

Improving the Z-Axis Straightness Verification on RenAM 500



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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: R.HARRIS

Date: 19/05/2024

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I would like to express gratitude to several individuals and groups who have been pivotal in the completion of this project.

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Abstract

This work details a project that addresses the ergonomic concern of the current verification method used in the Z-Axis assembly prior to its fitment and use in the RenAM 500 additive manufacturing machine. The primary aim of the project was to develop a test rig that would automate the testing procedure and verify the assembly's straightness within a 0.1mm tolerance across the build volume.

The project detailed, successfully met all outlined objectives designing and building a test rig that was compatible with the current mode of Z-Axis assembly transportation, ensuring ease of transport. The testing procedure for verifying straightness utilises the fitted servo drive to drive the motor as opposed to the original method of using a handheld drill. The rig was made user friendly, repeatable, and eventually CE compliant for safe operator use.

The project was completed within the budget set which was ensured by the effective salvaging of parts from the obsolete RenAM 250 machines. The project also contains research embedded throughout which helped to steer the projects direction. Relevant design techniques were utilised in the conception of the rig, as well as evaluation techniques used to distinguish the best concept to take forward. The concept was mocked in Siemens NX a computer aided design software to ensure the functionality.

The report also details a full bill of materials breakdown for the rig, an in depth return on investment and financial calculations for the rig's introduction, and images of the physical rig build. To verify the rigs testing procedure a gauge R&R study was performed, ensuring that the new rig could verify straightness to an acceptable tolerance.

Glossary

PMI	Preventative Maintenance Schedule
ASG	Assembly Systems Group
CPD	Current Products Division
MSD	Manufacturing Services Division
AMPD	Additive Manufacturing Product Division
AM	Additive Manufacturing
RSI	Repetitive Strain Injury
DTI	Dial Test Indicator
ULD	Upper Limb Disorder
EUC	Equipment Under Consideration
QFD	Quality Function Deployment
HOQ	House Of Quality
VOC	Voice Of the Customer
HMI	Human Machine Interface
PLC	Programmable Logic Controller
ROHS	Restriction of Hazardous Substances
WEEE	Waste Electrical and Electronic Equipment
CAD	Computer Aided Design
MJF	Multi Jet Fusion (3D Printing)
BOM	Bill of Materials
ROI	Return on Investment
R&R	Gauge Repeatability and Reproducibility
HSE	Health and Safety Executive

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1. Project Aim

The aim of the following project was to develop a Z-Axis Alignment Rig that addressed the ergonomic concern with the verification of the Z-Axis assembly. The Z-Axis Alignment Rig was to verify the assembly's straightness to the 0.1mm tolerance over 250mm of its build volume. This rig ensured the automation of the testing procedure and verified successful functionality of the Z-Axis Assembly within the RenAM 500 additive manufacturing machine.

2. Objectives

- Design, build, and implement a test rig for the testing of the Z-Axis assembly's straightness prior to its installation into the chamber during assembly and maintenance, ensuring capability with the current Z-Axis trolley used for transporting the Z-Axis assembly within Cell 1.
- Develop the testing process for verifying the straightness of the build plate as it moves down the build volume, ensuring utilisation of the fitted motor to drive the Z-Axis assembly up and down.
- The rig needs to be user friendly, repeatable, safe, meet all CE compliance standards that must be fully documented.
- Complete the physical test rig by 17/06/2024, with the final deadline targeted for 02/07/2024.
- Stay within the £5000 budget, with high emphasis on salvaging components from obsolete RenAM250 machines.
- Ensure that the rig has safety labelling including company name, serial number, safety warnings, and CE mark upon successful completion of all necessary documentation.
- The rig must be easily maintainable with a Preventative Maintenance Instruction (PMI) to ensure trained technicians can carry out the required work.

3. Report Structure

The following report is structured to provide a comprehensive overview of research conducted. Starting with an introduction, detailing the background information and context of the project. Then following onto sections that discuss the company and authors role. The background information includes details of the product RenAM 500, it's assembly line structure and utilisation of Kanban. The exploration of cost per cell is discussed leading into problem analysis and the drafted project charter. The problem overview delves into the specific areas of the project identifying the Z-Axis assembly, it's purpose and the importance of maintaining critical straightness. Methods of transporting the assembly and it's testing procedure are addressed looking at the inherent repetitive strain injury concern. The overview section presents the projects design brief, specification, and requirements specific to the customer needs of the test rig being implemented. Details of the projects timing plan are discussed along with what had to change to successfully deliver the project. A section details the methodology behind the rig build as well as results of a gauge R&R study finally leading into the recommendations for future improvement. It is important to note that this report has detailed research embedded throughout which helped to influence the projects direction.

4. Introduction

4.1. Company

Renishaw was founded in 1973, the first product that the company marketed was touch trigger probing for precise inspection of the Olympus engines at Rolls Royce (Renishaw, 2024). Renishaw is a worldwide leader within the metrology, encoders, and machine tool sector of industry. Sectors that Renishaw supply to include research, healthcare and additive manufacturing as shown in Figure 1. Renishaw has a massive global presence with 81 locations across 36 countries (Renishaw, 2024). UK sites are utilised to conduct most of the research and development on new products as well as the manufacturing of products.



Figure 1 - Renishaw's Key Products (Renishaw, 2020)

4.2. Authors Role

The author assumes the role of Senior Process Development Technician within the Assembly Systems Group (ASG) of the company. ASG operates as a pivotal group responsible for the development of test rigs and process automation for the Current Products Division (CPD). Comprising of expertise in electronic, software, automation, and mechanical design, ASG operates within the broader framework of the Manufacturing Service Division (MSD).

While ASG does not own the manufacturing processes, its primary function revolves around furnishing assembly solutions and test rigs that facilitate the manufacturing process that is controlled by the production teams. ASG extends support and expertise where required when there are breakdowns on the assembly lines that cannot be solved by the production engineers.

5. Background Information

AMPD (Additive Manufacturing Product Division) has recognised the importance of optimizing the assembly process for the RenAM 500 additive manufacturing machine variant. As a new product, there are plenty of opportunities for process improvements. ASG has been drafted to explore potential enhancement projects, with the aim of refining the assembly procedures and build efficiency of the RenAM 500.

5.1. RenAM 500

The RenAM 500 is a metal additive manufacturing machine commonly known as a 3D printer. Renishaw is one of the world leaders of this technology. According to Renishaw (2024) Additive manufacturing creates a three-dimensional part from a digital file. Fine layers of metal powder are deposited in the machines build plate and sintered using laser to create complex parts. These complex parts cannot be produced with more traditional manufacturing methods such as casting and machining.



Figure 2 - RenAM 500M

As documented in Renishaw's half-year financial results (6 months to 31st December 2023), the Additive Manufacturing Product Division (AMPD) were responsible for £46 million of the £330.5 million profit during this financial period. This equates to almost 14% of the overall business. The financial report also explains that there are strong order books for the second half of the financial year. Satisfying customer orders to standards set is critical in the successful delivery of this crucial product. The current rate of production for this product is two machines per week. Machines can often cost at the maximum £1 million with additional service package at £50,000.

5.2. Assembly Line Structure

This section provides insight into the assembly line structure for the RenAM 500 machine, offering a clear visualisation of the assembly process and line structure. As shown in Figure 3, particular attention must be given to Cell 1 as this is the cell dedicated to the verification of the Z-Axis assembly. This project looks to enhance the verification process of the Z-Axis assembly making the build process more efficient. The RenAM 500 additive machine manufactured at Renishaw Miskin site in South Wales follows a structured assembly line that comprises of six main assemblies:

Cell 1: This assembly cell focuses on the mechanical build components of the chamber.

Cell 2: This assembly cell deals with the electrical aspect of the chamber.

Cell 3: Here, the electrical module is manufactured and fitted.

Cell 4: This assembly involves the construction and fitment of the filter and pump components.

Cell 5: The pumps assembly is fully completed and fitted.

Cell 6: This assembly cell focuses on the gas and laser fitment.

Additionally, the assembly process includes three commissioning phases:

Cell 7: This phase involves the initial commissioning of the machine, known as the 'dry commission'.

Cell 8: At this stage all the wrap panels are fitted once happy with the initial commission in Cell 7. Cell 8 is split across the gangway as shown in Figure 3 this is due to the allowable space that the line occupies within the factory.

Cell 9: Final Commission known as 'wet' commission, this is where the machine's hopper is loaded with metal powder and a build is completed to ensure the machines functionality before shipment to the customer.

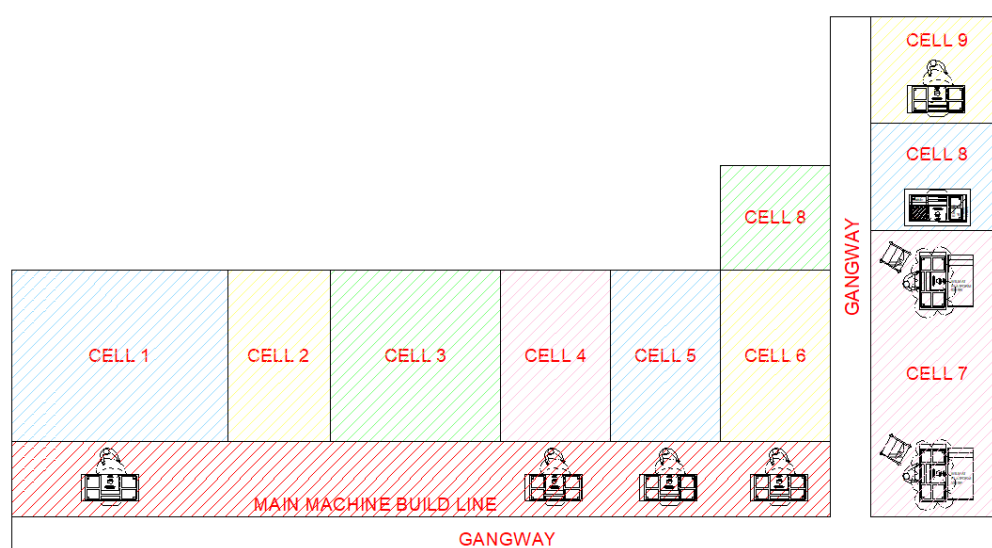


Figure 3 - RenAM 500 Assembly Line (Top Level)

These six assemblies as well as the commissioning phase of the machine build all have individual cells in which the sub-assemblies are made. These are added to the machine as it is progressed down the assembly line.

5.2.1. Kanban System

Understanding the assembly line structure and tactics is crucial when looking at improvements and making changes to equipment. This insight allows one to assess how the introduction of improvements may disrupt workflow and production efficiency. This section looks at how the RenAM 500 assembly line operates following principles of the Kanban system. It is essential that the intended Rig does not disrupt this way of working. Kanban is a lean manufacturing system that controls material flow using visual signals. According to Rahman (2013) it is an important strategy as it:

- Manages inventory by reducing excess stock.
- Provides visual cues for workflow management.
- Allows for flexible production adjustments.
- Encourages continuous improvement.
- Enhances communication and coordination.

Kanban improves efficiency, reduces waste, and supports better production management.

The RenAM 500 line is modelled around the principles of Kanban 'pull' system. Like the automotive manufacturing process. Parts are supplied through sub-assembly boxes located at the back of each cell. These sub-assemblies are then produced by the operators and added to the main machine assembly as it progresses down the line.

Each sub-assembly box is marked with a cross and a tick at respective ends of the box. Once emptied, operators place the boxes back on the shelf with the cross-facing outwards. This acts as a signal for the 'kitters' (operators that pick parts from shelves to create sub assembly kits) to re-kit these boxes. This ensures a continuous flow of parts preventing any production delays. This system enhances efficiency and ensures that the assembly process remains smooth and uninterrupted. This is useful for the project as the intended rig must be positioned to ensure that once the Z-Axis assembly is built, there is a smooth transition to the rig for the straightness test.

5.3. Exploring Breakdown Cost Per Cell

When investigating opportunities for process improvement, ASG explored the downtime per cell. AMPD log all line breakdowns on Syteline an internal database used to log production issues. This allowed ASG to refer to the log to help steer project direction. The results are outlined below:

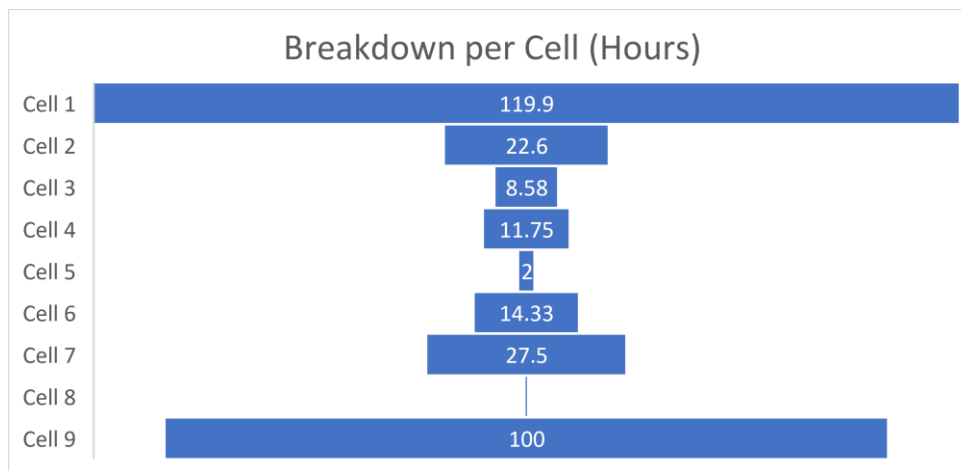


Figure 4 - Breakdown per Cell

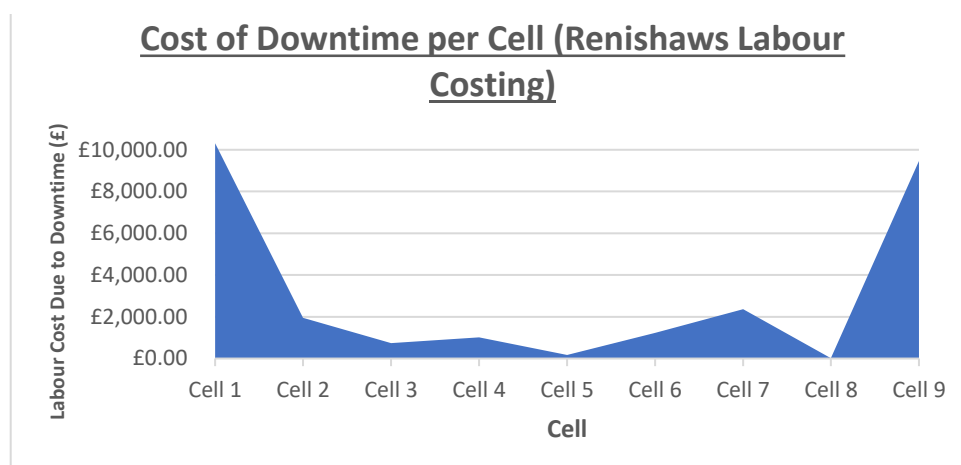


Figure 5- Cost per Cell

Having reviewed the results it was clear that Cell 1 was the highest contributor to downtime across the assembly line. The total amount of downtime recorded was approximately 120 hours. Renishaw as a company price labour at £86 per hour, the total downtime incurred in Cell 1 was approximately £10,320 in lost labour alone. It is apparent from Figure 5 that Cell 9 is also a cause for concern.

In terms of financial repercussions due to missing orders, MSD as a division avoid direct financial penalties, this is due to product distributed to subsidiaries for sale to clients outside of the UK. However, the primary penalty for AM lies in the loss of business opportunity, which can potentially result in significant losses of up to £1 million if failing to sell a machine due to lateness or delay. Moreover, there are further losses associated with the servicing package for the machine, which over the course of a year could amount to as much as £50,000. Furthermore, given that most of AM customers purchase multiple machines, the cumulative impact over a 3–5-year period could be 2 to 5 additional machines worth of lost revenue (Taylor, 2024).

The project team (Outlined on Page 13) quickly identified cell 1 as the biggest potential saving in downtime. Upon further investigation, there was also an RSI (Repetitive Strain Injury) concern related

to the current Z-Axis verification process. Even though cell 1 was identified as having the highest potential for improvement along with Cell 9, the RSI complaint signifies serious risk to operators' health, according to the Judicial Board Guidelines, historical cases of work-related repetitive strain injuries have averaged claims of £18,000 per case (Express Solicitors, 2023).

Implementing enhancements should not only prioritise operational efficiency but also employee well-being and compliance with health and safety regulations. Implementing ergonomic enhancements to the Z-Axis straightness verification process in cell 1 not only improves operational efficiency but also addresses the RSI complaint, effectively accomplishing dual objectives with a singular effort.

5.4. Problem Analysis

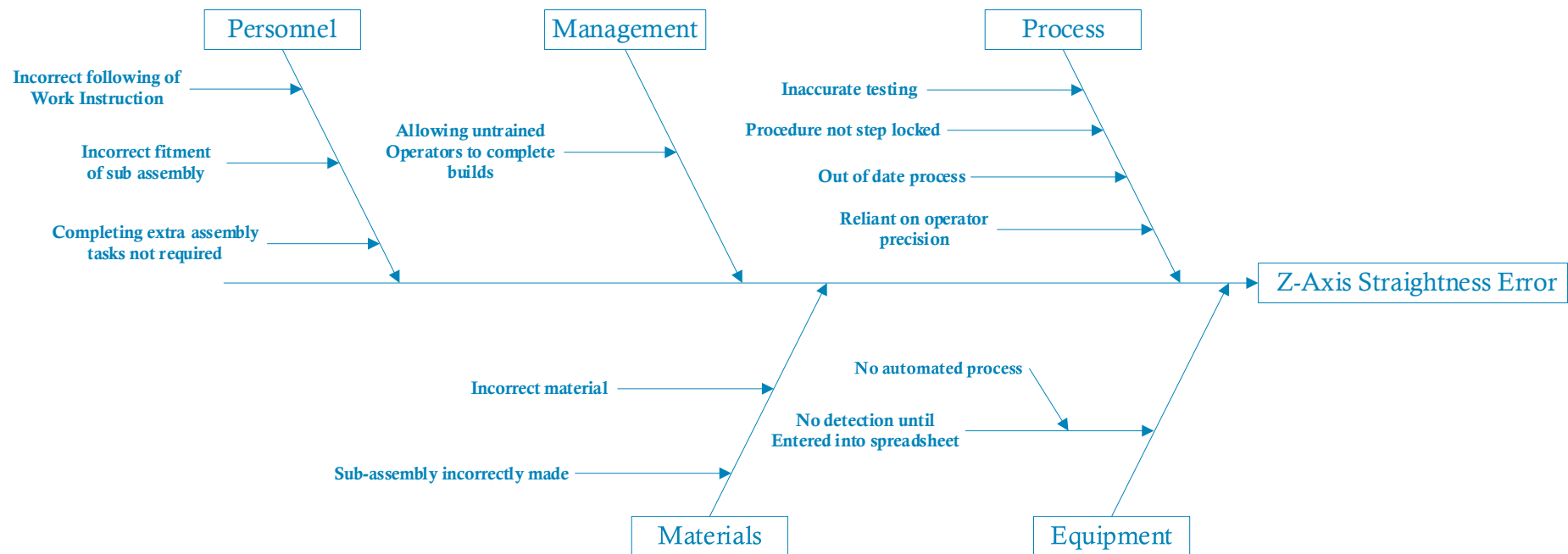


Figure 6 - Ishikawa (Fish Bone) Diagram

After recognizing the need for enhancement of the current Z-Axis straightness verification process within Cell 1, attributed to both downtime and RSI concerns, it became essential to analyze the causes and effects of Z-Axis straightness errors as shown in Figure 6. These errors not only incur downtime but heighten the risk of delayed orders. An Ishikawa diagram also known as a fish bone diagram is a quality management tool that helps improve the quality of products by identifying root causes. As Luca (2019) explains, increasing competitiveness has generated a new industry model, where quality is considered a key factor for progress. The fishbone diagram is an appropriate general representation to explore categorise, clearly and simply, the potential root cause of a problem (Coccia, 2018). For this problem it has helped the project team in laying out clearly issues that result in unwanted Z-Axis straightness errors.

5.5. Project Charter

An important step in undertaking any project is to identify resource. A project charter was crucial in defining purpose, scope, and key stakeholders. The project charter shown in Table 1 was the result of a team meeting to establish a clear roadmap for the projects execution. As McIntyre (2021) describes, the main purpose of the project charter is to describe the project and give the project manager and team the authority to begin utilizing the program resources and allocated funds.

Drafting the project charter with the project team and stakeholders ensures that all members agree with the project outcomes. The stakeholder's influence is the strongest at the project's conception, once the projects aims and objectives are set then stakeholder engagement drops as alteration becomes unprofitable IPG (2023).

Project Charter: Chamber Module Assembly – Z-Axis	
Process Name & Purpose: Z-Axis test - This is where the Z-Axis is tested for straightness before it is fitted back on to the machine. This process is not only time consuming but is also a health and safety concern from an ergonomics point of view. The operator will manually move the Z-Axis down in 10mm increments down to -250mm taking a rough reading form the DTI, with another operator driving the Z-Axis down using a handheld drill.	Process Owner: Paul Gay
	Workshop Leader: Leigh Taylor / Karl Rees
Process Boundaries: Starting Point: Z-Axis is assembled and tested in Cell 1 Ending Point: Fitted to the chamber before moving along to Cell 2	Team Members: Line operators - For expertise of the process Ryan Harris / Michael Cheeseman - Mechanical design Paul Gay / Ryan Harris - Documentation Alun Lloyd / Michael Cheeseman - Programming Alun Lloyd / Michael Cheeseman / Mark Sailes - Electrical Design
Process Sponsor: Leigh Taylor (Line Manager) Paul Richards (Assembly Development Manager)	Process Sponsor Expectations: To remove the need to use a handheld drill to move the build plate through the build volume of the Z-Axis assembly. Along with the verification of both the X and Y axis simultaneously, automating the verification process as much as possible.
Resource Team: Line operators - For expertise of the process Ryan Harris / Michael Cheeseman - Mechanical design Paul Gay / Ryan Harris - Documentation Paul Richards - Budget Alun Lloyd / Michael Cheeseman - Programming Alun Lloyd / Michael Cheeseman / Mark Sailes - Electrical Design	
Stakeholders: Line operators, Line manager, Assembly Development Manager, Process Owner.	

