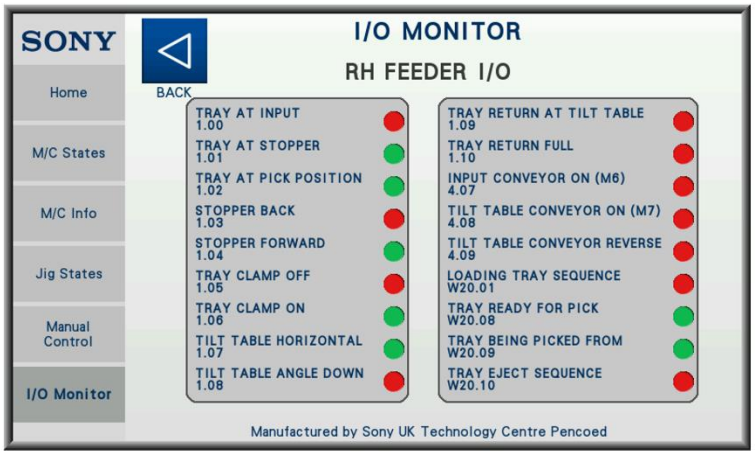
3.5d HMI Screens - Conveyor Controls



3.6 HMI Screens - I/O Monitor

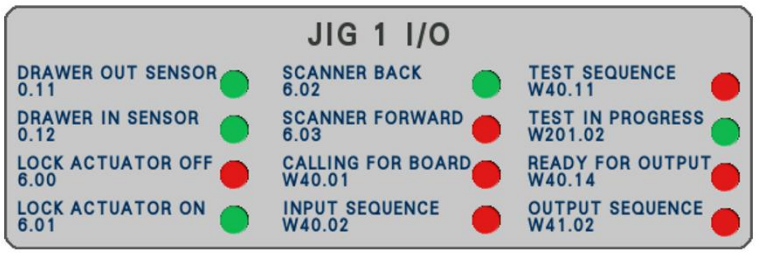


3.6a HMI Screens - Feeder I/O

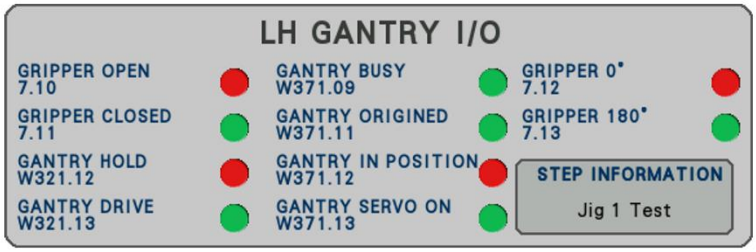


Note: The layout of the controls are flipped, depending on which HMI is being used

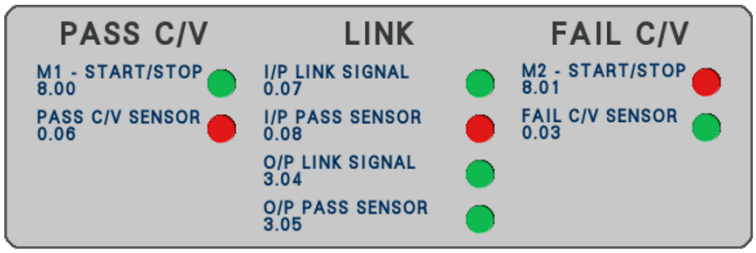
3.6b HMI Screens - Jig I/O



3.6c HMI Screens - Gantry I/O



3.6d HMI Screens - Conveyor I/O



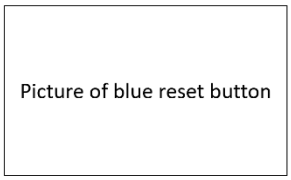
4.0 Electrical, Pneumatic Drawings and PLC Structure – Refer to file

Note: These documents cannot be shared due to confidentiality

5.0 Machine Control – Resetting E-stop



[Figure 1]



[Figure 2]

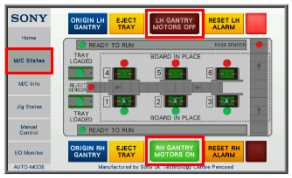


[Figure 3]

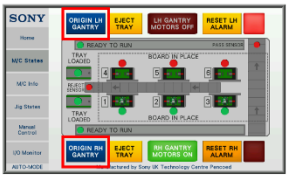
After the machine has entered emergency stop mode (as in *fig. 1*), it must be reset in order for the machine to continue running. Firstly, the machine should be checked to ensure that all boards and pallets have been removed before the reset procedure. This prevents the machine from damaging production boards if an error has occurred. Once the machine has been cleared to run, all e-stop buttons should be released, before pressing one of the blue reset buttons on the HMI panels (*fig. 2*). The machine will then prompt to verify that all jigs and pallet systems are clear before the program can be started (*fig. 3*).

Note: Refer to section 2.0 for more information

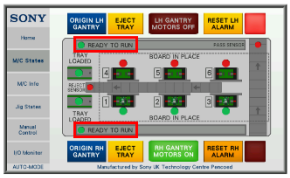
5.1 Machine Control – Start-up Procedure



[Figure 4]



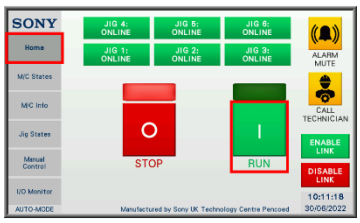
[Figure 5]



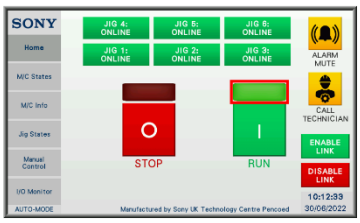
[Figure 6]

In order to set the machine up ready to run, it should be confirmed that the gantry motors are currently running. This is done through the M/C States screen, shown by a lamp on each side of the machine indicating servo motor status (*fig. 4*). After verifying that both motors are running, press the origin RH or LH gantry buttons *(fig. 5*). This will move the robot slowly to its datum. The gantry will origin each of its axis in order (axis 3, axis 2, axis 1 respectively, see section ?.?) Once this move has been complete, the gantry will move at normal speed to its home position. It is possible that the gantry will fail to reach its origin in the set time, at which point it will alarm. This will mean that the gantry is inoperable until the alarm is reset (see section ?.?). It is advised to re-origin the gantry if it does enter an alarm state. Once the gantry is at home it will be flagged as ready to run, which is shown by a lamp on the same M/C states screen (*fig. 6).*

5.2 Machine Control – Starting Program



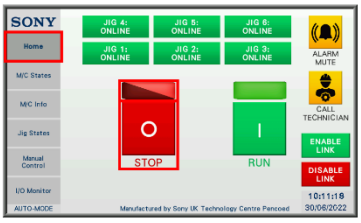
[Figure 7]



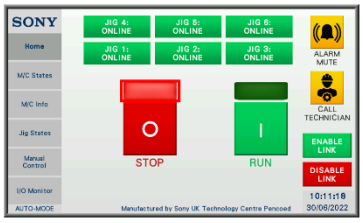
[Figure 8]

To start running the program for the automatic tester, the machine should undergo its start-up procedure first (see section 5.2). It can be observed from the Home screen that the program is not running, as shown by the red lamp lit in figure 7. The program can be started by pressing the green run button. This is verified by the red lamp becoming deactivated, and the green lamp becoming lit, shown in figure 8.

5.3 Machine Control – Stopping Program



[Figure 9]

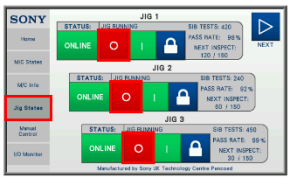


[Figure 10]

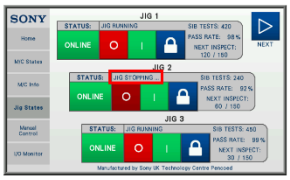
To stop a program that is currently running, tapping the stop button will cause the machine to cycle stop. This means that the machine will finish placing boards in jigs if it currently is, and wait for the boards to finish testing before removing all boards from the system and placing them on their respective outputs. This means that no boards will be left in jigs, however any pallet in use will stay inserted, ready to be picked from upon re-starting. Cycle stop can be seen as in progress when the red lamp flashes on the Home screen, whilst the green is still constantly lit, showing that the process is still running (*fig. 9*). When the machine has cleared all boards, it will enter a stopped state, indicated by the red lamp staying lit (*fig. 10*).

Alternatively, holding the stop button for 8 seconds will trigger a stop override, stopping the machine immediately. This should only be used by technicians in order to stop the machine when it is in fault.

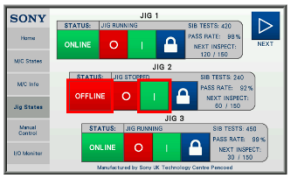
5.4 Machine Control – Starting/Stopping Jigs



[Figure 11]



[Figure 12]

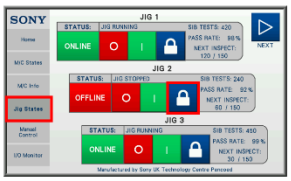


[Figure 13]

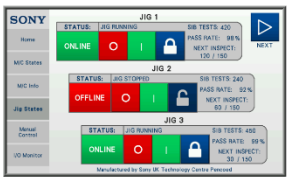
In order to turn a jig offline, access the Jig States screen. From this screen the controls and data for each jig can be monitored. Similar to cycle stop, when the stop button is pressed (*fig. 11*), the jig will finish testing the board currently in place and wait for it to be output before turning off. This is indicated in figure 12, with the text showing 'Jig stopping…' on the respective jig. Once all boards have been cleared from the jig, it will turn offline, meaning that no boards will be input until the jig is placed back online. This offline state is indicated by the status switching to 'Offline' (*fig. 13*). Alternatively, holding the stop button for 5 seconds will trigger a stop override, stopping the jig immediately, if the correct conditions are met. This should only be used by technicians in order to access jigs when the machine is in fault.

Jigs can be turned back on by holding the power on button for 0.5 seconds (*fig. 13*).

5.5 Machine Control – Unlocking Jigs



[Figure 14]



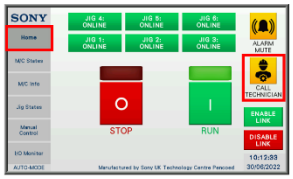
[Figure 15]



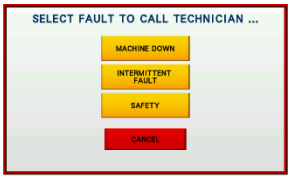
[Figure 16]

To inspect or replace the SIB in a jig, the jig must first be unlocked. This is done through the Jig States screen. Firstly, the jig must be stopped in order to unlock it (see section 5.4), after which the jig can be unlocked by pressing the unlock button (*fig. 14*). After this, the jig will unlock for 12 seconds before timing out, which is indicated by the lock button becoming pressed in with the padlock symbol showing the unlock status (*fig. 15*). The jig can now be pulled out or pushed back in to the machine. After reaching a fully-in or fully-out position, the jigs will re-lock. The jigs lock out in order to reduce risk of damage to the machine and the operator. After pushing the jig back in to a fully-in position, the HMI screen will prompt a jig action, as seen in figure 16. From this one can either select a new SIB, which will reset the test count on the Jig States screen, or can mark the SIB as inspected, which will reset the counter until the next mandatory SIB inspection.

