

Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

BWR Drive Upgrade Project Report

Independent Project ACMA6013

David Adams 1908506

1. 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: P. Adams Date: 1.7.24

2. Acknowledgements

I would like to express my deepest gratitude to everyone who has supported me throughout the journey of completing this dissertation.

First and foremost, I owe an immense debt of gratitude to my wife, Jodie. Her unwavering support, patience, and encouragement have been my greatest source of strength. Jodie, your love and belief in me have been the cornerstone of my perseverance, and I could not have achieved this without you.

I extend my heartfelt thanks to my line manager, Mark Powys. Your committed support and professional mentoring have been invaluable to my development. Your guidance has not only shaped my professional growth but also inspired my academic pursuits.

To my colleague, Ryan Williams, I am grateful for your insightful contributions and the inspiration you have provided. Your willingness to share your expertise and experiences has significantly enriched my work and broadened my perspective.

A special thanks to John Berry at BOSCH REXROTH for his technical advice, which has been crucial in navigating the complexities of this project. Your expertise and willingness to assist have greatly enhanced the quality of this thesis.

I would also like to acknowledge the exceptional support from my lecturers at UWTSD. Andrew Thorn, your continued support and guidance have been instrumental in my academic journey. Arnaud Marotin, your advice has been invaluable, providing clarity and direction when I needed it most.

Lastly, I extend my appreciation to my project supervisor from UWTSD, Kelvin Lake. Your mentorship and feedback have been appreciated in the completion of this project.

To all of you, thank you for your support, encouragement, and belief in me.

3. Table of Contents

1. Declaration of Authenticity 2
2. Acknowledgements 3
3. Table of Contents 4
4. Table of Figures 9
5. Table of Tables 10
6. Table of Equations 11
7. Abstract 12
8. Introduction 13
8.1. Project Significance 14
8.2. Asset Description 15
8.3. Review of current system 16
9. Define 20
9.1. Problem Statement 20
9.2. Project Scope 20
9.3. Objectives 22
9.4. Stakeholders 22
9.5. RACI Matrix 24
9.6. Voice of the customer (VOC) 27
9.6.1. Current System Performance Survey 27
9.6.2. Desired Future System Attributes Survey 29
9.6.3. Stakeholder Feedback 31
9.6.4. KANO Model 32
9.6.5. Word Cloud Diagrams 34
9.6.6. Translating VoC into Project Requirements 35
9.6.7. SIPOC Diagram 36
9.6.8. Quality Function Deployment (QFD) 38
9.7. Project Charter 40
9.8. High-Level Project Plan 41

9.8.1. Phase 1: Define 42
9.8.2. Phase 2: Measure 42
9.8.3. Phase 3: Analyse 43
9.8.4. Phase 4: Improve 43
9.8.5. Phase 5: Control 44
9.9. Initial Gantt Chart 44
9.10. Resources Required 49
9.11. Risk Management 49
10. Measure 50
10.1. Current Performance Measurements 50
10.1.1. Operational Downtime 50
10.1.2. Maintenance Costs 51
10.1.3. Energy Consumption 53
10.1.4. Data Collection Methods 56
11. Analyse 58
11.1. Data Analysis 58
11.1.1. System Reliability 58
11.1.2. Maintenance Costs 61
11.1.3. Energy Consumption 63
11.1.4. Operational Downtime 66
11.1.5. Stakeholder Insights 66
11.1.6. Condition Monitoring 67
11.2. Analytical Tools 67
11.2.1. Pareto Analysis 68
11.2.2. 5 Why Analysis 69
11.2.3. Fishbone Diagram (Ishikawa) 75
11.2.4. Current Failure Modes and Effects Analysis (FMEA) 77
11.2.5. Analysis Findings 82
11.2.6. Recommendations 82

12. Improve Phase 83
12.1. Pre-planning 83
12.1.1. Literature Review 84
12.1.2. Potential Solutions 84
12.1.3. Vendor Consultation 85
12.1.4. Vendor Selection 87
12.1.5. Evaluation Outcome 88
12.2. Design Phase 88
12.2.1. Finalising Technical Specifications 88
12.2.2. Structural Changes and Steelwork Requirements 92
12.2.3. Impact Assessment 94
12.2.4. Lifecycle Analysis 94
12.2.5. Role as Project Manager 98
12.3. Implementation Phase 99
12.3.1. Planning 99
12.3.2. Manufacturing 100
12.3.3. Installation 102
12.3.4. Commissioning 109
12.3.5. Training and Handover 109
13. Control Phase 110
13.1. Project Documentation 110
13.2. Project Close Out 111
13.2.1. Lessons Learned 112
13.3. Bathtub Curve Analysis 112
13.3.1. Pre-Upgrade Condition 113
13.3.2. Post-Upgrade Expectations 113
13.3.3. Useful Life Phase 114
13.3.4. Planning for Wear-Out Phase 114
13.4. Change Management 114

13.4.1. Stakeholder Engagement 115
13.4.2. Comprehensive Training 115
13.4.3. Compliance with Legal Requirements 115
13.5. Continuous Improvement 116
13.5.1. Performance Metrics 116
13.5.2. Quality Metrics 116
13.5.3. Adaptability 116
13.5.4. Reliability Metrics 117
13.5.5. Maintenance Metrics 117
13.5.6. Cost Metrics 117
13.5.7. Environmental Impact 117
13.5.8. Stakeholder Feedback 118
13.5.9. Validating ROI Calculations 118
13.6. PFMEA Review 118
13.6.1. Updated FMEA 119
14. Conclusion 125
14.1. Define Phase 125
14.2. Measure Phase 125
14.3. Analyse Phase 126
14.4. Improve Phase 126
14.4.1. Integration and Coordination Challenges 126
14.5. Control Phase 127
14.6. Project Suspension 127
14.7. Reflection and Future Considerations 128
15. Bibliography 129
16. Appendices 135
16.1. Appendix A: ABB Proposal (ABB, 1996) 135
16.2. Appendix B: BOSCH Proposal (BOSCH REXROTH, 2023) 150
16.3. Appendix C: Thyssen-Krupp Proposal (Thyssen-Krupp, 2023) 164

16.4. Appendix D: BOSCH Specifications and Quotation (BOSCH REXROTH, 2023) 169
16.5. Appendix E: Hydraulic Calculations (Ingleside Engineering, 2023)..... 187
16.6. Appendix F: Design Brief (Ingleside Engineering, 2023) 189
16.7. Appendix G: Walkway Design (Inglside Engineering, 2023)..... 194
16.8. Appendix H: Walkway Tender Document..... 196
16.9. Appendix I: Walkway Quotation (MII Engineering Ltd., 2023) 198
16.10. Appendix J: Load Dynamic Calculations (Ingleside Engineering, 2023)..... 199
16.11. Appendix K: Thickness Testing Plan (Ingleside Engineering, 2023) 200
16.12. Appendix L: Temporary Works Design (Ingleside Engineering, 2023) 201
16.13. Appendix M: Factory Acceptance Document (BOSCH REXROTH, 2023)..... 206
16.14. Appendix N: Detailed Lifting Plan 209

4. Table of Figures

Figure 1 - Bucket Wheel Reclaimer 13
Figure 2 - Current Drive System 14
Figure 3 - BWR Schematic 16
Figure 4 - Operator HMI 17
Figure 5 - Planetary Carrier Failure 18
Figure 6 - Gearbox Casing Damage 19
Figure 7 - Spur Gear Damage 19
Figure 8 - KANO Model 34
Figure 9 - Word Cloud - Issues (FreeWordCloudGenerator.com, 2024) 35
Figure 10 - Word Cloud - Solutions (FreeWordCloudGenerator.com, 2024) 35
Figure 11 - HOQ (QFD Online, 2007) 39
Figure 12 - Initial Gantt chart 48
Figure 13 - Availability 60
Figure 14 - MTTR 60
Figure 15 - MTBF 61
Figure 16 - Repair Costs 63
Figure 17 - Repair Times 63
Figure 18 – Annual Energy Usage 65
Figure 19 - Annual Energy Costs 65
Figure 20 - Annual CO2 Production 66
Figure 21 - PARETO Chart 69
Figure 22 - High MTTR 5 why diagram 70
Figure 23 - Gearbox planetary carrier failure 5 why diagram 71
Figure 24 - Gearbox bearing failure 5 why diagram 72
Figure 25 - Fishbone (ISHIKAWA) Diagram 76
Figure 26 - MODBUS Card 91
Figure 27 - Hydraulic Bucket Drive System (BOSCH REXROTH, 2023) 93
Figure 28 - Delivered System 102
Figure 29 - Gantt Chart 108
Figure 30 - Bathtub curve (Montanari, et al., 2020) 113

5. Table of Tables

Table 1 - Stakeholders 23
Table 2 - RACI Matrix 25
Table 3 - SIPOC Diagram 36
Table 4 - Data Types 50
Table 5 - Data Collection Plan 56
Table 6 - Delay Data 59
Table 7 - Maintenance Cost Data 62
Table 8 - Energy Data 64
Table 9 - Current System FMEA 78
Table 10 - Vendor Assessment 87
Table 11 – Current Operating Parameters 95
Table 12 - Future Operating Parameters 96
Table 13 - Updated FMEA 120

6. Table of Equations

Equation 1 (Beaty, 2000) 96
Equation 2 (Beaty, 2000) 96
Equation 3 96
Equation 4 97
Equation 5 97
Equation 6 98
Equation 7 98

7. Abstract

This project report addresses the urgent need to upgrade the drive system of the 2,000 tons per hour (tph) Bucket Wheel Reclaimer (BWR) at Tata Steel's Port Talbot plant. The existing electro-mechanical motor and gearbox assembly is outdated, leading to high operational and maintenance costs, largely due to the scarcity of spare parts. This project aims to replace the obsolete system with a modern, efficient hydraulic drive system to enhance the BWR's reliability and operational efficiency.

The report begins by analysing the current system's failures and maintenance issues, highlighting the significant downtime and inefficiencies caused by frequent breakdowns. A detailed study of maintenance costs, energy consumption, and operational disruptions underscores the need for a comprehensive upgrade. The project employs the DMAIC (Define, Measure, Analyse, Improve, Control) methodology to systematically address these challenges.

Potential solutions were rigorously evaluated using a weighted decision matrix, considering factors such as technical performance, cost, implementation timeline, vendor support, and historical reliability. The proposed solution involves transitioning to a hydraulic drive system, which promises reduced maintenance costs, improved energy efficiency, and enhanced operational reliability. This upgrade is projected to not only mitigate the current issues but also align with Tata Steel's sustainability goals by reducing the plant's overall environmental footprint.

The project plan includes phases from problem identification and root cause analysis to detailed design, procurement, installation, and testing of the new system. The use of project management tools such as Gantt charts and RACI matrices ensures effective planning, stakeholder engagement, and resource allocation. This strategic approach is aimed at minimizing operational disruptions during the transition and ensuring a smooth implementation.

Overall, this project represents a significant investment in the future efficiency and reliability of the Port Talbot plant, demonstrating a robust application of engineering and project management principles to address complex industrial challenges.

8. Introduction

Tata Steel's Port Talbot plant uses a 2,000tph Bucket Wheel Reclaimer (BWR) for handling bulk materials essential for steel production as shown in Figure 1. The current system is driven by an obsolete electro-mechanical motor and gearbox assembly as shown in Figure 2. The necessity for upgrading the drive system arises from the high operational and maintenance costs associated with the existing electric drive, compounded by the unavailability of spare parts and the system's obsolescence. Upgrading to a hydraulic drive system will mitigate these issues, enhance operational efficiency, and reduce environmental impact through improved energy efficiency.



Figure 1 - Bucket Wheel Reclaimer

This report aims to critically analyse the BWR drive system failures and propose a solution for the reliability issues. A study will evaluate the current maintenance techniques, costs, and the potential for improvement. By mapping and comparing the current processes and equipment against industry standards and best practices, the report seeks to identify areas for improvement and propose actionable solutions.