Table 1 - Project Charter

6. Problem Overview

6.1. Z-Axis Assembly Definition

The Z-Axis Assembly shown in Figure 7 comprises of bulky and intricate components, demanding precise assembly due to tight tolerance requirements. The assemblies core components include the Build Volume, Angle Bracket, Gearbox Assembly, Encoder and Motor Servo. These parts are pivotal to the accurate fabrication of 3D printed components. Other supplementary components include fasteners, bellows, seals, and rails which also contribute to overall functionality. To fully complete the Z-Axis Assembly identified as A-6521-4050, further components such as the Heater Top Plate Assembly, Chamber Blanking Kit and Heater/Top Plate Conversion kit are integrated.

6.1.1. System Purpose

The Z-Axis Assembly is one of the most critical components of the RenAM machine. The Assembly is fitted within the Chamber Module. The Assembly ensures a level and straight build plate, facilitating the precise and consistent 'printing' of components. Staying true to its name, the motor precisely traverses the Heater Plate down through the Build Volume along the Z-Axis during the printing process.

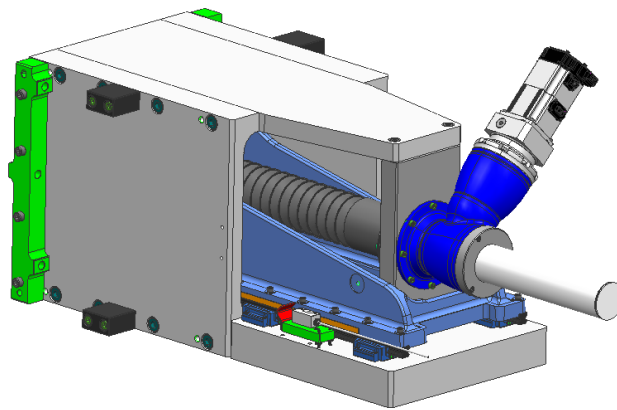


Figure 7 - Z-Axis Assembly

6.2. Maintaining Straightness: Crucial for Z-Axis Assembly

Ensuring the Z-Axis assembly maintains the stringent straightness tolerance of 0.1mm throughout the entire build volume is of paramount importance for the laser sintering process. Deviations beyond this threshold disrupts the lasers direct path, resulting in irregularities in the print. Despite the lasers relatively small spot size of 80 microns, heat dispersion occurs either side of the beam, affecting the melt pool geometry shown in Figure 8. As highlighted by Yang (2019) Consistent melt pool geometry is pivotal for stable laser bed fusion. Accurate melt pools contribute to desirable characteristics such as dimensional accuracy, structural integrity, defect minimisation, and improved surface finish quality, all critical features that keep the customers satisfied.

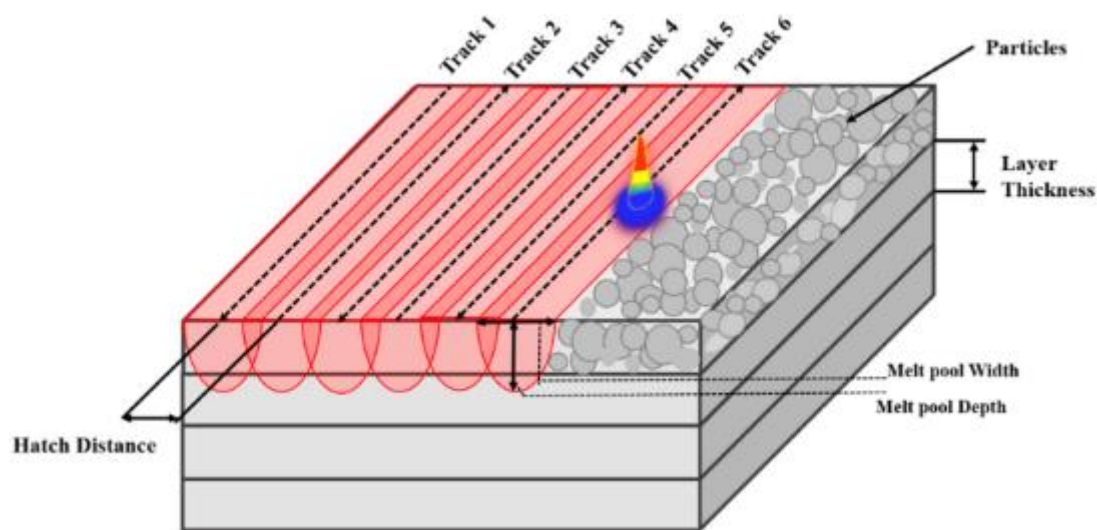


Figure 8 - Features of a Melt pool (MDPI, 2021)

According to Akbari (2022) there are some common terms used for describing defects such as lack of fusion, keyhole, and balling. These irregularities in the print are caused by issues with the sintering process itself, whether that's through issues with laser optics or miss alignment of the Z-Axis leading to slightly 'off' melt pooling. An undersized melt pool leads to a lack of fusion which will lead to structural stresses and failures in the components. On the other hand, an oversized melt pool will lead to defects that are known as keyhole such as porosity. Porosity of the part deteriorates the mechanical property and even hinders the further application of metal additive manufacturing (Wang, 2022). Figure 9 shows a droplet splatter with keyhole porosity.

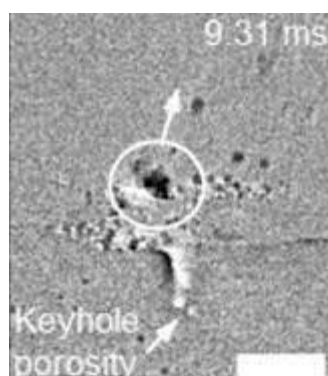


Figure 9 - Radiograph of Droplet Splatter (Rack, 2020)

6.3. Current Verification Method

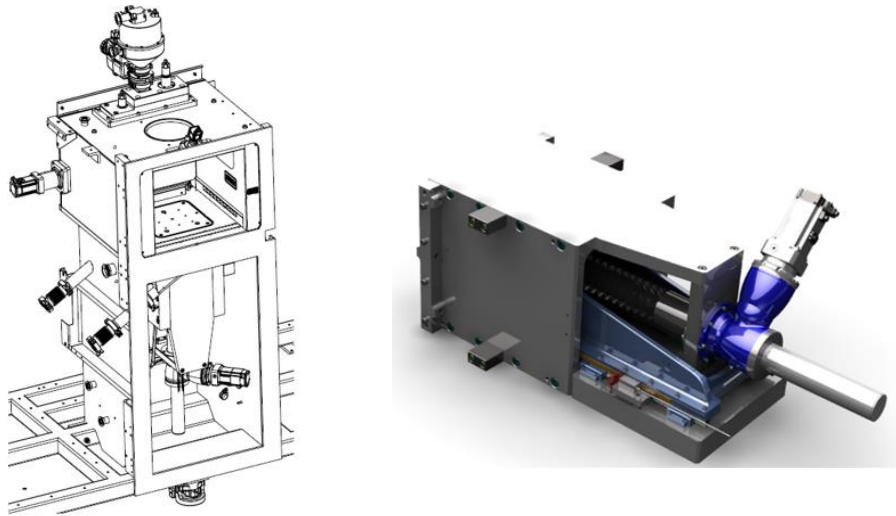


Figure 10 - RenAM 500M Bare Chassis & Assembly

To verify the straightness of the Z-Axis relative to its Z movement through the build volume, the current procedure involves securing two large engineer squares onto the build plate along both the X and Y axis. A DTI (Dial Test Indicator) is then clamped in position to contact the rear edge of the squares and are zeroed once in a stable position.

Subsequently, the Servo Motor is detached, and a handheld drill is used to manoeuvre the ball screw, thereby moving the build plate in the Z-Axis. An operator monitors the encoder feedback on screen holding the drill power trigger on, stopping every 10mm. The other operator is required to take the reading from the DTI and make a note of the measurement at each interval, this is repeated across 250mm. this process requires 25 readings. This is a time-intensive process that causes operator discomfort due to the motor's location.

The maximum allowable deviation across 200mm is 0.1mm in each axis. This is a meticulous test, and the process is duplicated for both the X and Y axes. If there is deviation greater than the 0.1mm tolerance, then the shimming procedure is required. The process must then be repeated to confirm the shim location.



Figure 12 - Clamping Engineers Square



Figure 11 - DTI Alignment

6.3.1. Shimming Procedure

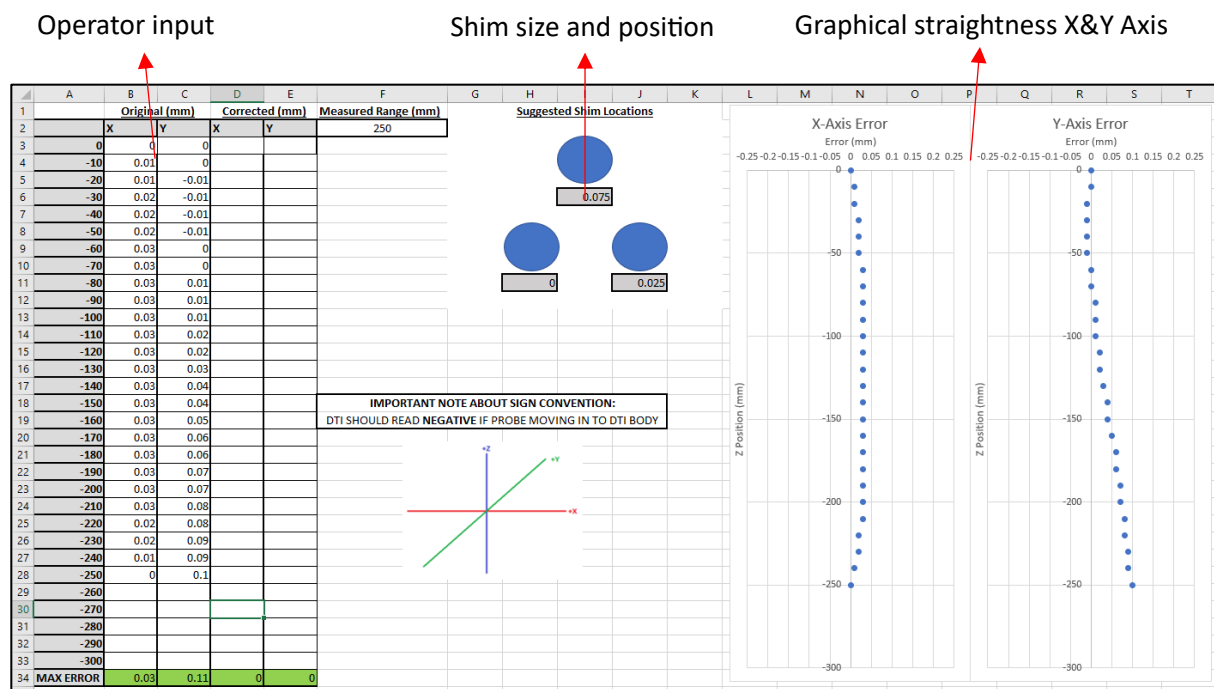


Figure 13 – Shim Selection Guide Spreadsheet

The spreadsheet shown in Figure 13 is filled in by the operator during the testing procedure. The operator input column requires input after every 10mm in both the x and y axis. There is a calculation from the variation in straightness that instructs the shim sizing and location. The above example shows a 0.075mm shim required in the back position (3 x 25 μ m shims) and a 0.025mm shim required in the front right position. Figure 14 shows the heater plate with the shimming locations. The 25 μ m shims used to adjust straightness is shown in Figure 15.

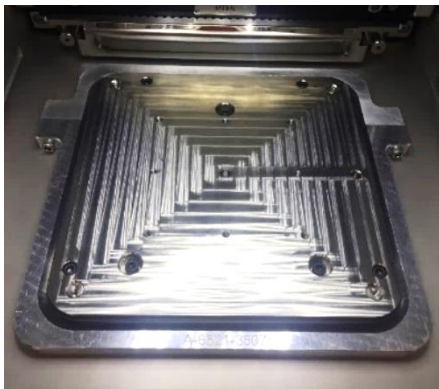


Figure 14 - Heater Plate Shimming Locations



Figure 15 - 25 μ m Shims

6.3.2. Current Method for Manoeuvring the Z-Axis Assembly

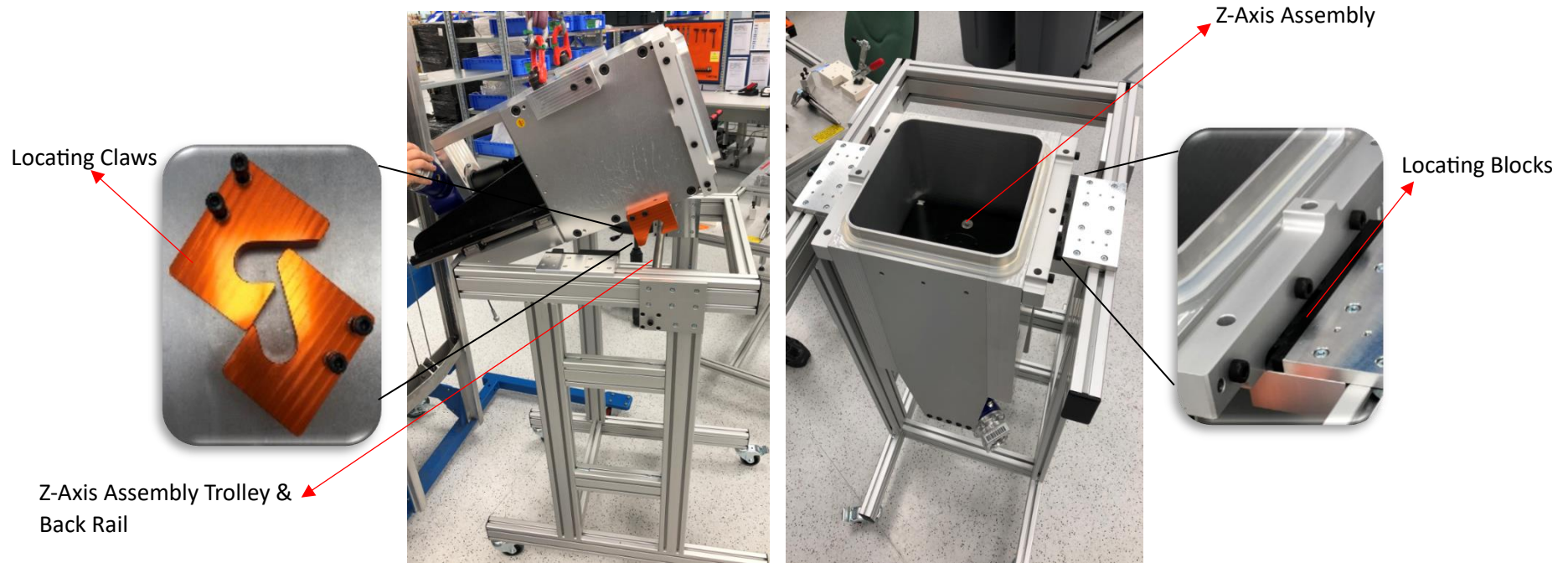


Figure 16 - Z-Axis Trolley

An important part of the project is understanding the current method for manoeuvring the Z-Axis assembly around the cell during the build. The Z-Axis assembly is loaded onto the Z-Axis trolley after it has been built on the assembly bench. The trolley is purpose built and designed to hold the Z-Axis assembly. There is built-in location positioning tooling that provides a safe method of positioning when lowering the assembly onto the trolley.

Figure 16 shows the trolley populated with the Z-Axis assembly prior to fitment of the build plate. The Z-Axis is lowered onto the trolley's back rail with use of the locating claws that are anodised orange in the above figure. Location blocks shown in the right-hand image help to guide and position the assembly central to the trolley.

The trolley plays a crucial role in the design and development of the solution. The trolley will be used to store assemblies when waiting for test and for any movement requirement. The trolley is mainly built with 80x40 Aluminium Extrusion, the drawing with noted dimensions is shown in Appendix B. This will be referred to when designing the proposed test rig.

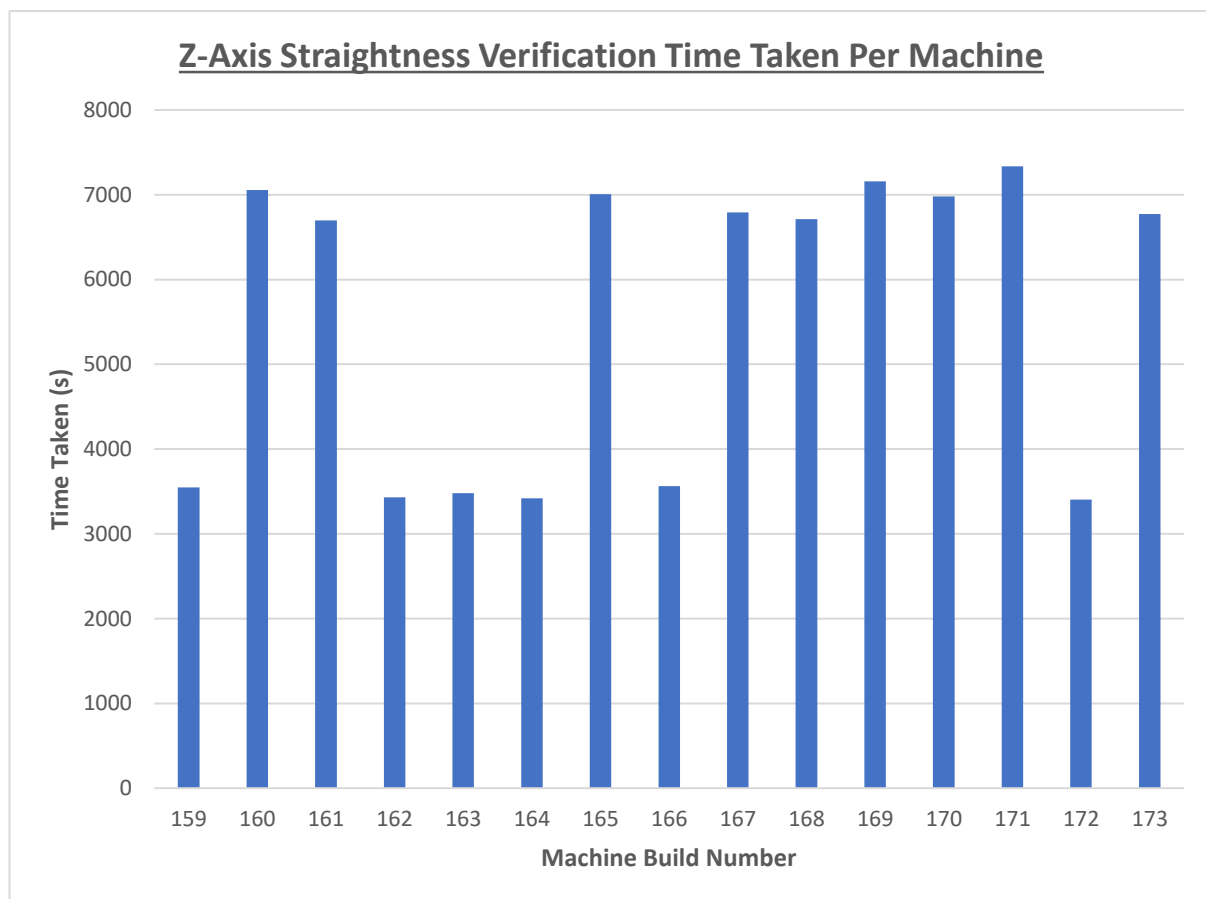


Figure 17 - Z-Axis Straightness Verification Timing

Timing measurements were conducted to establish a benchmark and gain insight into the Z-Axis verification process, results are shown in Figure 17. The timings were taken over an 8-week period. Over the course of the 8 weeks, 15 machines underwent the Z-Axis straightness verification. Each machines verification was timed for both the X and Y axes as these are verified separately. In instances where a machine was not verified first time, a re-verification timing was recorded (see Figure 17, machines 160, 161, 165, 167, 168, 169, 170, 171, 172 and 173). The total time taken for verification, including re-verifications, was calculated for each machine. Along with the time taken, a cost was also calculated using the labour time per operator costed at £86 per hour. This Figure is used throughout the business.

The analysis revealed several noteworthy observations. Firstly, certain machines required re-verification indicating potential inconsistencies. Notably, machine 171 which had a higher total cost compared to the others. The total cost of the verification process across 8 weeks was £3,983.19.

At this point it is important to note that while the data provides valuable insight into the efficiency and reliability of the current verification process, it is not the sole driving force for the project. An additional consideration as noted stems from the RSI complaint attributed to the manual nature of the current verification process.

6.4. Repetitive Strain Injury (RSI)

Repetitive strain injuries (RSI's) are a common occupational hazard caused by repetitive motions and overuse of muscles and tendons. Operators on the RenAM production line have raised concerns about the repetitive strain nature of the current Z-Axis straightness verification method. The HSE (Health and Safety Executive) (2020) describe an upper limb disorder (ULD) as “aches and pains in the shoulders, arms, wrists, hands and fingers, as well as the neck”. Some of the main causes of ULD's include prolonged repetitive work, using the same hand or arm action and working with handheld power tools for long periods of time.

As discussed in section 6.3, the process of the current Z-Axis straightness verification method an operator is required to operate the handheld drill for a long period of time. This is to lower the build plate through the build volume as the test is taking place. This is also done at an uncomfortable working height due to the motors positioning. RSI's incur significant costs for employers in terms of compensation claims and productivity loss. According to the Judicial Board Guidelines, historical cases of work-related repetitive strain injuries have averaged claims of £18,000 per case (Express Solicitors, 2023).

Renishaw as an employer must address this complaint to not only reduce the cost impact but as a fulfilment of legal duties under the health and safety at work act 1974. An internal investigation has been carried out and is attached as Appendix A. With reference to Figure 18, the exposure score given to the process was 12 which is a medium risk and intervention is required. This was carried out by the internal Health and Safety Team following HSE guidance.