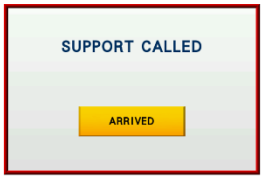
5.6 Machine Control – Call Technician



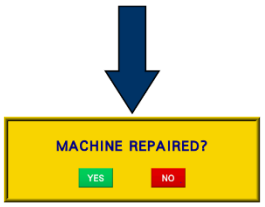
[Figure 17]



[Figure 18]



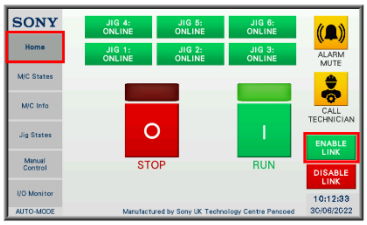
[Figure 19]



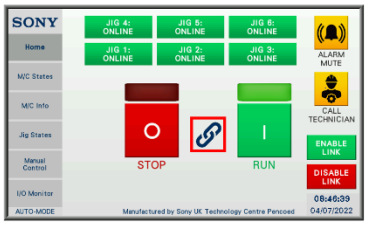
[Figure 20]

The call technician function is used to alert technicians to a fault on the machine. This can be accessed on the Home screen, as shown in figure 17. This will open a new screen, where a fault type must be selected *(fig. 18)*. 'Machine down' is used when the auto-tester is not operating correctly and cannot be run; 'Intermittent fault' is used when a problem is recurring inconsistently; and 'Safety' is used when there is a newly identified safety hazard involved with the machine. Cancel will not send any signal to the technician area. Upon selecting the fault, a screen will show that support has been called (fig. 19). Upon a technician arriving, they must press 'Arrived', which closes the screen. After this point the prompt 'Machine repaired?' will show until the fault has been fixed and 'Yes' has been selected *(fig. 20)*.

5.7 Machine Control – Link Mode



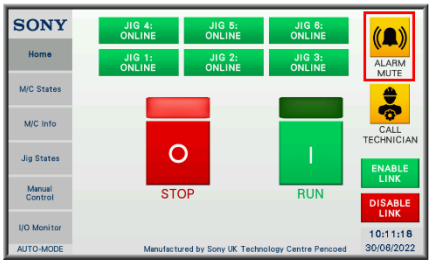
[Figure 21]



[Figure 22]

It is possible to enable 'link mode' on the CM4 auto-testers. This works on the premise that the pass conveyors for each pod are lined up, so that boards can move from one pods conveyor onto the next. This allows both machines to be run with only one packing operator. To enable this, on the Home screen, press the 'Enable Link' button (*fig. 21*). This will disable the sensor which prevents boards from falling off the end of the pass conveyor for one of the pods. Link mode is indicated as enabled when the 'link' symbol is shown on the Home screen (*fig.* 22). The pods must be configured correctly, with CM4-001 placed to output onto CM4-002's pass conveyor. The configuration of these is set in the 'Advanced Settings' tab on the Home screen (see section 3.1). Link mode can be enabled and disabled from either pod. When disabling link mode, it should be known that it is possible for boards to stop on the CM4-002 conveyor, just after where the conveyors meet, as such this area should be checked during changeover procedures.

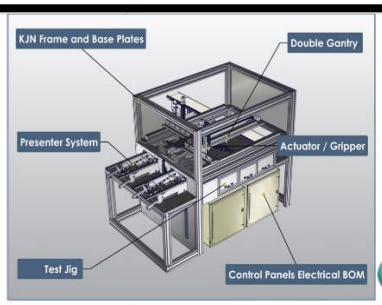
5.8 Machine Control – Alarm Mute



[Figure ?]

Alarm mute is used to stop the buzzer from emitting noise for a temporary amount of time. This should only be done in order to prevent excess noise from the machine whilst it is being seen to be a technician. It should not be used by operators during the normal process of the machine, as the alarms from the buzzer are to alert either the loader operator or the packing operator that a board needs to be cleared or a tray needs to be loaded. The time set for the alarm mute is set to 30 seconds.

Appendix Six – Machine BOM Sample



BILL OF MATERIALS

Project / Equipment	
No. of Units	
Cost Per Unit	
Total Cost/Project	

Click Here

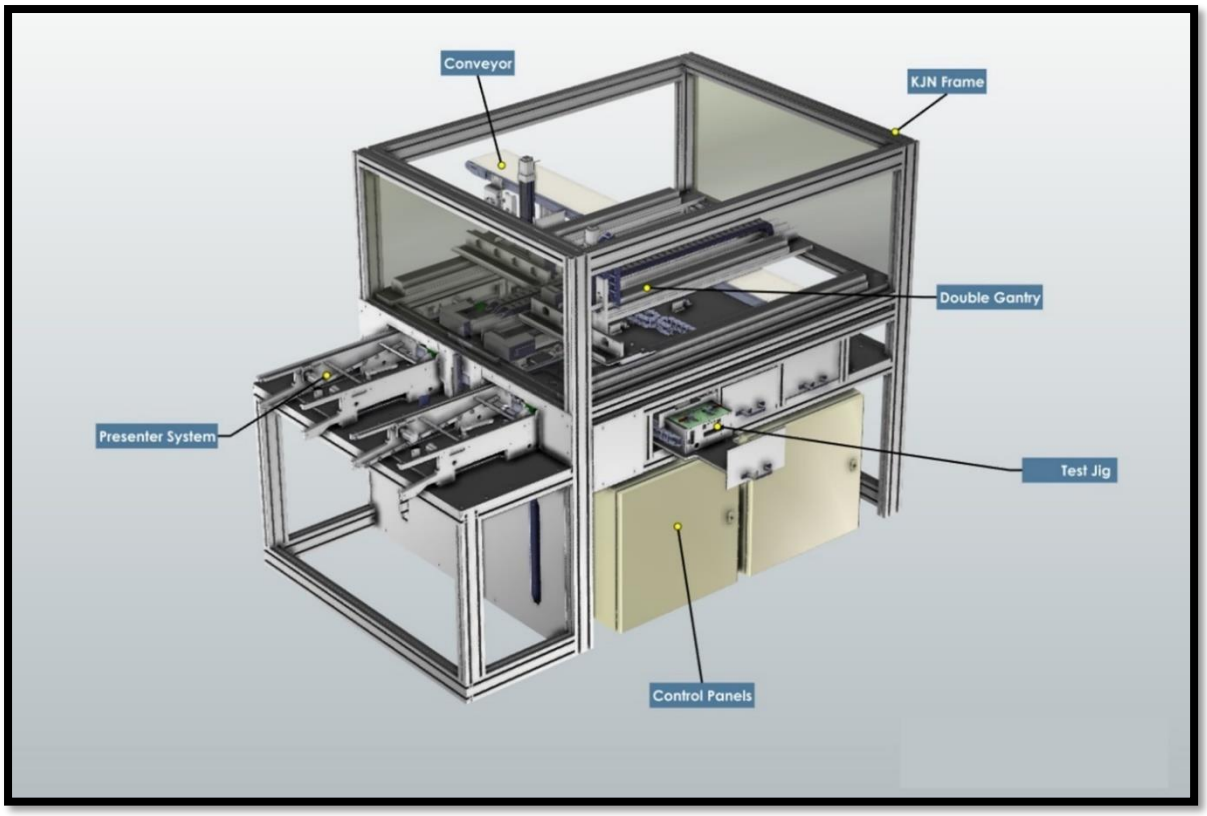
Supplier: KJN Ltd; Metal Goods (Wales) Ltd; Misumi Europa GmbH; Mouser Electronics Inc; Proto Labs Ltd; RS Components Ltd; The Barcode Warehouse Ltd; X-STK Applied Automation (U...; (blank)

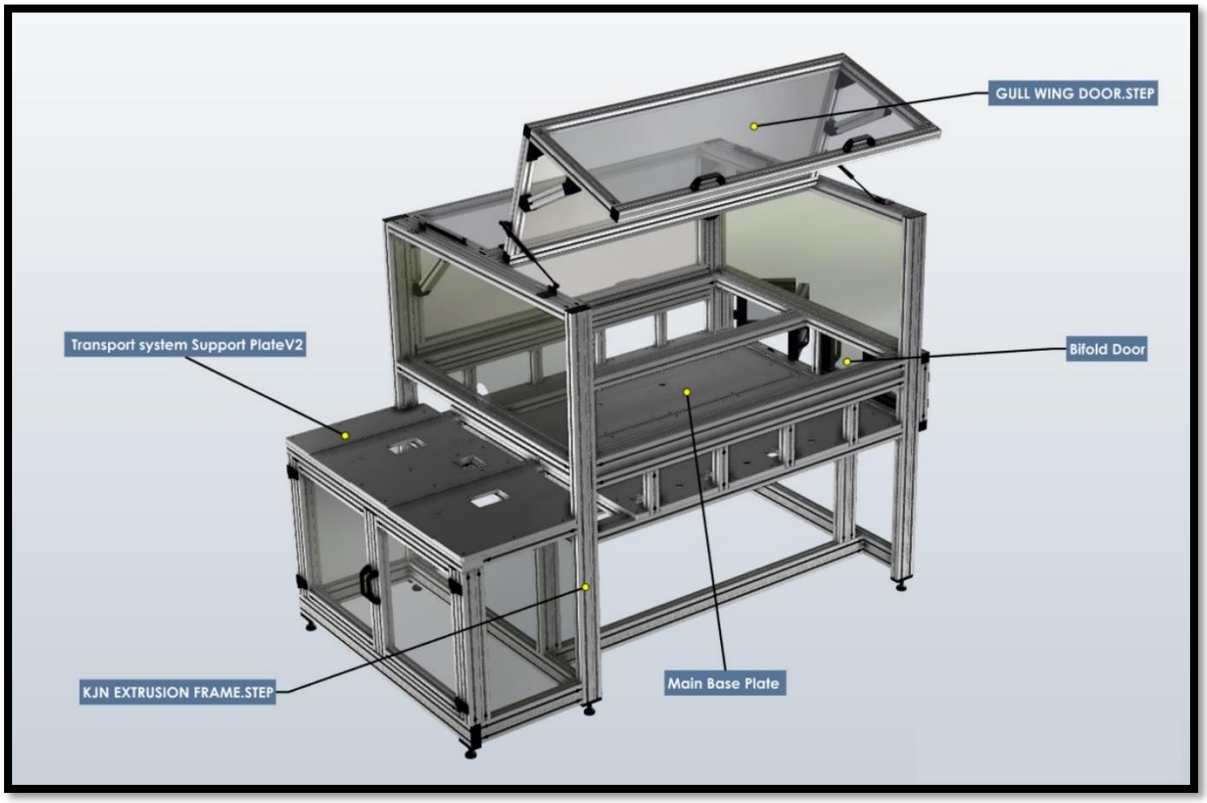
Category: Electrical; IE; Mech/Elec; Mechanical; Test; #REF!

