



Project: Improving the Z-Axis Straightness Verification on RenAM500

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BEng (Hons) Manufacturing Systems Engineering

Introduction



Figure 1 - RenAM 500M Additive Manufacturing Machine

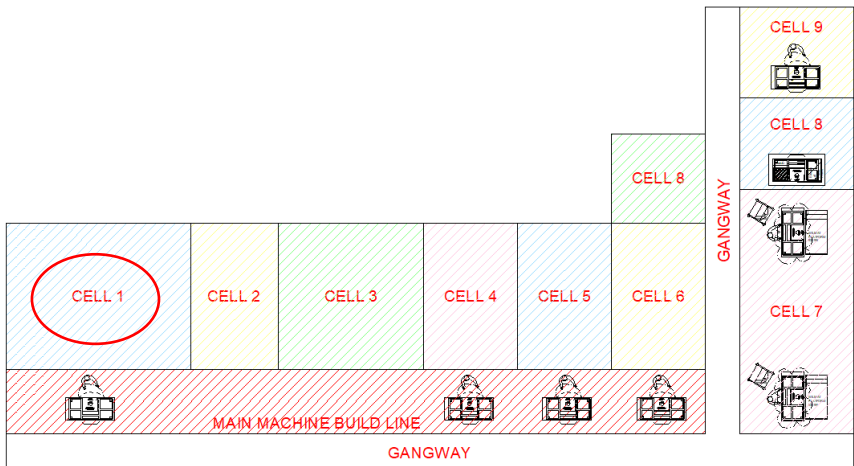


Figure 2 - Assembly Line Layout

- RenAM 500:** A metal additive manufacturing machine (3D printer) by Renishaw (Figure 1).
- Additive Manufacturing:** Creates complex three-dimensional parts from digital files using fine layers of metal powder sintered with lasers.
- Financial Impact:** Renishaw's Additive Manufacturing Product Division (AMPD) contributed £46 million (14% of overall profit) in the last half-year financial results. Strong order books for the second half of the year.
- Production Rate:** Two RenAM 500 machines per week, costing up to £1 million each with a £50,000 service package.
- Assembly Line (Figure 2):** Focus on Cell 1 (Z-Axis assembly verification) to reduce downtime (approx. 120 hours, £10,320 in lost labour) (Figure 3). Cell 9 also a concern.
- Missing Orders:** Lateness or delay can result in up to £1 million in lost business opportunity. Additional losses from servicing packages.
- RSI Concern:** Addressed by enhancing Z-Axis verification process in Cell 1, prioritizing both efficiency and employee well-being.

Cost of Downtime per Cell (Renishaws Labour Costing)