Figure 2 - Current Drive System

8.1. Project Significance

Port Talbot steelworks is one of the largest steel producers in the UK, with two 3Mt blast furnaces and an annual steel output of over 5 million tonnes. It plays a crucial role in the global steel market, manufacturing a broad spectrum of steel products, including heavy plates, hot rolled coils, and galvanised steel, catering to diverse markets such as construction, automotive, and aerospace industries. (Tata Steel Europe, 2022)

The BWR is integral to the steel production process, handling the primary bulk raw materials (iron and coal) required for ironmaking. operating under harsh conditions characterised by heavy loads, abrasive materials, and continuous usage, the BWR's performance is critical to maintaining the efficiency and output of the entire operation. BWRs are also used in other processes such as mining and ports to reclaim bulk materials from stockpile or blend materials from various parts of the stockpile to ensure a consistent mix of material.

The 2,000 tonne per hour reclaimer at Port Talbot steelworks was manufactured and commissioned in 1958 by Babcock Mosey. It has a planned lifecycle of 35 years and has undergone various projects and upgrades over its campaign to extend its operational lifecycle, including replacement of structural components, hydraulic slew system

upgrade, hydraulic luff system upgrade, bucket wheel assembly changes, slew bearing changes, and long travel drive upgrades.

8.2. Asset Description

The BWR consists of seven main components, each with multiple mechanical, electrical and control systems. As shown in Figure 3.

Bucket Wheel Assembly

Consists of a large wheel with a series of 10 buckets attached to its perimeter. As the wheel rotates at 6.6rpm, the 0.5T capacity buckets collect material from the stockpile. This is driven by a 3.3Kv, 75Kw, three-phase electric motor and a two-stage 93Kw, 224:1 reduction gearbox, consisting of a bevel-helical gear stage and a planetary gear stage.

Boom Conveyor

Driven by two 55Kw electric motors and two 19.7:1 helical bevel reduction gearbox, the conveyor receives the material feed from the bucket wheel and transports it away from the cutting face to its centrally located hopper and feeder.

Hopper and Feeder

Receives and holds the reclaimed materials from the boom conveyor to provide a small buffer and ensure a constant and uniform feed of material to the yard conveyor depending on the material being reclaimed. It is driven by a 37Kw Motor and 270:1 reduction gearbox.

Slewing System

Allows the reclaimer to rotate (slew) around its axis, enabling it to access different areas of the stockyard, this is driven by two hydraulic motors and a 220bar hydraulic pressure unit.

Luffing System

Two 4-metre-long x 250mm-diameter hydraulic cylinders, driven by a 270bar hydraulic pump, raise and lower the boom assembly and bucket wheel to reach different heights within the material stockpiles.

Long Travel System

Consisting of sixteen 5.5Kw electric motors and 6:1 helical bevel reduction gearbox directly coupled to individual drive bogies, allowing the reclaimer to travel the length of the stockyards along two heavy duty rails.

Yard Conveyor

Situated underneath the hopper and feeder, this 1200mm wide conveyor transports the excavated material from the bucket wheel away to further processes.

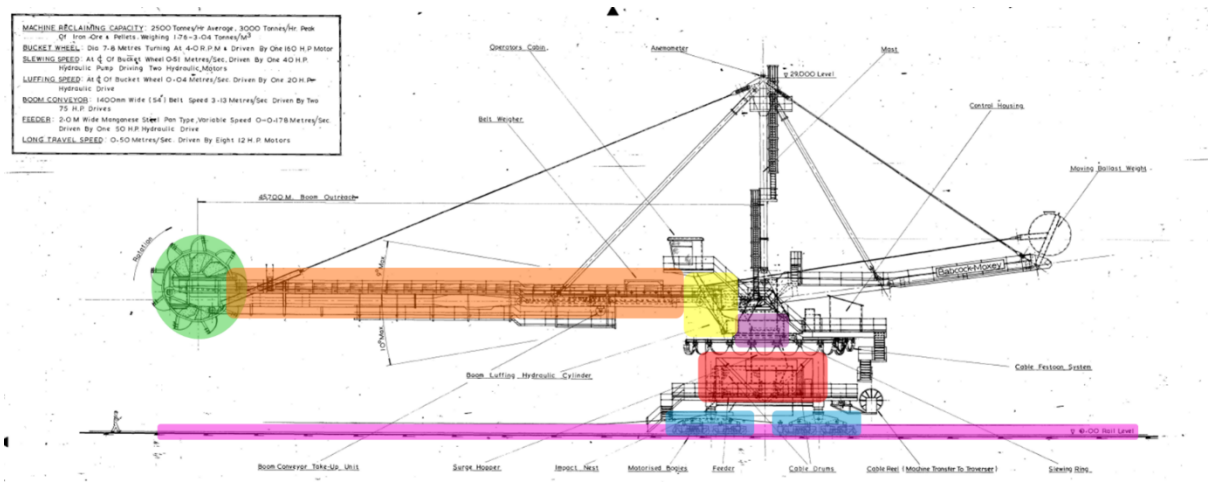


Figure 3 - BWR Schematic

8.3. Review of current system

The existing drive system comprises a high-power electric motor coupled with a multi-stage gearbox. This setup was initially chosen for its reliability and ability to handle the significant load requirements of the excavator. However, over time, the system has shown vulnerabilities. Continuous operation under harsh conditions has led to significant wear of mechanical components, particularly within the gearbox. As components age, they operate less efficiently, consuming more power and requiring more frequent adjustments to maintain performance. Also the operator control station (HMI) as shown in Figure 4 is very old, has limited information and functionality and is difficult to understand and operate effectively.



Figure 4 - Operator HMI

The maintenance strategy has historically focused on scheduled downtime for regular checks and unscheduled repairs following breakdowns. This approach has several drawbacks as the reliance on scheduled and unscheduled maintenance sessions often results in inefficiencies and unpredictability in production planning. Although techniques like vibration analysis, thermal imaging, and oil analysis could be used to predict failures before they occur, their use has not been fully integrated into the maintenance strategy or an automated control system. This oversight has resulted in missed opportunities to prevent breakdowns and extend the lifespan of components.

The system experiences regular failures as shown in Figure 5, Figure 6 and Figure 7, which often lead to prolonged downtimes and substantial disruption in operations. Due to the age of the system, replacement parts are no longer manufactured so are increasingly difficult to find and are expensive, forcing the maintenance team to rely on expensive

custom-made parts or inadequate substitutes. Additionally, the complexity of repairs often requires specialised skills.



Figure 5 - Planetary Carrier Failure



Figure 6 - Gearbox Casing Damage



Figure 7 - Spur Gear Damage

9. Define

The purpose of this DMAIC project is to replace the existing electric motor and gearbox assembly of the bucket wheel excavator with a more efficient and reliable system at Tata Steel's Port Talbot plant. This upgrade aims to enhance operational efficiency, reduce maintenance costs, and meet sustainability goals.

9.1. Problem Statement

The current electric drive system of the bucket wheel excavator is subject to frequent mechanical failures, high maintenance costs, and inefficient energy consumption. The aging system, characterised by worn components and reliance on obsolete parts, has led to increased operational downtime and escalated operational costs.

9.2. Project Scope

The project focuses on the complete replacement of the electric drive system with a hydraulic system, covering design, procurement, installation, and testing phases. The scope includes managing the transition with minimal disruption to ongoing operations.

Project Name	Project Manager	Date
BWR Availability & Reliability Improvement	David Adams	01/02/2023
Business Justification		
Increased failure rate of BWR drive system, increased repair costs, reduced availability below required target to achieve AP (95%). Repair vendor indicated obsolescence of spares during recent breakdown. Alternative solutions/systems to be explored.		
Project Scope		
Inclusions		
Delay Analysis of Bucket Wheel Drive Failures (Engineering) Spares Rationalisation Spares Obsolescence prevention Maintenance Costs System efficiency and operating costs		

Exclusions
Change of KPI target Operational delays Slow running periods
Business Objectives
Achieve 95% Asset Availability target Reduce Operating costs Reduce Maintenance Activities and Costs Reduce Spares Costs Implement Continuous Improvement of Failure Reduction Process
Project Deliverables
Improve Availability Improve MTBF Improve Quality – material mix consistency / laying control Improve Safety – increased safety features / overload warning Improve Efficiency Improve Customer Satisfaction – serviceability, operational stability Reduce Maintenance Costs Reduce Operation Costs Reduce Spares Costs Reduce Obsolescence risk Reduce MTTR
Constraints
Implementation to have minimal effect on production Project to be completed in addition to current front-line engineering activities
Assumptions
Access to company data to complete data analysis Budget for solution to be provided pending justification/business case External specialist contractor may be required to supply solutions and provide technical support

(Tata Steel UK, 2022)

9.3. Objectives

1. Enhance the responsiveness and adaptability of the reclaimer to different material densities and conditions.
2. Improve the speed and efficiency of operations, reducing cycle times and increasing throughput.
3. Minimise operational disruptions caused by equipment downtime and failures.
4. Decrease the frequency and extent of maintenance required.
5. Eliminate the dependency on obsolete parts and reduce the time and cost associated with sourcing these parts.
6. Implement a more predictable and manageable maintenance schedule that aligns with production demands.
7. Lower the energy consumption of the reclaimer operations.
8. Contribute to the plant's overall energy reduction targets as part of Tata Steel's commitment to reducing its environmental footprint.
9. Align the new system with the latest environmental standards, reducing the overall environmental impact of operations.
10. Support Tata Steel's sustainability objectives by implementing technologies that reduce potential pollution and enhance energy conservation.
11. Invest in a technology that is supported by robust supply chains and technological advancements, ensuring long-term viability and support.
12. Provide a solution that allows for future upgrades and integrations with smart technologies and IoT (Internet of Things) capabilities, preparing for predictive maintenance and advanced operational analytics.
13. Ensure that all operational staff are fully trained and competent in managing the new hydraulic system.
14. Engage with all relevant stakeholders to ensure the project aligns with broader operational and strategic goals, ensuring a smooth transition and effective integration into existing processes.

9.4. Stakeholders

Once the scope of the project has been determined, it is a requirement to establish the project team and identify all relevant stakeholders involved in the project. This involves

selecting and appointing individuals with the necessary skills and expertise to fulfil the roles and responsibilities essential for the successful execution of the project. It also entails identifying key stakeholders who will influence or be impacted by the project, as shown in Table 1.

(Project Management Institute, 2021) documents that engaging these stakeholders early on ensures their interests and requirements are understood and addressed, fostering collaboration and support throughout the project's lifecycle.

Table 1 - Stakeholders

Stakeholder Type	Description
Project Sponsor	Senior Manager securing resources for the project, ensuring alignment with organisational goals.
Project Manager	Responsible for planning, executing, and closing the project, managing the team, schedule, budget, and scope.
Engineering Team	Engineers, designers, and technical specialists executing the upgrade, directly responsible for technical success.
Operations Team	End-users of the system being upgraded, providing feedback and requirements.
Quality Assurance Team	Ensures the upgrade meets required standards and specifications, conducts testing and validation.
Safety and Compliance Officers	Ensures compliance with safety regulations and industry standards, mitigating risks.
Suppliers and Vendors	Provide necessary materials, components, or services, critical for timely delivery and quality.
Financial Department	Manages budget, funding, and financial tracking, ensuring the project stays within financial constraints.
IT/ OT Support Team	Provides technical support for integration and operation of new technologies with existing, ensuring compatibility and support.
Regulatory Bodies	Government or industry organisations enforcing regulations, ensuring adherence to legal and regulatory requirements.

Human Resources	Manages staffing needs, training, and development, ensuring the project team is adequately supported.
External Consultants	Provide specialised knowledge or skills not available within the organisation, offering independent assessments and recommendations.
Local Community	Individuals and groups in the area affected by the upgrade, whose support and cooperation can be crucial, especially in public projects.

9.5. RACI Matrix

The RACI matrix as shown in Table 2 is a valuable tool in project management, particularly in complex engineering upgrade projects. It clarifies roles and responsibilities, ensuring that all stakeholders are aware of their specific contributions and the extent of their involvement. By delineating who is Responsible, Accountable, Consulted, and Informed for each task, the RACI matrix helps prevent overlap, confusion, and potential conflicts among team members and stakeholders. For instance, in the project planning phase, the Project Manager is both Responsible and Accountable, while the Engineering Team and Operations Team are Consulted to provide their expertise and input. This structured approach enhances communication and coordination, leading to more efficient project execution and improved outcomes. (Project Management Institute, 2021) shows that the use of RACI can be particularly beneficial in aligning diverse teams, such as engineering, operations, and quality assurance, by ensuring everyone understands their roles and the expectations from them. (Suhanda & Pratami, 2021) have shown that implementing a RACI matrix can significantly improve project performance and stakeholder satisfaction by providing clear guidance and facilitating accountability.