To summarise, the main outcome of this project is to minimise the risk to operators with the bonus of improving the process efficiency. The main driving force must be highlighted in this section, it is of major importance to Renishaw that ergonomic intervention is undertaken to remove risk.

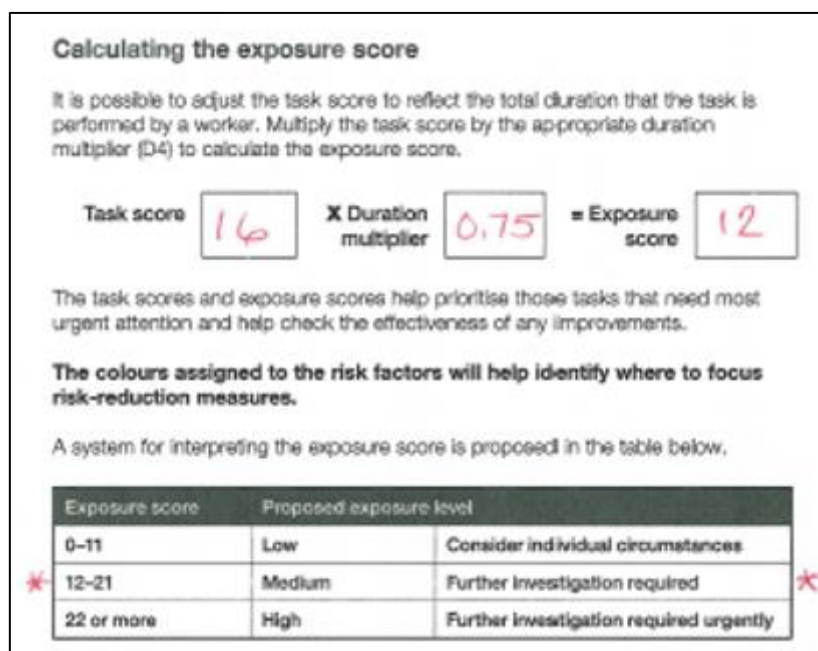


Figure 18 - Page 8 Appendix A, ULD Score

7. Project Overview

This section provides insight into the overall aims and objectives of the project. The overview discusses the design brief and specification that serve as the foundational elements in any project report. They provide the crucial context and direction on which the project will be deemed either a success or a failure in complying with these criteria. The brief and specification are essential in understanding the purpose, scope, and requirements of the project, helping to steer decisions from initial inception to implementation.

7.1. Project Design Brief

Z-Axis Tester Design Brief	
Business Name / Main Client	The main client for the project is the RenAM 500 assembly line at Renishaw with the Stake holders including Line Operators, Line Manager, Assembly Development Manager, and the Process Owner.
Problem Statement	The Z-Axis assembly needs to be square within 0.1mm across 250mm of the Z-Axis movement to function successfully when used by customers. During the maintenance and build of the AM500ML machine platform, The Z-Axis is required to be assembled and tested for straightness. There is a concern regarding the ergonomics of the current process. There needs to be a process implemented to verify the Z-Axis straightness in a safe and efficient way.
Design Statement	Design, build and implement a system that can test the Z-Axis assembly before it is fitted inside a chamber during its assembly and maintenance. The testing must include the straightness test of the heater plate as it is driven down the build volume. The solution requires the Z-Axis assembly to be driven up and down using the fitted motor. It would be ideal if the design could be replicated to be able to test the Z-Axis on the NexGen AM machine. The solution should be repeatable, easy to use and safe for the operators. The solution will need to be CE compliant, and fully documented following the tooling process used within ASG. Any measuring equipment used will have to be calibrated to ensure it is accurate before releasing to production.
Due date for completion	The due date for the project's completion is 02/07/24. With the volume of compliance documentation, the project could span across to August, however the Physical tester is targeted for completion 17/06/24.

Budget	The budget for the full Z-Axis project is £5,000. However, there is emphasis on being able to salvage components from the obsolete RenAM250 machine as there are many electrical components that can be recycled for use on this project.
Product Name	The product name is Z-Axis Alignment Rig.
Regulations and Compliance	Standard Documentation: Specification, Risk Assessment, PUWER. CE Marking: Risk Assessment, Optical Safety Assessment, Machinery Safety, Electrical Safety, Electromagnetic compatibility, EU Declaration, EU DoC. Markings on Equipment: Company Name, EUC name, Serial Number, Country of Origin, Safety Warning, CE Marking etc. User Guide Electrical Safety
Constraints	There are some restrictions to satisfy several regulations and compliance documentation. The main constraint is for the tester to be compatible with the Z-Axis Trolley and Must fit in the assembly Cell.

7.2. Product Design Specification

The product design specification is crucial as it outlines the project requirements, objectives, constraints, and effective communication among the stakeholders. This is a standard template in Renishaw for the design of any custom tooling/rig. To draft the product design specification, the design team met with key project stakeholders to ensure that the rig will align with all expectations. As can be seen below, the design specification is detailed and specific, this was due to the meeting containing all key stakeholders who each contributed to innovative suggestions that were fully considered. Overall, the well-crafted specification will facilitate a smooth project execution, reduce misunderstandings, and increase the likelihood of delivering a high-quality solution. This will be used to assess the potential project solutions, as well as provide a criterion for overall performance assessment.

Key:

E = Essential

D = Desirable

Table 2 - Functional Requirements

7.2.1. Functional Requirements					
Ref	Target Requirement	E / D	Justification	Solution	Validated
1.1	To be a fixed test rig for validation of the Z-Axis Assembly at its Sub Assembly stage and its variants.	E	Required to be fixed to facilitate the safe validation of the Z-Axis.		
1.2	To be able to drive the completed Z-axis assembly up and down using the fitted motor.	E	To be able to test the entire completed assembly.		
1.3	To measure the straightness of the build plate as it travels down the assembly.	E	As part of the current test procedure.		
1.4	To be able to fit the seals to the heater plate as part of the Z-axis assembly and to test the sub assembled unit.	E	To be able to correctly test the assembly.		
1.5	Compatible with the Z-Axis Trolley T-99205.	E	Reduce transportation waste.		
1.6	Test straightness of both X and Y axis simultaneously.	E	To reduce section of testing time ≥50%.		
1.7	Needs to hold a measurement device in a locked and stable position.	E	Essential to Ref 1.1, 1.3 and 1.6.		
1.9	The Z-Axis Assembly must be secure and stable when tested.	E	Essential to Ref 1.1.		

Table 3 - Mechanism Requirements

7.2.2. Rig Mechanism					
Ref	Target Requirement	E / D	Justification	Solution	Validated
2.1	Complete the test with the motor fitted to the assembly.	D	To prove-out the full assembly to ensure it works as expected.		
2.2	Rig to fully support build volume during the testing process.	E	Health and Safety.		
2.3	Fully enclosed rig that is compatible with the current Z-Axis Assembly.	E	To ensure safe operation of the motor and gearbox of the Z Axis.		
2.4	Rig Requires Mains Power Supply.	D	To enable safe operation, HMI, data logging, movement of Z Assembly.		
2.5	Suitable HMI (Human Machine Interface).	E	Operator ease.		
2.6	Traceability of testing.	D	To be able to Trace testing.		

Table 4 - Environmental Requirements

7.2.3. Environmental Protection					
Ref	Target Requirement	E / D	Justification	Solution	Validated
3.1	Must be RoHS (Restriction of Hazardous Substances) and WEEE (Waste Electrical and Electronic Equipment) Compliant.	E	To be able to make it CE compliant.		

Table 5 - Transport Requirements

7.2.4. Transport Requirements					
Ref	Target Requirement	E / D	Justification	Solution	Validated
4.1	Intention is for the rig to be in one position.	E	Requirement for a fixed, robust rig to cope with large heavy components and their transfer.		
4.2	Rig needs to be able to move if required.	E	Required for relocation.		

Table 6 - Set-up Requirements

7.2.5. Set-up Requirements					
Ref	Target Requirement	E / D	Justification	Solution	Validated
5.1	The rig must have a minimal set up time.	D	Save time needed to set up the test rig.		

Table 7 - Operational Requirements

7.2.6. Operational Requirements					
Ref	Target Requirement	E / D	Justification	Solution	Validated
6.1	Test results must be recorded.	E	For traceability of products.		
6.2	All tests should be able to run automatically without the need of operator supervision.	D	To be able to free up operators if required.		
6.3	Rig to allow retry attempts of any unit that failed to pass test successfully.	E	Setting may require multiple attempts.		
6.4	Work and rework procedure must be intuitive with on-screen prompts.	D	Ease of use and to assist in error prevention / missed steps.		

6.5	Needs to be simple for users to easily understand how to use the jig correctly and efficiently.	E	To ensure process is efficiency and to ensure no time is wasted trying to understand how the tooling works.		
6.6	Components of test rig should be error proofed to mitigate incorrect set up of tooling is impossible.	E	Jig setting errors are non-value adding, contributing to poor operational efficiency yields and poor quality.		
6.7	Extra tooling needed to operate the tooling design should be minimised or easily accessible.	D	Reduce any non-value-added time within the process.		
6.8	Instructions on how to operate tooling need to be clear and easily accessible.	E	To ensure process is efficiency and to ensure no time is wasted trying to understand how the tooling works.		

Table 8 - Legislative Requirements

7.2.7. Legislative & Safety					
Ref	Target Requirement	E / D	Justification	Solution	Validated
7.1	Must Conform to CE and UKCA Requirements.	E	To ensure the bench is safe to use by operators.	Complete DL440 and risk assessment to achieve CE through compliance procedure.	
7.2	To meet the requirements outlined in the Risk assessment &, machine safety report.	E	To obtain CE certification	Actions addressed although Risk assessment has not been reviewed.	

Table 9 - Other Requirements

7.2.8. Other					
Ref	Target Requirement	E / D	Justification	Solution	Validated
8.1	Lighting to be 1000 Lux or greater.	E	Required for accurate assembly and inspection.	Provided with current level of factory design.	
8.2	Needs to be designed ergonomically using guidance from Internal DS312 documentation detailing ergonomic requirements.	E	Reduce exposure to work hazards and improve productivity.		

8. Timing Plan

The Gantt chart was utilised as a key project management tool, providing a visual representation of tasks, timelines, and key project milestones. The Gantt chart helped in planning, scheduling, and tracking the projects progress. It also ensured that all team members were aware of their roles and responsibilities providing target completion dates (Kumar, 2005).

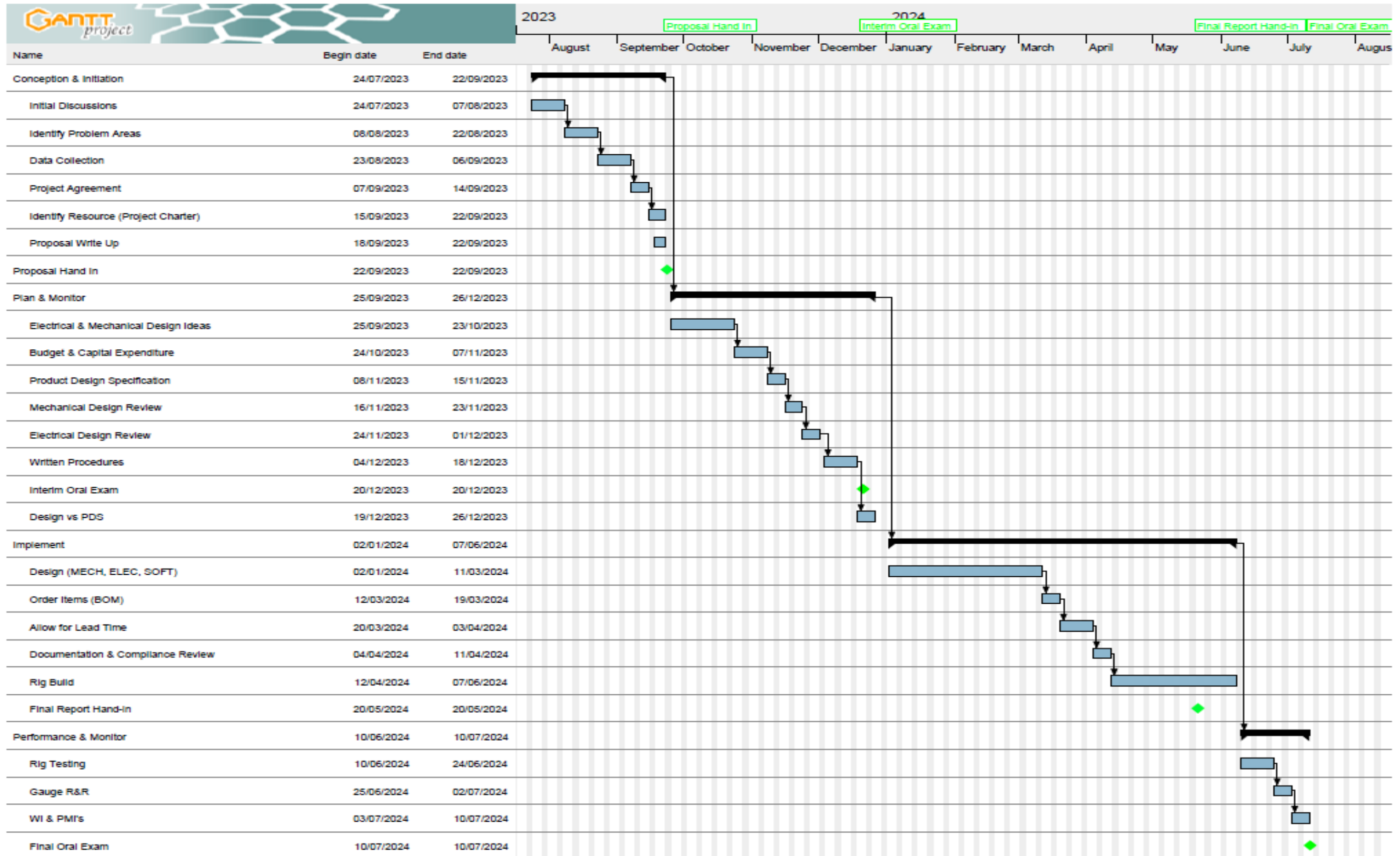
The initial and final Gantt chart is detailed on pages 30 and 31 respectively. The initial Gantt chart started brief but provided a blueprint for the project's successful execution. As the project progressed, the complexity and scale of the design task meant that modifications were required. Specifically, the design section had to be expanded into manageable parts to accommodate tasks such as modification of existing Z-Axis trolleys, importing the rig frame work from a .STEP file designed in ITEM 24 software, the design of the trolley dampeners, resting plates, bridge design and use of IAI elecylinder, implementation of the interlocks and interaction with the trolley, as well as the control cabinet and understanding where to mount it. These modifications reflect the dynamic nature of project management where flexibility is critical.

Further changes were made, in particular the deadline for completion of compliance documentation. The internal DL440 (compliance checklist) highlighted the requirement for more regulatory documentation than what was first anticipated. The final Gantt chart details the date change, the project continued through testing and gauge R&R whilst the documentation remained ongoing. This method ensured that the completion of the rig was not delayed.

8.1. Initial Gantt Chart

TOP LEVEL GANTT

Gantt Chart



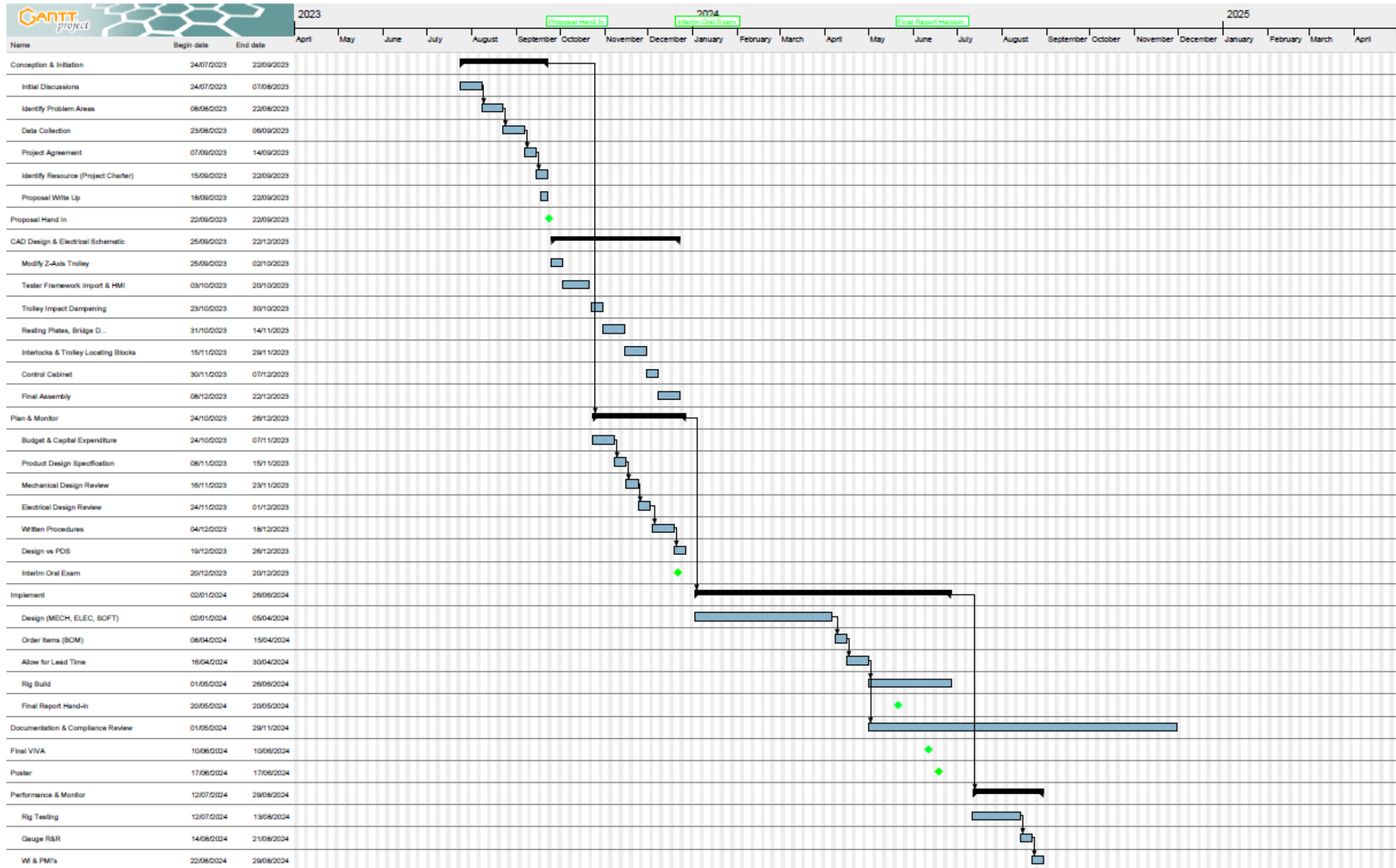
8.2. Final Gantt Chart

TOP LEVEL GANTT

15 May 2024

3

Gantt Chart



9. Methodology

This section of the report outlines the design process of the rig, including details regarding design concepts and development utilising the product design specification, house of quality and use of a design matrix to ensure that the specification is met as best as possible. This section will also detail research that influenced decision making and techniques used, providing insight into both the authors and other team members roles in finalising a concept to take forward for further development.

The team must ensure that the design is error proofed, step locked, future proofed and contains elements of 5S. These will all contribute to the rigs success when delivered to the customer. Further research has been carried out on these principles to ensure that they are fully considered from conception through to delivery.

9.1. Error Proofing

Error proofing also referred to as poka-yoke is a concept that involves designing products or parts in a way that prevents error or is immediately detectable and easy to correct (Chao, 2005). Using this concept of design for the test rig will allow the team to improve the quality of the testing procedure, as well as minimise any potential mistakes during set up procedures.

9.2. Step Locking

Step-locking refers to the way in which processes are structured, ensuring that every step of the process is completed accurately before moving onto the next. This method of working will be critical for the Z-Axis Test Rig to ensure that the testing procedure cannot be completed in an incorrect manner. This will mitigate downtime, re-work and in the worst case rejected parts. Step-locking the process through programming, the use of sensors and actuators, as well as accurate work instruction will contribute to improved efficiency and quality.

9.3. Future Proofing

Future Proofing is a methodology that considers designing the product with flexibility and adaptability, Ryan (2018) explains that future-proof design is a way to create a design that deals with obsolescence and extends the systems service life. It is critical that the test rig considers any future design changes with the introduction of the next variant of additive manufacturing machine. If the Z-Axis assembly changes, it is critical that the test rig can change with it. Considering the future will allow the team to avoid any costly re-designs.

9.4. 5S

5S is an industry methodology for the organisation of workspaces in a bid to improve productivity and overall efficiency (Moulding, 2010). The five principles are sort, set in order, shine, standardise, and sustain. Implementation of 5S in a products design will help streamline the process. 5S will be considered by the product team for the storage of items that will be required to carry out the straightness verification of Z-Axis Assembly.

9.5. Quality Function Deployment- House of Quality (HOQ)

House of Quality (HOQ) is a tool used in Quality Function Deployment (QFD). QFD involves listening to the voice of the customer and systematically, translating the customers' requirements through each stage of the product development as requirements that must be met (Madu, 2006). The origins of the QFD approach can be traced back to Mitsubishi's heavy industry shipyard in Japan in the late 1960's. Following QFD methodologies has many benefits including:

Customer focus – QFD methodology allows better understanding of customer needs, ensuring that the product is designed with the customer in mind.

Improvement in Quality – QFD allows businesses to target quality issues during the development of the product. Allowing the project team to identify areas of improvement, this approach yields higher quality designs.

Efficiency – Translating customer requirements following a systematic approach streamlines the product development process, reducing the risk of rework or design changes in turn saving time and unrewarded effort.

Identification of Problems – This methodology has the Voice of the Customer at the forefront of the design process making it easier to identify problems. Identification of discrepancies between the project team and customer are easily identified by visible tools such as the House of Quality.