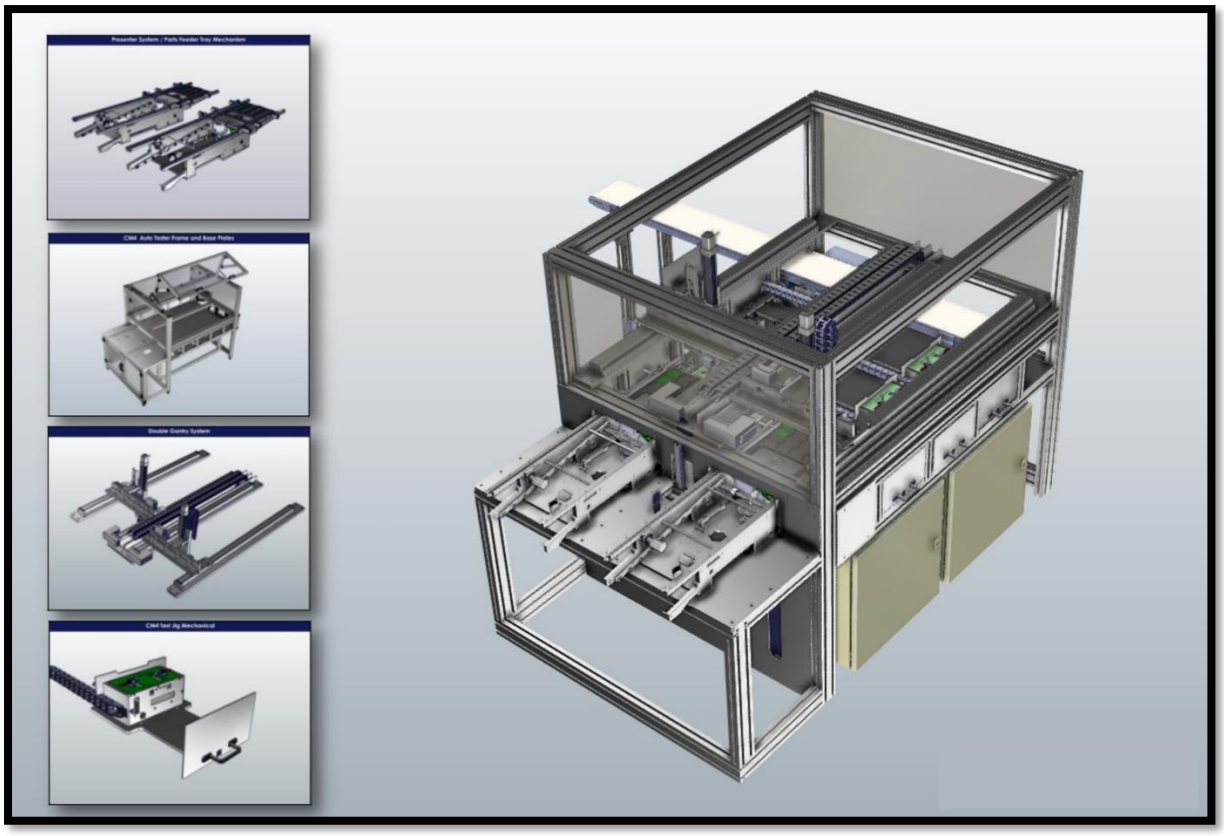
Assembly/Type: Auto Tester; Control & Electrical; Control Panel; Conveyor; Electrical; Frame; Gantry; Jig; Jigs

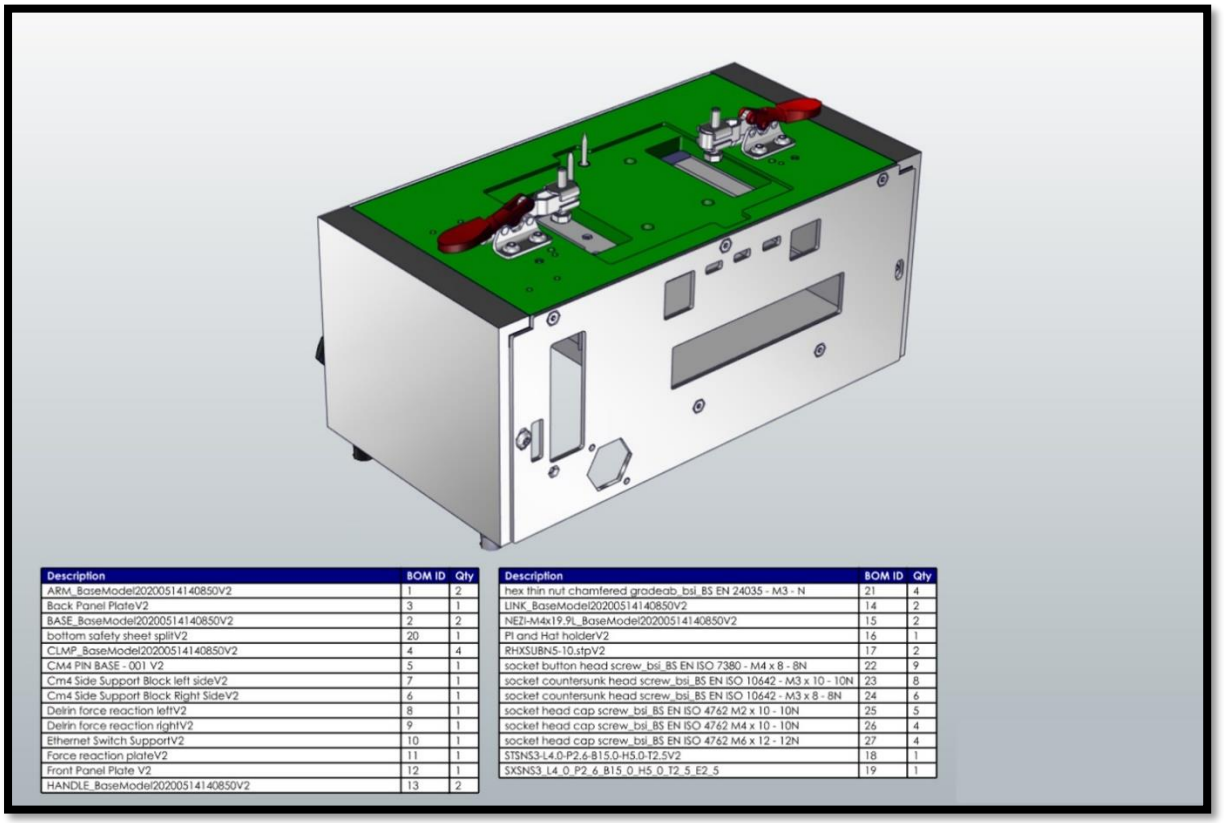
Part Number	Supplier Part Description	Supplier Name	Part Link	BOM Qty	Qty Ordered	UOM	Unit Price in Currency	Currency	Total in Currency	Total Amount (GBP)	Category	Project Name	Assembly/Type	Sub-assembly
CXSM10-75	Air Cylinder	X-STK Applied Automation (U	Request Quote		6	Each	149.33	GBP	895.98	895.98	Mechanical	21-046/C	Auto Tester	Pneumatics
D-A93L	Auto Switch 24vdv	X-STK Applied Automation (U	Request Quote		12	Each	15.56	GBP	186.72	186.72	Mechanical	21-046/C	Auto Tester	Pneumatics
D-M9PZ	Auto Switch (5M)	X-STK Applied Automation (U	Request Quote		4	Each	26.46	GBP	105.84	105.84	Mechanical	21-046/C	Auto Tester	Pneumatics
D-Z73L	Auto-Switch For Cp95 Units	X-STK Applied Automation (U	Request Quote		12	Each	17.63	GBP	211.56	211.56	Mechanical	21-046/C	Auto Tester	
E39-L117	Mounting bracket for EST-5* sensor, rear mounting	X-STK Applied Automation (U	Request Quote		15	Each	3.35	GBP	50.25	50.25	Mechanical	21-046/C	Auto Tester	Sensors
E3T-SL232M 2M	Photoelectric sensor, side view, limited to 5 to 30mm, light-ON, PNP, 2m cable	X-STK Applied Automation (U	Request Quote		15	Each	65.66	GBP	984.90	984.9	Mechanical	21-046/C	Auto Tester	Sensors
MHF2-8D	Low Profile Air Gripper	X-STK Applied Automation (U	Request Quote		2	Each	294.97	GBP	589.94	589.94	Mechanical	21-046/C	Auto Tester	Pneumatics
SS5Y3-41-15-C6F-Q	15 stattion manifold mm push fittings	X-STK Applied Automation (U	Request Quote		1	Each	81.25	GBP	81.25	81.25	Mechanical	21-046/C	Auto Tester	Pneumatics
SY100-68-A-30	3 m lead for sy solenoid valves	X-STK Applied Automation (U	Request Quote		15	Each	7.11	GBP	106.65	106.65	Mechanical	21-046/C	Auto Tester	Pneumatics
SY3140-5LOU-Q	5/2 solenoid valve 24vdc	X-STK Applied Automation (U	Request Quote		15	Each	36.74	GBP	551.10	551.1	Mechanical	21-046/C	Auto Tester	Pneumatics
SXSNS3-L4.0-P2.6-B9.0-H5.0-T2.	LOCATING PIN	Misumi Europa GmbH	https://uk.misumi-ec.co		50	Each	17.34	EUR	867.00	744.49	Mechanical	21-046/C	Pin Base	Jig Pins
Delivery	Freight	Misumi Europa GmbH	Other Cost		1	Each	36.50	EUR	36.50	31.34	Mechanical	21-046/C	Pin Base	Shipping
134-8185	Ultimaker 2.85mm Black PLA 3D Printer Filament, 750g	RS Components Ltd	https://uk.rs-online.com/		4	Each	32.50	GBP	130.00	130	Mechanical	21-046/CM4 Link Phase 1 Test		3D Printed Parts
B07H96FWY9	SUNGUY USB C to C Cable,80.3m x2?90 Degree Right Angle Type C to C	Amazon Payments Europe SC	https://www.amazon.co		10	Each	6.99	GBP	69.90	69.9	Test	21-046/C	Pin Base	Power Supply
B08FWXR18Y	UGREEN USB C Plug 20W PD Fast Charger Power	Amazon Payments Europe SC	https://www.amazon.co		20	Each	14.99	GBP	299.80	299.8	Test	21-046/C	Pin Base	Power Supply
B099K9PS7W	UGREEN USB C to USB C Cable 100W PD Type C Fast Charger Cable Data Trans	Amazon Payments Europe SC	https://www.amazon.co		20	Each	12.99	GBP	259.80	259.8	Test	21-046/C	Pin Base	Power Supply
CJ1W-ID211	Digital input unit, 16 x 24 VDC inputs, screw terminal	X-STK Applied Automation (U	Request Quote		5	Each	127.75	GBP	638.75	638.75	Mech/Elec	21-046/C	Auto Tester	Controllers
CJ1W-OC211	Digital output unit, 16 x relay outputs, 250 VAC/24 VDC, 2 A max, screw termini	X-STK Applied Automation (U	Request Quote		4	Each	189.77	GBP	759.08	759.08	Mech/Elec	21-046/C	Auto Tester	Controllers
CJ2M-CPU33	CPU with built-in EtherNet/IP port, 20K steps program, 32K words data memory	X-STK Applied Automation (U	Request Quote		1	Each	853.10	GBP	853.10	853.1	Mech/Elec	21-046/C	Auto Tester	Controllers
279126	1P 10A C Miniature Circuit Breaker	X-STK Applied Automation (U	Request Quote		2	Each	53.77	GBP	107.54	107.54	Mech/Elec	21-046/C	Auto Tester	Electrical
3030213	FBS 10-5 Jumper Bar for Terminal Block	X-STK Applied Automation (U	Request Quote		30	Each	2.09	GBP	62.70	62.7	Mech/Elec	21-046/C	Auto Tester	Electrical
3044076	2.5mm Single Terminal	X-STK Applied Automation (U	Request Quote		100	Each	0.58	GBP	58.00	58	Mech/Elec	21-046/C	Auto Tester	Electrical