Table 2 - RACI Matrix

Task/Activity	Project Sponsor	Project Manager	Engineering Team	Operations Team	Quality Assurance Team	Safety and Compliance Officers	Suppliers and Vendors	Financial Department	IT Support Team	Regulatory Bodies	Human Resources	External Consultants	Local Community	Shareholders
Define project scope	A	R	C	C	C	C	I	I	I	I	I	C	I	I
Develop project plan	I	A/R	C	C	C	I	I	C	C	I	I	C	I	I
Budget approval	A	R	I	I	I	I	I	C	I	I	I	I	I	C
Technical design and development	I	R	A/R	C	C	C	C	I	C	I	I	C	I	I
Risk assessment and mitigation	A	R	C	C	C	A/R	I	I	I	I	I	C	I	I
Implementation and execution	I	A/R	A/R	C	C	C	I	I	C	I	I	C	I	I
Testing and validation	I	R	C	C	A/R	C	I	I	C	I	I	C	I	I
Compliance and safety checks	I	R	C	C	C	A/R	I	I	I	A/R	I	C	I	I
User training and support	I	R	C	A/R	I	I	I	I	C	I	A/R	I	I	I
Go-live and deployment	I	A/R	A/R	C	C	C	I	I	C	I	I	I	I	I

Post-implementation review	A	R	C	C	C	I	I	I	I	I	I	C	I	I
Continuous Improvement	I	R	C	A/R	A/R	C	C	I	C	I	I	C	I	I
Stakeholder Communication	A	R	I	I	I	I	I	I	I	I	I	I	I	I
Change Management	A	R	I	C	C	C	I	I	I	I	A/R	I	I	I

Key:

R = Responsible: The person(s) who do the work to complete the task.

A = Accountable: The person who is ultimately accountable and has the power to vote Yes or No.

C = Consulted: The person(s) who must be consulted before a decision or action is taken.

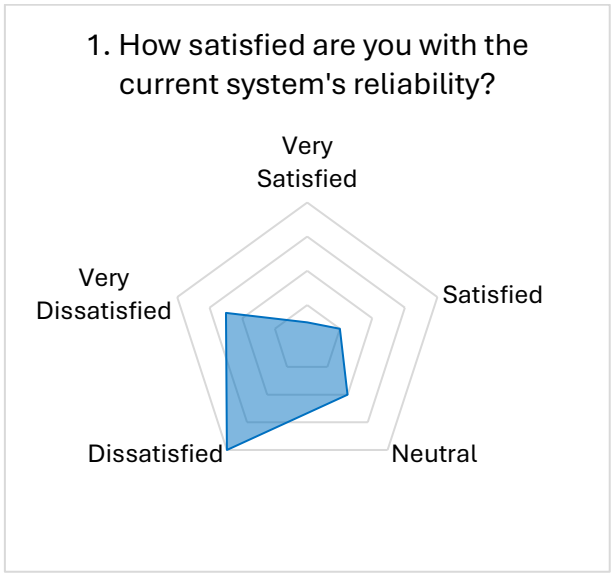
I = Informed: The person(s) who must be informed that a decision or action has been taken.

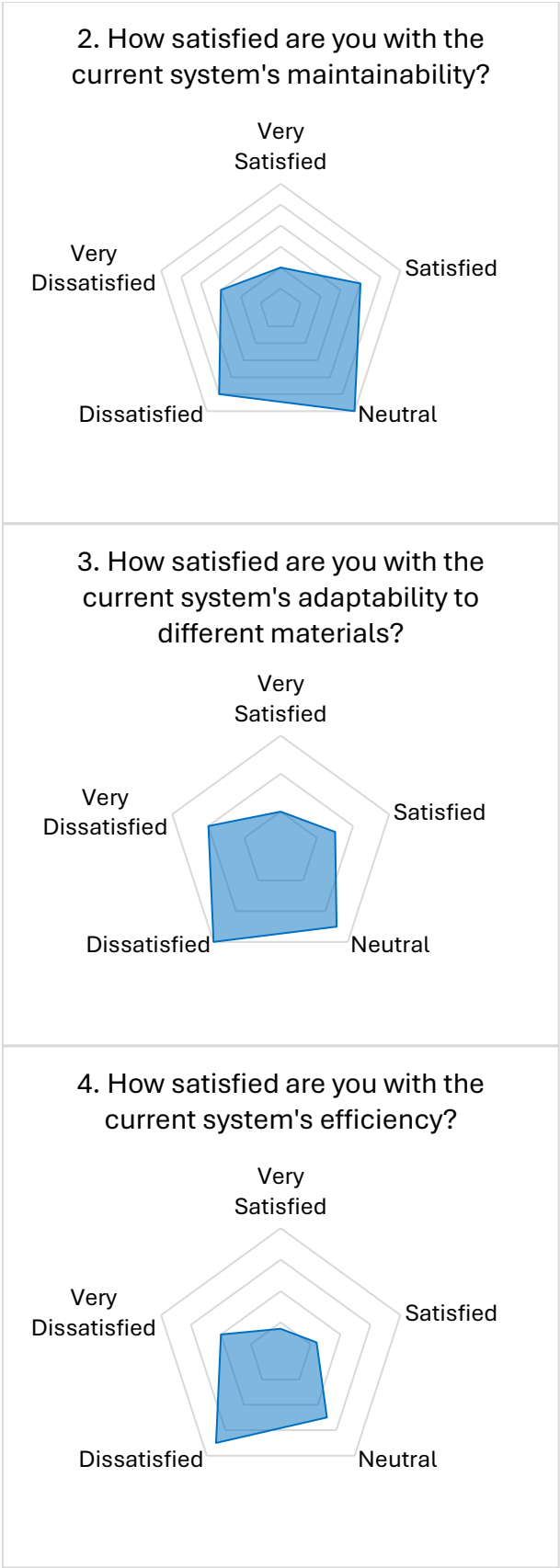
9.6. Voice of the customer (VOC)

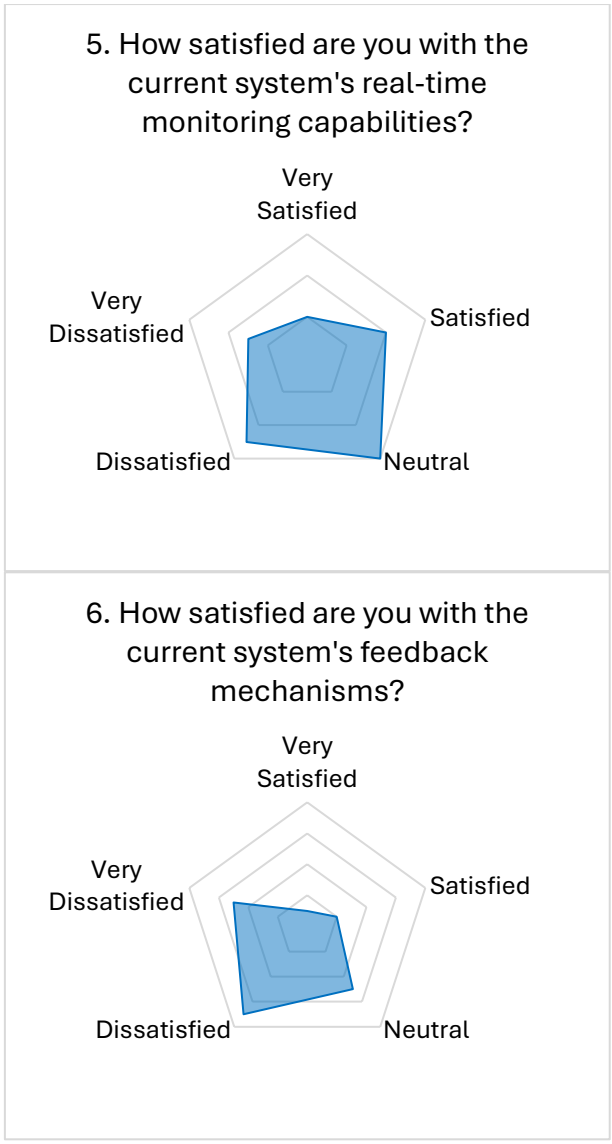
The Voice of the Customer (VoC) involves gathering and understanding the needs, expectations, and feedback of all stakeholders who are affected by the performance of the BWR. (Griffin & Hauser, 1991) document how this information helps ensure that the project addresses the key concerns and requirements of those who rely on the equipment.

The Voice of the Customer was established through feedback sessions and interviews. The views are captured, interpreted and translated into actions. 9.6.1 shows the results of the current system performance surveys, whist 9.6.2 shows the results of the desired system attributes survey.

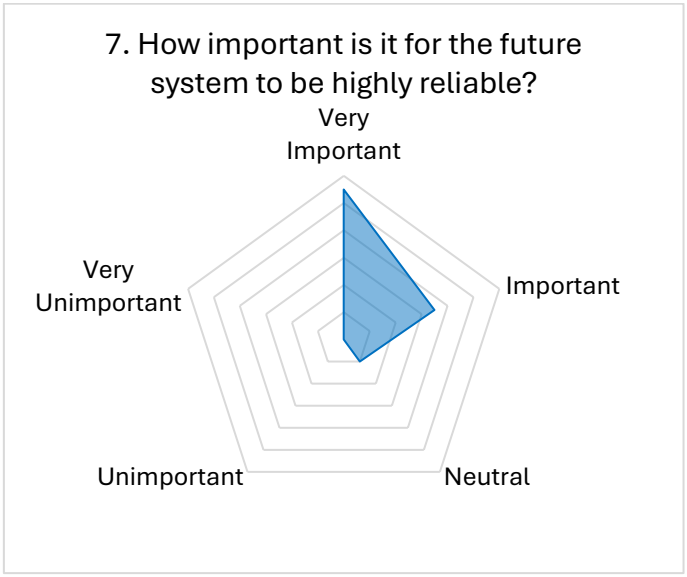
9.6.1. Current System Performance Survey

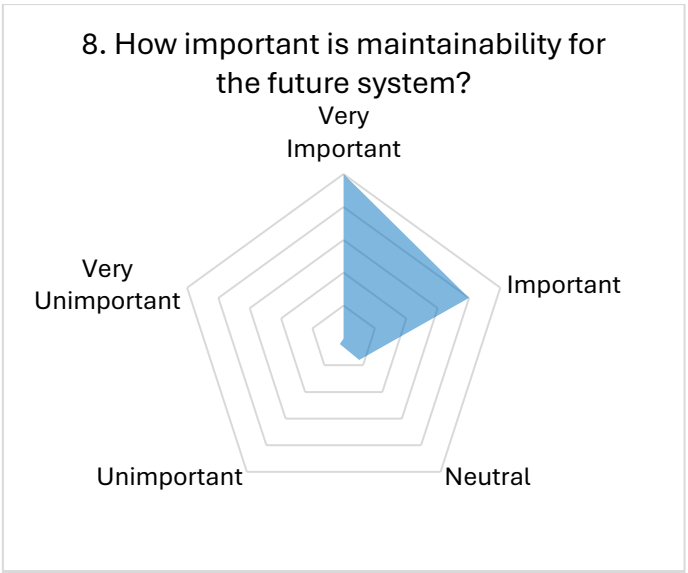


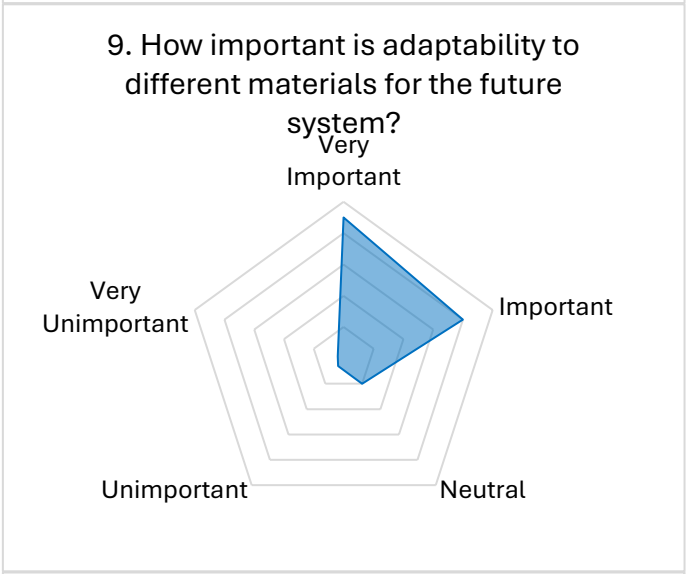

2. How satisfied are you with the current system's maintainability?
Very Satisfied
Satisfied
Neutral
Dissatisfied
Very Dissatisfied
3. How satisfied are you with the current system's adaptability to different materials?
Very Satisfied
Satisfied
Neutral
Dissatisfied
Very Dissatisfied
4. How satisfied are you with the current system's efficiency?
Very Satisfied
Satisfied
Neutral
Dissatisfied
Very Dissatisfied