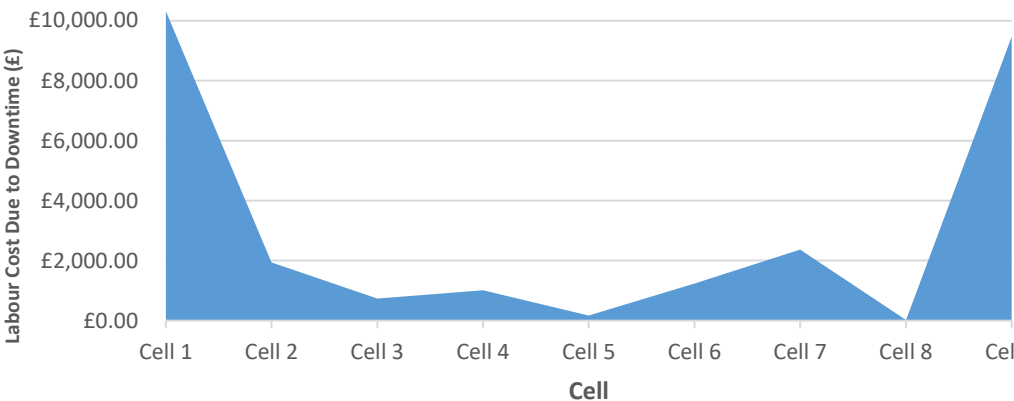


Figure 3 – Cost of Downtime per Cell

Problem Overview

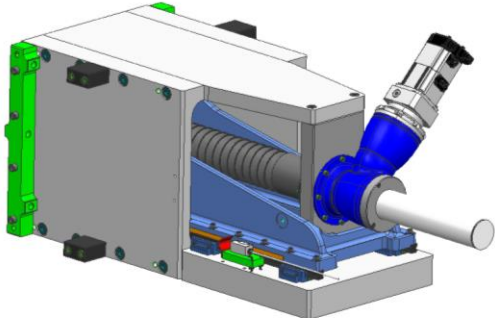


Figure 4 – Z-Axis Assembly

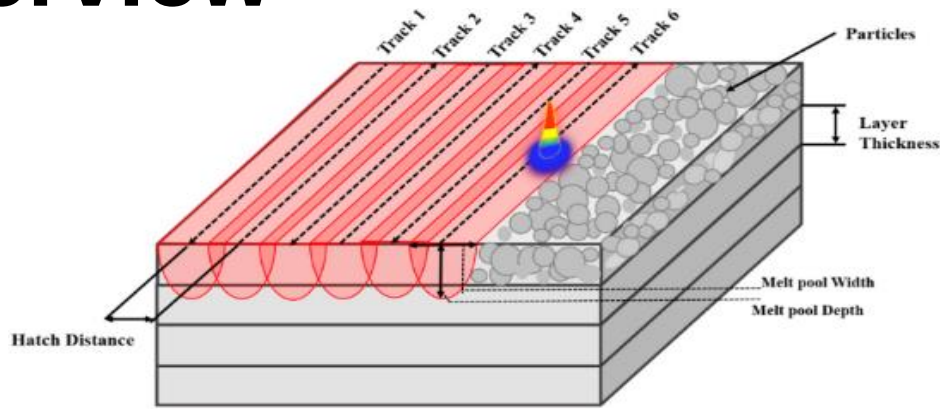


Figure 5 - Features of a Melt pool (MDPI, 2021)

•**Components:** The Z-Axis Assembly consists of bulky and intricate components, including the Build Volume, Angle Bracket, Gearbox Assembly, Encoder, and Motor Servo. Supplementary components like fasteners, bellows, seals, and rails contribute to overall functionality.

•**Critical Role:** The Z-Axis Assembly is crucial for the RenAM machine. It ensures a level and straight build plate, allowing precise and consistent 3D printing.

•**Straightness Tolerance:** Maintaining a stringent straightness tolerance of 0.1mm throughout the entire build volume is essential for laser sintering. Deviations beyond this threshold disrupt the laser's path, resulting in print irregularities.

•**Melt Pool Geometry:** Consistent melt pool geometry is pivotal for stable laser bed fusion. Accurate melt pools contribute to desirable characteristics in printed components.

•**Defects:** Issues with the sintering process (e.g., laser optics or Z-Axis misalignment) can cause defects like lack of fusion, keyhole, and balling.

•**Operator Procedure:** To verify Z-Axis straightness, engineer squares are secured on the build plate, and a Dial Test Indicator (DTI) is used. Operators monitor encoder feedback while moving the build plate in the Z-Axis using a handheld drill (**Major RSI concern**).

•**Tolerance Check:** The maximum allowable deviation across 200mm is 0.1mm in each axis. If deviation exceeds this, a shimming procedure is required.

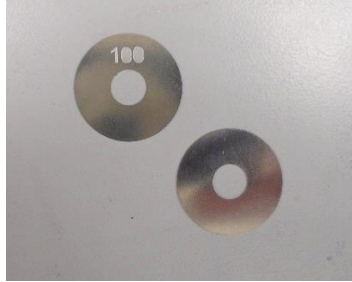
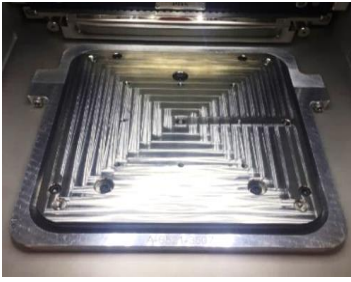


Figure 6 – Current Verification Method

•**Timings and Costs:** Over an 8-week period, 15 machines underwent Z-Axis straightness verification. Re-verification timings were recorded for some machines. The total cost of verification (including re-verifications) was £3,983.19.