Appendix Seven – Full Machine Design and Subsystem Design



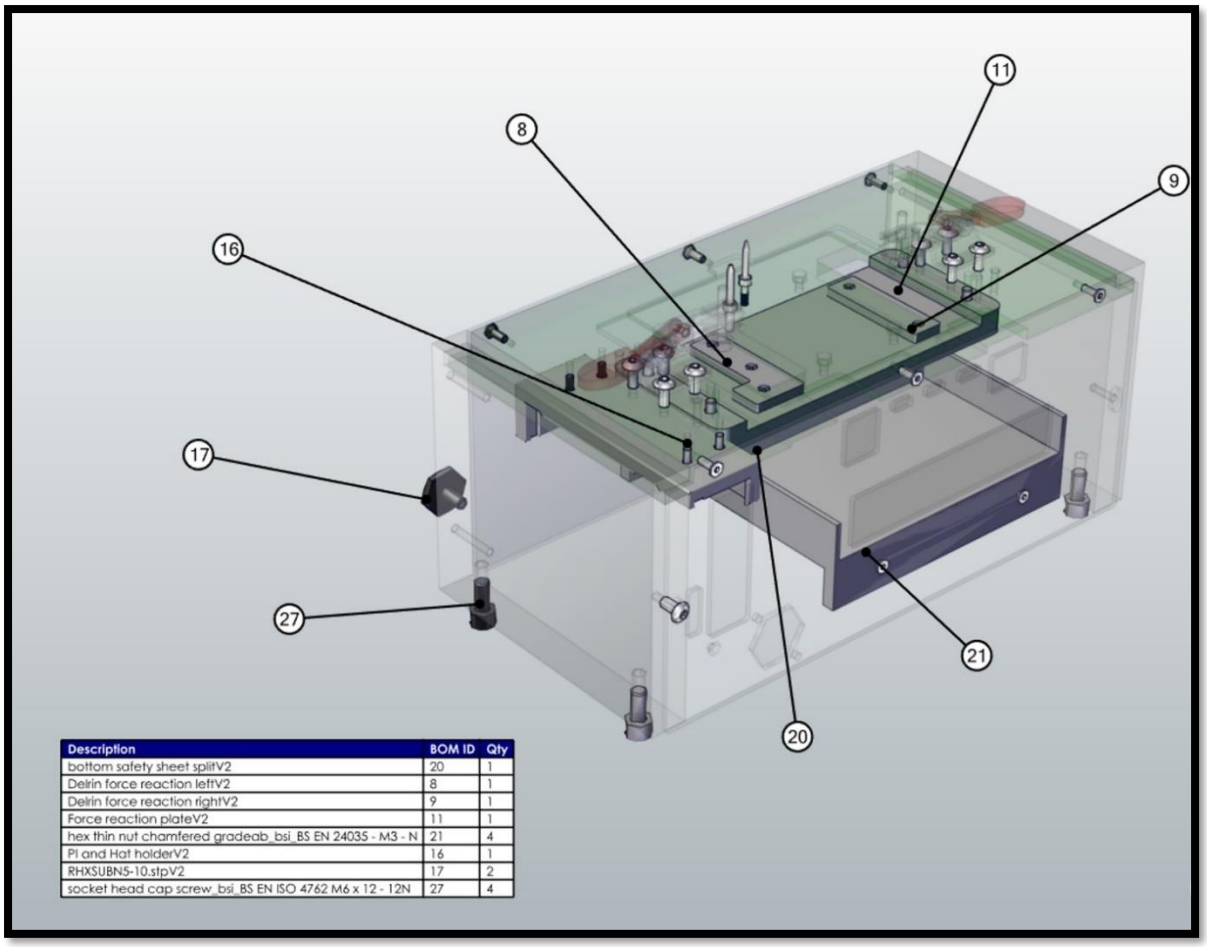




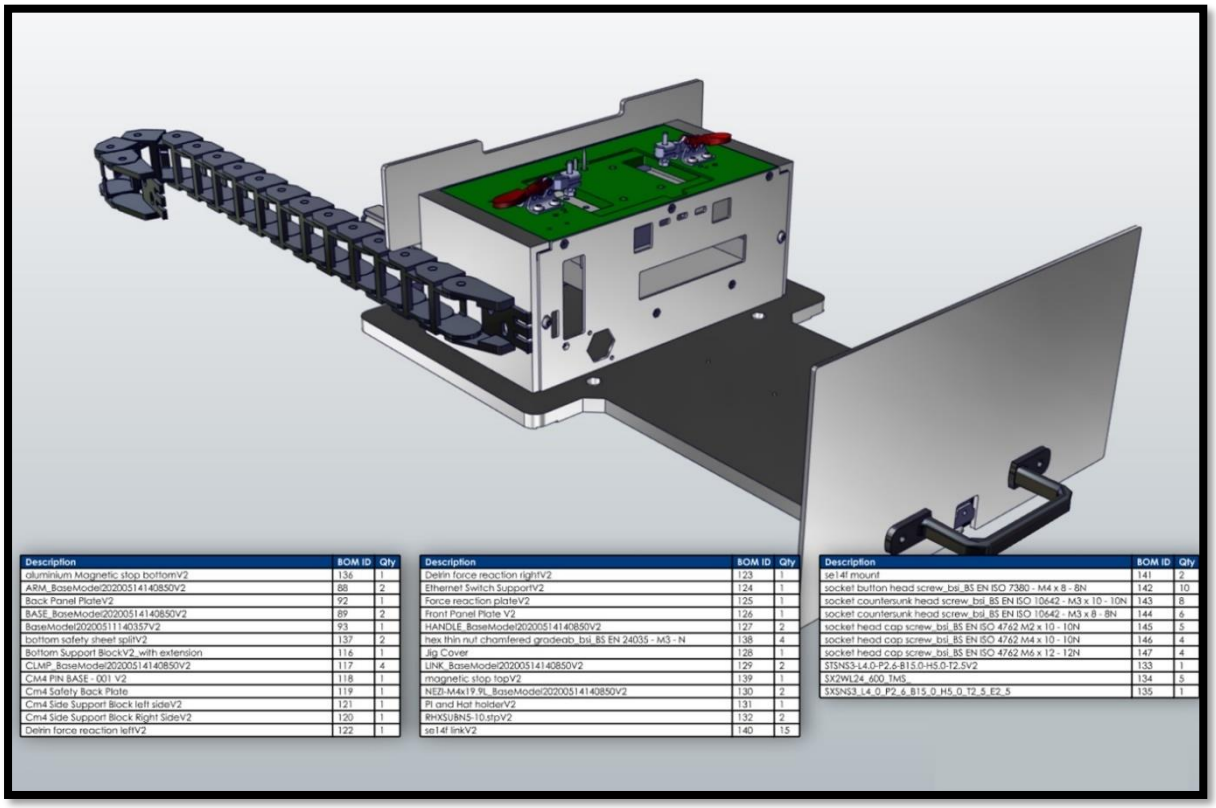


Description	BOM ID	Qty
ARM_BaseModel20200514140850V2	1	2
Back Panel PlateV2	3	1
BASE_BaseModel20200514140850V2	2	2
bottom safety sheet splitV2	20	1
CLMP_BaseModel20200514140850V2	4	4
CM4 PIN BASE - 001 V2	5	1
Cm4 Side Support Block left sideV2	7	1
Cm4 Side Support Block Right SideV2	6	1
Delrin force reaction leftV2	8	1
Delrin force reaction rightV2	9	1
Ethernet Switch SupportV2	10	1
Force reaction plateV2	11	1
Front Panel Plate V2	12	1
HANDLE_BaseModel20200514140850V2	13	2

Description	BOM ID	Qty
hex thin nut chamfered gradeab_bsi_BS EN 24035 - M3 - N	21	4
LINK_BaseModel20200514140850V2	14	2
NEZI-M4x19.9L_BaseModel20200514140850V2	15	2
PI and Hat holderV2	16	1
RHXSUBNS-10.stpV2	17	2
socket button head screw_bsi_BS EN ISO 7380 - M4 x 8 - 8N	22	9
socket countersunk head screw_bsi_BS EN ISO 10642 - M3 x 10 - 10N	23	8
socket countersunk head screw_bsi_BS EN ISO 10642 - M3 x 8 - 8N	24	6
socket head cap screw_bsi_BS EN ISO 4762 M2 x 10 - 10N	25	5
socket head cap screw_bsi_BS EN ISO 4762 M4 x 10 - 10N	26	4
socket head cap screw_bsi_BS EN ISO 4762 M6 x 12 - 12N	27	4
STSNS3-L4.0-P2.6-B15.0-H5.0-T2.5V2	18	1
SXSNS3_L4.0_P2.6_B15.0_H5.0_T2.5_E2.5	19	1



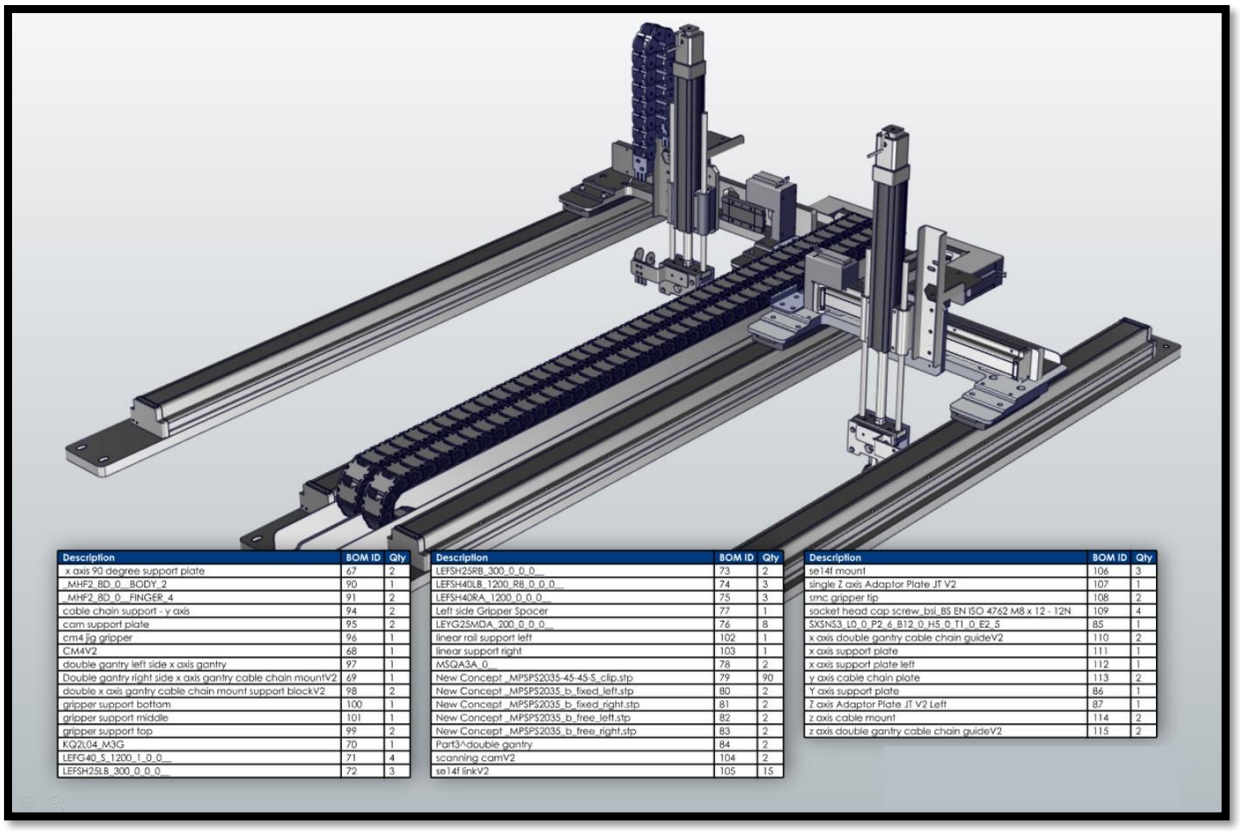
Description	BOM ID	Qty
bottom safety sheet splitV2	20	1
Delrin force reaction leftV2	8	1
Delrin force reaction rightV2	9	1
Force reaction plateV2	11	1
hex thin nut chamfered gradeab_bsi_BS EN 24035 - M3 - N	21	4
PI and Hat holderV2	16	1
RHXSUBN5-10.stpV2	17	2
socket head cap screw_bsi_BS EN ISO 4762 M6 x 12 - 12N	27	4