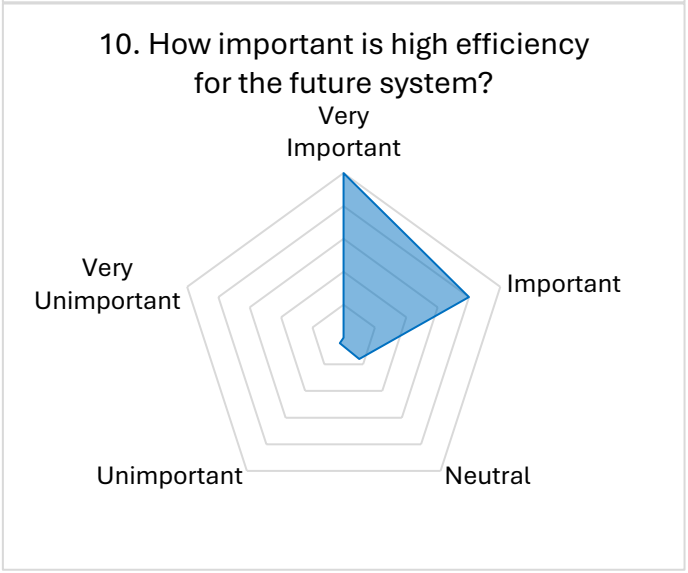


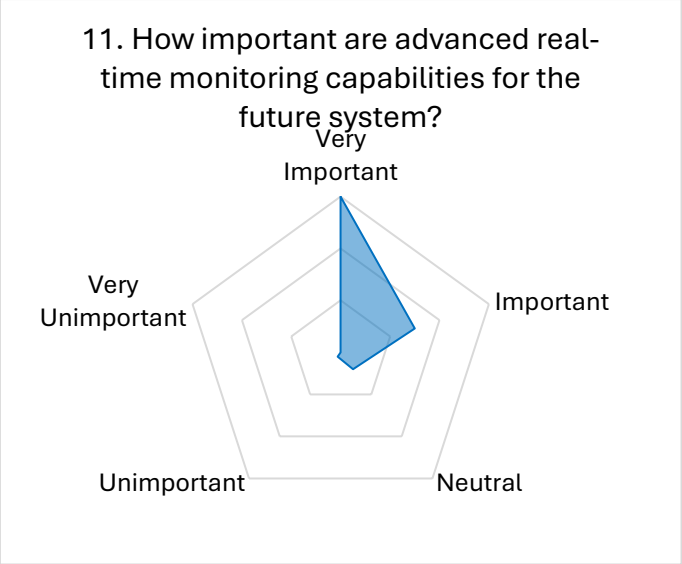
9.6.2. Desired Future System Attributes Survey

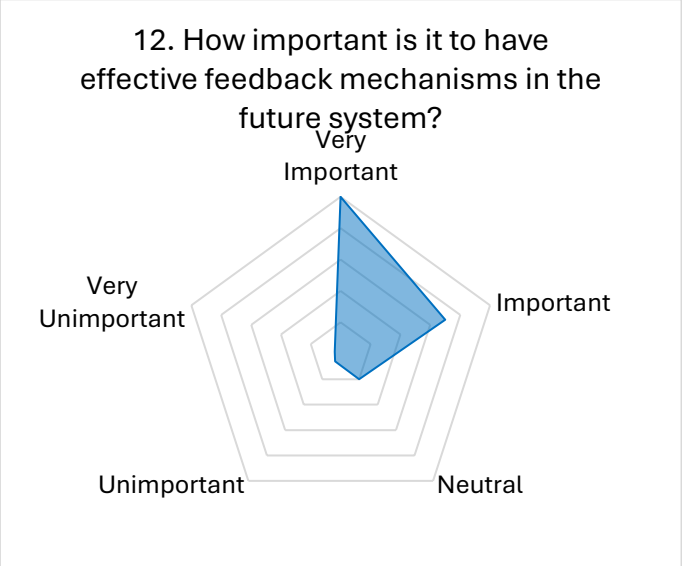



8. How important is maintainability for the future system?
Very Important
Important
Neutral
Unimportant
Very Unimportant


9. How important is adaptability to different materials for the future system?
Very Important
Important
Neutral
Unimportant
Very Unimportant


10. How important is high efficiency for the future system?
Very Important
Important
Neutral
Unimportant
Very Unimportant





9.6.3. Stakeholder Feedback

Using surveys and interviews to understand the voice of the customer was essential to determine the project scope and impact of project deliverables. The feedback was categorised by stakeholder group to further understand the impact of upgrade features.

9.6.3.1. Operations Managers

- Emphasised the need for a more reliable drive system to reduce unplanned downtime.
- Highlighted the importance of improving operational efficiency to meet production targets.
- Focused on reducing maintenance and operational costs.

9.6.3.2. Maintenance Teams

- Reported frequent breakdowns and difficulties in sourcing obsolete parts for the current electric drive system.
- Concerned about long repair times affecting overall productivity.
- Requested training for new systems and technologies to enhance maintenance effectiveness.
- Requested better access to bucket wheel drive system components.

9.6.3.3. Equipment Operators

- Preferred a system that is easier to operate and requires less manual intervention.
- Reported that frequent downtimes disrupt work schedules and create safety risks.
- Desired quicker response times for handling varying material densities.

9.6.3.4. Production Engineers

- Needed accurate and reliable data on system performance for better planning and optimisation.
- Emphasised the importance of seamless integration with existing systems and processes.

9.6.3.5. Finance Department

- Focused on achieving a favourable return on investment (ROI) through reduced maintenance and energy costs.
- Highlighted the need to stay within budget while achieving project goals.

9.6.3.6. Environmental and Safety Officers

- Stressed the importance of reducing the environmental impact and ensuring compliance with regulations.
- Highlighted the need for a system that minimises safety risks for operators and maintenance personnel, potentially through reduced maintenance requirements

9.6.4. KANO Model

The KANO model was used to better understand and prioritize customer needs and expectations. The KANO model as shown in Figure 8, is a valuable tool in quality management and product development, categorizes customer requirements into four

key categories: must-be, performance, attractive, and indifferent. By conducting interviews and surveys with key stakeholders, including maintenance staff, operations personnel, and senior management, we were able to identify and classify their requirements effectively. Must-be requirements, such as basic system reliability and compliance with safety regulations, were considered essential and non-negotiable. Performance requirements, including improved energy efficiency and reduced maintenance costs, were recognized as factors that directly influence customer satisfaction and would lead to greater satisfaction if fulfilled well. Attractive requirements, such as advanced real-time condition monitoring and ease of maintenance access, were identified as features that would delight stakeholders if implemented, though their absence would not cause dissatisfaction. Indifferent requirements, which neither significantly affect satisfaction nor dissatisfaction, were also noted but not prioritized. This systematic categorization allowed the project team to focus on the critical aspects of the upgrade that would ensure stakeholder satisfaction while also identifying areas for potential innovation and enhancement. As suggested by (Gregory & Parsa, 2013), integrating the insights gained from the KANO model into the project charter and planning process, helps to ensure that the hydraulic system upgrade would meet and or exceed stakeholder expectations, thereby increasing the likelihood of project success and acceptance.

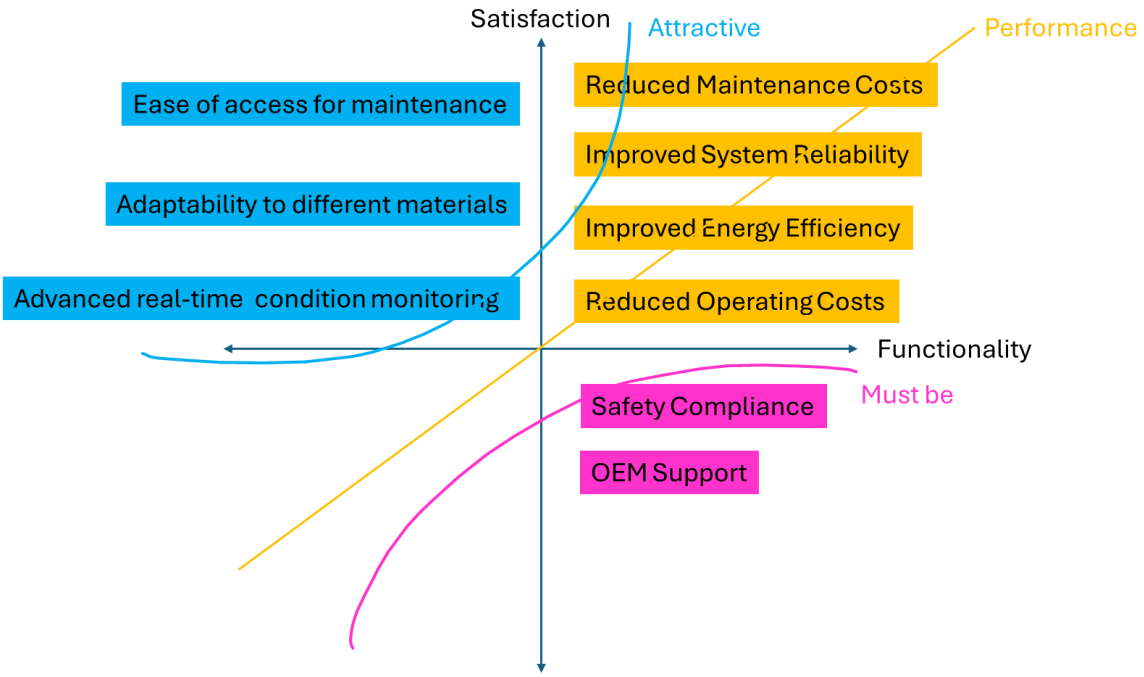


Figure 8 - KANO Model

9.6.5. Word Cloud Diagrams

Word cloud diagrams were utilized as a visual tool to capture and prioritize the most frequently mentioned terms and concepts from stakeholder feedback sessions. By conducting comprehensive interviews and surveys with maintenance staff, operations personnel, and senior management, we collected extensive qualitative data regarding their needs, concerns, and expectations. The word cloud diagrams as shown in Figure 9 and Figure 10 provide a clear and immediate visual representation of this data, highlighting the most prominent themes and key issues. Words and phrases such as "reliability," "maintenance cost," "accessibility," and "efficiency" appeared prominently, indicating their critical importance to stakeholders.

Additionally, word clouds served as an effective communication tool, (Heimerl, et al., 2014) argues that using word clouds allows us to present complex qualitative data in an easily digestible format to various project stakeholders, ensuring that everyone was aligned on the primary objectives and focus areas of the project. By leveraging word cloud diagrams, we were able to streamline the initial phase of the project, ensuring that the most critical stakeholder needs were addressed in the project charter and planning stages.