House of Quality

HOQ is a product planning matrix that is structured around the voice of the customer. The requirements directly relate to the methods companies utilise in achieving customer 'what's'. The House of Quality matrix is a design that resembles the structure of a house creating technical benchmarking data (ASQ, 2024).

Some of the many benefits as ASQ (2024) detail include:

- Customer needs and requirements are established, and they can be efficiently prioritised in order of importance.
- Identifying and visualising the customer requirements ensures that they are achieved, this better satisfies the customer.
- The methodology allows for a better understanding of the customer leading to better utilisation.
- Highlight required resource, the QFD will highlight the importance of each element of the customers' requirements. This can help the project team assign resource appropriately.

The project team utilised the HOQ tool to help aid the product design process for the concept phase of the project. The result of the completed HOQ is shown in Figure 19.

Title: Z-Axis Straightness Verification Test Rig QFD

Author: Ryan Harris

Date: 20/03/2024

Notes: Project Team and Stakeholders Noted in Project Charter.

Legend		
⊖	Strong Relationship	9
○	Moderate Relationship	3
△	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
-	Negative Correlation	
▼	Strong Negative Correlation	
▽	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

5

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Whats")	Column #															Competitive Analysis (0=Worst, 5=Best)					
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)																					
				Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Weight	Size	HMI	Salvage Parts & Budget	Materials	Sensors & Actuators	Storage For Equipment	CE Mark	Work Instruction	Poke Yoke Parts	Appearance	Ergonomics	Use Already Fitted Servo Drive	Use of Spline Database For Data	Rig Design Fit For Trolley						
1	9	11.7	7.0	Ease of Use	○	○	⊖			○			⊖	⊖		⊖	○		▲						
2	9	10.0	6.0	Quick Set Up		▲	▲			○	▲		▲	⊖		○	⊖		○						
3	9	15.0	9.0	Compatible With Z-Axis Trolley		▲						▲		▲					⊖						
4	9	8.3	5.0	Low Cost	▲		○	⊖	○	▲					▲										
5	9	3.3	2.0	Automatic Plotting of Data														⊖							
6	9	13.3	8.0	Verify Both Axes Simultaneously		▲				⊖							○								
7	9	16.7	10.0	Remove Handheld Drill From Process								⊖				⊖	⊖								
8	1	13.3	8.0	Reliable													▲								
9	9	5.0	3.0	Small Footprint	○	⊖			○						▲										
10	9	3.3	2.0	Parts Holder for Equipment	▲	○			▲		⊖			▲	▲										
				Target or Limit Value	<200Kg	1500 x 1000	12" Screen	65,000	Lightweight	Each Axis (2)	7-8 Items	DL440	N/A	N/A	N/A	N/A	No Handheld Drill	Fitted Motor	N/A	N/A					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	2	2	5	2	2	4	5	1	3	3	4	5	10	6						
				Max Relationship Value in Column	3	9	9	9	3	9	9	9	9	9	1	9	9	9	9						
				Weight / Importance	61.7	128.3	140.0	75.0	43.3	193.3	40.0	166.0	115.0	213.3	16.7	265.0	328.3	30.0	176.7						
				Relative Weight	3.1	6.4	7.0	3.7	2.2	9.6	2.0	8.2	5.7	10.6	0.8	14.2	16.3	1.5	8.8						

Powered by QFD Online (<http://www.QFDOnline.com>)

Figure 19 - House of Quality Z-Axis Test Rig

Figure 19 shows the HOQ matrix created for the Z-Axis test rig. This was a vital tool used by the project team during initial design conception. By aligning the customer requirements by order of importance, the quality matrix facilitated appropriate allocation of resource. This ensures that priority is given to the most customer critical requirements. Using this approach has demonstrated which requirements need to be met ensuring the satisfaction of the customer.

In Figure 19 each area has been labelled to explain the results of the analysis, to use the HOQ matrix successfully and effectively, it is critical that the project team understand the structure and method for population. The house of quality is structured as follows (Feldman, 2023):

- 1- Correlation**
- 2- Functional Requirements**
- 3- Interrelationship Matrix**
- 4- Performance Requirements**
- 5- Customer Needs**

Correlation provides insight to the balance between requirements. The functional requirements are scored via positive or negative correlation which illustrates the relationship between them. For the Z-Axis test rig, there is plenty of correlation between the requirements. Some of the most notable requirements include strong positive correlation between requirements such as rig size against weight, use of the Z-Axis' servo drive in improving rigs ergonomics and use of an HMI (human machine interface) and its positive affect on rig appearance. There are also negative correlations such as ensuring that parts salvaged help to minimise rig size. These relationships help to mould the rig design process for the project team.

Customer needs is the voice of the customer, what they require from the test rig. In this section, each requirement is weighted by importance. This is critical as it is important to understand the requirements most critical to satisfaction. Without understanding this, resource could be misused leading to dissatisfaction. Some of the scoring with the highest importance include:

- Removal of the handheld drill (Score: 10)
- Compatibility with the Z-Axis trolley (Score: 9)
- Verification of both X and Y axis simultaneously (Score: 8)
- Rig reliability (Score: 8)

Functional requirements state how the voice of the customer or customer needs will be met. The functional requirements have direct effect on how to satisfy what the customer wants. These are controllable requirements that will be used by the project team to ensure customer satisfaction. These are scored along with performance targets and are given a relative weighting. From the HOQ some of the most notable requirements include:

- Use of the assembly fitted servo drive (Importance: 328.3)
- Ergonomics or removal of handheld drill (Importance: 285)
- Designing Poka-yoke parts for ease of use (Importance: 213)
- Using sensors and actuators to ensure verification axes simultaneously (Importance: 193)

The interrelationship section of the matrix reveals how the different characteristics interact with each other. In its entirety this section helps provide insight into how changing the characteristics of one requirement may affect another. This section is critical to the project team in the optimisation of the solution. There are several strong relationships within the matrix, these include Components that will help with ease of use, an HMI screen, work instruction, poka yoke parts and rig ergonomics. It is

clear to see that utilising this section will show the importance of each characteristic in meeting the voice of the customer.

Performance requirements section of the HOQ matrix outlines specific customer needs regarding the project outcome. This section helps to translate customer desire into measurable characteristics to enable the project team to successfully meet the target. Some of the notable target requirements include the weight of the rig to be less than 200kg, the footprint of the rig to be approximately 1500mm x 1000mm or smaller and to be less than £5000, utilising salvaged parts from the obsolete RenAM 250 machines.

After crafting a design specification and design brief, along with research into the problem of Z-Axis straightness verification the project team utilised this work as guiding principles in the creation of the HOQ matrix. The matrix crafted served as navigation for the conceptual designs. The project team drafted 3 concepts for review.

9.6. Concept Design

9.6.1. Concept 1

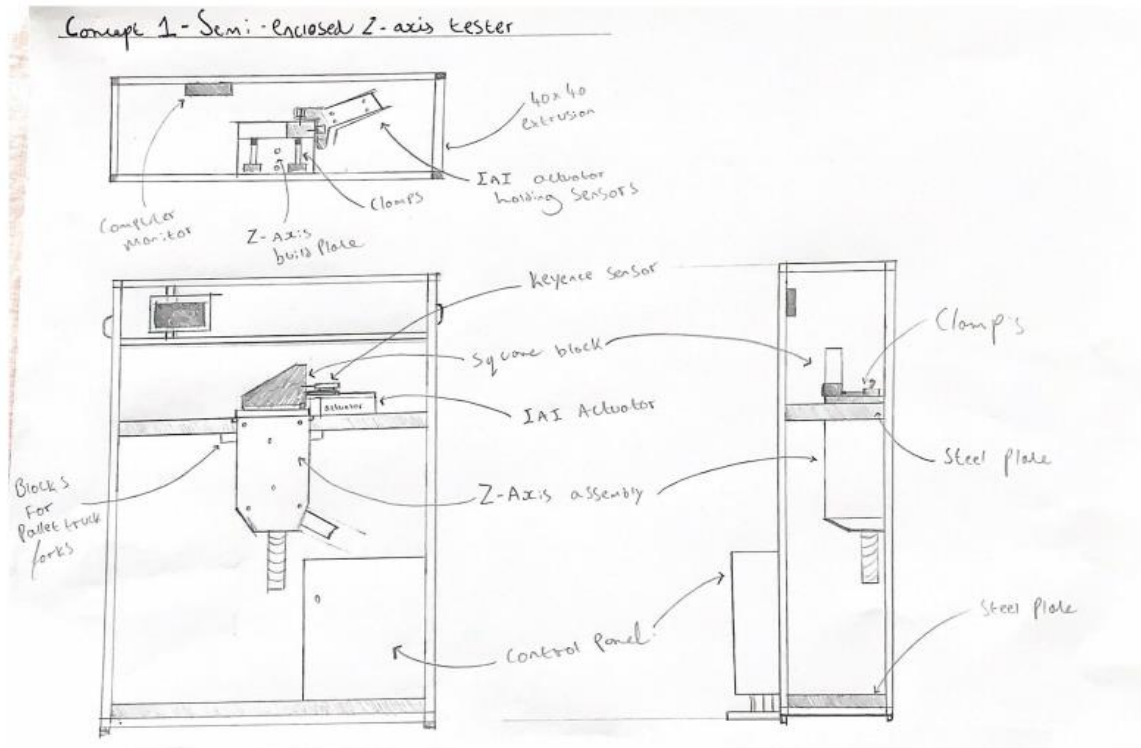


Figure 20 - Initial Sketch of Concept 1

Figure 20 shows the sketch of Concept 1, the Z-Axis is positioned centrally within the rig. The enclosure is not fully guarded, the idea is to allow operators to utilize existing equipment (pallet truck with stacker) to load the assembly into the tester. The base plate that is in the middle of the rig allows for easy insertion of the forks to help aid with the lowering of the Z-Axis.

Operators will use the Human Machine Interface (HMI) that is mounted on a VESA adjustable arm to follow on screen instructions. The tested is automated via the use of PLC (Programmable Logic Controller). Positional sensors will be loaded onto engineers' squares clamp to the build plate via the linear IAI actuator.

The framework is constructed using 40x40 Item MBS (aluminium extrusion). This is a simplistic design with a notable drawback of this concept being the lack of guarding. Moving parts are fully exposed which can pose a threat to operators within the cell.

9.6.2. Concept 2

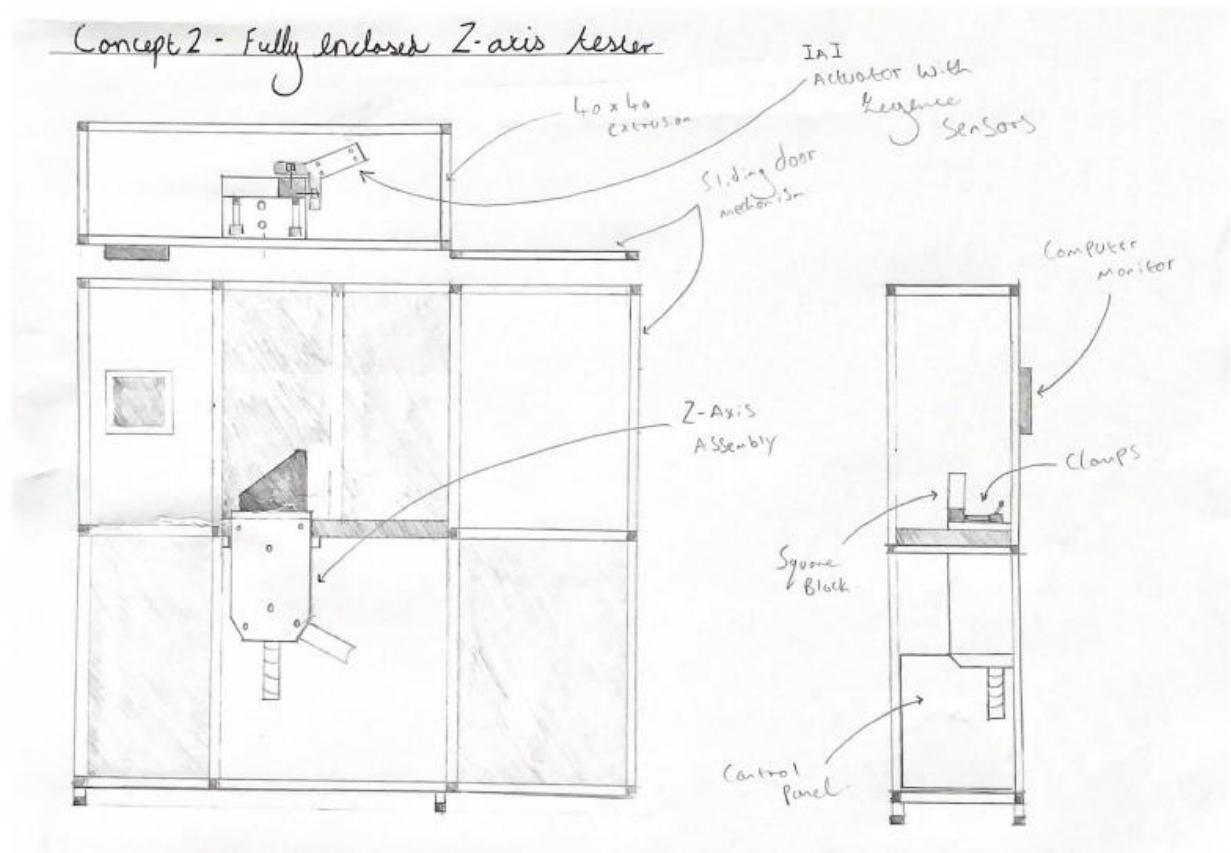


Figure 21 - Initial Sketch of Concept 2

Figure 21 shows Concept 2, similarly constructed with the Z-Axis assembly located in the same position. The main difference between the concepts is the addition of full shrouding with the introduction of a sliding door with interlock. Operators will still use the existing lifting equipment to place the Z-Axis assembly within the tester.

Once the assembly is loaded, the sliding door can be closed with use of a physical interlock to confirm that the assembly is safe to move. Operators will utilise on screen instructions from the HMI that has now been located within the purpose built guarding. Sensors and actuators will also be used when verifying the Z-Axis assembly's straightness.

The framework is constructed using a combination of 40x40 and 80x40 aluminium extrusion. This is a far more complex design with a primary concern being the weight of the tester and the wear of the sliding door.

9.6.3. Concept 3

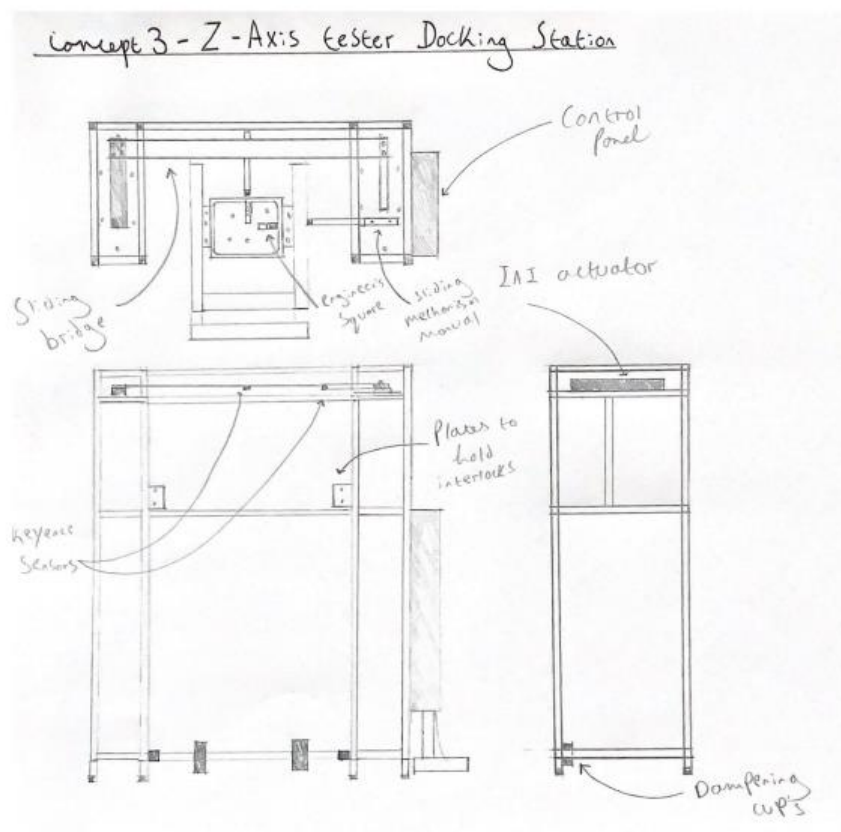


Figure 22 - Initial Sketch of Concept 3

Figure 22 shows Concept 3 that deviates from both concept 1 and 2. The thought process with this concept is to enhance the existing Z-Axis trolley that is used to manoeuvre the assembly. Creating a stationary or nested test rig to allow for the docking of the trolley into the test rig removing the need to lift the z-assembly.

This concept adopts a bridge design that allows for the automatic positioning of the Y-Axis sensor via the IAI actuator. The X-Axis is a lever mechanism that will be easily loaded by the operator. The rig also features dampeners to minimise the impact of loading the trolley.

The concept does not feature interlocks however these will be integrated to enable the docking of the trolley is confirmed and remains in the same position during the completion of the verification. The existing trolley will modify to feature acrylic sides that will guard any movement from the servo drive. Instruction and interaction will be through a HMI that will be affixed to the rig via a VESA mount design that will be adjustable.

9.7. Concepts vs Product Design Specification

Specification Requirements	Concept 1	Concept 2	Concept 3	Result
Functional Requirements	5	5	8	Con 3
Rig Mechanism	4	5	6	Con 3
Environmental Protection	1	1	2	Con 3
Transport Requirements	0	0	1	Con 3
Set Up Requirements	1	1	1	NCW
Operational Requirements	5	5	5	NCW
Legislative & Safety	0	1	1	NCW
Other	1	1	2	Con 3
Total Scores / 31	17	19	26	Con 3

NCW	No Clear Winner
	Specification Point fully met
	Specification Point partially met
	Specification Point not met

Figure 23 - RAG Matrix Concepts vs PDS

The project team (defined in section 5.5 page 21) rated each concept against the product design specification to decide which concept to take forward and develop. There were several ways to evaluate the concepts, such as a benefit to cost ratio, economic models, and an internal rate of return graph. The project team felt that using a RAG matrix would give a better visual representation of the decision.

Evaluation of scoring:

Functional Requirements:

All concepts feature a fixed rig design to validate the Z-Axis assembly safely. Concept 1, 2 and 3 all utilise the built-in servo drive to drive the build plate through the build volume. The only issue for Concept 1 is the lack of precision components for successful straightness verification which is an opportunity for development. Concept 2 also faces similar challenges in verifying straightness, however it does not conform to the seal fitment process due to its enclosed structure. Concept 3 excels in meeting functional requirements by holding the Z-Axis assembly safely, testing straightness and allowing for seal fitment. The X and Y axes can also be simultaneously verified giving it the edge.

Rig Mechanism:

Both Concept 1 and 2 utilise the servo drive for validation, however Concept 1 is semi enclosed which draws safety concern due to its design. Concept 2 is fully enclosed allowing it to meet safety standards. Concept 3 ensures rig safety by using shrouding and interlocks. In terms of rig mechanism all concepts safely support the Z-Axis assembly structure.

Environmental Requirements:

All concepts are designed to conform to CE marking requirements, which ensures compliance with both RoHS and WEEE standards. Restriction of Hazardous Substances and Waste Electrical and Electronic Equipment are regulatory standards that protect both the environment and human health. They ensure that manufactured equipment can be disposed of responsibly (RoHS Guide, 2024). It is critical that any parts used on the rig comply to these requirements to ensure that the rig can receive CE marking for safe operator use.

Transport Requirements:

Each concept satisfies the need for a fixed and robust tester. Both Rig Concept 1 and 2 are going to be difficult to manoeuvre if required due to the size and structure. Concept 3 features a docking design for the Z-Axis assembly trolley for ease of product transportation.

Set Up Requirements:

The product design specification requires minimal set up time. At this stage it is difficult to understand the exact validation procedure and its duration. Concept 3 stands out with its ease of loading the Z-Axis assembly into the test rig and removing the need of the lifting pallet truck.

Operational Requirements:

An important requirement from the product design specification is for the automatic recording of the straightness verification. This is an issue for all 3 Concepts due to the need for an established database. Automated verification capabilities are present across all Concepts, however Concept 3 features additional error proofing features to aid rig set up for the verification process.

Legislative and Safety:

Whilst Concept 1 faces difficulties in conforming to CE and UKCA requirements due to its semi-enclosed design with moving parts easily accessible. Both Concept 2 and 3 are likely to obtain certification due to safety being at the forefront of each concepts design.

Other:

The lighting requirements are met across all concepts. This is due to the location already set for the rig where lighting is a 1000 lux. In improving the ergonomics as per DS312, all rigs have designed out the manual handheld drill opting to use the built-in servo drive. Further consideration will be given to the design to ensure that all aspects are designed with operator ease of use at the forefront of decisions.