•**Inconsistencies:** Certain machines required re-verification, highlighting potential inconsistencies. Machine 171 had a higher total cost compared to others.

•**RSI Concerns:** Operators raised concerns about repetitive strain injuries (RSIs) due to the manual nature of the verification process. Prolonged repetitive work and use of handheld power tools contribute to upper limb disorders (ULDs).

•**Health and Safety:** Renishaw must address the RSI complaint to reduce costs and fulfil legal duties. An internal investigation and exposure score assessment (medium risk) were conducted.

•**Project Outcome:** Minimize operator risk and improve process efficiency through ergonomic intervention.

Project Aims & Objectives

Aims:

- ✓ Develop a Z-Axis Alignment Rig to address ergonomic concerns during Z-Axis assembly verification.
- ✓ Verify assembly straightness within **0.1mm** tolerance over **250mm build volume**.
- ✓ **Automate testing procedure** for RenAM 500 additive manufacturing machine.

Objectives:

- ✓ Design and implement a test rig **compatible with the current Z-Axis trolley** in Cell 1.
- ✓ Develop a testing process for build plate straightness **using the fitted motor**.
- ✓ Ensure **user-friendliness, repeatability, safety, and CE compliance**.
- ✓ Complete the rig by 17/06/2024 (final deadline: 02/07/2024).
- ✓ Stay within the **£5000** budget, **salvaging components** from RenAM250 machines.
- ✓ Include **safety labelling** (company name, serial number, warnings, CE mark).
- ✓ Provide a Preventative Maintenance Instruction (**PMI**) for easy maintenance