Description	BOM ID	Qty
aluminium Magnetic stop bottomV2	136	1
ARM_BaseModel20200514140850V2	88	2
Back Panel PlateV2	92	1
BASE_BaseModel20200514140850V2	89	2
BaseModel20200511140357V2	93	1
bottom safety sheet splitV2	137	2
Bottom Support BlockV2_with extension	116	1
CLMP_BaseModel20200514140850V2	117	4
CM4 PIN BASE - 001 V2	118	1
Cm4 Safety Back Plate	119	1
Cm4 Side Support Block left sideV2	121	1
Cm4 Side Support Block Right SideV2	120	1
Delrin force reaction leftV2	122	1

Description	BOM ID	Qty
Delrin force reaction rightV2	123	1
Ethernet Switch SupportV2	124	1
Force reaction plateV2	125	1
Front Panel Plate V2	126	1
HANDLE_BaseModel20200514140850V2	127	2
hex thin nut chamfered gradeab_bsi_BS EN 24035 - M3 - N	138	4
Jig Cover	128	1
LINK_BaseModel20200514140850V2	129	2
magnetic stop topV2	139	1
NEZI-M4x19.9L_BaseModel20200514140850V2	130	2
PI and Hat holderV2	131	1
RHXSUBN5-10.stpV2	132	2
se14f linkV2	140	15

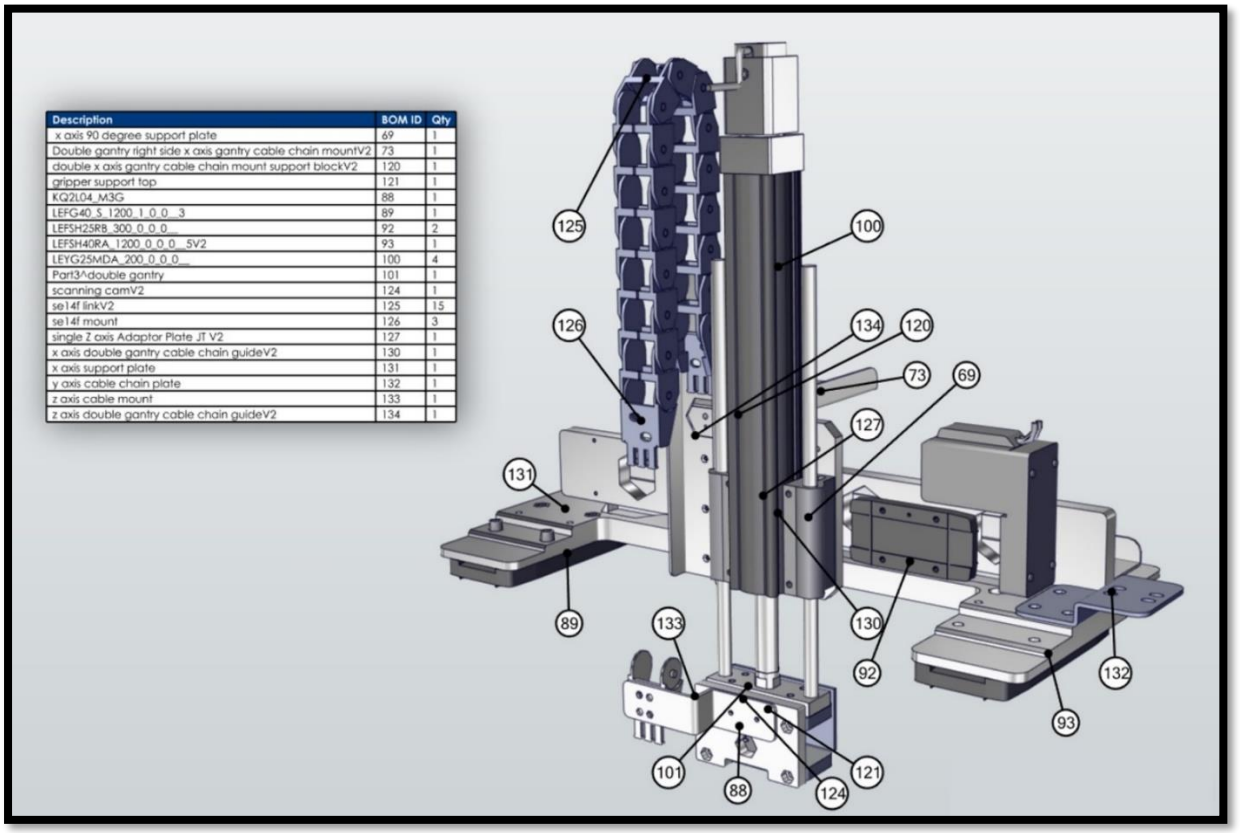
Description	BOM ID	Qty
se14f mount	141	2
socket button head screw_bsi_BS EN ISO 7380 - M4 x 8 - 8N	142	10
socket countersunk head screw_bsi_BS EN ISO 10642 - M3 x 10 - 10N	143	8
socket countersunk head screw_bsi_BS EN ISO 10642 - M3 x 8 - 8N	144	6
socket head cap screw_bsi_BS EN ISO 4762 M2 x 10 - 10N	145	5
socket head cap screw_bsi_BS EN ISO 4762 M4 x 10 - 10N	146	4
socket head cap screw_bsi_BS EN ISO 4762 M6 x 12 - 12N	147	4
STSNS3-L4.0-P2.6-B15.0-H5.0-T2.5V2	133	1
SX2WL24_600_TMS_	134	5
SXSNS3_L4_0_P2_6_B15_0_H5_0_T2_5_E2_5	135	1



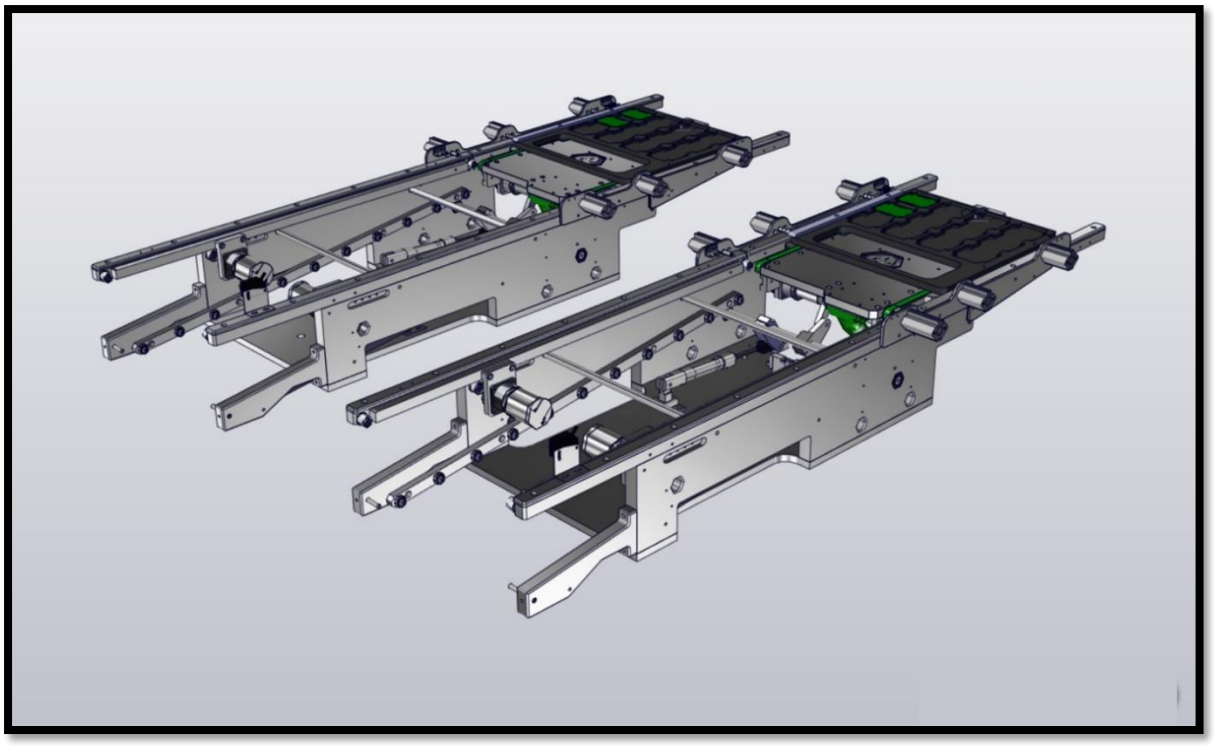
Description	BOM ID	Qty
x axis 90 degree support plate	67	2
_MHF2_8D_0__BODY_2	90	1
_MHF2_8D_0__FINGER_4	91	2
cable chain support - y axis	94	2
cam support plate	95	2
cm4 jig gripper	96	1
CM4V2	68	1
double gantry left side x axis gantry	97	1
Double gantry right side x axis gantry cable chain mountV2	69	1
double x axis gantry cable chain mount support blockV2	98	2
gripper support bottom	100	1
gripper support middle	101	1
gripper support top	99	2
KQ2L04_M3G	70	1
LEFG40_S_1200_1_0_0__	71	4
LEFSH25LB_300_0_0_0__	72	3

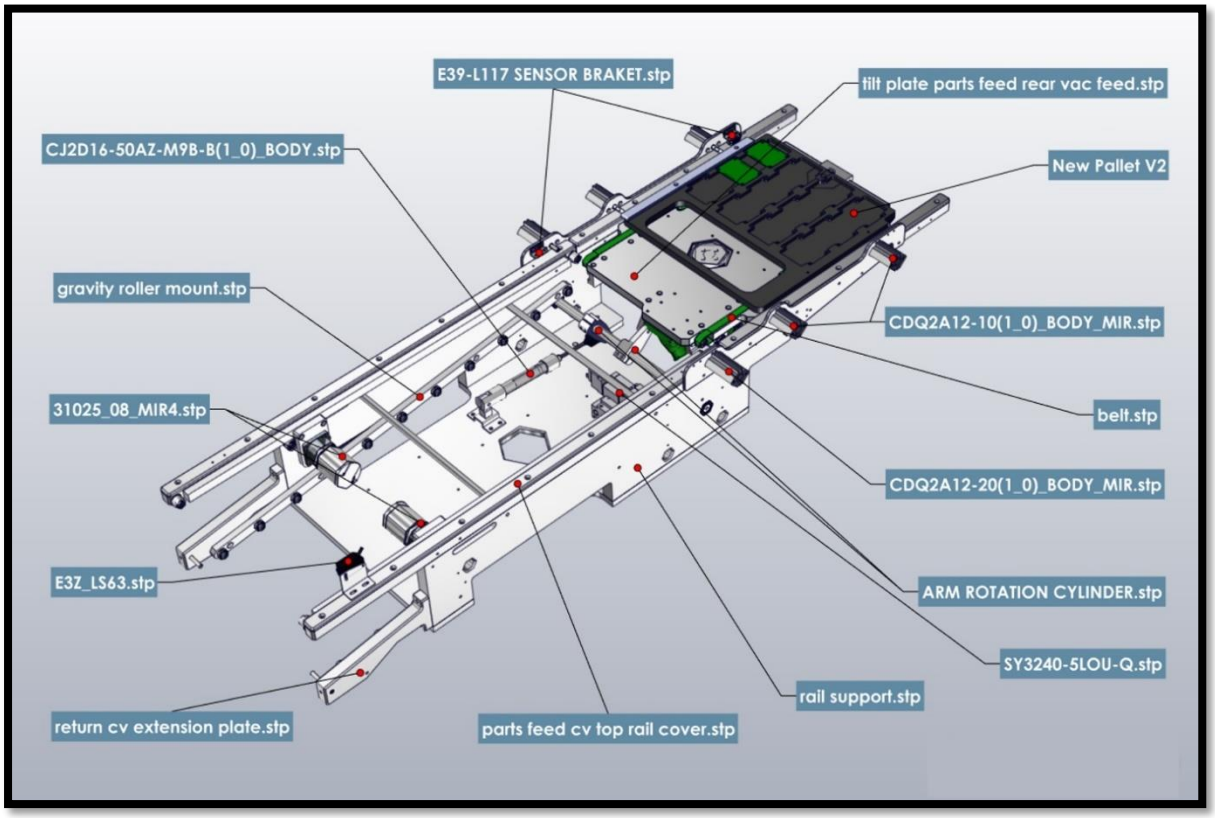
Description	BOM ID	Qty
LEFSH25RB_300_0_0_0__	73	2
LEFSH40LB_1200_R8_0_0_0__	74	3
LEFSH40RA_1200_0_0_0__	75	3
Left side Gripper Spacer	77	1
LEYG25MDA_200_0_0_0__	76	8
linear rail support left	102	1
linear support right	103	1
MSQA3A_0__	78	2
New Concept _MPSPS2035-45-45-S_clip.stp	79	90
New Concept _MPSPS2035_b_fixed_left.stp	80	2
New Concept _MPSPS2035_b_fixed_right.stp	81	2
New Concept _MPSPS2035_b_free_left.stp	82	2
New Concept _MPSPS2035_b_free_right.stp	83	2
Part3^double gantry	84	2
scanning camV2	104	2
se14f linkV2	105	15