9.8. Conceptual Design Development

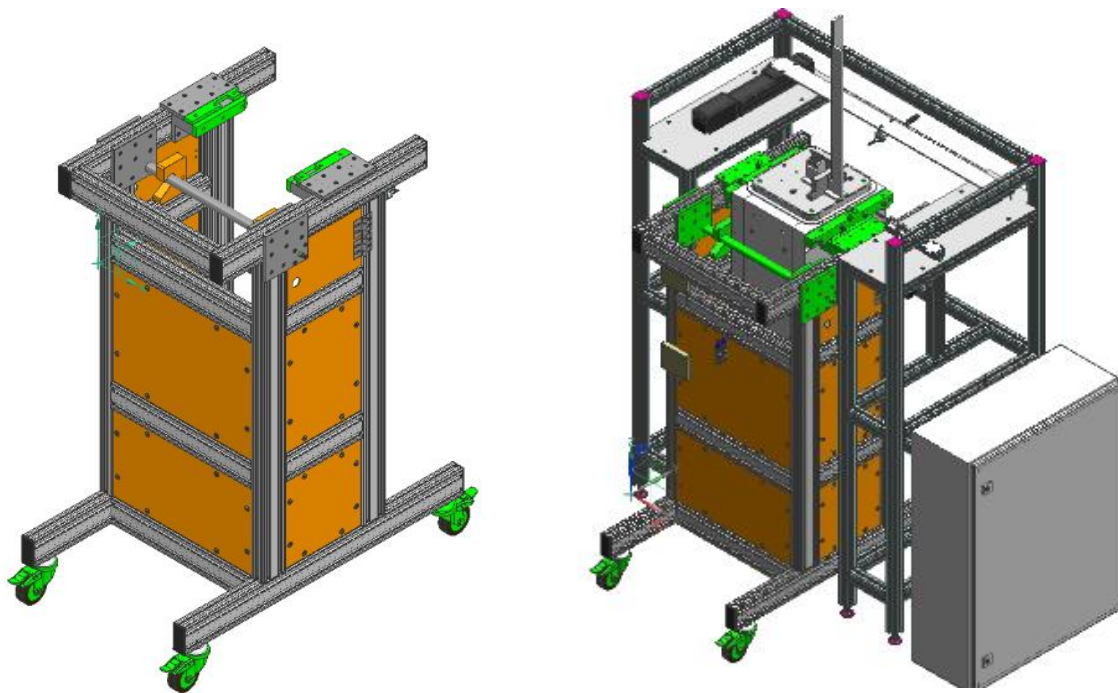


Figure 24 - Final Concept Design Development

The project team utilised Siemens NX as the Computer Aided Design (CAD) software to further develop the concept. Some of the main features of the rig include:

Existing Trolley Modification:

The Z-Axis trolley was modified for safety, featuring acrylic panelling to shield moving parts during the verification. There are also side doors that allow operator access to provide power to the servo drive and motor encoder via a cable connection. Locating blocks have been added to the trolley to help with the location of the Z-Axis assembly on the trolley.

Tester Framework:

The tester framework was modelled using ITEM 24 software and then transferred via a .STEP file exported direct from the software. The framework is assembled with 40mm x 40mm aluminium extrusion. Shown in Appendix C, the framework is U shaped allowing for the docking of the modified Z-Axis trolley.

Trolley Impact Dampening & Interlocks:

It was apparent to the project team that there was potential for the trolley to be over docked (if the operator loads trolley with too much force). A design was made for the trolley to be dampened as it is loaded into the test rig. It utilises a spring dampening system with use of plastic MJF 3D printed parts. The test rig also has MJF interlock guides that ensure the central position of the trolley in the tester. Interlock keys that are mounted on the trolley confirm the dock and ensure that the trolley cannot be removed during the testing procedure.

Sensor Positioning:

The side mechanism facilitates the positioning of the X-Axis Keyence sensor for the precise alignment with the edge of the engineer's square. It includes components such as rails, slides, a lever mechanism, and a clamp to securely hold the Keyence sensor. A pull pin design is used to retract the sensor when required. The Y-Axis Keyence sensor is positioned via a bridge design which is drive by an IAI elecylinder.

Key CAD Features of the Final Design:

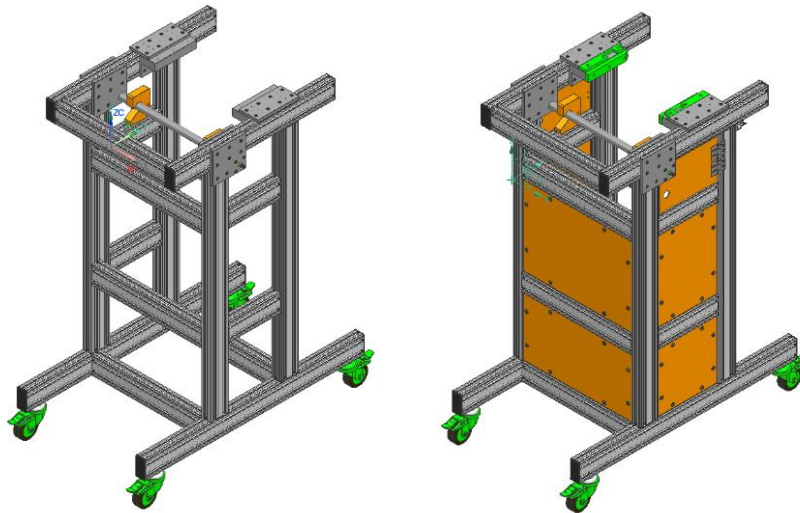


Figure 25 - Z-Axis Trolley Modification

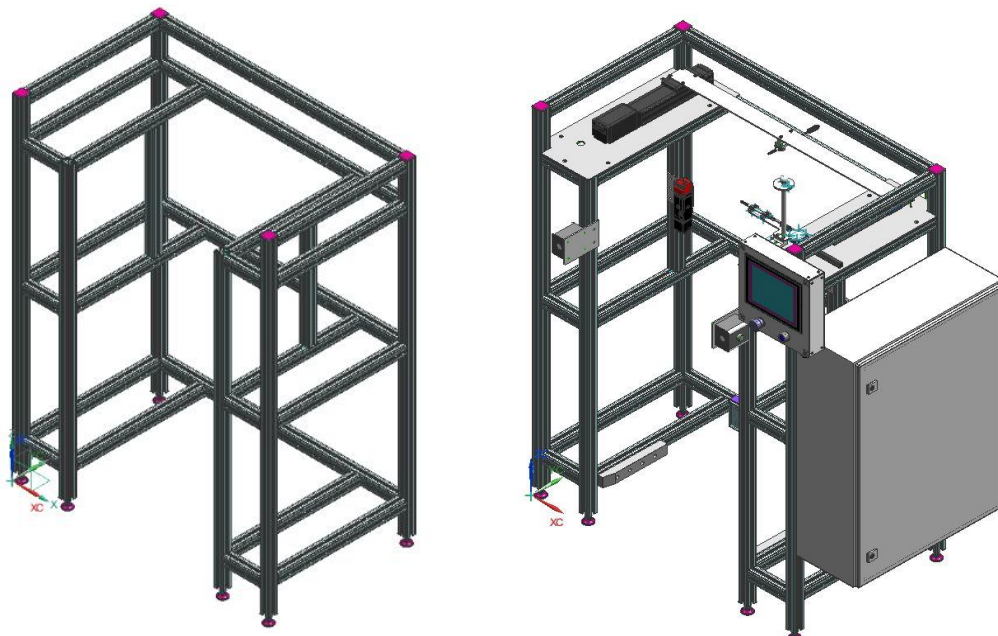


Figure 26 - Tester Framework

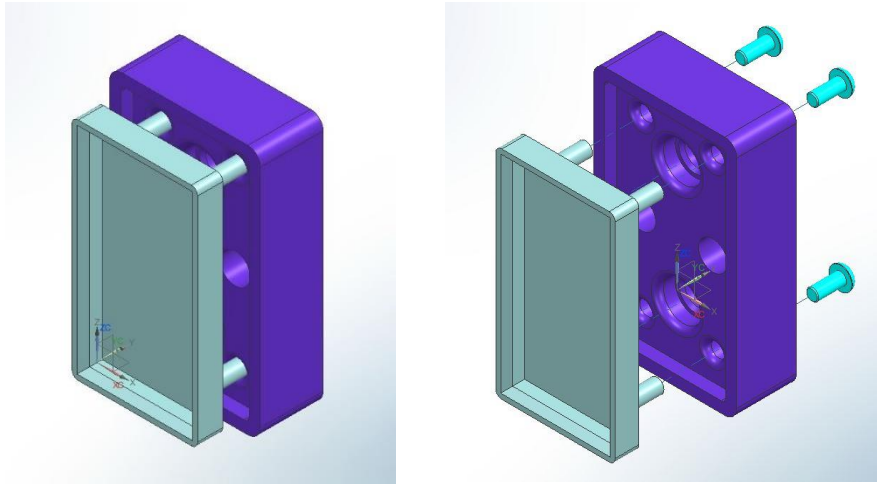


Figure 27 - Trolley Dampening Design

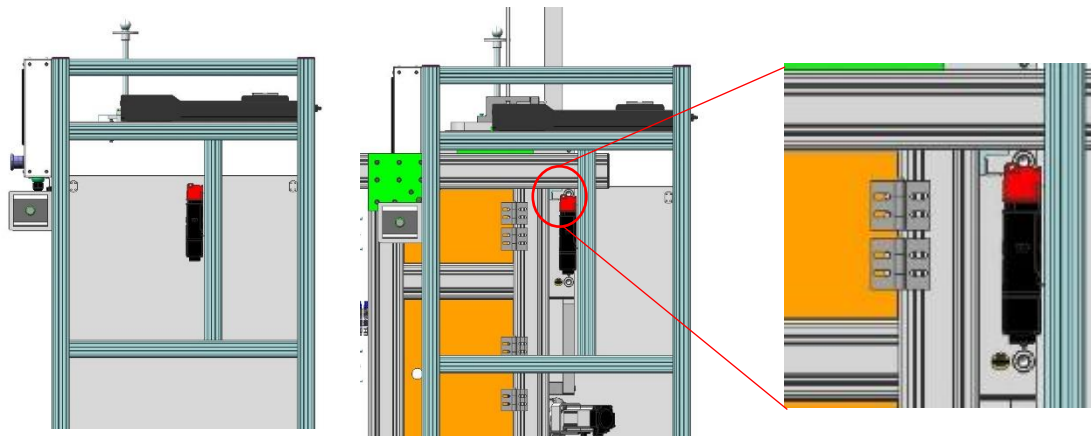


Figure 28 - Interlock Actuation

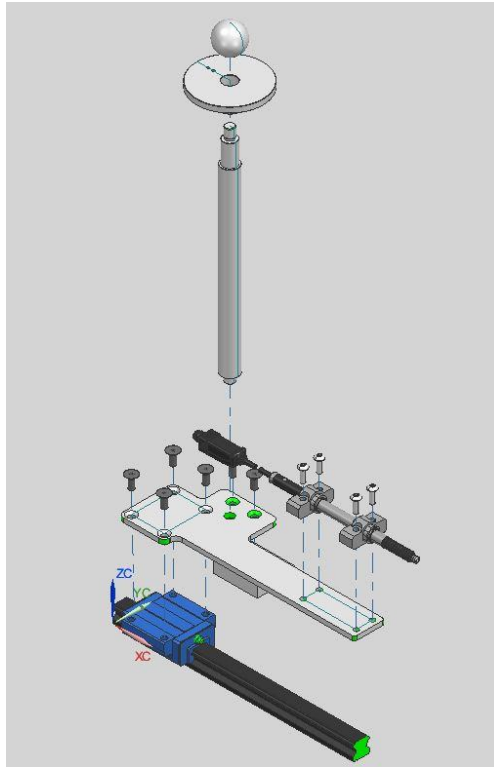


Figure 30 - Side Mechanism (X-Axis) Exploded View

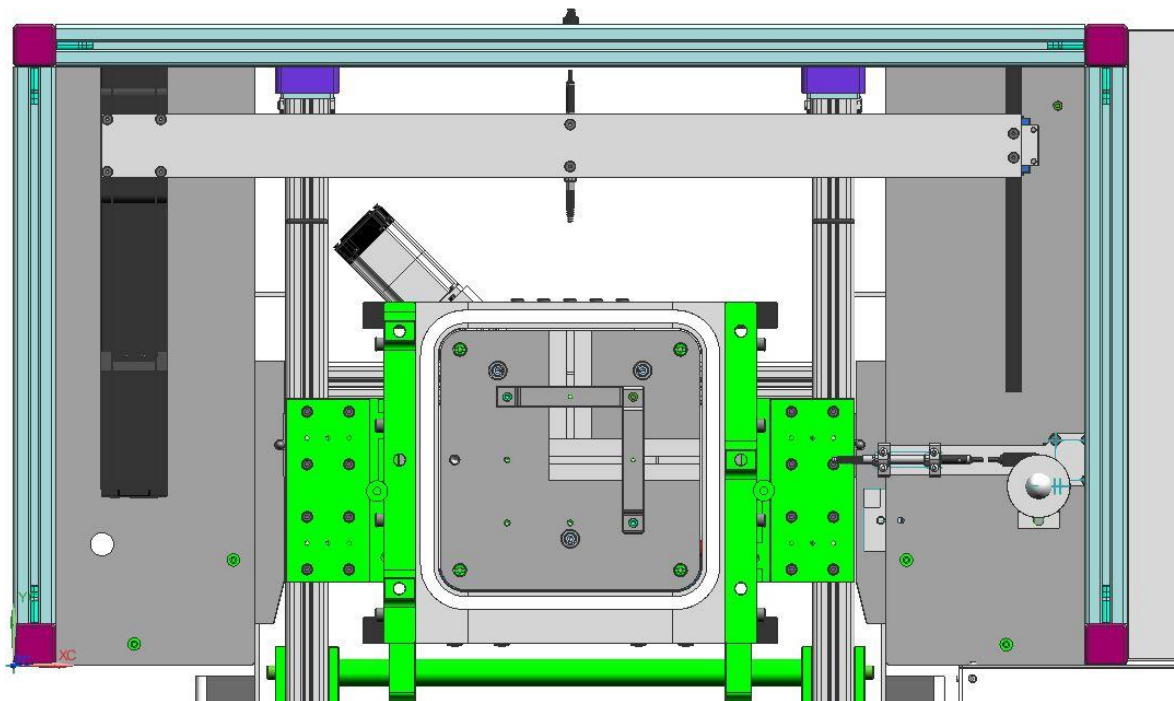


Figure 29 - Keyence Sensor Positioning

10. Implementation

10.1. Compliance Documentation Consideration

Regulatory compliance was a critical component in successful project delivery. Ensuring that the project adheres to laws, standards, regulations relevant to safety, environmental impact, and quality. It is critical in mitigating risk and protecting employees. Noncompliance has the potential to lead to legal penalties, endangerment of employees, project delay, and reputational damage (Nekvi, 2014).

For the project, the team had to comply to Renishaw's Regulatory Requirements that are governed by a document that is known as a DL440. This form is filled in by the project members very similar to a specification but describing the method of operation and reason for the rig's requirement. This is sent to the compliance team who then correspond with a checklist of compliance documentation required. To be used on the assembly line by the operators officially, the rig must be CE compliant, and this is ensured by the completion of the DL440.

Renishaw (2023) explain that the purpose of the DL440 – Regulatory Requirements Checklist is to specify the technical regulations and standards applicable to a product or equipment under consideration (EUC), and to identify detailed actions, so that product safety can be designed in from the start of the project. The following checklist was received by the project team upon submitting the DL440, shown on Pages 45 to 48.

Requirement	Reference documents	Applicability	Compliance evidence / notes	Date Complete
Risk Assessment	DTS150 , DL412 EN ISO 12100	Required for all equipment		
Laser safety assessment	EN 60825-1 EN ISO 11252	No		N/A
Optical safety assessment	EN 62471	Yes		

Machinery safety (UK SI 2008/1597; EU Directive 2006/42/EC)

Machinery Instructions		Required for all machinery	<i>Need to understand if the equipment falls within scope of machinery. Further discussion may resolve this uncertainty.</i>	
Evaluation of the EHSRs	DL431 - machinery EN ISO 11553-1 machinery with lasers	Yes		
Standards required by EUC e.g. Ergonomics, ATEX,	ATEX 2014/34/EU	Yes		
Functional safety	FS321 EN ISO 13849-1 EN ISO 13849-2	Yes		

Lifting Equipment / accessory / attachment	DL328	No		N/A
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Pressure Equipment Directive 2014/68/EU

Pressure Safety Assessment	Sound Engineering Practice Statement Or Conformity Assessment	No		N/A
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Requirement	Reference documents	Applicability	Compliance evidence / notes	Date Complete
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Electrical safety (UK SI 2016/1101; EU Directive 2014/35/EU)

Electrical safety assessment - instruments	DTS100 , DTS125 , DL445 EN 61010-1	No		N/A
Electrical safety assessment – Low-voltage switchgear and control gear assemblies. General rules	EN 61439-1	No		N/A
Electrical safety assessment - machinery	DTS125 , DL430 EN 60204-1	Yes		
IP rating	DTS614 EN 61010-1	Yes		

Electromagnetic compatibility (EMC) (UK SI 2016/1091; EU Directive 2014/30/EU)

EMC assessment	DTS200 EN 61326-1 or EN 61000-4 EN 61000-6	Yes	<i>The circuit should be presented to Gerry Vuolo for assessment</i>	
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Radio equipment (UK SI 2000/730; EU Directive 2014/53/EU)

Radio equipment type approval and EMC	DTS225 , DL443 ETSI EN 300 328 ETSI EN 301 489-1 ETSI EN 301 489-17	No		N/A
Bluetooth	External testing	No		N/A

Requirement	Reference documents	Applicability	Compliance evidence / notes	Date Complete
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The restriction of the use of certain hazardous substances (RoHS) (UK SI 2012/3032; EU Directive 2011/65/EU)

Compliance assessment	EN 63000 Syteline RoHS declaration header COM302 Or DS463	No	<i>An easement exists for in house tooling. Therefore not required.</i>	N/A
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CE marking

Identify signatory (Division DGM or delegate)		Yes	Name: Title:	
EU Declaration	DL320	Yes	DOC or DOI: Declaration of Conformity Document no: EUD 2021-00578	
EU DoC to accompany EUC	Applies to: Machinery, RED and ATEX	Yes	<i>This equipment is for in house use and has elements place within scope of machinery directive.</i>	

Table 10 - Regulatory Compliance Checklist

10.2. Rig Build

10.2.1. Bill of Materials (BOM)

A bill of materials (BOM) is critical for project management, providing a detailed inventory of required components crucial for efficient planning, procurement, and budgeting (Rusk, 1990). In this report, Appendices D and E meticulously detail the BOM for both the Z-Axis test rig itself as well as its electrical control cabinet.

The BOM in this case helps to demonstrate the incredible effort that went into salvaging parts from the obsolete RenAM 250 machines, resulting in substantial cost savings. For instance, out of the 176 different items needed for fabrication of the rig, 93% or 164 parts were salvaged. This salvage operation yielded a significant saving of £7047, with the projects total cost at £10,669 without this effort. The project team would have been required to source cheaper options if the salvaging was unavailable, this could have risked the quality of the rig.

Furthermore, every component used in the electrical cabinet was from a scrapped/obsolete RenAM 250 machine which led to an impressive repurpose of equipment. While there were components that were required to be purchased detailed in Appendix D, such as the electrical cabinet itself, an extra Keyence sensor, two critical interlock switches, and the tests rigs extrusion framework to name the main items. The overall project still came under budget at £3622, leaving a surplus of £1378 from the allocated £5000 capital expenditure budget.

The satisfaction of key stakeholders, such as the AM production manager and AMPD, underscores the significance of precise BOM management. It highlights how careful planning, coupled with strategic repurposing of equipment, can successfully achieve project objectives within budgetary constraints.

10.2.2. Build Images

The following section presents some images of the build progress, including the control cabinet wiring in which the salvaged electrical components can be seen, the HMI from bare mechanical build to fitted and loaded with the programme, the rigs aluminium extrusion chassis to being fitted with all components and the mechanical side mechanism for the loading of the X-Axis Keyence sensor.

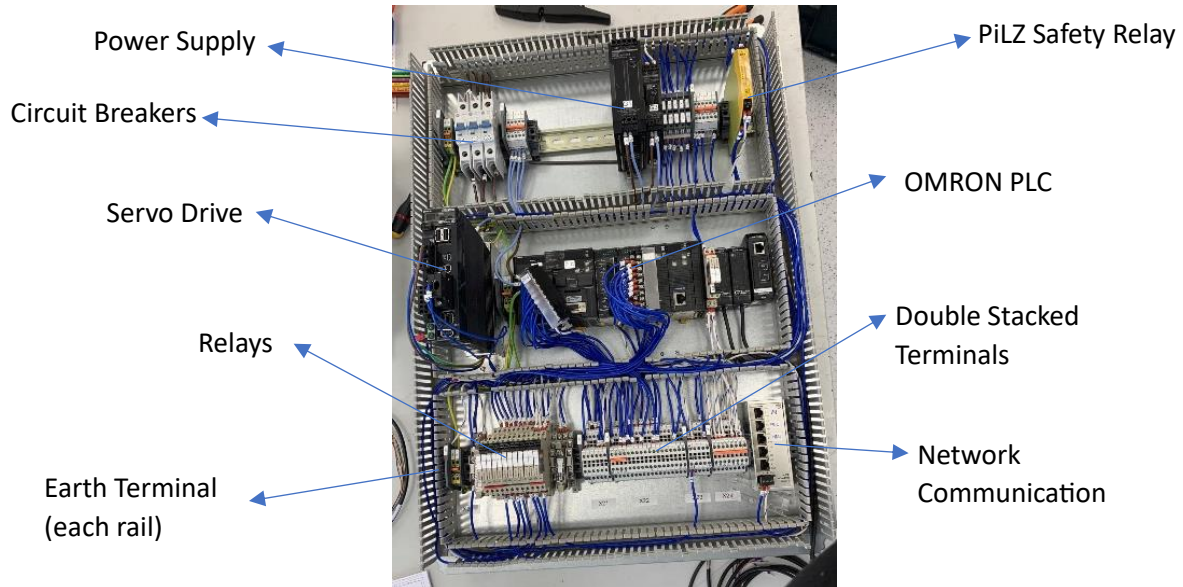


Figure 31 - Electrical Panel

Figure 31 shows the electrical panel prior to its fitment in the control cabinet. This shows the salvaged parts used from obsolete RenAM 250 machines. The key components of the electrical panel are labelled above, included items such as the PLC, Power Supplies and Servo Drive. There is also suitable segregation that can be seen between any mains AC and high-speed signal cables along with 24Vdc circuit, this limits any noise or distortion in the signals.