Figure 9 - Word Cloud - Issues (FreeWordCloudGenerator.com, 2024)

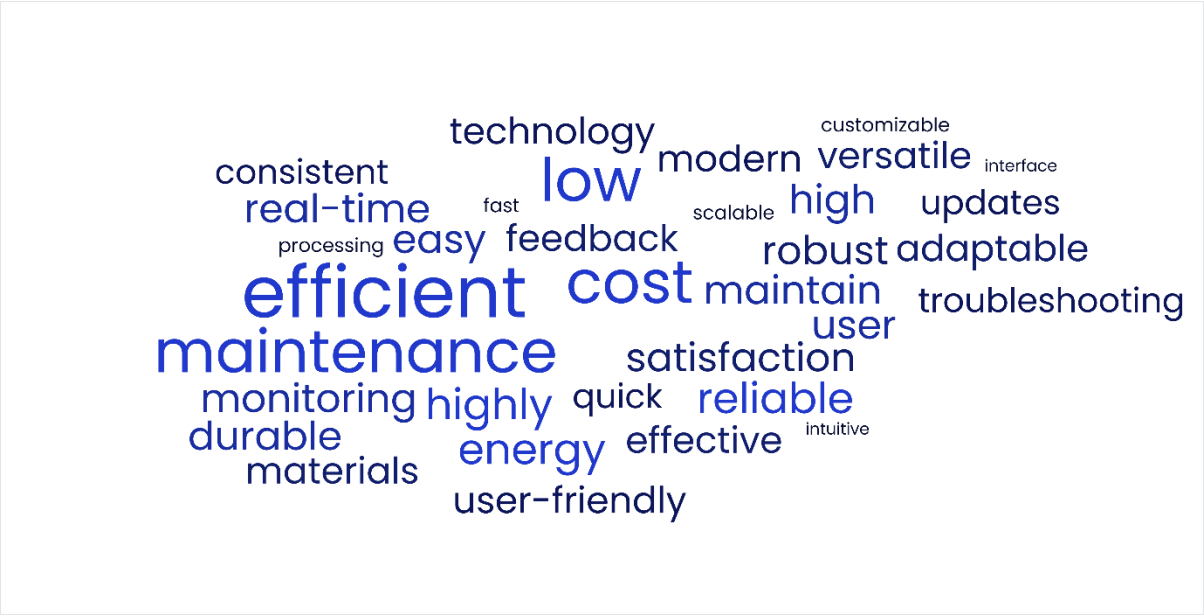


Figure 10 - Word Cloud - Solutions (FreeWordCloudGenerator.com, 2024)

9.6.6. Translating VoC into Project Requirements

Based on the VoC findings, the project requirements can be summarised as follows:

1. Implement a more reliable hydraulic drive system to reduce unplanned downtime and enhance operational efficiency to meet production targets.
2. Reduce maintenance and operational costs through improved system reliability and efficiency.

3. Ensure the new system is easy to operate with minimal manual intervention and provide comprehensive training for maintenance teams on new technologies.
4. Integrate robust performance monitoring tools for accurate and reliable data collection.
5. Ensure the new system complies with environmental regulations and improves safety for operators and maintenance personnel.
6. Stay within the allocated budget while achieving the desired project outcomes.

9.6.7. SIPOC Diagram

A SIPOC (Suppliers, Inputs, Process, Outputs, Customers) diagram was utilized to provide a high-level overview of the project's critical components. The SIPOC diagram as shown in Table 3 helped to map out the entire process from suppliers to customers, ensuring a clear understanding of the project scope and stakeholder relationships. By identifying key suppliers, such as BOSCH for the hydraulic system, Ingleside Engineering for the design work and MII for the walkway assemblies, we could outline the necessary inputs, including technical specifications, design documents, and raw materials. The process steps were defined, detailing the manufacturing, installation, and commissioning phases. Outputs were specified as the fully installed and operational hydraulic system and the new walkway assemblies. Finally, the primary customers were identified, including the maintenance and operations teams who would directly benefit from the upgrade. As supported by (Pyzdek & Keller, 2014) , Utilizing the SIPOC diagram facilitated clear communication among stakeholders, ensuring that all critical elements were considered and aligned with the project's goals. This tool also helped in identifying potential bottlenecks and areas for improvement early in the project lifecycle, contributing to a more efficient and effective implementation.

Table 3 - SIPOC Diagram

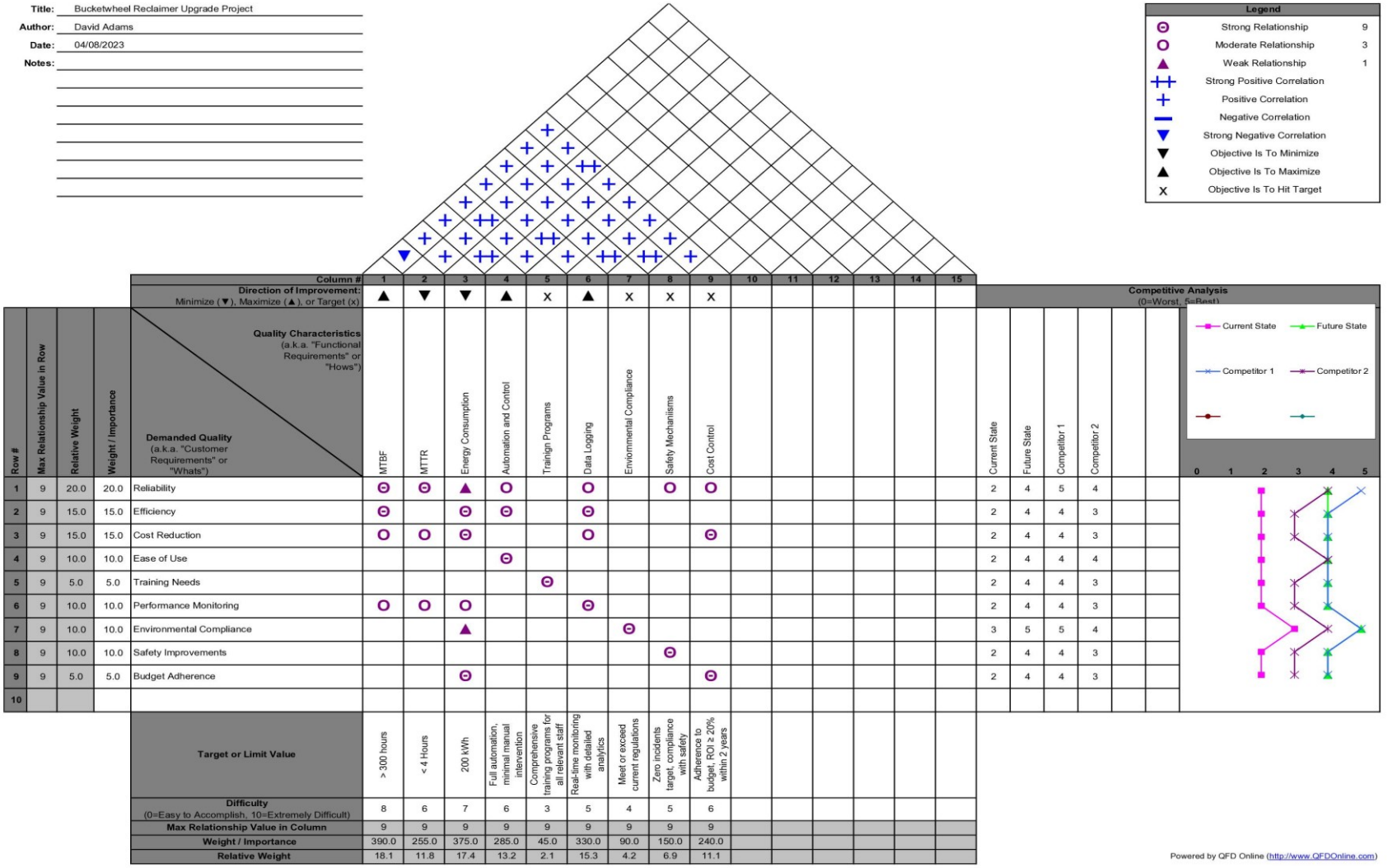
Suppliers	Inputs	Process	Outputs	Customers
Internal: Engineering Team	Current electric drive system Maintenance records	**1. Define Phase:** Identify stakeholders and their needs	Project Charter	Operations Managers Maintenance Teams

Maintenance Team Project Manager **External:** Alternative system suppliers Training providers Consultants Industry experts	Energy consumption data Downtime logs Financial records Supplier catalogues Technical specifications Condition monitoring tools SCADA and CMMS data Feedback from stakeholders Environmental compliance data	Develop project charter Map current process **2. Measure Phase:** Develop data collection plan Collect data on system reliability, maintenance costs, energy consumption, and operational downtime Conduct Gage R&R study **3. Analyse Phase:** Perform root cause analysis Conduct statistical analysis Validate hypotheses **4. Improve Phase:** Develop and evaluate potential solutions Design and implement hydraulic system Conduct pilot testing	SIPOC Diagram High-level Process Map Baseline Performance Data Measurement System Analysis (MSA) Report Root Cause Analysis Report Statistical Analysis Report Validated Hypotheses Solution Design and Implementation Plan Pilot Test Results Optimised Hydraulic Drive System	Equipment Operators Production Engineers Finance Department Environmental and Safety Officers External Vendors (for system components and technical expertise)

		Optimise system performance **5. Control Phase:** Develop control mechanisms Implement monitoring processes Conduct training sessions Update documentation and SOPs	Control Plan Performance Monitoring Reports Updated Standard Operating Procedures (SOPs)	

9.6.8. Quality Function Deployment (QFD)

Using the information gathered during the VOC exercise, it is possible to create a House of Quality (HOQ) as shown in Figure 11. This is a QFD visual tool used to rank and display the important features of a project for the various stakeholders. (Hauser, et al., 1988) shows the use of a HOQ helps to ensure that the solution has the maximum impact for the users and other stakeholders and helps to deliver the project successfully.



Title: Bucketwheel Reclaimer Upgrade Project
Author: David Adams
Date: 04/08/2023
Notes:

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
- Objective Is To Hit Target

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	1 MTBF	2 MTTR	3 Energy Consumption	4 Automation and Control	5 Trainign Programs	6 Data Logging	7 Enviornmental Compliance	8 Safety Mechanisms	9 Cost Control	Current State	Future State	Competitor 1	Competitor 2
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	▼	▲	x	▲	x	x	x				
1	9	20.0	20.0	Reliability	Θ	Θ	▲	O		O		O	O	2	4	5	4
2	9	15.0	15.0	Efficiency	Θ		Θ	Θ		Θ				2	4	4	3
3	9	15.0	15.0	Cost Reduction	O	O	Θ			O			Θ	2	4	4	3
4	9	10.0	10.0	Ease of Use				Θ						2	4	4	4
5	9	5.0	5.0	Training Needs					Θ					2	4	4	3
6	9	10.0	10.0	Performance Monitoring	O	O	O			Θ				2	4	4	3
7	9	10.0	10.0	Environmental Compliance			▲				Θ			3	5	5	4
8	9	10.0	10.0	Safety Improvements								Θ		2	4	4	3
9	9	5.0	5.0	Budget Adherence			Θ						Θ	2	4	4	3
10																	
				Target or Limit Value	> 300 hours	< 4 Hours	200 kWh	Full automation, minimal manual intervention	Comprehensive training programs for all relevant staff	Real-time monitoring with detailed analytics	Meet or exceed current regulations	Zero incidents target, compliance with safety	Adherence to budget, ROI ≥ 20% within 2 years				
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	8	6	7	6	3	5	4	5	6				
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9				
				Weight / Importance	390.0	255.0	375.0	285.0	45.0	330.0	90.0	150.0	240.0				
				Relative Weight	18.1	11.8	17.4	13.2	2.1	15.3	4.2	6.9	11.1				

Competitive Analysis (0=Worst, 5=Best)

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

Figure 11 - HOQ (QFD Online, 2007)

9.7. Project Charter

TATA Engineering Project Charter			
Project Name	BWR Availability & Reliability Improvement	**Business/Dept.**	Port Talbot Harbour
Change Agent	David Adams	**Tel. Number**	01639 603480
Champion	Mark Powys	**Tel. Number**	01639 605065
Start Date	01/02/2023	**End Date**	31/01/2023
Project Details			
Description	Improve Asset Reliability using Six Sigma methodology to identify root cause and determine most valuable workstreams.		
Business Case	Increased failure rate of BWR drive system, increased repair costs, reduced availability below required target to achieve AP (95%). Repair vendor indicated obsolescence of spares during recent breakdown. Alternative solutions/systems to be explored.		
Problem Statement	Catastrophic Failure of BWR drive system causing significant impact to operations.		
Process Function	Harbour Engineering.		
Project Goals	**Measure**	**Current**	**Target**
Improve Availability	Maximum Uptime (24hr operation, 365 days per year), Planned Maintenance (12 hrs per week over 51 weeks) - Breakdowns / Maximum Uptime	70%	95%
Improve MTBF	Maximum uptime/ count of breakdowns	2728 mins	8640 mins
Improve Quality – material mix consistency / laying control	Laying Control	70%	95%
Improve Safety – increased safety features / overload warning	*Qualitative Data*	*N/A*	*N/A*
Improve Efficiency	Component Efficiency (100% Load) Electric Motor = 0.94 Electric Motor Power Factor = 0.85 Fluid Coupling = 0.98 Gearbox = 0.94	74%	93%
Improve Customer Satisfaction – serviceability, operational	*Qualitative Data*	*N/A*	*N/A*
Reduce Maintenance costs	Monthly Accounting Report	£3.6M pa	£2.2M pa
Reduce Operation Costs	Monthly Accounting Report	£4.1M pa	£3.1M pa
Reduce Spares Costs	Monthly Accounting Report	£1.8M pa	£0.9M pa