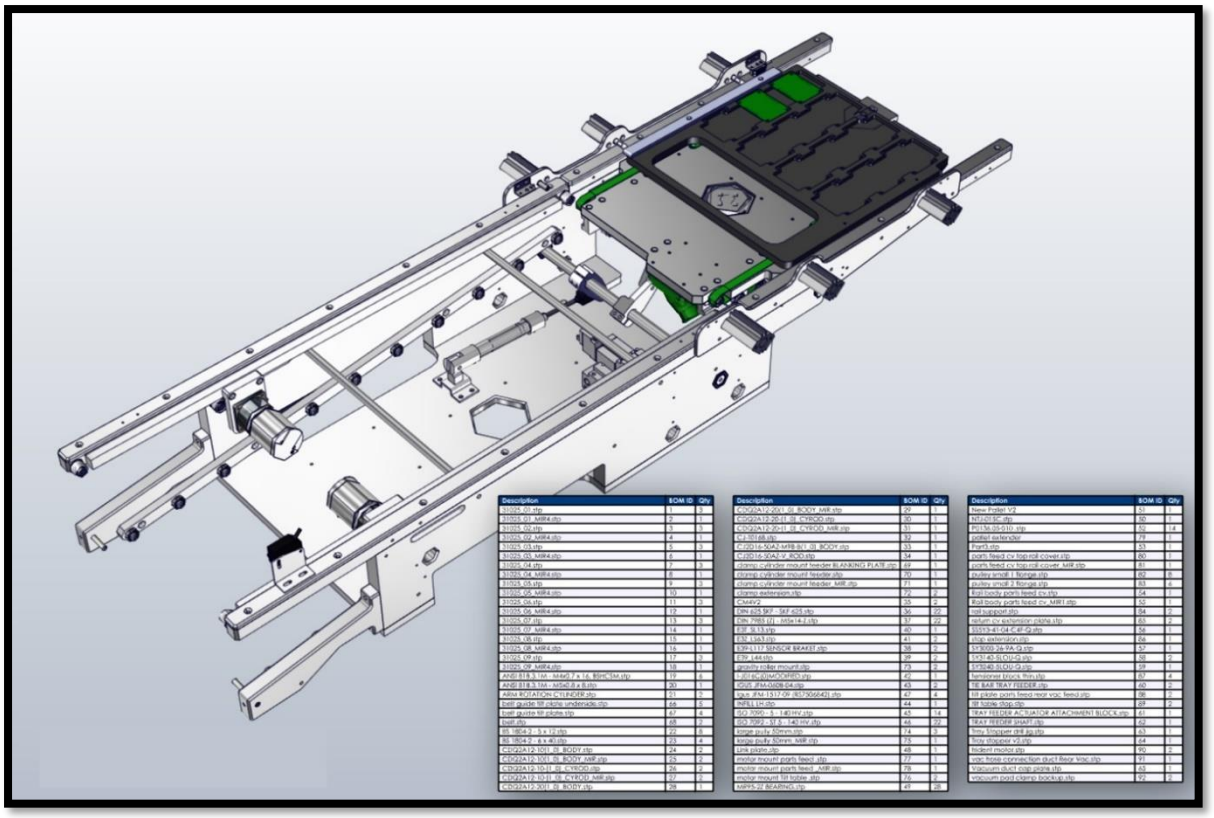
Description	BOM ID	Qty
se14f mount	106	3
single Z axis Adaptor Plate JT V2	107	1
smc gripper tip	108	2
socket head cap screw_bsi_BS EN ISO 4762 M8 x 12 - 12N	109	4
SXSNS3_L0_0_P2_6_B12_0_H5_0_T1_0_E2_5	85	1
x axis double gantry cable chain guideV2	110	2
x axis support plate	111	1
x axis support plate left	112	1
y axis cable chain plate	113	2
Y axis support plate	86	1
Z axis Adaptor Plate JT V2 Left	87	1
z axis cable mount	114	2
z axis double gantry cable chain guideV2	115	2

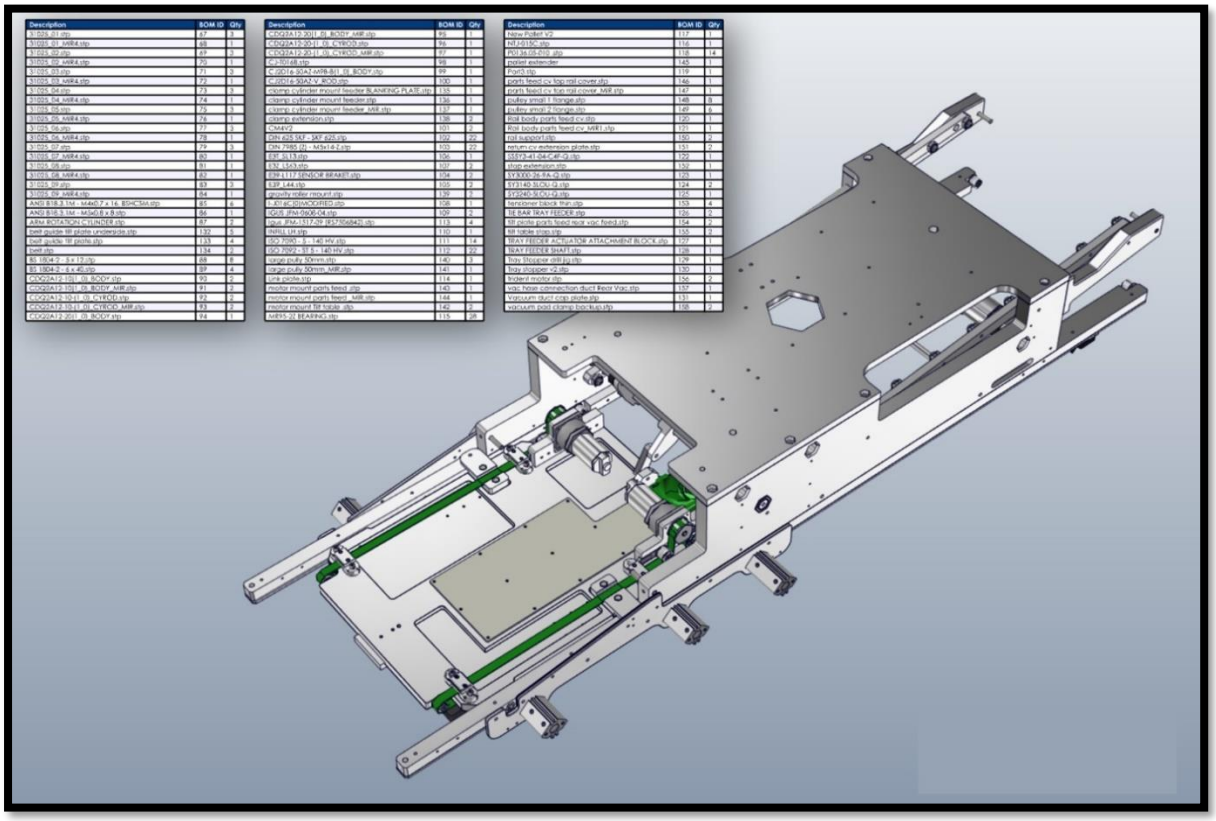


Description	BOM ID	Qty
x axis 90 degree support plate	69	1
Double gantry right side x axis gantry cable chain mountV2	73	1
double x axis gantry cable chain mount support blockV2	120	1
gripper support top	121	1
KQ2L04_M3G	88	1
LEFG40_S_1200_1_0_0__3	89	1
LEFSH25RB_300_0_0_0__	92	2
LEFSH40RA_1200_0_0_0__5V2	93	1
LEYG25MDA_200_0_0_0__	100	4
Part3^double gantry	101	1
scanning camV2	124	1
se14f linkV2	125	15
se14f mount	126	3
single Z axis Adaptor Plate JT V2	127	1
x axis double gantry cable chain guideV2	130	1
x axis support plate	131	1
y axis cable chain plate	132	1
z axis cable mount	133	1
z axis double gantry cable chain guideV2	134	1