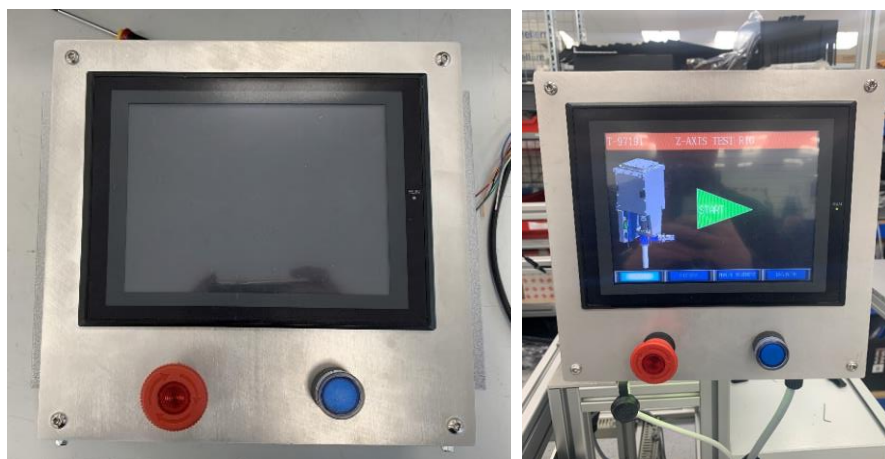


Figure 32 - Human Machine Interface

Figure 32 shows the Omron HMI screen that is used to control the rig as well as display operator instruction for the testing procedure. The first image shows the screen assembly, whilst the second image shows the screen fitted with the programme loaded. The HMI features an E-Stop and a reset button to help ensure safety of the rigs use.

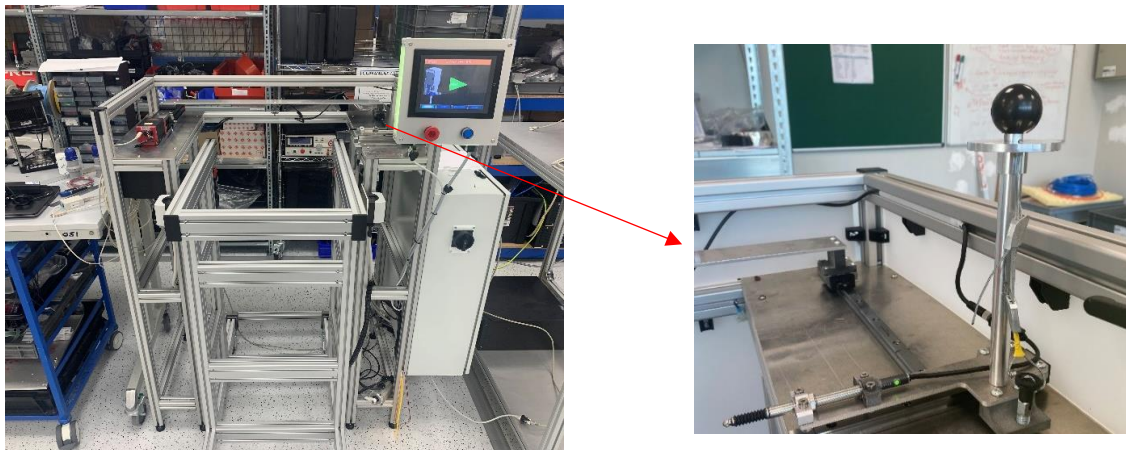


Figure 33 - Rig Set Up

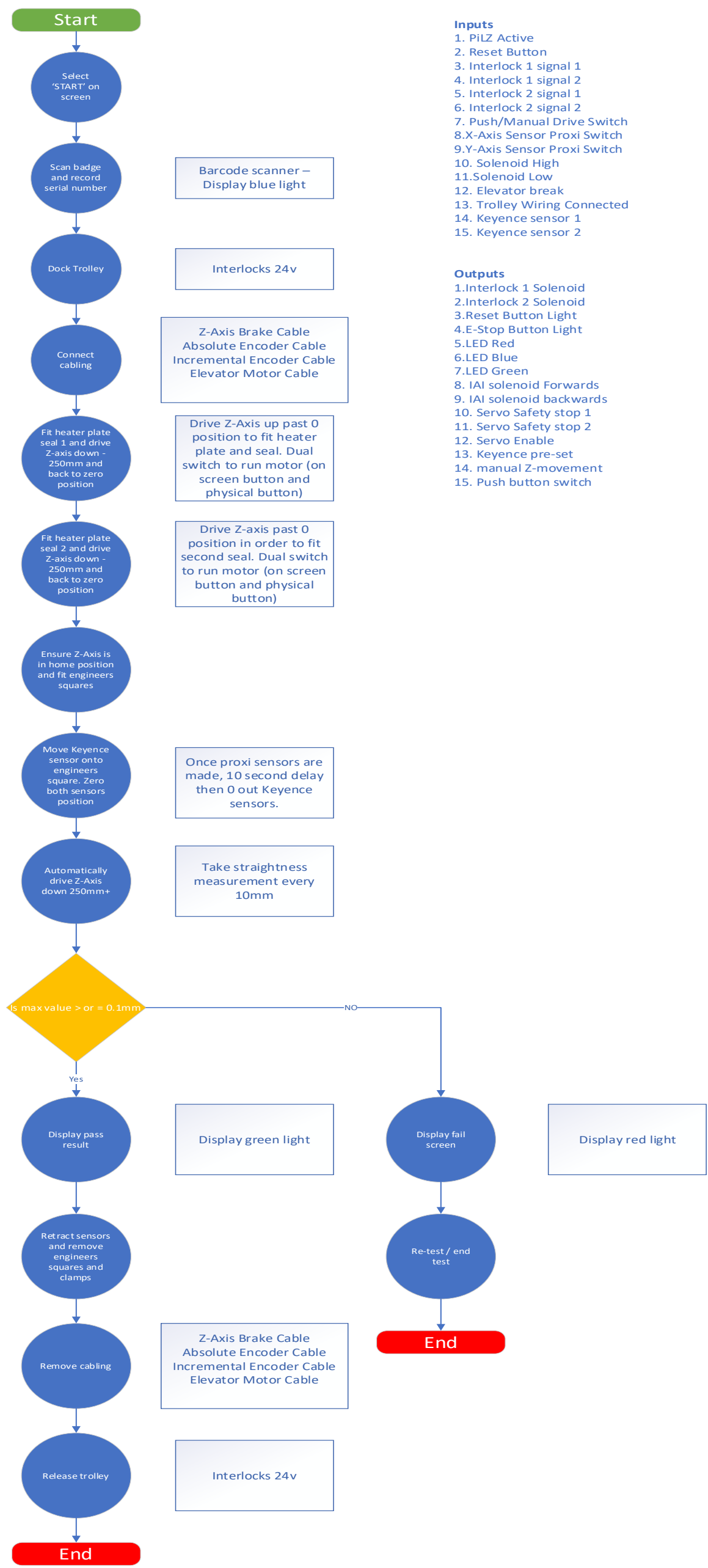
Figure 33 shows the rig set up. The first image is the bare chassis with the unmodified Z-Axis assembly trolley placed in the docking position. The second image illustrates the X-Axis side mechanism with the Keyence sensor. The lever has a collar that when pulled upwards releases the pin to allow the placement of the Keyence sensor on the X-Axis engineers square.



Figure 34 - Rig Final Build

Figure 34 shows the Z-Axis test rig complete and ready for testing. The Figure also labels key features of the rig that have been discussed throughout the report, such as the Y and X-Axis Keyence sensors, bridge design, interlocks, and trolley dampener. The image also illustrates the acrylic guarding placed around the test rig.

10.3. Program Process Flow



10.4. Return On Investment

This section looks at some of the costs prior to the introduction of the Z-Axis test rig as well as potential payback and additional positive financial benefits.

Looking at the **initial cost of downtime** in Cell 1 - the chamber cell where the Z-Axis is assembled:

- Total recorded downtime: 120 hours
- Labour cost per hour (Renishaw Figure): £86/hour/operator
- Total cost of downtime: £10,320

Financial Repercussions due to missing orders:

- Loss of machine sale due to delay: £1,000,000
- Annual servicing package per machine: £50,000 per year
- Potential additional machine sales over 3-5 years: 2 to 5 machines

Potential loss:

- Minimum: £2,000,000
- Maximum: £5,000,000

Original Z-Axis Verification Cost:

- Total cost of the verification cost over 8 weeks: £3,983.19
- Annual cost: £25,890.74

Savings from salvaging parts from RenAM 250:

- Percentage of parts used on rig from salvage: 93%
- Cost savings due to salvaging parts: £7,047

Project cost and budget:

- Total project cost without part salvaging: £10,669
- Total cost of project: £3,622
- Project budget: £5,000
- Surplus: £1,378

Efficiency improvement:

- Time reduction of verification process: 50%
- Labour requirements: 1 operator for initial set up

Return on investment:

- With a 50% reduction: £10,320/2: £5,160 potentially saved in downtime
- Annually verification cost savings: £25,890.74/2: £12,945.37
- Total annual savings: £12,945.37+£5,160 = £18,105.37

$$ROI = \frac{NET\ BENEFIT - INVESTMENT\ COST}{INVESTMENT\ COST} \times 100$$

$$ROI = \frac{£18,105.37 - £3,622}{£3,622} \times 100 \approx 399\%$$

This ROI calculation indicates the efficiency and profitability of the investment, 399% demonstrates a significant return relative to cost.

Project Payback:

$$Payback = \frac{£3,622}{£18,105.37} = 0.2\ years\ or\ \approx\ 2.5\ months$$

It is important to note that the cost saving was not the main motivator for this project, key considerations must be given to:

- RSI risk mitigation which could save up to £18,000 per claim.
- Business opportunity retention, avoiding loss of sales up to £1,000,000 per machine due to delays.
- The significant saving due to salvaging parts from the obsolete RenAM 250 machines saving £7,047 in cost.

11. Results

11.1. Gauge Repeatability & Reproducibility Study (Gauge R&R)

In manufacturing, continuous improvement is crucial for competition. Introducing process change is a very common strategic practice used to raise production levels, improve efficiency and quality as well as minimise health and safety risks. However, these changes cannot be introduced without ensuring robust evaluation when assessing measuring systems critical to key processes.

A gauge R&R study is used to determine the level of variation in a measurement system. Then comparing measurement variation to the total variation observed. Repeatability is due to the equipment variation, whereas reproducibility is due to operator variation (Quality-One, 2024). Gauge R&R can identify issues such as:

- The level of equipment variation compared to process.
- Variation of measurement data caused by operator influence.
- The measurements systems capability to distinguish between parts.

A gauge R&R study was carried out to distinguish any differences between the original method of Z-Axis verification and the new semi-automated Z-Axis assembly verification using the developed test rig. This study would act as confirmation that the new process was as repeatable if not more repeatable in accuracy over the original method.

11.2. Methodology

This section contains the method undertaken to gather and interpret the results of the study. Following a systematic approach detailed by Croft (2023):

Step 1 - Selection of Parts, Operators, and trials:

For the Gauge R&R study to compare both the original and semi-automated verification procedure, careful consideration was given to the selection of parts, operators, and number of trials. The study aimed to ensure that the new method maintained or improved the repeatability and accuracy of the verification procedure.

Throughout the study, the same Z-Axis assembly was utilised to maintain consistency between the tests. The Z-Axis had been already tested to ensure that it is within the acceptable tolerance. To note, the original testing procedure required two operators, whereas only one operator was required for the new semi-automated test rig. Operator 1 was used over both of tests and is an experienced assembler.

Step 2 - Data Collection:

During the original verification test, readings were taken over 250mm of the Z-Axis' build volume. Operator 1 used the handheld drill to drive the servo, stopping the build plate every 10mm allowing Operator 2 to take the reading from the DTI. This process was repeated 10 times for every 10mm interval, resulting in 10 readings for every 10mm of movement across the 250mm span.

Operator 1 conducted the test using the semi-automated rig, following the same method. However, this time, the test was automated, requiring only 1 operator for set up and then running the test autonomously. The consistency of operators ensured the comparability of the collected data.

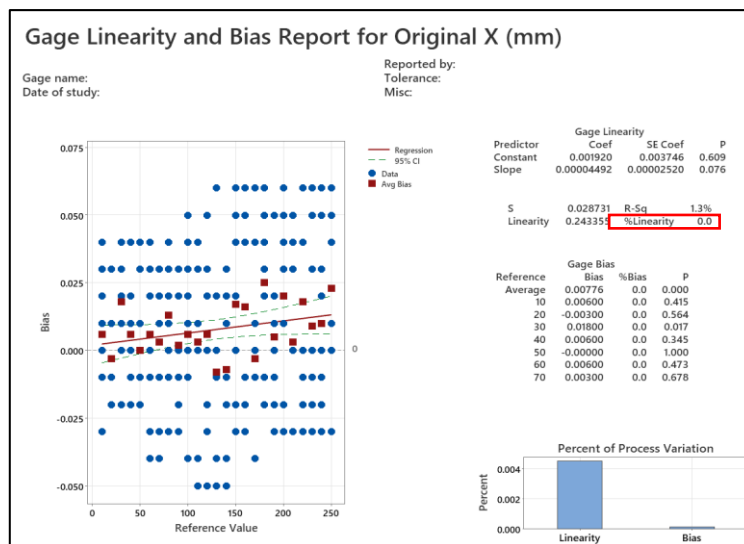
Step 3 - Data Analysis:

Having gathered all the data, Minitab software was utilised for data analysis. The collected data consisted of paired readings for both the original test (X and Y axis) and the semi-automated test (X and Y axis).

A gauge R&R crossed study was conducted for each axis of both methods determining the ANOVA or analysis of variation in the data sets. A standard deviation of 5.15 was used for modeling, adhering to industry standards (Quality-Assurance-Solutions, 2024). The total variation calculated for each of the datasets was then used to conduct a gauge linearity and bias study, which assessed the accuracy of the two different gauges (Dial Test Indicator for the original method and Keyence Sensors for the improved method).

11.3. Minitab Results

11.3.1. Original Method X Axis – Total Variance & Gauge Linearity & Bias



Gage R&R

Variance Components

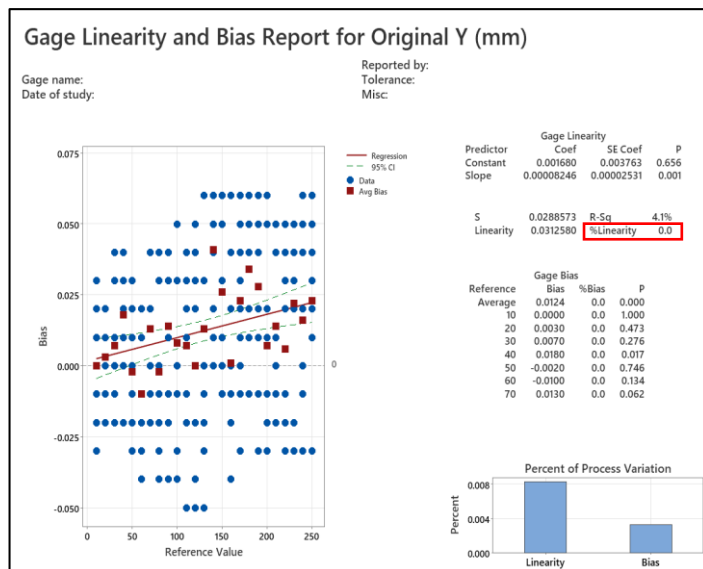
Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.00	0.00
Repeatability	0.00	0.00
Part-To-Part	5417.15	100.00
Total Variation	5417.15	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (5.15 x SD)	%Study Var (%SV)
Total Gage R&R	0.0289	0.149	0.04
Repeatability	0.0289	0.149	0.04
Part-To-Part	73.6013	379.047	100.00
Total Variation	73.6013	379.047	100.00

Number of Distinct Categories = 3592

11.3.2. Original Method Y Axis – Total Variance & Gauge Linearity & Bias



Gage R&R

Variance Components

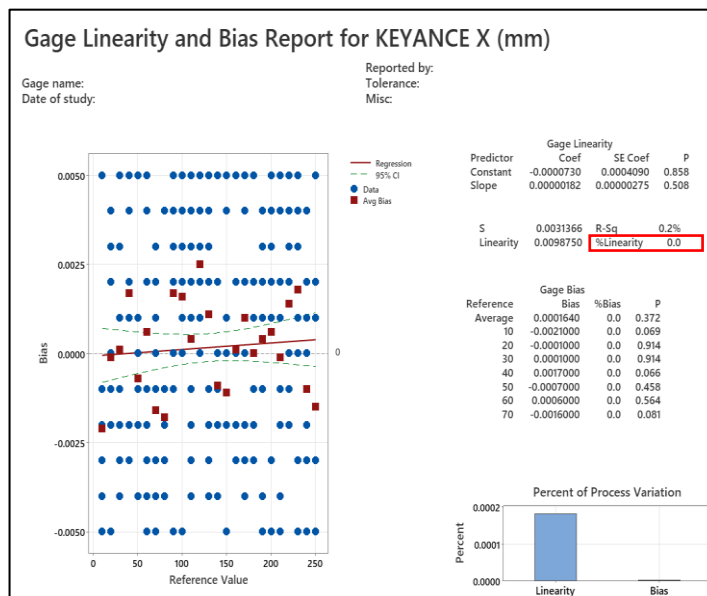
Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.00	0.00
Repeatability	0.00	0.00
Part-To-Part	5417.56	100.00
Total Variation	5417.56	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (5.15 × SD)	%Study Var (%SV)
Total Gage R&R	0.0282	0.145	0.04
Repeatability	0.0282	0.145	0.04
Part-To-Part	73.6041	379.061	100.00
Total Variation	73.6041	379.061	100.00

Number of Distinct Categories = 3682

11.3.3. Improved Method X Axis – Total Variance & Gauge Linearity & Bias



Gage R&R

Variance Components

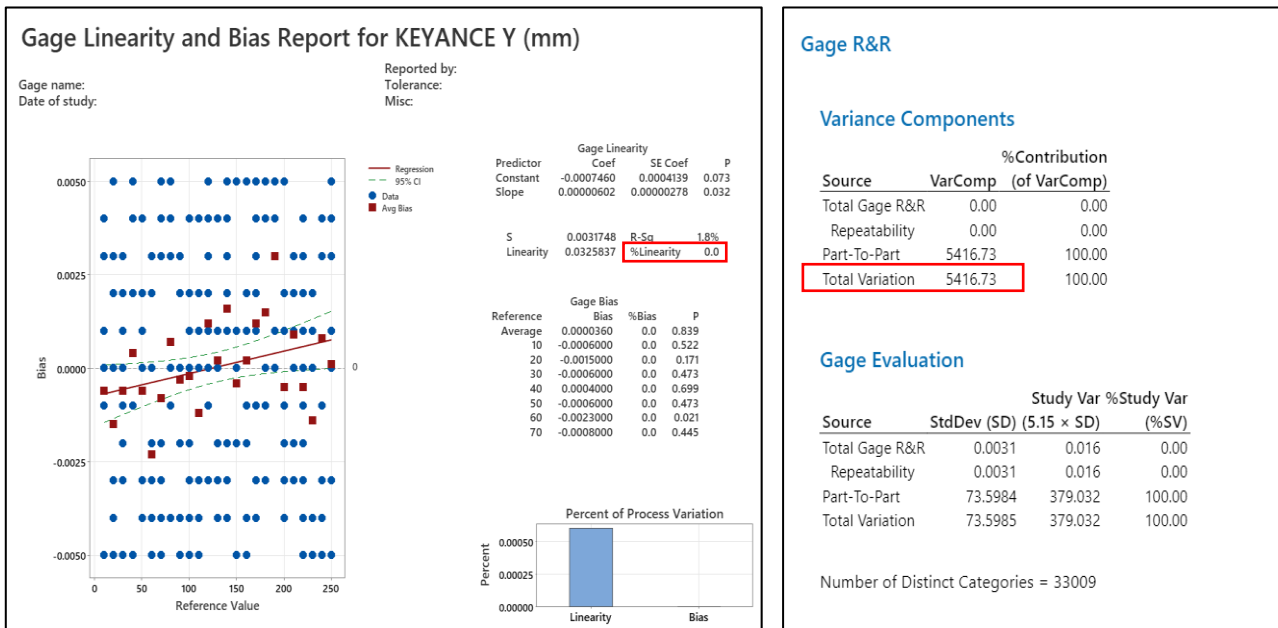
Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.00	0.00
Repeatability	0.00	0.00
Part-To-Part	5416.69	100.00
Total Variation	5416.69	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (5.15 × SD)	%Study Var (%SV)
Total Gage R&R	0.0030	0.016	0.00
Repeatability	0.0030	0.016	0.00
Part-To-Part	73.5981	379.030	100.00
Total Variation	73.5981	379.030	100.00

Number of Distinct Categories = 34291

11.3.4. Original Method Y Axis – Total Variance & Gauge Linearity & Bias



11.3.5. Discussion

Key Results of study are shown in Table 11:

	Original		Improved	
	X-Axis	Y-Axis	X-Axis	Y-Axis
Total Variance	5417.15	5417.56	5416.69	5416.73
Linearity (%)	0	0	0	0

Table 11 - Gauge R&R Key Results

Key Points:

Reduced Variation: The data indicates a slight decrease in variation in the improved verification method results when compared with the original.

Impressive Linearity: Linearity for both the original and improved gauges is 0%, signifying excellent performance and accuracy of the gauges in verifying the straightness.

Higher Resolution: Data gathered by the Keyence sensors in the improved method boasted higher resolution readings down to microns of accuracy, enhancing precision.

Project Goals Achieved: The primary project goals of removing the handheld drill, verifying X and Y axes simultaneously, and mitigating the risk of future RSI complaints have been achieved. This gauge R&R study was performed to confirm that the Z-Axis test rig is acceptable in accuracy required.

Cost and Time Efficiency: The improved verification method significantly reduced time and cost implications on the process. It took one operator just 15 minutes to set up per test over the 10 iterations required. Compare that to two operators carrying out the test using the original method which took 10.25 hours. This translates to £1763 versus £215, using the improved verification method has allowed the operator to be free to carry out other value adding tasks due to its autonomous testing once set up.

Operator Satisfaction: Operators expressed satisfaction with the improved method, particularly as the handheld drill was eliminated. This led to an ergonomic working environment.

Acceptable Accuracy: Overall, the study concludes that the level of accuracy is acceptable with the new method of verification. It validates its usability for future testing.