Reduce Obsolescence risk	OEM Report	>1year	<10 Years
Reduce MTTR	Duration of Breakdowns/Count of Breakdowns	854 mins	60 mins
Team Members	David Adams (Manufacturing Engineer), Mark Powys (Engineering Manager)		
Support Required	Mark Powys (Engineering Manager), Mark Davies (Production Manager), Kirsty Hamlyn (Spares and Planning Manager), Ingleside Engineering, Bosch Rexroth, Sheffield Transmission Developments		
Risks/Constraints	Management of Change procedure to be used, Limited Asset Improvement budget - all proposals require business justification with 6-12month ROI		

(Tata Steel UK, 2020)

9.8. High-Level Project Plan

A high-level project plan serves as a critical roadmap during the initial phases of a project, establishing a clear framework for objectives, timelines, resources, and key activities. This plan outlines the project's scope and major milestones, enabling stakeholders to understand the project's direction and their roles within it. As the project progresses, continuous updating of the project plan is essential to accommodate new information, emerging risks, and changing conditions. This dynamic approach ensures that the project remains aligned with its goals and can adapt to unexpected challenges. According to (Turner, 2008), effective project planning and ongoing plan adjustments are vital for maintaining project control and ensuring successful outcomes. This iterative process of planning and re-planning helps manage stakeholder expectations, facilitates proactive risk management, and ensures resource optimisation. Additionally, (Project Management Institute, 2021) emphasises that a living project plan, which is regularly reviewed and updated, supports better decision-making and increases the likelihood of project success. By keeping the project plan current, it is possible to track progress, make informed adjustments, and ensure the project stays on course, ultimately leading to more effective execution and delivery.

9.8.1. Phase 1: Define

Estimated Duration: 1 month

Objectives

- Define the project scope, goals, and objectives.
- Identify stakeholders and their needs.
- Develop a project charter.
- Map the current process.

Key Activities

- Kick-off meeting with stakeholders – Project Manager
- Conduct Voice of the Customer (VoC) analysis - Project Manager
- Create a project charter and SIPOC (Suppliers, Inputs, Process, Outputs, Customers) diagram – Project Manager
- Develop a high-level process map of the current system – Engineering Team

Deliverables

- Project Charter
- SIPOC Diagram
- High-level Process Map

9.8.2. Phase 2: Measure

Estimated Duration: 2 months

Objectives

- Collect data to establish baseline performance.
- Identify key performance indicators (KPIs).
- Validate the measurement system.

Key Activities

- Develop a data collection plan – Data Analyst
- Collect data on system reliability (MTBF, MTTR), maintenance costs, energy consumption, and operational downtime – Maintenance Team
- Conduct a review to validate the measurement system – Data Analyst

Deliverables

- Data Collection Plan

- Baseline Performance Data
- Measurement System Analysis (MSA) Report

9.8.3. Phase 3: Analyse

Estimated Duration: 2 months

Objectives

- Analyse the collected data to identify root causes of issues.
- Perform statistical analysis to understand variations and trends.
- Develop hypotheses about potential improvements.

Key Activities

- Perform root cause analysis (e.g., Fishbone Diagram, Pareto Analysis) – Engineering Team
- Conduct statistical analysis (e.g., ANOVA, regression analysis) – Data Analyst
- Validate hypotheses through additional data collection and analysis – Engineering Team

Deliverables

- Root Cause Analysis Report
- Statistical Analysis Report
- Validated Hypotheses

9.8.4. Phase 4: Improve

Estimated Duration: 3 months

Objectives

- Develop and implement solutions to address root causes.
- Test and validate improvements.
- Optimise the new hydraulic drive system.

Key Activities

- Brainstorm and evaluate potential solutions – Engineering Team
- Develop detailed design and implementation plans for the hydraulic system – Engineering Team
- Implement Solutions – Project Manager
- Conduct pilot testing and validate improvements – Maintenance Team

- Optimise the new system for performance - Engineering Team

Deliverables

- Solution Design and Implementation Plan
- Pilot Test Results
- Optimised Hydraulic Drive System

9.8.5. Phase 5: Control

Estimated Duration: 2 months

Objectives

- Establish control mechanisms to sustain improvements.
- Monitor and measure the performance of the new system.
- Document the new process and update standard operating procedures (SOPs).

Key Activities

- Develop a control plan with KPIs and monitoring processes – Project Manager
- Implement control mechanisms (e.g., control charts, regular audits) – Maintenance Team
- Conduct training sessions for operators and maintenance staff – Project Manager
- Update documentation and SOPs – Engineering Team

Deliverables

1. Control Plan
2. Performance Monitoring Reports
3. Updated SOPs

9.9. Initial Gantt Chart

The creation of an initial high-level Gantt chart as shown in Figure 12 was pivotal in mapping the project for the bucket wheel reclaimer. This chart served as a visual timeline, outlining the key phases and milestones from project inception to completion. By delineating tasks such as literature review, vendor consultations, procurement, design, manufacturing, installation, and commissioning, the Gantt chart provides a clear roadmap for the project. It facilitates efficient project management by allowing the identification of dependencies, critical paths, and potential bottlenecks. (Kerzner, 2017)

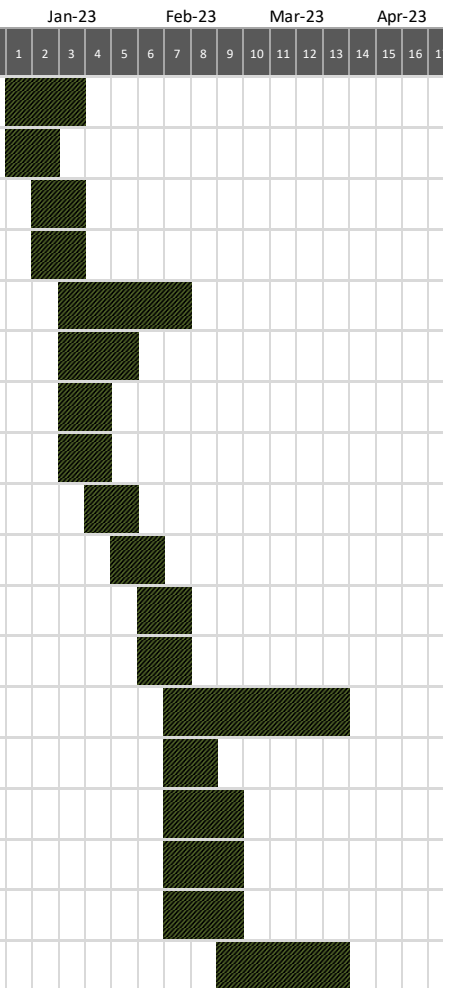
suggests a high-level Initial Gantt chart enables effective communication with stakeholders by presenting a comprehensive overview of the project's timeline and progress. This strategic planning tool was essential for aligning resources, managing risks, and ensuring that all team members had a shared understanding of the project's scope and objectives from the start of the project.

BWR Gearbox Failures

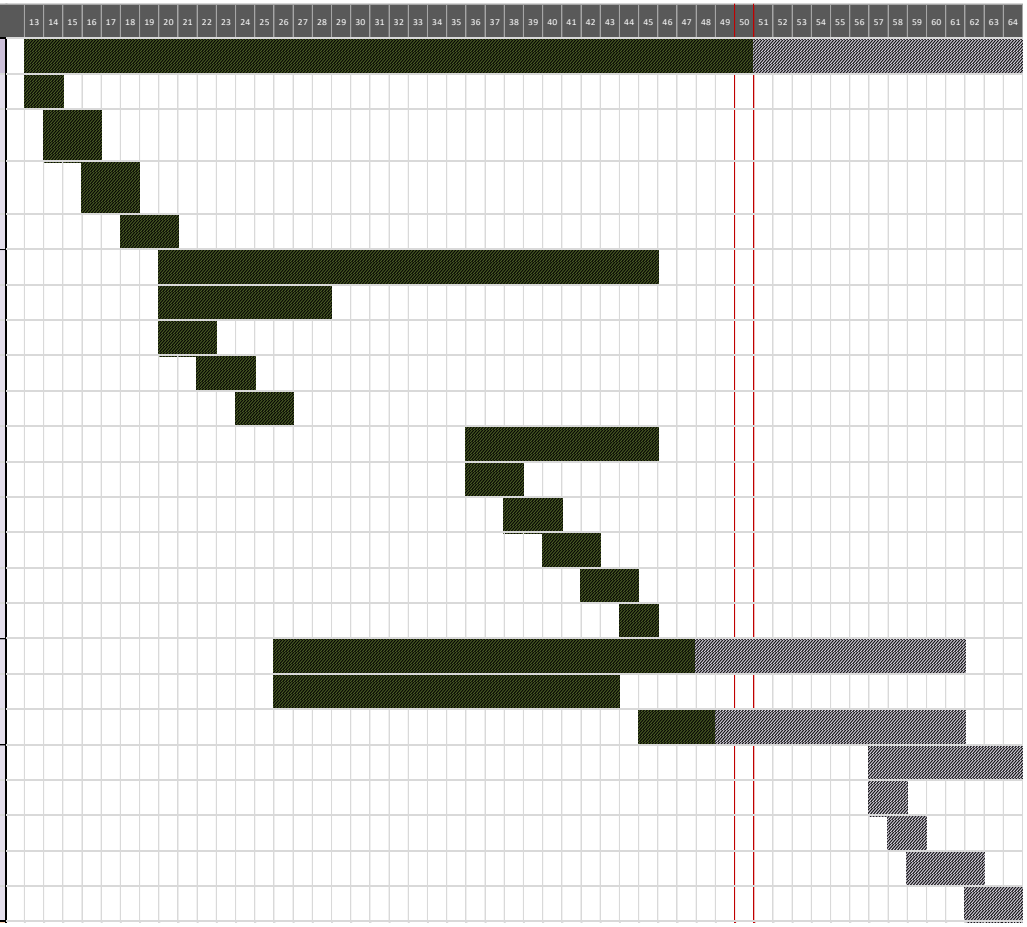
Tata Steel UK
David Adams

		Project Start:	Mon, 02/01/2023		

TASK	OWNER	PROGRESS	START	DURATION (WEEKS)	END
Define		**100%**	**2/1/23**	**2**	**16/1/23**
Gearbox Failure	Mark Powys	100%	2/1/23	1	9/1/23
Failure Reduction Meeting	Mark Powys	100%	9/1/23	1	16/1/23
Project Charter	David Adams	100%	9/1/23	1	16/1/23
Measure		**100%**	**16/1/23**	**4**	**13/2/23**
Delay Data	David Adams	100%	16/1/23	2	30/1/23
Efficiency Data	Mark Powys	100%	16/1/23	1	23/1/23
Cost Data	Mark Powys	100%	16/1/23	1	23/1/23
Repair Reports	David Adams	100%	23/1/23	1	30/1/23
Operator Interviews	Mark Powys	100%	30/1/23	1	6/2/23
Supplier Interviews	David Adams	100%	6/2/23	1	13/2/23
OEM Interviews	David Adams	100%	6/2/23	1	13/2/23
Analyse		**100%**	**13/2/23**	**6**	**27/3/23**
Pareto Analysis	David Adams	100%	13/2/23	1	20/2/23
Root Cause	David Adams	100%	13/2/23	2	27/2/23
5 Why	David Adams	100%	13/2/23	2	27/2/23
Fishbone	David Adams	100%	13/2/23	2	27/2/23
Research into alternative solutions	David Adams	100%	27/2/23	4	27/3/23