Project Overview

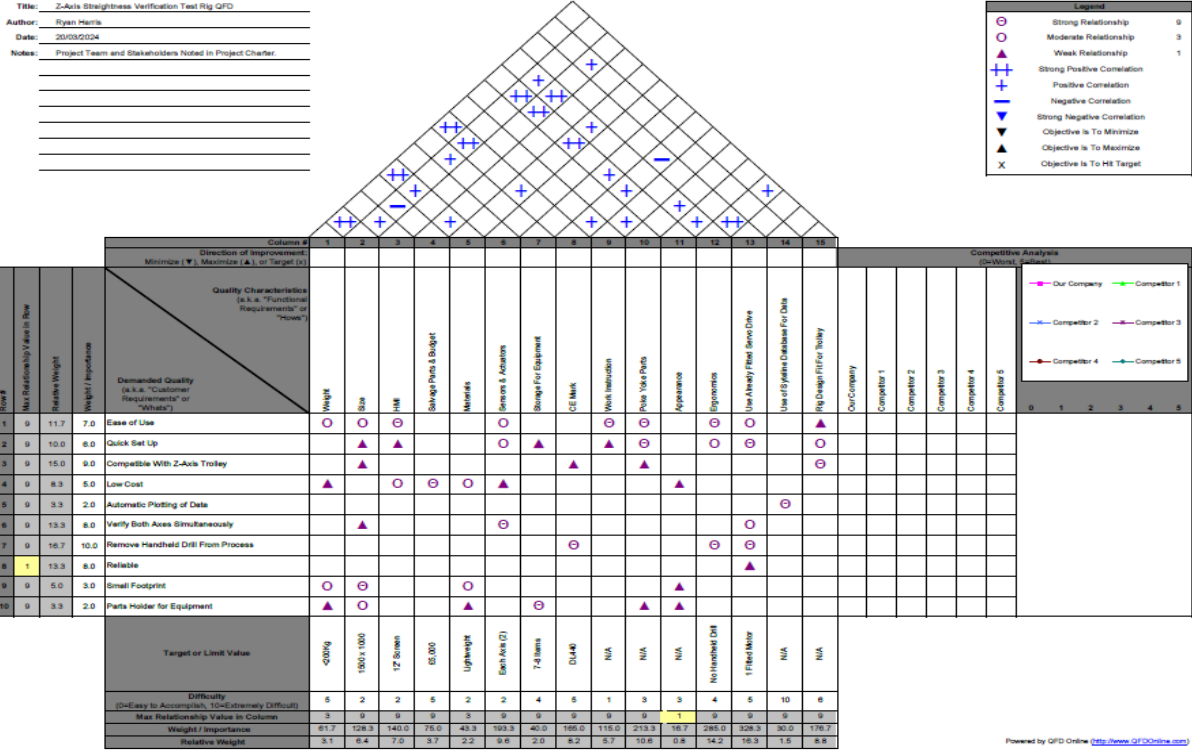


Figure 7 - House of Quality Z-Axis Test Rig

House of Quality (HOQ) Matrix for Z-Axis Test Rig:

Quality Function Deployment Tool known as a House of Quality matrix allowed the project team to align customer needs with specific engineering requirements. By organising these requirements, the HOQ helped steer the conceptual design process.

Key Results from Figure 7:

➤ Correlation and Functional Requirements:

Correlation analysis provided insight into the balance between the requirements.

Key functional requirements:

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

➤ Interrelationship Section:

Reveals how different characteristics interact. Strong relationships include components for ease of use, HMI screen, work instructions, Poka-yoke parts, and rig ergonomics.

➤ Performance Requirements:

- Translate customer desires into measurable characteristics. Notable target requirements:
 - Rig weight < **200kg**.
 - Rig footprint ≈ **1500mm x 1000mm or smaller**.
 - Cost < £5000**, utilizing salvaged parts.

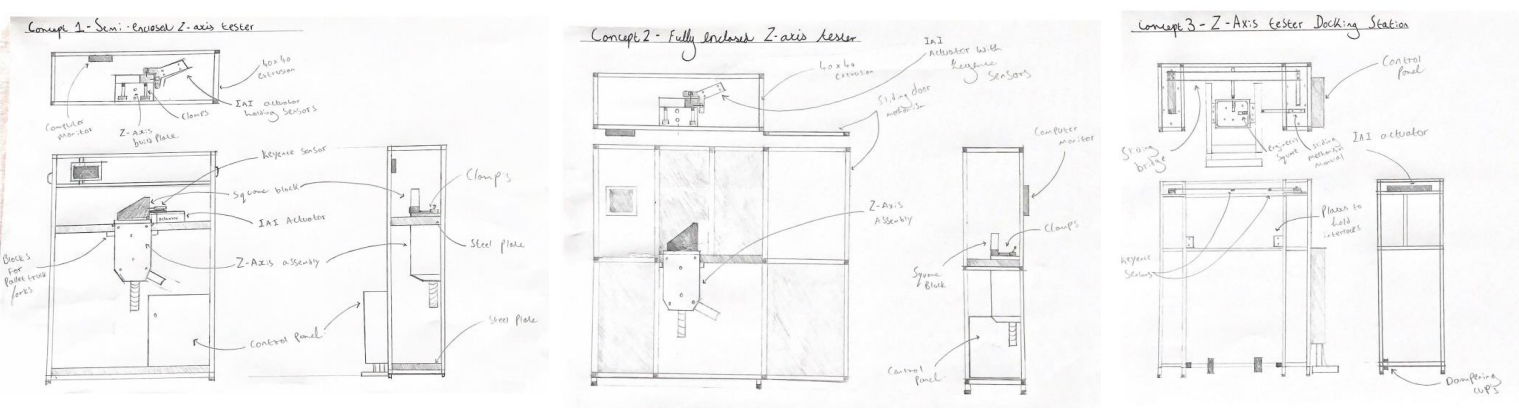


Figure 8 – Initial Concepts

Concepts were drawn by the project team with the influence of the HOQ matrix (Figure 8):

- ❖ **Concept 1:**
 - Z-Axis positioned centrally.
 - Enclosure not fully guarded.
 - Operators use existing equipment (pallet truck with stacker) to load the assembly.
 - Simple framework (40x40 Item MBS) but lacks guarding.
 - Moving parts exposed, posing risks to operators.
- ❖ **Concept 2:**
 - Like Concept 1 but with full shrouding.
 - Sliding door with interlock for safety.
 - Operators follow on-screen instructions from HMI within guarding.
 - Framework combines 40x40 and 80x40 aluminium extrusion.
 - Concerns: Weight of tester and wear on sliding door.
- ❖ **Concept 3:**
 - Enhances existing Z-Axis trolley.
 - Creates a nested test rig for docking the trolley.
 - Bridge design for automatic Y-Axis positioning.
 - X-Axis lever mechanism loaded by operator.
 - Dampeners minimize impact during trolley loading.
 - No interlocks initially, but integration planned.
 - Acrylic sides guard servo drive.
 - HMI interaction via adjustable VESA mount.