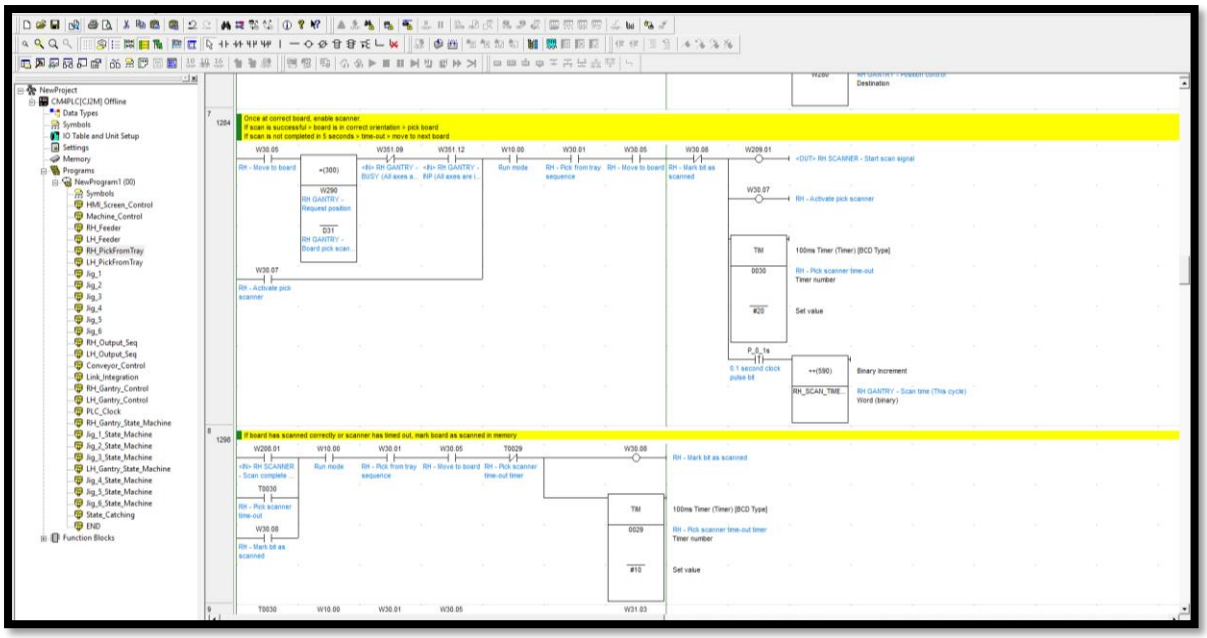


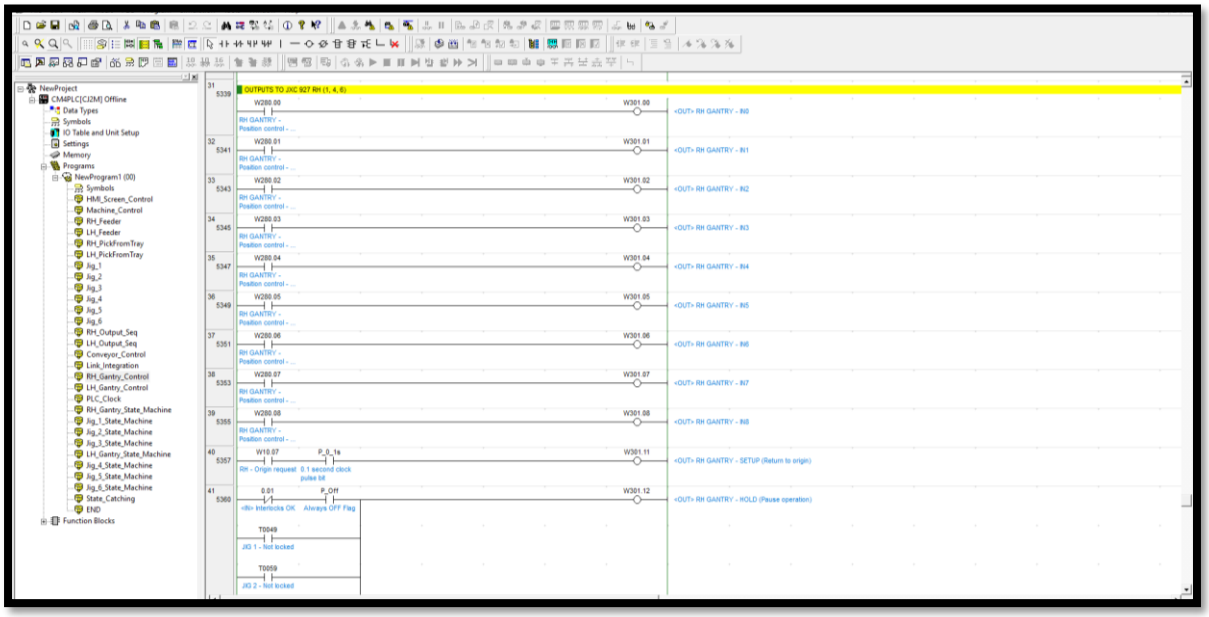

E39-L117 SENSOR BRAKET.stp
tilt plate parts feed rear vac feed.stp
CJ2D16-50AZ-M9B-B(1_0)_BODY.stp
New Pallet V2
gravity roller mount.stp
CDQ2A12-10(1_0)_BODY_MIR.stp
31025_08_MIR4.stp
belt.stp
CDQ2A12-20(1_0)_BODY_MIR.stp
E3Z_LS63.stp
ARM ROTATION CYLINDER.stp
SY3240-5LOU-Q.stp
rail support.stp
return cv extension plate.stp
parts feed cv top rail cover.stp