TASK	OWNER	PROGRESS	START	DURATION (WEEKS)	END
Improve		**73%**	**27/3/23**	**51**	**21/3/24**
Project outline sent to vendors for quotation	David Adams	100%	27/3/23	1	3/4/23
Site visits to finalise contract scope	Sheffield Transmission Developments, David Brown Gearboxes, Bosch Rexroth	100%	3/4/23	2	17/4/23
Quotations Received and Vendor Selection	Sheffield Transmission Developments, David Brown Gearboxes, Bosch Rexroth	100%	17/4/23	2	1/5/23
CAPEX Funding Application	David Adams	100%	1/5/23	2	15/5/23
Design Phase		**100%**	**15/5/23**	**25**	**6/11/23**
Hydraulic System Design	**Bosch Rexroth**	**100%**	**15/5/23**	**8**	**10/7/23**
Hydraulic Design Review #1	David Adams	100%	15/5/23	2	29/5/23
Hydraulic Design Review #2	David Adams	100%	29/5/23	2	12/6/23
Hydraulic Design Buy-off	David Adams	100%	12/6/23	2	26/6/23
Structural Design	**Ingleside Engineering**	**100%**	**4/9/23**	**8**	**6/11/23**
Structure Design Review #1	David Adams	100%	4/9/23	2	18/9/23
Structure Design Review #2	David Adams	100%	18/9/23	2	2/10/23
Structure Design Buy-off	David Adams	100%	2/10/23	2	16/10/23
Structural Manufacture Tender Documentation	David Adams	100%	16/10/23	2	30/10/23
Structural Manufacture Vendor Selection	David Adams	100%	30/10/23	1	6/11/23
Manufacture Phase		**63%**	**26/6/23**	**35**	**26/2/24**
Hydraulic System Manufacture	Bosch Rexroth	100%	26/6/23	17	23/10/23
Sturctural Steelwork Manufacture	Systems Engineering Group	25%	6/11/23	16	26/2/24
Installation Phase		**0%**	**1/2/24**	**7**	**21/3/24**
Removal of Redundant gearbox	Tata DST	0%	1/2/24	1	8/2/24
Removal of existing steelwork	Systems Engineering Group	0%	8/2/24	1	15/2/24
Installation of new structural steelwork	Systems Engineering Group	0%	15/2/24	3	7/3/24
Installation of new hydraulic drive system	Bosch Rexroth	0%	7/3/24	2	21/3/24



TASK	OWNER	PROGRESS	START	DURATION (WEEKS)	END
Control		0%	21/3/24	9	23/5/24
Testing under 0% load	David Adams, Bosch Rexroth	0%	21/3/24	1	28/3/24
Testing under coal load	David Adams, Bosch Rexroth	0%	28/3/24	1	4/4/24
Testing under ore load	David Adams, Bosch Rexroth	0%	4/4/24	1	11/4/24
Validation of improvements against KPI	David Adams, Mark Powys	0%	11/4/24	4	9/5/24
Communicate Project Findings and close project	David Adams, Mark Powys	0%	9/5/24	2	23/5/24
University		25%	4/9/23	41	17/6/24
Proposal	David Adams	100%	4/9/23	1	11/9/23
Viva 1	David Adams	0%	12/12/23	1	19/12/23
Report	David Adams	0%	20/5/24	1	27/5/24
Viva 2	David Adams	0%	10/6/24	1	17/6/24

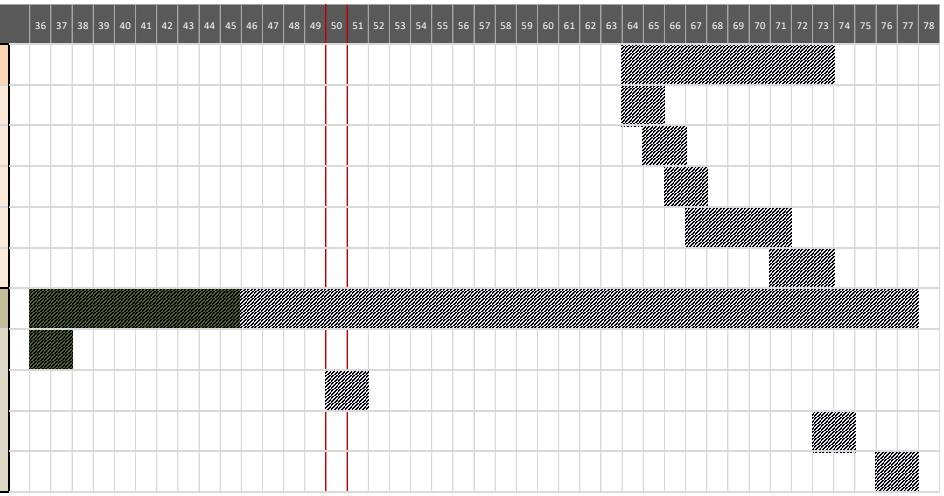


Figure 12 - Initial Gantt chart

9.10. Resources Required

- Project Manager to oversee project execution and ensure milestones are met.
- Engineering Team to Design and implement the chosen solution.
- Maintenance Team will provide input on current issues and assist with testing and validation.
- Data Analyst to conduct data collection, analysis, and MSA.

9.11. Risk Management

Effective risk management is crucial for the success of the project, The potential risks identified include delays in data collection or system implementation, inaccurate baseline data due to measurement system errors, resistance to change from operators or maintenance staff, and budget overruns due to unforeseen expenses. These risks, if not properly managed, could significantly impact the project timeline, quality of outcomes, and overall budget.

To mitigate these risks, a detailed project plan created with buffer time allocated for potential delays, ensuring that the project can accommodate unforeseen interruptions without jeopardising deadlines. Secondly, the accuracy of baseline data will be ensured by validating the measurement system. This will help in identifying and rectifying any measurement system errors early in the project.

Additionally, engaging stakeholders early in the process and providing regular updates helps to manage resistance to change. As discussed by (Bryson, 2004), by involving stakeholders from the beginning, their concerns can be addressed, and they can be more easily aligned with the project's goals. Finally, expenses will be closely monitored, and the budget will be adjusted as needed to prevent overruns. This proactive financial oversight will help in identifying any potential budget issues early, allowing for timely adjustments and ensuring the project remains financially viable.

10. Measure

10.1. Current Performance Measurements

It is critical to collect data to understand the current performance of the existing electric drive system. This will establish a baseline against which the improvements introduced by the hydraulic system can be measured. Table 4 shows there is a variety of qualitative and quantitative data available for analysis to understand the performance of the system.

Table 4 - Data Types

Quantitative	Qualitative
Condition Monitoring Data	Operation Reports
Downtime & OEE Data	Maintenance Reports
Planned Maintenance Costs	
Unplanned Maintenance Costs	
Energy Efficiency	

10.1.1. Operational Downtime

Operational Downtime directly impacts production schedules and overall plant efficiency. (Smith & Hinchcliffe, 2003) demonstrate that measuring unplanned downtime is essential in assessing the reliability of the system. Frequent downtimes suggest underlying issues that need to be addressed to improve system reliability. According to (Kennedy, 2017), monitoring and analysing downtime frequency helps in identifying trends and the impact of various interventions on reducing these incidents.

10.1.1.1. System Reliability

The Mean Time Between Failures (MTBF) measures the average operational time between failures. For the bucket wheel excavator, a low MTBF indicates frequent breakdowns. (Mobley, 2001) discusses how this metric helps identify reliability issues and the effectiveness of maintenance strategies

Mean Time to Repair (MTTR) measures the average time taken to repair the system after a failure. (Moubray, 2001) documents how measuring MTTR provides insights into repair

process efficiency and spare parts availability, where prolonged repair times impact productivity

10.1.2. Maintenance Costs

This includes all costs associated with maintaining the system, such as labour, parts, and unplanned maintenance costs (breakdowns). High maintenance costs are often indicative of underlying issues such as frequent failures, expensive spare parts, and labour-intensive repairs. (Wireman, 2004) shows that measuring these costs helps in identifying areas where cost savings can be achieved through improved maintenance strategies or system upgrades.

(Levitt, 2009) argues that understanding the cost per failure helps in assessing the financial impact of each downtime incident and prioritising interventions that can reduce these costs.

10.1.2.1. Planned Maintenance Costs

The primary rationale for planned maintenance is to prevent equipment failures before they occur, aiming to minimise unplanned downtime and associated costs. As detailed by (Jardine & Tsang, 2021) the cost of planned maintenance must be balanced against the costs of potential failures, including the direct costs of repairs and the indirect costs of downtime. By conducting a cost-benefit analysis, organisations can assess whether the expenses incurred through regular maintenance activities or system upgrades are justified by the savings achieved through reduced failures and extended equipment life.

The analysis of planned maintenance costs contributes to understanding the Total Cost of Ownership (TCO) of the bucket wheel reclaimer. TCO includes purchase price, operation, maintenance, and eventual disposal costs. Efficient planned maintenance strategies or upgrade activities can significantly reduce TCO by extending the useful life of the equipment and optimising its operational efficiency. According to (Agustiady & Cudney, 2016) a well-executed maintenance plan directly influences TCO by mitigating the need for costly emergency repairs and replacements.

Investing in planned maintenance activities or system upgrades can be justified through a Return on Investment (ROI) analysis. ROI considers the ratio of cost savings and increased revenue attributable to upgrades relative to the costs of those upgrades. As

explored by (Levitt, 2009), effective planned maintenance or upgrades can enhance equipment reliability and productivity, contributing to greater production outputs and quality, which in turn can positively affect the ROI of maintenance expenditures.

10.1.2.2. Unplanned Maintenance Costs

Unplanned maintenance, often resulting from unexpected equipment failures, can lead to significant costs, not only in terms of the direct expenses related to repairs but also due to the downtime and lost production opportunity. By examining the costs associated with unplanned maintenance, organisations can evaluate the effectiveness and efficiency of their current maintenance strategies and make informed decisions on potential adjustments, improvements or upgrades.

1. **Direct Cost Analysis**: The direct costs of unplanned maintenance include parts, labour, and any other resources required for the repair. Analysing these costs can reveal patterns or recurring issues with specific components or systems, suggesting areas where improvements could be made. According to (Mobley, 2001) understanding these costs is crucial for justifying investments in systems that could reduce the incidence of unplanned repairs.
2. **Downtime Cost Impact**: Unplanned maintenance often leads to unexpected downtime, which can significantly impact production schedules and output. The cost of downtime can be several times higher than the direct costs of maintenance. As detailed by (Levitt, 2009) analysing the impact of downtime on production and revenue can justify the need for more robust maintenance strategies or newer equipment to help minimise the risk of unexpected equipment failures.
3. **Efficiency and Reliability Improvement**: By reducing unplanned maintenance, it is possible to improve the overall efficiency and reliability of equipment. The analysis of unplanned maintenance costs provides a quantitative basis for justifying the upgrading of systems or adoption of more proactive maintenance strategies, such as predictive maintenance, which can anticipate and prevent failures before they occur. (Swanson, 2001) illustrates how improvements in maintenance practices can lead to better equipment reliability and performance,

ultimately justifying the implementation costs through improved operational efficiency.

4. **Strategic Decision Making**: The analysis of unplanned maintenance costs supports strategic decision-making regarding TCO and understanding the true cost impact of unplanned maintenance, organisations can better prioritise maintenance activities and allocate resources more effectively, ensuring that maintenance efforts are focused on areas that will provide the greatest benefit in terms of reducing unplanned downtime and associated costs.

This data helps to identify areas for improvement, justify investments in preventive and predictive maintenance technologies, and make informed decisions that enhance equipment reliability and operational efficiency. Through a detailed understanding of the direct and indirect costs of unplanned maintenance, maintenance managers can develop strategies that not only reduce these costs but also improve the overall productivity and profitability of their operations.

10.1.3. Energy Consumption

High energy usage is a significant operational cost and contributes to the plant's carbon footprint. Measuring energy consumption provides a clear picture of the system's efficiency and identifies opportunities for energy savings as discussed by (Petrecca, 2012)

For the existing system, energy efficiency is relatively low, with significant losses occurring due to mechanical and thermal inefficiencies. (Thumann & Younger, 2008) show that tracking energy efficiency helps in understanding how well the system converts energy into productive work and highlights potential improvements.