12. Project Performance Evaluation

Evaluation of Project success against the Product Design Specification set out:

Functional Requirements			
Ref	Target Requirement	Validated	Evaluation
1.1	To be a fixed test rig for validation of the Z-Axis Assembly at its Sub Assembly stage and its variants.	✓	Rig has been designed to suitably hold and test the Z-Axis assembly with use of Keyence sensors and engineers' squares.
1.2	To be able to drive the completed Z-axis assembly up and down using the fitted motor.	✓	The Tester makes use of the fitted motor as a means of moving the build plate up and down for the validation of the test.
1.3	To measure the straightness of the build plate as it travels down the assembly.	✓	Build plate straightness measured every 10mm across 250mm of movement, Keyence sensors output a signal every 10mm and the results are calculated, the test will pass the rig if the straightness is within 0.1mm.
1.4	To be able to fit the seals to the heater plate as part of the Z-axis assembly and to test the sub assembled unit.	✓	Test allows for the fitment of the seals; the build plate is also sent down to ensure that the seals are fitted correctly.
1.5	Compatible with the Z-Axis Trolley T-99205.	✓	The Z-Axis test rig is fully compatible with the Z-Axis trolley T-99205, incorporating the trolley into the test itself.
1.6	Test straightness of both X and Y axis simultaneously.	✓	Two engineers' squares are used with two Keyence sensors for both the validation of the X and Y axis.
1.7	Needs to hold measurement device in locked and stable position.	✓	Y axis bridge holds the Y axis Keyence sensor in a locked and stable condition. The X axis Keyence sensor is held in place on the X-axis side mechanism ensuring that the Keyence sensor is locked and stable.
1.8	Increase range of vertical testing to test full capacity of Z-Axis movement.	✓	Testing has successfully been altered from 230mm to 250mm offering a far more accurate measurement of the Z-Axis Assembly's Straightness.
1.9	The Z-Axis Assembly must be secure and stable when tested.	✓	Z-Axis assembly held stable in the Z-Axis trolley during the test.

Rig Mechanism			
Ref	Target Requirement	Validated	Evaluation
2.1	Complete the test with the motor fitted to the assembly.	✓	The motor fitted to the Z-Axis assembly is used to complete the test as was desired from the start of the project.
2.2	Rig to fully support build volume during the testing process.	✓	Trolley is used to support the Z-Axis assembly during the testing procedure as was required. The build volume is well supported during the testing procedure.
2.3	Fully enclosed rig that is compatible with the current Z-Axis Assembly.	✓	The rig is fully enclosed with no trap points from an operator's perspective, acrylic sheet is used to shroud any entrapment points that may occur during the test.
2.4	Rig Requires Main Power Supply.	✓	Mains power supplied to the Z-Axis test rig.
2.5	Suitable HMI.	✓	HMI used is at a great height and is easy to read from.
2.6	Traceability of testing.	-	Yet to fully verify this part of the P.D.S which was marked as a desirable specification point.

Environmental Protection			
Ref	Target Requirement	Validated	Evaluation
3.1	Must be RoHS and WEEE Compliant	✓	Project conforms to all regulations.

Transport Requirements			
Ref	Target Requirement	Validated	Evaluation
4.1	Intention is for the rig to in one position.	✓	Test rig stays in one stable position and trolley docks into the tester.
4.2	Rig needs to be able to move if required	✓	Approximately 100KG with control panel and can be lifted with a pump truck if needed

Set-up Requirements			
Ref	Target Requirement	Validated	Evaluation
5.1	The rig must have a minimal set up time	✓	Most of the rig set up is automatic, the only operator input will be to dock the trolley, connect cabling, and slide side mechanism into place. The only input during test will be the raising of the build volume to fit seals and locating 0 position using dual push buttons.

Operational Requirements			
Ref	Target Requirement	Validated	Evaluation
6.1	Test results must be recorded.	-	Test results will eventually be recorded, currently the previous five test results are stored, however will be deleted when the next test is taken. Future development will be to programme in a database. Automatic data storage needs to be developed; test results will be inputted via the operator until a database can be established.
6.2	All tests should be able to run automatically without the need of operator supervision.	✓	Operator input is very minimal, the test itself will be run completely automatically.
6.3	Rig to allow retry attempts of any unit that failed.	✓	Operator will be able to retest the straightness of the Z-Axis assembly three time before having to completely re-start the test.
6.4	Work and Re-work procedure must be intuitive with on screen prompts.	✓	Human Machine Interface is used for onscreen instructions, this ensures that rework is intuitive and easy to follow by the operator.
6.5	Needs to be simple for users to easily understand how to use the jig correctly and efficiently.	✓	The test rig has been step locked and is easy to use, the test has been made automatic with minimal user input.
6.6	Components of test rig should be error proofed, so incorrect set up of tooling is impossible.	✓	The test rig has been step locked and is easy to use, as mentioned above. The onscreen instructions are easy to follow with very minimal set up time, the test itself is automatic and requires no operator input.

6.7	Extra tooling needed to operate the tooling design should be minimised or easily accessible.	✓	With the rig design being semi-automatic, extra tooling has been minimised with the aim of reducing non-value-added time within the process.
6.8	Instructions on how to operate tooling need to be clear and easily accessible.	✓	The new process is efficient, and no time has been wasted in trying to understand how tooling works from an operator point of view. On screen work instruction that is shown on the HMI is clear and easy to follow.

Legislative & Safety			
Ref	Target Requirement	Validated	Evaluation
7.1	Must conform CE and UKCA Requirements	-	DL440 compliance documentation still progressing. No problems from a compliance point of view will meet CE and UKCA requirements before being put on the assembly line.
7.2	To meet the requirements outlined in the risk assessment & machinery safety report.		DL412 Risk Assessment complete prior to gauge R&R study carried out by operators, detailed Appendix F.

Legislative & Safety			
Ref	Target Requirement	Validated	Evaluation
8.1	Lighting to be 1000 Lux or greater	✓	Lighting deemed to be sufficient within hall 1, the proposed area for the test rig.
8.2	Needs to be designed ergonomically using guidance from DS312	✓	Tester designed following guidance from DS312.

Initial Project Aims & Objectives:

The Z-Axis Alignment Rig successfully achieved its primary aim of developing a rig that addresses ergonomic concerns and verifies the Z-Axis' assembly's straightness to the 0.1mm tolerance verified over 250mm of the build volume. This project not only automated the testing procedure but also ensured the functionality of the Z-Axis assembly within the RenAM 500 additive manufacturing machine.

All objectives detailed on page 5 of this report have been met: the rig has been designed, built, and implemented, and is fully compatible with the assembly trolley. The testing procedure for verifying the straightness has been developed and verified, utilising the fitted servo motor as required. The rig is repeatable, user friendly and safe. Furthermore, it adheres to the CE compliance standards, though the regulatory compliance documentation is ongoing due to the quantity required by the internal compliance team. This is due to be completed on 20-11-2024 before the rig can be officially CE stamped. A risk assessment was successfully completed (see Appendix F) on the rig prior to operators testing for the purpose of the gauge R&R study.

The project was completed well within the £5,000 budget set, purely due to the efforts made in the salvaging of components from the 250 variants of the additive manufacturing machine. Lastly, a draft for the Preventative Maintenance Instruction has been created, ensuring that trained technicians are able to reliably maintain both the test rig and assembly trollies. The completion of both the PMI and remaining regulatory compliance documentation will mark the final steps in successful operational readiness and compliance certification.

Key lessons have been learnt by the author that will be used in future projects, such as:

Effective Planning and Time Management - the project has hit all key milestones on its way to completion which is partly down to effective time management through planning techniques such as the Gantt chart.

Budget Adherence - utilising techniques such as the salvaging of scrap components was an effective use of company resource that otherwise would have been scrapped.

Risk Management – Implementing the risk assessment on the rig to ensure it is fit for purpose prior to the operator conducting trials, which mitigated potential issues and ensured project safety.

Stakeholder Communication – The project was well communicated to key stakeholders who were informed of decisions throughout the project, this was essential in aligning expectations and addressing any concerns in a timely manner.

Documentation and Compliance – Clear documentation was kept throughout the project's completion which smoothly transitioned into information that was utilised in the regulatory compliance documents.

13. Future Recommendations

The following recommendations have been suggested for further improvement:

1. Implement Automatic Data Tracking

Develop a system that automatically tracks and stores test data in a database integrated with the internal Syteline system. This will reduce the requirement for manual data entries, saving time, and providing reliable data repository for performance analysis and any reference requirement.

2. Finalise PMI Documentation:

Complete the Preventative Maintenance Instruction and ensure it is reviewed and signed off by the production team. This will standardize the maintenance procedures and bring the rig in line with other equipment across the assembly line, also ensuring that trained technicians can efficiently perform required maintenance tasks.

3. Operator Feedback Mechanism:

Introduce a questionnaire to capture key operator feedback. This will ensure the identification of any issues, gathering suggestions for improvements to future rigs, and elevate the rigs user satisfaction. Positive feedback will also highlight the rigs overall benefit from individuals expected to operate it.

Addressing these recommendations will ensure the enhancement of operational efficiency and long-term reliability, whilst having the user's satisfaction at the forefront of the project's direction. Continued improvements fuelled by feedback will support the rigs successful transition from the design development phase to fully line implemented, helping to ensure the successful verification of the Z-Axis assembly within the RenAM 500 additive manufacturing machine.

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Appendices

A) Z-Axis Internal RSI Assessment Following HSE Guidance

Health and Safety
Executive

Assessment of repetitive tasks of the upper limbs (the ART tool)

Guidance for employers



INDG438
Published 03/10

The assessment of repetitive tasks (ART) tool is designed to help you risk assess tasks that require repetitive moving of the upper limbs (arms and hands). It helps you to assess some of the common risk factors in repetitive work that contribute to the development of upper limb disorders (ULDs).

ART is aimed at those responsible for designing, assessing, managing and inspecting repetitive work. It can help identify those tasks that involve significant risks and where to focus risk-reduction measures. It will be useful to employers, safety representatives, health and safety practitioners, consultants and ergonomists.

Further information on ART, including online training on how to use the tool, can be found at www.hse.gov.uk/msd/uld/art.

The ART tool

Page 1 of 16

Frequency and repetition

A1 Arm movements

Observe the movement of the arm and select the category that is most appropriate. It is possible to select intermediate scores. Assess both the left (L) and right (R) arm.

NO ARM MOVEMENT = 0

		L	R
Arm movements are	Infrequent (eg some intermittent movement)	0	0
	Frequent (eg regular movement with some pauses)	3	3
	Very frequent (eg almost continuous movement)	6	6

A2 Repetition

This refers to movement of the arm and hand, but not the fingers. Observe the movement of the arm and hand and count the number of times the same or a similar pattern of motion is repeated over a set period of time (eg 1 minute). Assess both the left (L) and right (R) arm.

NO ARM OR HAND MOVEMENT = 0

		L	R
Similar motion pattern of the arm and hand is repeated	10 times per minute or less	0	0
	11–20 times per minute	3	3
	More than 20 times per minute	6	6

Force

B Force

Use the grid below to determine the level of force exerted with the hand and the amount of time that the force is exerted. It is possible to select intermediate scores on the grid if appropriate. If more than one type of force is exerted, select the highest score obtained with the grid.

There are two methods to determine the level of hand force:

- Ask the person doing the work if there are any actions that require muscle effort of the arm, hand or fingers. If such actions are identified, ask the worker to describe the level of force involved in each action (eg light force, moderate force, strong force, or very strong force).
- Otherwise, use the written descriptions below to determine the level of force exerted with the hand.

Light force	There is no indication of any particular effort.
Moderate force	Force needs to be exerted. For example: ■ Pinching or gripping objects with some effort ■ Moving levers or pushing buttons with some effort ■ Manipulating lids or components with some effort ■ Pushing or forcing items together with some effort ■ Using tools with some effort
Strong force	Force is obviously high, strong or heavy
Very strong force	Force is near to the maximum level that the worker can apply

FORCE TO HOLD DRILL & DEPRESS TRIGGER = G0

Worker's description of the level of force exerted with the hand

	Light	Moderate	Strong	Very strong
Infrequent	G0	A1	R6	Changes required*
Part of the time (15-30%)	G0	A3	R9	Changes required*
About half the time (40-60%)	G0	A6	R12	Changes required*
Almost all the time (80% or more)	G0	R6	Changes required*	Changes required*

* Changes to the task are required due to unacceptable levels of force.

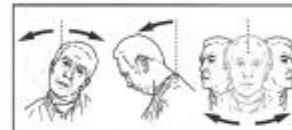
Awkward postures

Determine the amount of time that the worker spends in the postures described below. This includes the time spent moving to a bent or twisted position repetitively and the time spent holding a bent or twisted position.

C1 Head/neck posture

The neck is considered to be bent or twisted if an obvious angle between the neck and back can be observed as a result of performing the task.

The head or neck is:

	In an almost neutral posture	0	= 0
	Bent or twisted part of the time (eg 15–30%)	1	
	Bent or twisted more than half of the time (more than 50%)	2	

C2 Back posture

The back posture is considered awkward if more than 20° of twisting or bending is observed.

The back is:

	In an almost neutral posture	0	= 0
	Bent forward, sideways or twisted part of the time	1	
	Bent forward, sideways or twisted for more than half of the time	2	

C3 Arm posture

The arm is considered to adopt an awkward posture if the elbow is raised to around chest height and the arm is unsupported (eg not resting on a workbench).

The elbow is:

		L	R	= 2
	Kept close to the body or supported	0	0	
	Raised away from the body part of the time	2	2	
	Raised away from the body more than half of the time	4	4	

C4 Wrist posture

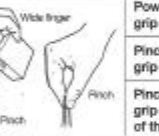
The wrist is considered to be bent or deviated if an obvious wrist angle can be observed.

The wrist is:

	L	R
 Bent wrist	0	0
 Deviated wrist	1	1
	2	2

C5 Hand/finger grip

The hands or fingers hold objects in a:

	L	R
 Power	0	0
 Wide finger	1	1
 Pinch	2	2

Additional factors

D1 Breaks

Determine the maximum amount of time that individuals perform the repetitive task without a break. Breaks are significant changes or pauses (eg of at least 5–10 minutes) in arm or hand activity. They include structured breaks such as meal breaks. They also include time spent performing other tasks that do not involve similar repetitive arm movements (eg a visual inspection task).

The worker performs the task continuously, without a break, for:

Less than one hour, or there are frequent short breaks (eg of at least 10 seconds) every few minutes over the whole work period	0
1 hour to less than 2 hours	2 = 2
2 hours to less than 3 hours	4
3 hours to less than 4 hours	6
4 hours or more	8

D2 Work pace

Speak to the workers about any difficulties they might have keeping up with the work. Select the most appropriate category. If the score is amber or red, ask for more information about this aspect of the work.

Not difficult to keep up with the work	0
Sometimes difficult to keep up with the work	1 = 1
Often difficult to keep up with the work	2

DEPENDANT ON WHETHER ADJUSTMENT IS REQUIRED

D3 Other factors

Identify any other factors that are present in the task. For example:

- gloves affect gripping and make the handling task more difficult;
- a tool (eg hammer, pick) is used to strike two or more times a minute;
- the hand is used as a tool (eg hammer) and struck ten or more times per hour;
- the tools, workpiece or workstation cause compression of the skin; ✓
- the tools or workpiece cause discomfort or cramping of the hand or fingers; ✓
- the hand/arm is exposed to vibration; ✓
- the task requires fine precise movements of the hand or fingers;
- operators are exposed to cold or draughts or grip cold tools; and
- lighting levels are inadequate.

Select the most appropriate category. Assess both the left (L) and right (R) arm.

	L	R
No factors present	0	0
One factor is present	1	1
Two or more factors are present	2	2

$= 2$

D4 Duration

Determine the amount of time that a worker performs the repetitive task in a typical day or shift (excluding breaks). Select the most appropriate category.

Duration of task by a worker	Duration multiplier
Less than 2 hours	X 0.5
2 hours to less than 4 hours	X 0.75 ✓ = 0.75
4 hours to 8 hours	X 1
More than 8 hours	X 1.5

D5 Psychosocial factors

Psychosocial factors are not given a score. However, they should be considered, through discussion with workers, and, if present in the workplace, recorded on the score sheet. They include things such as:

- little control over how the work is done;
- incentives to skip breaks or finish early;
- monotonous work;
- high levels of attention and concentration;
- frequent tight deadlines;
- lack of support from supervisors or co-workers;
- excessive work demands; and
- insufficient training to do the job successfully.

- NO FORMAL WRITTEN INSTRUCTIONS FOR THE TASK
- AUTOMATED J14 IS ALMOST COMPLETE TO REMOVE THE MANUAL TASK

Completing the score sheet

Enter the colour band and numerical score for each risk factor on the score sheet. There is also a place on the score sheet to record other important findings of the assessment.

If you assess both arms, several factors only need to be assessed once. These are head/neck posture, back posture, breaks, and work pace. However, these scores should be entered into the columns for both the left arm and right arm.

Follow the instructions below to calculate the task score and exposure score.

Calculating the task score

To calculate the task score, add together the scores on the score sheet.

$$\text{Task score} = A1 + A2 + B + C1 + C2 + C3 + C4 + C5 + D1 + D2 + D3$$

If you assess both arms, the scores for the left arm and right arm should be kept separate and not combined.

Calculating the exposure score

It is possible to adjust the task score to reflect the total duration that the task is performed by a worker. Multiply the task score by the appropriate duration multiplier (D4) to calculate the exposure score.

$$\text{Task score } 16 \times \text{Duration multiplier } 0.75 = \text{Exposure score } 12$$

The task scores and exposure scores help prioritise those tasks that need most urgent attention and help check the effectiveness of any improvements.

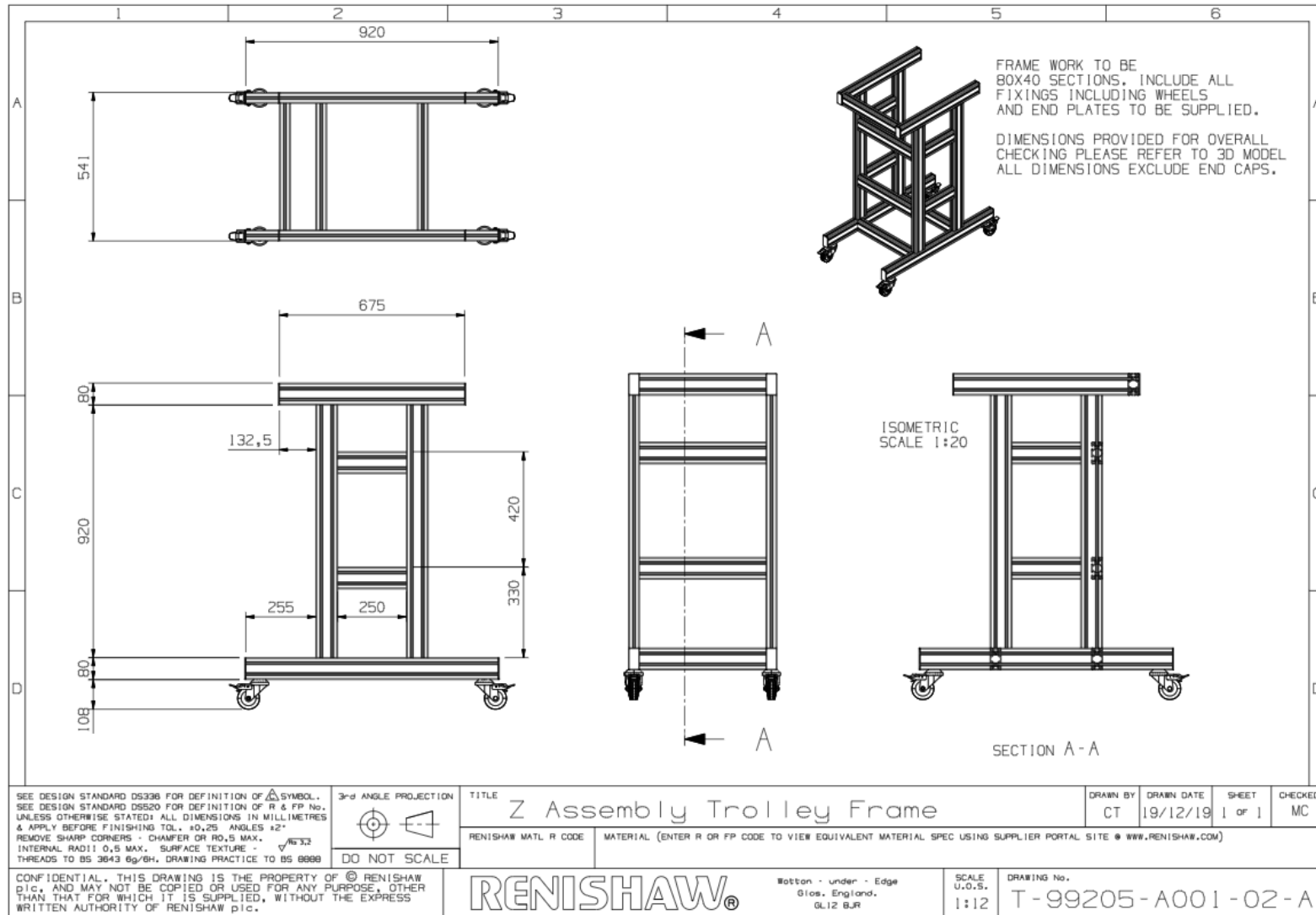
The colours assigned to the risk factors will help identify where to focus risk-reduction measures.

A system for interpreting the exposure score is proposed in the table below.