Specification Requirements	Concept1	Concept2	Concept3	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 9 – RAG Matrix Concepts VS Specification

Having drawn the concepts, it was important to score each concept against the key design specification. It is clear to see that Concept 3 was the concept to take forward as a final design for further development. The RAG matrix utilised specification points such as Functional Requirements, Rig Mechanism, Environmental Protection, Transport Requirements, Set Up Requirements, Operational Requirements and Regulatory Compliance. Concept 3 outscored the next best option (Concept 2) by 7 points.

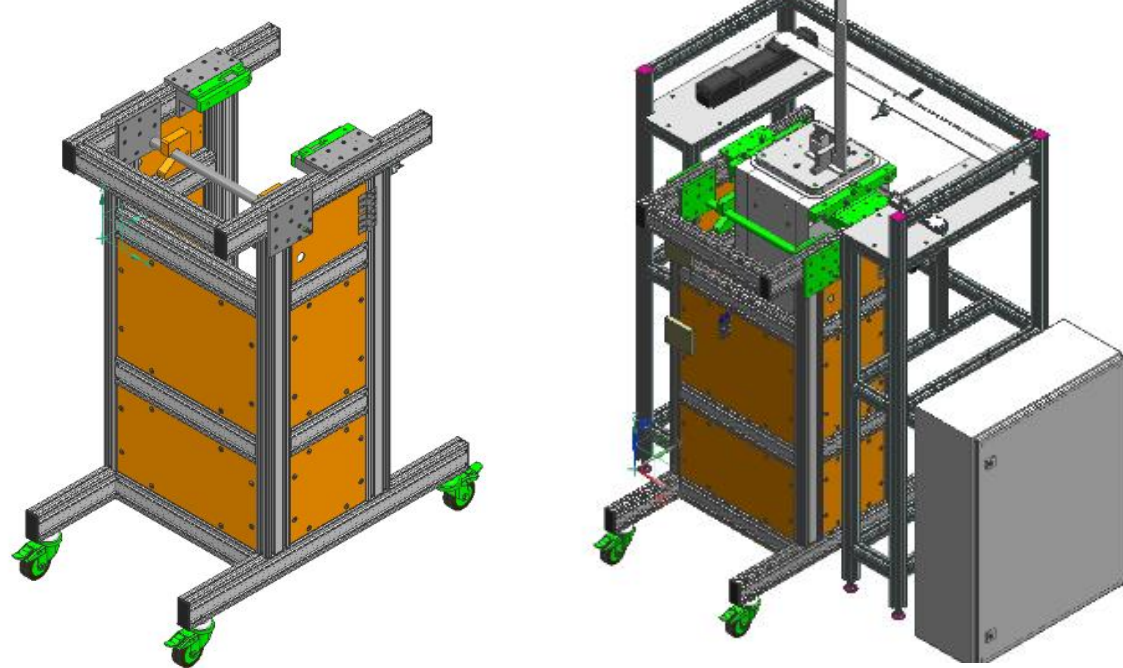


Figure 10 - Final Concept Design Development

Some key features of the final design include:

- **Trolley Modification:**
 - The Z-Axis trolley was modified for safety, with acrylic panels shielding moving parts during verification.
 - Side doors allow operator access for power connection to the servo drive and motor encoder.
 - Locating blocks aid Z-Axis assembly placement on the trolley.
- **Tester Framework:**
 - The framework, assembled with 40mm x 40mm aluminium extrusion, was modelled using ITEM 24 software.
 - A U-shaped design allows docking of the modified Z-Axis trolley.
- **Trolley Impact Dampening & Interlocks:**
 - To prevent over-docking, a spring dampening system (using MJF 3D printed parts) cushions trolley loading.
 - MJF interlock guides ensure trolley central positioning in the tester.
 - Interlock keys mounted on the trolley confirm the dock and prevent removal during testing.
- **Sensor Positioning:**
 - The side mechanism precisely aligns the X-Axis Keyence sensor with the edge of the engineer's square.
 - Components include rails, slides, a lever mechanism, and a retractable clamp.
 - The Y-Axis Keyence sensor is positioned via a bridge design driven by an IAI electrolyser.