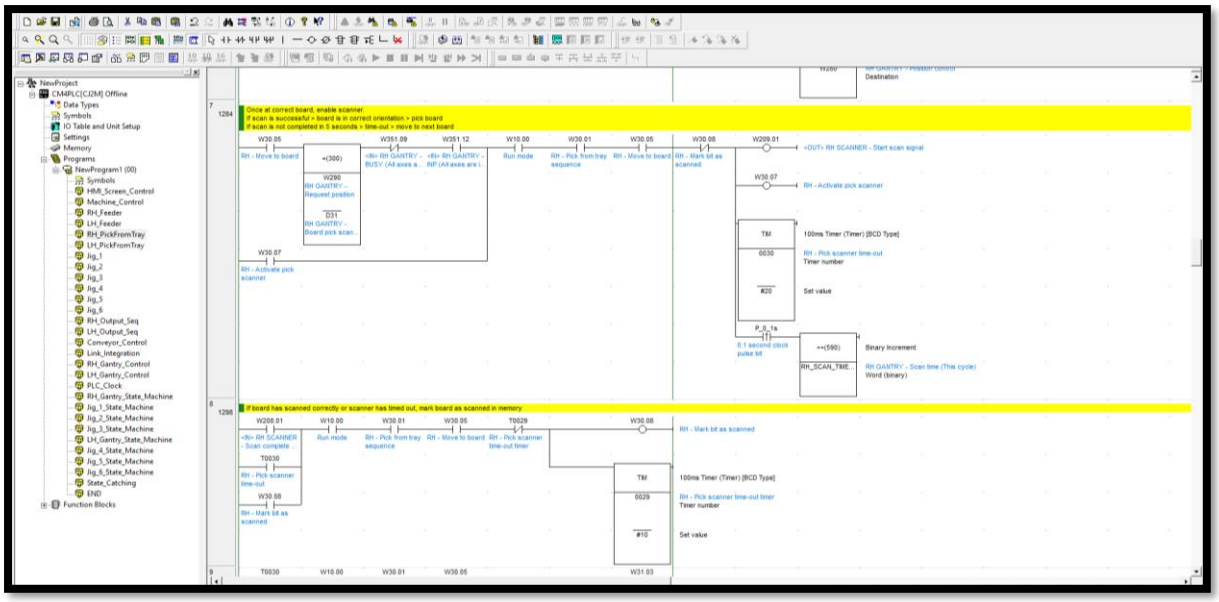


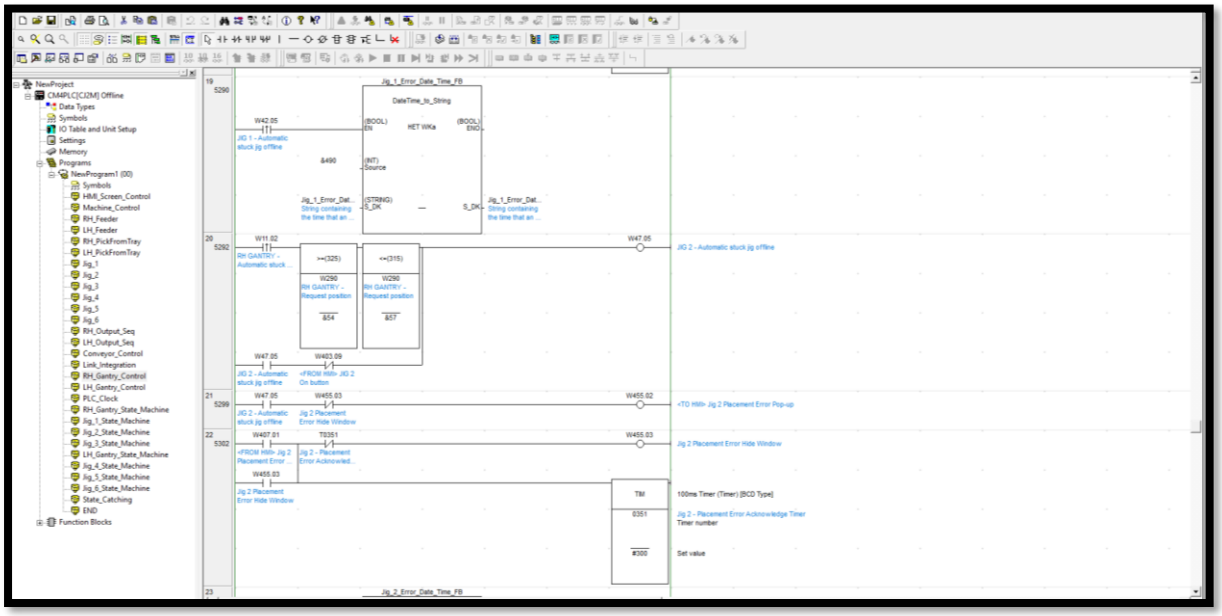


Appendix Eight – PLC Program Examples

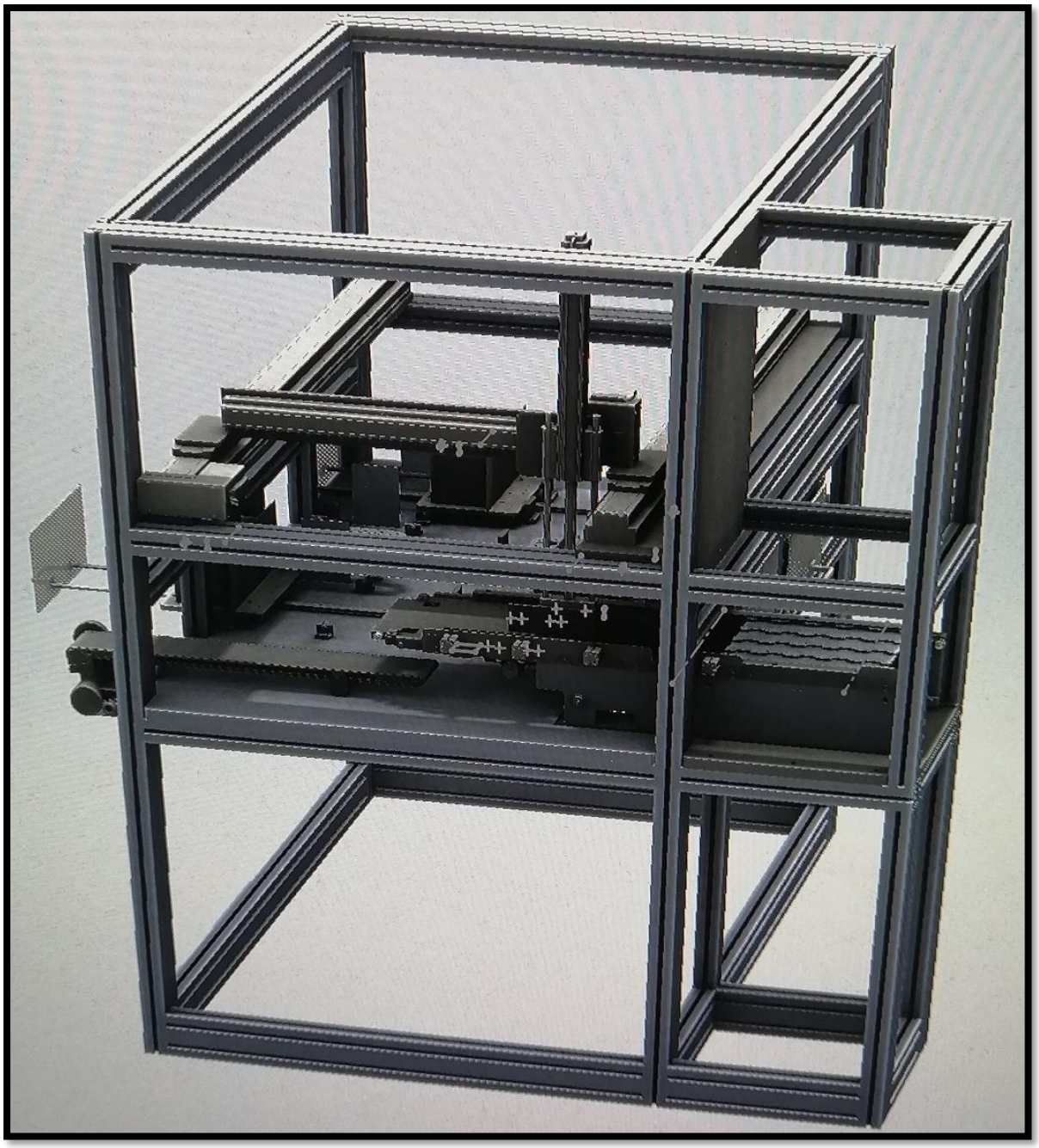








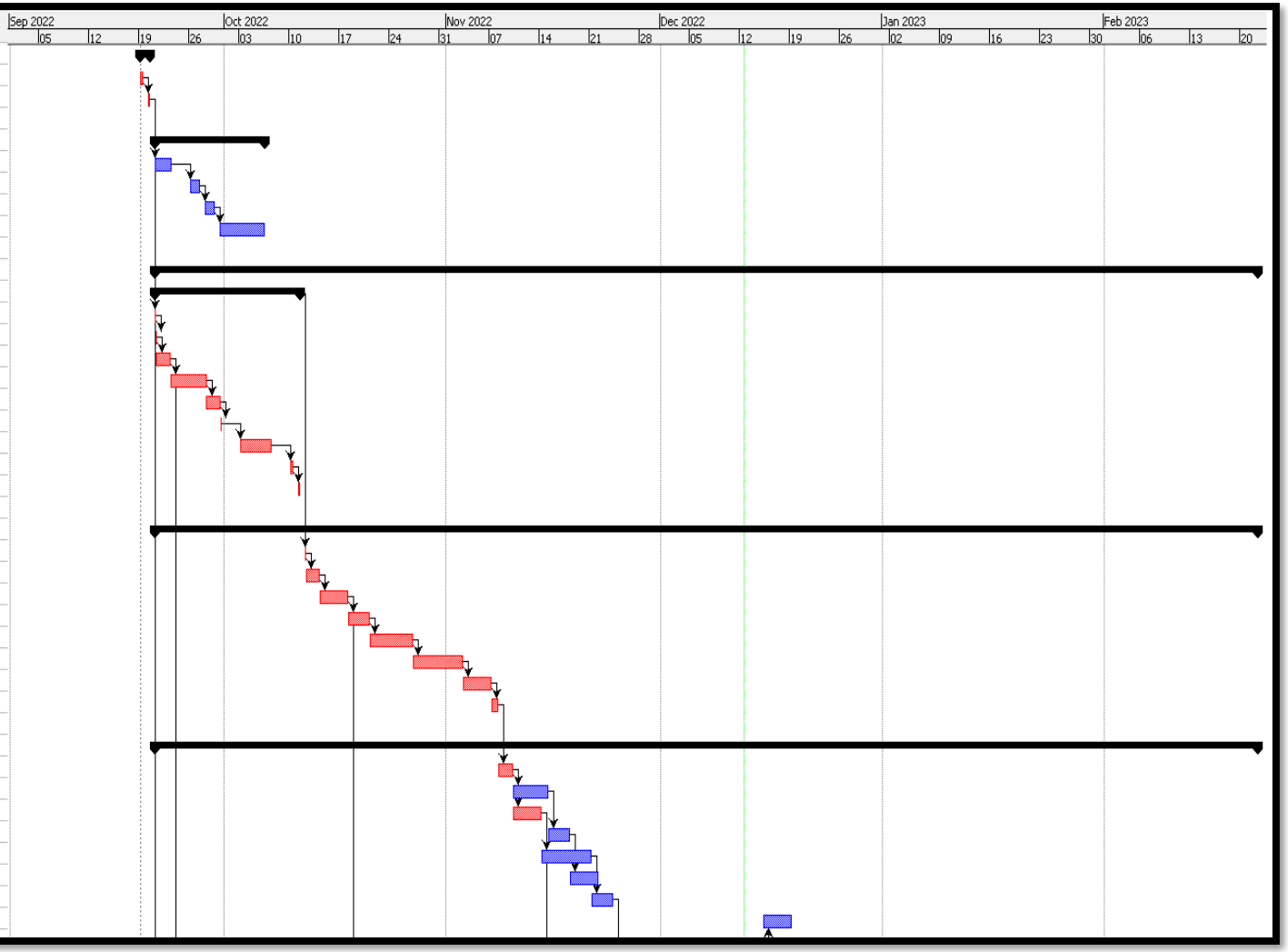
Appendix Nine – Single Gantry System Design



This concept is for a single Gantry system with 6 Test Jigs, One Output system (Conveyor) and one Input system (Feeder system).

Appendix Ten – Gantt Chart (Project Timeline)

	Name	Duration	Start	Finish
1	**Design Plan**	2 days	**19/09/22 08:00**	**20/09/22 17:00**
2	Understand the Problem	1 day	19/09/22 08:00	19/09/22 17:00
3	Create Design Specification for Design Brief	1 day	20/09/22 08:00	20/09/22 17:00
4	**Research**	12 days	**21/09/22 08:00**	**06/10/22 17:00**
5	Investigate Automations Impact on the UK Economy	3 days	21/09/22 08:00	23/09/22 17:00
6	Inviestigate Automation Perception	2 days	26/09/22 08:00	27/09/22 17:00
7	Investigate Design Methodologies	2 days	28/09/22 08:00	29/09/22 17:00
8	Investigate Various Automation Machinery and Mechanism	5 days	30/09/22 08:00	06/10/22 17:00
9	**Development**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
10	**Test Jigs**	15 days	**21/09/22 08:00**	**11/10/22 17:00**
11	Design Pinbed for testjig pins	0.25 days	21/09/22 08:00	21/09/22 10:00
12	Design Cradle for Board	0.25 days	21/09/22 10:00	21/09/22 13:00
13	Design Testjig Frame/Housing	2 days	21/09/22 13:00	23/09/22 13:00
14	Create Engineering Drawings	3 days	23/09/22 13:00	28/09/22 13:00
15	Create Protoype using 3D printing	2 days	28/09/22 13:00	30/09/22 13:00
16	Test Prototype	0.5 days	30/09/22 13:00	30/09/22 17:00
17	Mass Manufacturing order	5 days	03/10/22 08:00	07/10/22 17:00
18	Assemble Jig	1 day	10/10/22 08:00	10/10/22 17:00
19	Final Test of Jig	1 day	11/10/22 08:00	11/10/22 17:00
20	**Feeder System**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
21	Design Pallet	0.25 days	12/10/22 08:00	12/10/22 10:00
22	Design Feeder Mechanism	2 days	12/10/22 10:00	14/10/22 10:00
23	Design Feeder Frame	2 days	14/10/22 10:00	18/10/22 10:00
24	Create Engineering Drawings	3 days	18/10/22 10:00	21/10/22 10:00
25	Create Prototype from Onsite Manufacturing	4 days	21/10/22 10:00	27/10/22 10:00
26	Mass Manufacturing Order	5 days	27/10/22 10:00	03/11/22 10:00
27	Assemble Feeder System	2 days	03/11/22 10:00	07/11/22 10:00
28	Test	1 day	07/11/22 10:00	08/11/22 10:00
29	**Gantry System**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
30	Investigate Linear Actuators for High Tolerances & Spe	2 days	08/11/22 10:00	10/11/22 10:00
31	Design Componets to Connect Gantry Togther	3 days	10/11/22 10:00	15/11/22 10:00
32	Design End Effector	2 days	10/11/22 10:00	14/11/22 10:00
33	Create Engineerings Drawings for Components	3 days	15/11/22 10:00	18/11/22 10:00
34	Order Components Required	5 days	14/11/22 10:00	21/11/22 10:00
35	Create Prototype for Gripper End Effector	2 days	18/11/22 10:00	22/11/22 10:00
36	Assemble Gantry System	3 days	21/11/22 10:00	24/11/22 10:00
37	Test	2 days	15/12/22 10:00	19/12/22 10:00



38	**Power Panel**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
39	AutoCad Design of Electrical System	5 days	21/09/22 08:00	27/09/22 17:00
40	Order Panel with Dimensions Suitable for Design	5 days	28/09/22 08:00	04/10/22 17:00
41	Wire Electrical Panel	5 days	05/10/22 08:00	11/10/22 17:00
42	**Output System**	63.25 days	**21/09/22 08:00**	**19/12/22 10:00**
43	Design Output System for Tested Prodcut (Passed	2 days	21/09/22 08:00	22/09/22 17:00
44	Order Components Required	10 days	23/09/22 08:00	06/10/22 17:00
45	Assemble Output System	2 days	07/10/22 08:00	10/10/22 17:00
46	Test	2 days	15/12/22 10:00	19/12/22 10:00
47	**Control Panel**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
48	Create Input/Output List based on Mechanical Desi	1 day	28/09/22 08:00	28/09/22 17:00
49	Design Prototype PLC Programme	15 days	24/11/22 10:00	15/12/22 10:00
50	Test Intial Programme with Various Systems	5 days	15/12/22 10:00	22/12/22 10:00
51	Implement programme into machine	0.1 days	05/01/23 10:00	05/01/23 10:48
52	**Pneumatic Panel**	5.5 days	**24/11/22 10:00**	**01/12/22 15:00**
53	Design Pneumatic Layout	0.5 days	24/11/22 10:00	24/11/22 15:00
54	Order Pneumatic Components	3 days	24/11/22 15:00	29/11/22 15:00
55	Assmble Pneumatics	1 day	29/11/22 15:00	30/11/22 15:00
56	Test	1 day	30/11/22 15:00	01/12/22 15:00
57	**Frame**	110.5 days	**21/09/22 08:00**	**22/02/23 13:00**
58	Design Frame with CAD	2 days	21/09/22 08:00	22/09/22 17:00
59	Intergrate Feeder System into Design	2 days	18/10/22 10:00	20/10/22 10:00
60	Integrate Gantry System into Design	2 days	14/11/22 10:00	16/11/22 10:00
61	Integrate Jigs into Design	2 days	23/09/22 13:00	27/09/22 13:00
62	Design Bulkheads for Stability	0.25 days	14/11/22 10:00	14/11/22 13:00
63	Design Mounting Plates	0.5 days	14/11/22 13:00	14/11/22 17:00
64	Design Entry Points for Maintenance	0.5 days	15/11/22 08:00	15/11/22 13:00
65	Create Engineering Drawings	5 days	15/11/22 13:00	22/11/22 13:00
66	Order Frame and Manufacutred Components	15 days	22/11/22 13:00	13/12/22 13:00
67	Assemble Frame	15 days	13/12/22 13:00	03/01/23 13:00
68	**Machine Assembly**	11 days	**03/01/23 13:00**	**18/01/23 13:00**
69	Install Gantry System into Frame	3 days	03/01/23 13:00	06/01/23 13:00
70	Install Feeder System into Frame	2 days	06/01/23 13:00	10/01/23 13:00
71	Install Test Jigs into Frame	2 days	10/01/23 13:00	12/01/23 13:00
72	Install Output System into Frame	2 days	12/01/23 13:00	16/01/23 13:00
73	Install all Required Input Sensors into Frame	2 days	16/01/23 13:00	18/01/23 13:00
74	Install all Required Scanners into Frame for Pro	1 day	03/01/23 13:00	04/01/23 13:00
75	Install Power Panel Into Frame	0.5 days	03/01/23 13:00	03/01/23 17:00
76	Install Control Panel Intro Frame	0.5 days	04/01/23 08:00	04/01/23 13:00
77	Install Pneumatics into Frame	0.5 days	04/01/23 13:00	04/01/23 17:00
78	Install PCs Into Frame	0.25 days	05/01/23 08:00	05/01/23 10:00
79	**Machine Testing & Commisioning**	25 days	**18/01/23 13:00**	**22/02/23 13:00**
80	Test Various Systems with Product	5 days	18/01/23 13:00	25/01/23 13:00
81	Test Machine as a Whole (Test Redundancy)	5 days	25/01/23 13:00	01/02/23 13:00
82	Integrate Machine into the Production Line	5 days	01/02/23 13:00	08/02/23 13:00
83	Test Machine insitu	5 days	08/02/23 13:00	15/02/23 13:00
84	Gather Data for Machine	5 days	15/02/23 13:00	22/02/23 13:00