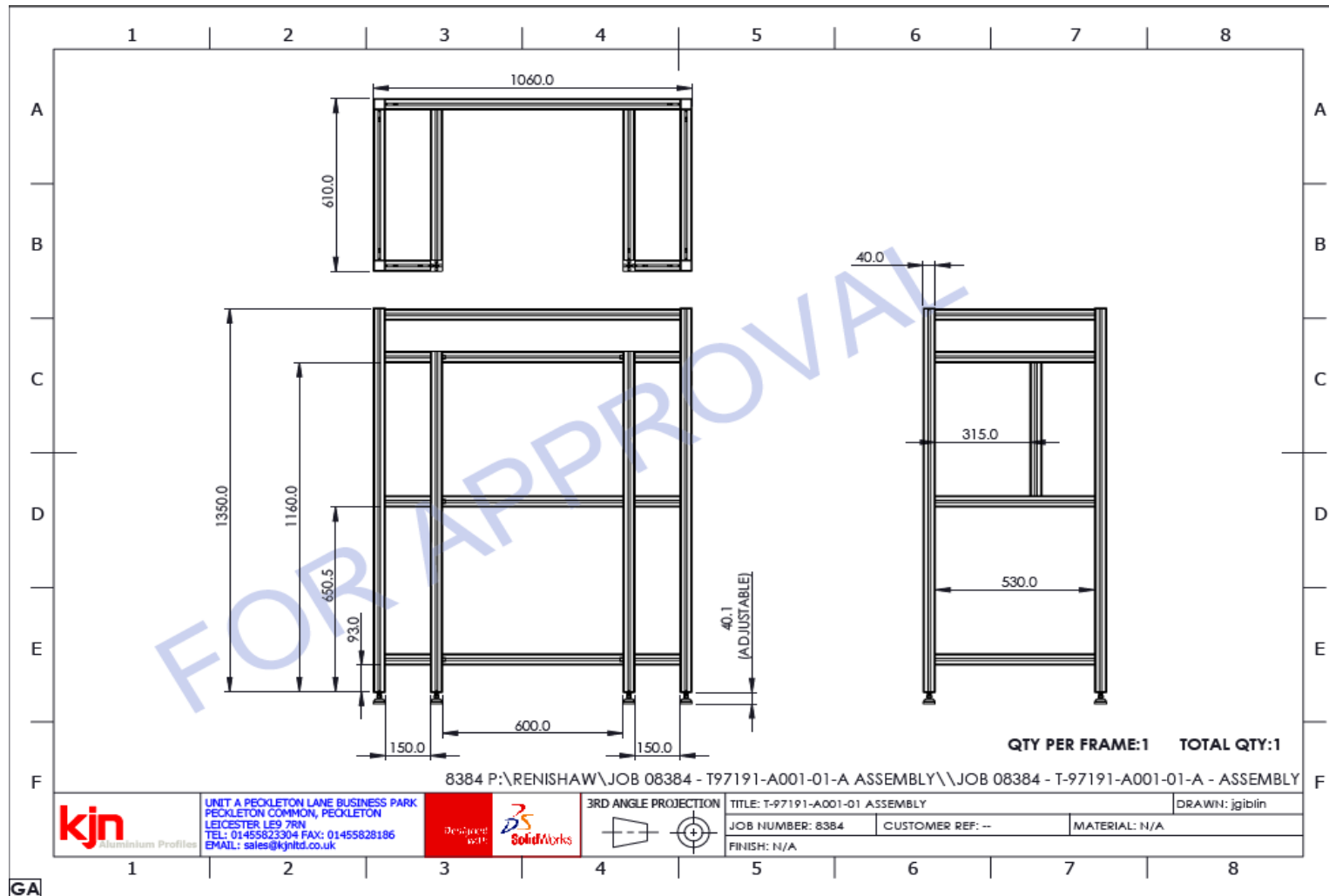
Exposure score	Proposed exposure level	
0-11	Low	Consider individual circumstances
12-21	Medium	Further investigation required
22 or more	High	Further investigation required urgently

Even if the exposure score is low, take into account the requirements of certain individuals and groups where appropriate (eg new and expectant mothers, workers that are new, returning to work, or having difficulties with repetitive work). Individual adjustments to the work may still be needed to help accommodate these people.

B) Z-Axis Trolley Dimension



C) Z-Axis Tester Framework



D) Z-Axis Test Rig Bill of Materials

Current Item	Quantity	Description	Cost
LC STEEL ENCLOSURE	1	electrical panel	£272
IAI ACTUATOR	1	IAI LINEAR ACTUATOR FOR BRIDGE	£550
KEYENCE GT2 BRACKET	2	KEYENCE GT2 BRACKET	-
KEYENCE GT2	1	KEYENCE GT2 SENSOR & AMP	£525
T-97191-A001-01	1	Frame-Work	£635
T-97191-P100-01	1	ITEM PROFILE 40x40x1350	-
T-97191-P104-02	1	ITEM PROFILE 40x40x150	-
T-97191-P103-01	1	ITEM PROFILE 40x40x980	-
T-97191-P101-01	1	ITEM PROFILE 40x40x1200	-
T-97191-P105-01	4	ITEM CAP 40x40	-
T-97191-P102-01	13	ITEM PROFILE 40x40x530	-
T-97191-P100-01	3	ITEM PROFILE 40x40x1350	-
T-97191-P104-02	5	ITEM PROFILE 40x40x150	-
T-97191-P101-01	1	ITEM PROFILE 40x40x1200	-
T-97191-P102-01	1	ITEM PROFILE 40x40x530	-
T-97191-P103-01	3	ITEM PROFILE 40x40x980	-
T-97191-P106-01	6	ITEM 8MM FOOT	-
T-97191-P107-01	134	ITEM FASTENING SET	-
T-97191-P109-01	134	ITEM M6 T-NUT	£106
T-97191-P113-01	2	ITEM PROFILE 40x40x465	-
T-99205-02	1	Z Assembly Trolley(s)	£996
A-6521-2126-03	1	Z-AXIS ASSEMBLY	-
P-SC08-0616	4	Screw Hex Skt Cap Hd M6x16	Internal
M-6521-3543-02	1	SQUARE CLAMP	Internal
T-99205-P055-02	2	Support Block	Internal
T-97853-P069-01	23	PANEL BRACKET	Internal
T-99205-P056-01	2	Bottom side panel	-
P-SC17-0052	21	Screw Hex Skt Flanged Button Hd M6x12	Internal
T-99205-P058-01	1	Bottom centre panel	-
T-99205-P062-01	1	Side door panel	-
Acrylic for Panelling	7	Acrylic for Panelling	£250
T-98135-P036-02	3	Door Hinge Part 1	Internal
T-98135-P037-02	3	DOOR HINGE PART 2	Internal
Side door assembly	1	T-99205-A003-01	-
Side door assembly2	1	T-99205-A003-01	-
T-99205-A002-01	2	Door Hinge Assy	£88.20
T-98135-P038-01	3	DOOR HINGE PIN	Internal
T-99205-A005-01	1	Left side door assembly	-
T-98135-P038-01	1	DOOR HINGE PIN	Internal
T-98135-P036-02	1	Door Hinge Part 1	Internal
T-99205-P062-01	1	Side door panel	-
T-98135-P037-02	1	DOOR HINGE PART 2	-

T-99205-A004-01	1	Middle right door assembly	-
T-99205-P061-01	1	Middle right door panel	-
T-98135-P038-01	2	DOOR HINGE PIN	-
T-98135-P037-02	2	DOOR HINGE PART 2	-
T-98135-P036-02	2	Door Hinge Part 1	-
T-99205-P063-01	2	INTERLOCK KEY HOUSING	
P-SW10-0021	2	Switch Safety Key - Vertical Mtd	
T-99205-P061-01	1	Middle right door panel	-
T-99205-P078-01	1	CABLE BRACKET	Internal
T-99205-A006-01	1	Y-Axis Engineers Square Assy	£64.60
P-SC01-0416	2	Screw Hex Skt Cap Hd M4x16	Internal
P-SC01-0416	2	Screw Hex Skt Cap Hd M4x16	Internal
T-99205-P079-01	1	Y-Axis Engineer Square	-
T-99205-P080-01	1	Y-Axis Base Plate	-
T-99205-A007-01	1	X-Axis Engineer Square Assy	-
T-99205-P081-01	1	X-Axis Engineer Square	-
T-99205-P082-01	1	X-Axis Engineer Square Base Plate	-
P-SC01-0416	2	Screw Hex Skt Cap Hd M4x16	Internal
P-SC01-0416	2	Screw Hex Skt Cap Hd M4x16	Internal
T-97191-P112-01	1	SQUARE CLAMP (R/Hs)	Internal
P-SC01-0035	1	Screw Hex Skt Cap Hd M5x30	Internal
P-SC01-0009	2	Screw Hex Skt Cap Hd M5x20	Internal
T-99205-P060-02	1	Centre Panel	Internal
A-6521-0228-04	1	CHAMBER CONNECTOR PLATE ASSY	Internal
M-6291-0344-03	1	LOWER CHAMBER ELECTRICAL PLATE	Internal
P-CN21-0090	1	Con Circ 2W Rect Str Plg/Skt Contacts	Internal
P-CN21-0093	1	Con Circ 5W Rect Str Plg/Skt Contacts	Internal
P-CN21-0094	1	Con Circ 6W Rect Str Plg/Skt Contacts	Internal
P-CN21-0091	1	Con Circ 4W Rect Str Plg/Skt Contacts	Internal
P-CN21-0092	1	Con Circ 4W Rect Str Plg/Skt Contacts	Internal
P-CN21-0106	1	Con Circ 7W Rect Str Plg/Skt Con Panel	Internal
P-SC01-0620	6	Screw Hex Skt Cap Hd M6x20	Internal
P-SC01-0620	6	Screw Hex Skt Cap Hd M6x20	Internal
P-TD03-0019	1	Pressure Transducer 2bar 4-20mA	Internal
T-99205-P083-01	4	MAGNET / RS390-2117	£30
T-99205-P084-01	4	MAGNET STRIP / RS390-2117	-
T-97191-P108-02	1	Resting Plate	-
ITEM 0.0.480.50	18	ITEM T-SLOT NUT V 8 ST M6	-
P-SC02-0010	12	Screw Hex Skt Csk Hd M6x12	Internal
T-97191-P110-01	1	L/S Resting Plate	Internal
T-97191-A004-01	2	TROLLEY CUP	Internal
T-97191-P151-01	1	TOLLEY RECEIVER	Internal
P-SC17-0007	4	Screw Hex Skt Button Hd M5x12	Internal
T-97191-P150-01	1	CUP BASE	Internal
T-97191-P154-01	1	Y-AXIS PROBE SUPPORT	Internal

T-97191-P153-01	1	BRIDGE SUPPORT	Internal
T-97191-P152-01	1	SLIDING BRIDGE	Internal
T-97191-P155-01	1	Y-AXIS RAIL	Internal
P-SC56-0512	8	Screw Hex Skt Csk Hd M5x12	Internal
T-97191-P158-01	2	INTERLOCK BASE PLATE	Internal
P-SW14-0023	2	Switch Guard Lock Safety - Door	Salvage £400
T-97191-P159-01	2	LOCATING BLOCK	Internal
T-00242-A001-02	1	HMI ENCLOSURE	Internal
P-SW01-0023	1	Switch Head Emerg Stop 40mm	Salvage £22
P-SW01-0017	1	Switch Push Button Illuminated Blue	Salvage £25
T-00242-P003-01	4	PROFILE 60MM	Internal
T-00242-P002-02	1	HMI BACK PLATE	Internal
P-PC01-0036	1	HMI NS8 Terminal 8.4inch TFT Screen	Salvage £2500
T-00242-P001-01	1	HMI FRONT PLATE	Internal
T-00242-P004-02	1	HMI PANEL 1	Internal
T-00242-P005-01	1	HMI PANEL 2	Internal
T-00242-P006-02	1	HMI PANEL 3	Internal
T-00242-P007-01	16	M4 T-NUT 5 PROFILE	Salvage £20
P-SC17-S410	16	Screw Hex Skt Button Hd M4x10	Internal
P-SC17-0004	8	Screw Hex Skt Button Hd M6x12	Internal
P-CN13-0035	1	Con Skt Micro RJ45 Coupler Panel IP65	Internal
P-CN13-0035	1	Con Skt Micro RJ45 Coupler Panel IP65	Internal
T-00242-P012-01	1	HMI PANEL 4	Internal
T-97191-P161-02	2	PUSH BUTTON PLATE	-
T-97191-P160-01	2	PUSH BUTTON/ EATON RS399-3977	£80
T-97191-A005-01	1	SIDE MECHANISM ASSY	Internal
P-PM02-0008_BLOCK	1	Slider Block THK HSR15A1SS	Internal
T-97191-P156-01	1	X-AXIS RAIL	Internal
T-97191-P157-02	1	X-AXIS SUPPORT	Internal
T-97191-P165-01	1	PULL PIN HOUSING	£25.28
P-SC56-0512	6	Screw Hex Skt Csk Hd M5x12	Internal
T-97191-P163-02	1	LEVER SHAFT	Internal
T-97191-P164-02	1	LEVER SLEEVE	Internal
KEYENCE GT2 BRACKET	2	KEYENCE GT2 BRACKET	Salvage
KEYENCE GT2	1	KEYENCE GT2 SENSOR	Salvage
T-97191-P162-01	1	LEVER KNOB M8 / RS686-036	Internal
P-SC17-0042	4	Screw Hex Skt Button Hd M4x12 Special	Internal
T-97191-P167-01	1	M8 3PIN BALLUFF SENSOR RS 902-7647	Salvage £10
P-SC17-0023	2	Screw Hex Skt Button Hd M6x20 - 10.9	Internal
T-97191-P168-01	1	X-AXIS SENSOR HOUSING	Internal
T-97191-P169-01	1	BOTTOM LEFT SIDE PANEL	Internal
T-97853-P069-01	78	PANEL BRACKET	Internal
P-SC17-0052	78	Screw Hex Skt Flanged Button Hd M6x12	Internal

T-97191-P171-01	2	TOP LEFT SIDE PANEL	Internal
T-97191-P172-01	1	TOP CENTRE PANEL	Internal
T-97191-P173-01	1	CENTRE PANEL	Internal
T-97191-P175-01	1	BOTTOM CENTRE PANEL	Internal
T-97191-P176-01	2	BOTTOM FRONT PANEL	Internal
T-97191-P177-01	1	FRONT RIGHT PANEL	Internal
T-97191-P178-01	1	FRONT LEFT PANEL	Internal
T-97191-P179-01	1	PANEL	Internal
T-97191-P170-01	1	MIDDLE LEFT PANEL (SHADOWBOARD)	Internal
P-SW01-0023	1	Switch Head Emerg Stop 40mm	Salvage £40
T-97191-P174-01	2	CLAMP HOLDER	Internal
P-SC08-0512	1	Screw Hex Skt Cap Hd M5x12	Internal
T-97191-P181-01	2	Engineers' Square Holder (BASE)	Internal
T-97191-P180-01	2	Engineers' Square Holder (BRIDGE)	Internal
T-97191-P183-01	2	SEAL FRAME HOLDER	Internal
T-97191-P182-01	1	SCREW HOLDER	Internal

E) Main Electrical Components Bill of Material

Part Number	Description	QTY	Cost (All Salvaged)
ABB_2CSM259343R0721	M1363 Socket outlet	1	£25
LP1K0910BD3	Contactor AC-3 4KW 680V 1 NO 24VDC 3-pole size S00 screw connection	1	£50
P-CA82-0190	Cable Assy Brake Servo Motor 3M	1	£264.90
P-CA82-0191	Cable Assy Encoder Servo Motor 5M	0 M	£200.52
P-CN34-0008	Terminal Ground Block 4W 2.5mm2 G/Y	6	£25
P-CN34-0012	Terminal Through 2W 4mm2 Grey	12	£7
P-CN34-0066	Terminal Relay Assy 24Vdc 6A Green	14	£158.20
P-CN47-0086	Term Block 2W 4mm2 Grey+Marker DIN	43	£191.35
P-CN47-0125	Terminal Block Fused 6mm2 Skt Str DIN Rail	5	£15
P-CNAC-1004-RT	Con Rect 4 Way 1 Row Skt Free	2	-
P-CX02-2001	Con Crimp Skt 22-30AWG (L)(R)	8	-
PILZ_750101	Safety Relay 24V 2 Safety Contacts	1	£131.78
P-MC10-0016	G5 Servo Drive 230V/200W	1	£1634.20
P-ME01-0004	Transistor Unit 16 O/P 12-24VDC	1	£350
P-ME01-0020	Basic DC Input Unit 16 I/P 24Vdc 7mA	2	£320
P-ME01-0031	CPU unit 10K Prog 32K Data DIN	1	£1042
P-ME01-0058	Position Control Unit 2 Axis	2	£440
P-ME01-0060	Ethernet Switch eCon 2000	1	£30
P-MT01-0049	Motor Servo 230V 3000 RPM 400W 1.27Nm	2	£1200
P-NM20-0038	5VDC 3A AC/DC DIN Rail Power Supply	1	£25
P-NM20-0040	DIN Rail Power Line Filter 16A 250V	1	£20
P-NM20-0044	24VDC 5A DIN Rail Power Supply	1	£100
P-PW01-0037	PSU CJ Series 100-240Vac 14W	1	£272
P-RE05-0011	Relay Module DPDT 1A 24V Dinrail	2	£80
P-SW02-0027	Switch Pushbutton Blk 32V 400mA	6	£117
P-SW10-0047	Switch Isolator on/off Selector Knob	2	£12
P-SW14-0054	Cct Breaker 230Vac 6A 1 Pole C Curve	3	£114
P-SW14-0103	Switch Mains 400V 63A 3 Pole + N	1	£107
P-SW14-0111	Switch Safety 1NC/1NO 24V 4A	1	£60
P-TL50-0158	End Cover for NJ Series CPU	1	£55

F) Part of DL412 Risk Assessment

Assessment Date	24/06/21	Location	Cell 1 of the RenAM 500ML Assembly Line
Assessor(s)	Michael Cheeseman Ryan Harris	<i>Where the EUC/PUC was assessed or is intended to be used</i>	
Responsible person(s) Mark Sailes Paul Richards Paul Gay		Equipment/product design	Z-Axis Alignment Rig (T-97191-03)
		Workplace	RenAM 500ML Assembly Line

Delete unused hazard groups and rows as required, add/remove task/hazard rows and re-number as required

<u>No</u>	<u>Task / Hazard</u>	<u>Harm</u>	<u>Actions already completed prior to Initial Assessment</u>	<u>Initial Risk</u>			<u>Completed risk elimination / reduction/ control actions</u>	<u>Residual Risk</u>			<u>Result</u>
				<u>S</u>	<u>L</u>	<u>R</u>		<u>S</u>	<u>L</u>	<u>R</u>	
1	Mechanical										
1.1	Entrapment between sides of trolley and dual push button holder when manoeuvring Z-Axis assembly trolley in and out of the test rig.	Entrapment, back of hand caught on the edges of the dual push button holder.	None	1	2	3	Signage added to entrapment points to better identify the hazard.	1	2	3	Pass

No	Task / Hazard	Harm	Actions already completed prior to Initial Assessment	Initial Risk			Completed risk elimination / reduction/ control actions	Residual Risk			Result
				S	L	R		S	L	R	
1.2	Entrapment when the Elecylinder moves in the Y-Axis.	Hands/fingers potentially caught by the slide of the elecylinder or edges of the bridge.	None	1	2	3	Velocity of the elecylinder reduced to allow for operators to move hands clear to minimise the hazard.	1	2	3	Pass
8	Ergonomics										
8.1	Manoeuvring the Z-Axis assembly trolley in and out of the test rig.	Strain muscles, potential back strain.	None	3	1	4	Signage added to the trolley to illustrate where hands should be when manoeuvring the trolley.	3	1	4	Pass
9	Environmental										
9.1	Trip hazard with the legs of the Z-Axis assembly trolley.	Operator could trip over the legs of the trolley and injure themselves or others.	None	2	2	4	Hazard tape added to the legs of the trolley to better illustrate the potential hazard.	2	2	4	Pass
12	Reasonably foreseeable actions/misuse										
12.1	Fingers caught when moving the heater plate down from 23mm position.	Entrapment, Crushed Finger.	Motor RPM reduced during this stage of the test; also, manual dual push buttons used to ensure that the operators' hands are clear of the heater plate during movement.	3	1	4	None	3	1	4	Pass

Key to ratings: Calculate $R = S + L$.

<u>Severity</u>		<u>Likelihood</u>		<u>Rating Acceptability</u>	
0	Temporary pain, 0 injury.	0	Effectively 0, will never happen	0-5	Acceptable
1	Minor injury with minimal time lost	1	Never expected to happen	6	Acceptable, if reduction is not reasonably practicable. All appropriate risk reduction methods including design, guards, user information and safety circuits must be used if possible.
2	Injury with up to 3 days lost	2	Extremely unlikely		
3	Reportable injury with over 3 days lost	3	Very unlikely		
4	Major injury / long term absence	4	Unlikely		
5	Death	5	Multiple occurrences expected, almost certain	7-10	Unacceptable, must be reduced.

If S=4 or S=5 the hazard must be eliminated if possible, if not its likelihood must be as low as is reasonably practicable. If S=0 or L=0 the hazard is acceptable. If R=7 or higher the project cannot proceed (without explicit board approval). It may not be possible to reduce the risk rating, if the initial risk rating is 6 or less this may be acceptable.

Initial risk assessment and definition of hazards that require detailed assessment.

Hazard groups	Initial assessment	Detailed assessment required?
Mechanical	Hazard of entrapment has been minimised with the use of guarding around both the trolley and test rig, shrouding any moving parts. When the heater plate is required to drive above the zero position the operator can only jog the heater plate down with the use of dual push buttons that must be used simultaneously. This ensures that the operators' hands are clear of the heater plate. At this stage of the test, the motor will drive the heater plate at a much slower RPM further minimising the risk of entrapment.	Yes
Electrical	Electrical hazards have been minimised as all single-phase power is inside the panel except for the power to the servo motor which will not have any power until the program calls for the Z-Axis to move. Only electrically trained personnel will have access to the control panel.	No
Thermal	No hazard	No
Noise	No hazard	No
Vibration	No hazard	No
Radiation	No hazard	No
Material / substance	No hazard	No
Ergonomic	Hazard seen when moving the trolley.	Yes
Environmental	Tripping hazards identified upon initial assessment.	Yes
Combination	No hazard	No
Other	No hazard	No
Reasonably foreseeable actions / misuse	Upon initial assessment hazard identified for misuse of equipment.	Yes