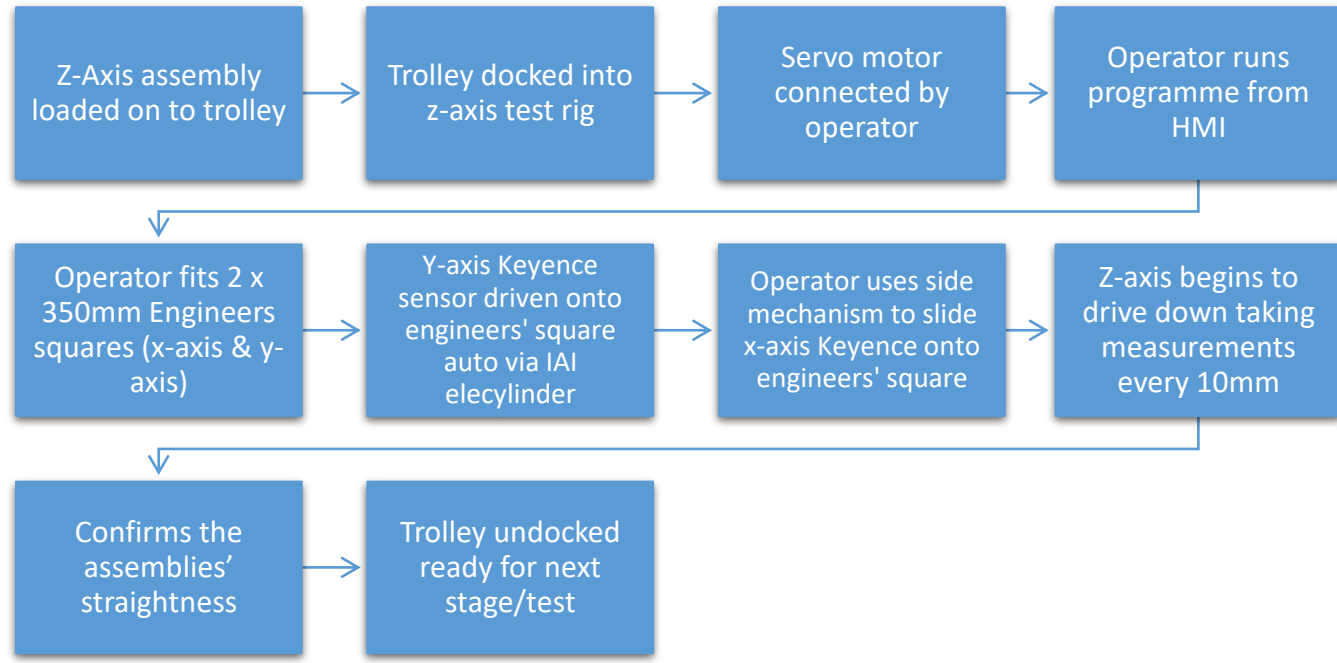


Figure 11 – Rig Final Build

Return on Investment

- Savings from Salvaging Parts:**
 - 93% of parts used on the rig are **salvaged**.
 - 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:**
 - 50% reduction in verification process time.
 - Labour requirements: 1 operator for initial setup.
- Return on Investment (ROI):**
 - ROI ≈ 399%
 - Demonstrates significant profitability relative to cost.
- Project Payback:**
 - Payback period ≈ 2.5 months.
 - Considerations beyond cost savings:
 - RSI risk mitigation (up to £18,000 per claim).
 - Retaining business opportunities (avoiding £1,000,000 per machine sales loss due to delays).
 - Significant savings from salvaging parts (£7,047).