10.1.3.1. Energy Efficiency Data

Energy efficiency serves as a crucial performance indicator for heavy machinery, indicating how well the equipment converts energy into work. For a bucket wheel reclaimer, which consumes significant amounts of energy, small improvements in efficiency can lead to substantial cost savings and environmental benefits.

1. **Reduction in Energy Consumption**: Maintenance activities can lead to a reduction in energy consumption by ensuring that all components of the bucket

wheel reclaimer operate optimally. For instance, lubrication, alignment, and replacement of worn parts can reduce friction and resistance, thereby requiring less energy for operation. This direct correlation between maintenance and energy consumption can be used to justify the investment in regular and preventive maintenance practices.

2. **Cost Savings**: The analysis of energy efficiency data often reveals cost savings as a result of maintenance activities. By quantifying the reduction in energy costs associated with specific maintenance interventions or upgrades, organisations can provide a compelling financial justification for their implementation. (Thumann & Younger, 2008) offers methodologies for quantifying energy savings.
3. **Improvement in OEE**: Energy efficiency improvements can also be reflected in the OEE metric, which includes availability, performance, and quality. Since energy efficiency impacts the performance aspect of OEE, improvements in this area can justify upgrades by demonstrating their contribution to the overall effectiveness of the equipment.
4. **Sustainability and Environmental Compliance**: Enhancing energy efficiency aligns with broader sustainability goals and compliance with environmental regulations. Activities and upgrades that lead to improved energy efficiency not only reduce operational costs but also minimise the carbon footprint of the equipment. This aspect is increasingly important in industries striving for sustainability and can be supported by the ISO50001:2018 standard, which provides a framework for energy management practices. (International Standards Organisation, 2018)

10.1.3.2. Operation Reports

The analysis of operator/operation reports can provide firsthand insights into the equipment's operational performance, issues encountered during operations, and the effectiveness of past maintenance interventions. These reports, generated by the personnel directly interacting with or overseeing the equipment, offer qualitative and quantitative data critical for evaluating the system and highlighting potential improvements.

Operator reports often include detailed accounts of the equipment's performance, noting any deviations from expected operational parameters. By analysing these reports, maintenance teams can identify patterns or recurring issues that may not be evident through automated monitoring systems alone. For instance, if operators consistently report unusual noises, behaviour or vibrations before a failure, maintenance strategies can be adjusted to address these early warning signs more proactively.

Recurring issues noted in operation reports can justify the enhancement or modification of current systems. For example, if operators frequently report issues with specific components, this could indicate the need for more frequent inspections or replacements of those parts, justifying improvements for those components. (Smith & Hinchcliffe, 2003) supports the use of operation reports in identifying and addressing the root causes of equipment failures, thereby justifying upgrades focused on reliability and performance improvement.

Feedback on the performance of the equipment following maintenance activities provides invaluable insights into the effectiveness of current maintenance methods. Positive reports on equipment performance post-improvement can justify the further projects. Conversely, reports indicating little to no improvement post-intervention can signal the need for revising strategies. (Gulati & Smith, 2009) highlights how operator reports contribute to a holistic understanding of equipment health and performance.

Operators can often provide recommendations based on their hands-on experience with the equipment. These suggestions can include adjustments to maintenance schedules, recommendations for specific interventions, or proposals for operational changes to extend equipment life. Incorporating these recommendations into asset management can justify upgrades, ensuring they are aligned with operational realities and expertise.

10.1.4. Data Collection Methods

Table 5 shows the different sources of data and their classification, enabling the creation of a data collection plan that will be used for validating the scope of the problem and the factors for determining success.

Table 5 - Data Collection Plan

Measure Title	Data Required	Data Type	Data Source	Data Collection Method	Constraints	Resource Required	Data Collection Plan
System Reliability	Failure rates, repair times, Parts replaced, labour hours	Quantitative	CMMS	Review and categorise maintenance logs	Data accuracy, historical completeness	Maintenance staff, CMMS access	Collect historical data over the past 2 years
Maintenance Costs	Annual maintenance costs, Cost per failure	Quantitative	CMMS, financial records	Extract detailed financial reports	Accounting consistency, record completeness	Financial analyst, CMMS access	Extraction and review of financial records for the past year
Energy Consumption	Energy usage per hour, Energy Efficiency	Quantitative	SCADA, energy meters	Collect real-time data	Meter calibration, data logging intervals	Energy meters, SCADA system	Continuous data logging over a 6-month period

Operational Downtime	Unplanned downtime hours, Downtime Frequency	Quantitative	CMMS, operational logs	Review downtime records, log incidents	Data entry consistency, accurate time logging	Maintenance staff, CMMS access	Collect historical data over the past 2 years
Stakeholder Insights	Perceived reliability issues, Maintenance challenges, suggestions for improvement	Qualitative	Interviews with operators, maintenance staff	Conduct structured interviews, distribute surveys	Subjective data, response bias	Interviewers, survey tools	Conduct interviews and surveys over 2 week period
Condition Monitoring	Vibration levels, temperature hotspots, oil contamination indicators	Quantitative and qualitative	Vibration analysis tools, thermal cameras, oil analysis kits	Perform regular condition monitoring checks	Equipment availability, environmental conditions, sample handling	Monitoring tools, trained personnel	Collect historical data over the past 2 years

11. Analyse

The analyse phase aims to identify and validate the root causes of frequent failures in the bucket wheel excavator's gearbox, focusing on the rapid onset and unpredictable catastrophic failures of the planetary components.

11.1. Data Analysis

Data analysis is a crucial part of the project, it is where the meaningful information is identified and extracted from the gathered data, to determine trends, patterns, and anomalies that could impact project outcomes. Key performance indicators (KPIs) such as Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), energy consumption, maintenance costs, and operational downtime are meticulously analysed. This comprehensive data analysis informs the decision-making process, guiding the project team in developing targeted solutions to enhance system performance and reliability. It also provides a baseline against which the effectiveness of the system upgrade can be measured, ensuring that the project meets its objectives of improving efficiency, reducing costs, and minimizing environmental impact.

11.1.1. System Reliability

To assess the reliability of the current gearbox system, historical failure data as shown in Table 6 was analysed focusing on key reliability metrics such as Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR). Historical maintenance logs and operational records from the Computerised Maintenance Management System (CMMS) were reviewed to calculate these metrics. Figure 13, Figure 14 and Figure 15 show the following trends;

1. Mean Time Between Failures decreased significantly over the years, indicating an increasing frequency of failures. For instance, MTBF dropped from 3578 hours in 2017 to 1820 hours in 2020, and slightly recovered to 2055 hours in 2022. This downward trend is a clear indicator of declining reliability.

2. Mean Time to Repair fluctuated, reflecting variations in the complexity and severity of repairs. In 2021, MTTR peaked at 1481 hours, indicating extensive downtime for significant repairs.

Table 6 - Delay Data

Year	Duration	Count	Availability	MTTR	MTBF
2017	161403	147	62%	1098	3578
2018	142133	148	73%	960	3554
2019	209547	152	60%	1379	3460
2020	115993	289	78%	401	1820
2021	271035	183	48%	1481	2874
2022	121754	256	77%	476	2055

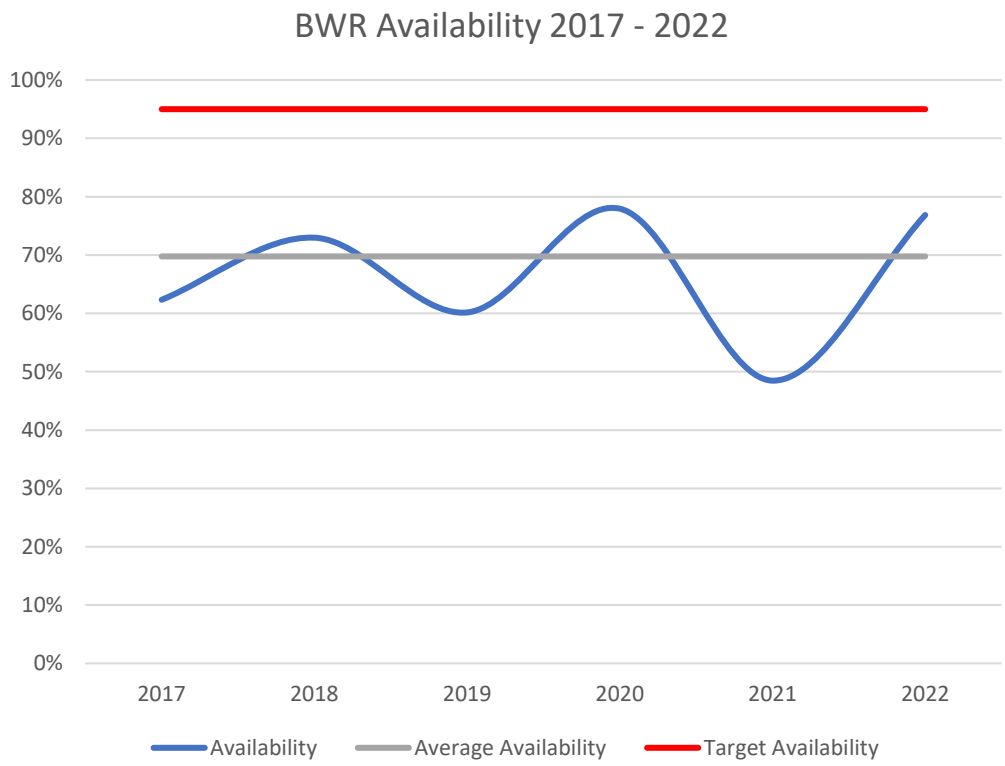


Figure 13 - Availability

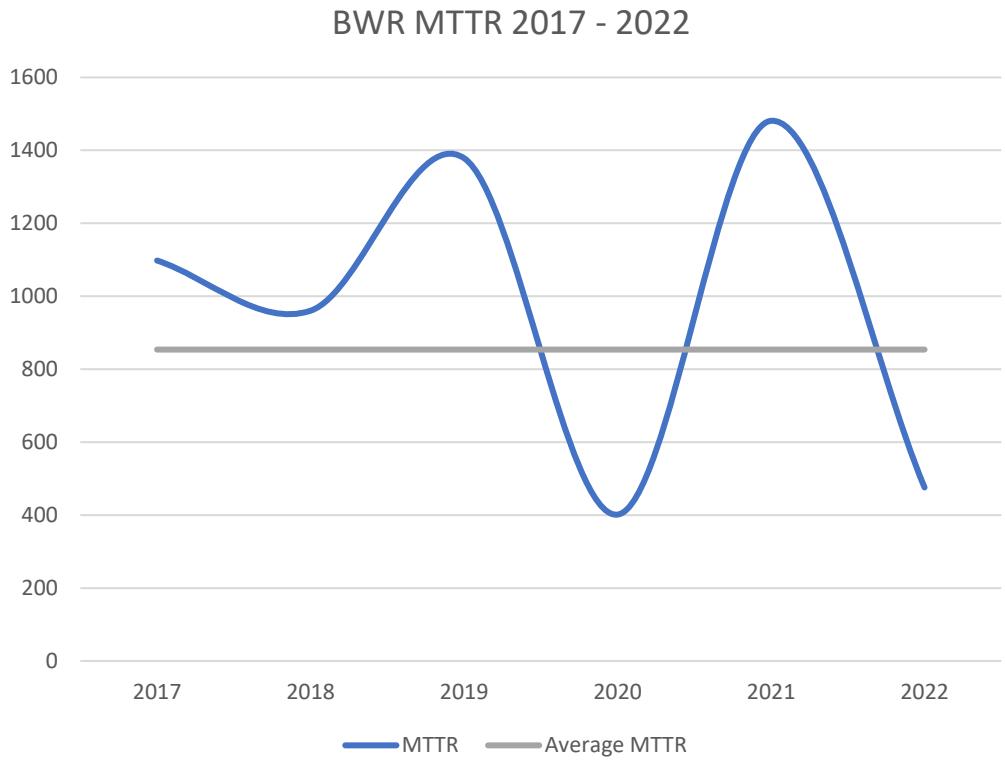


Figure 14 - MTTR

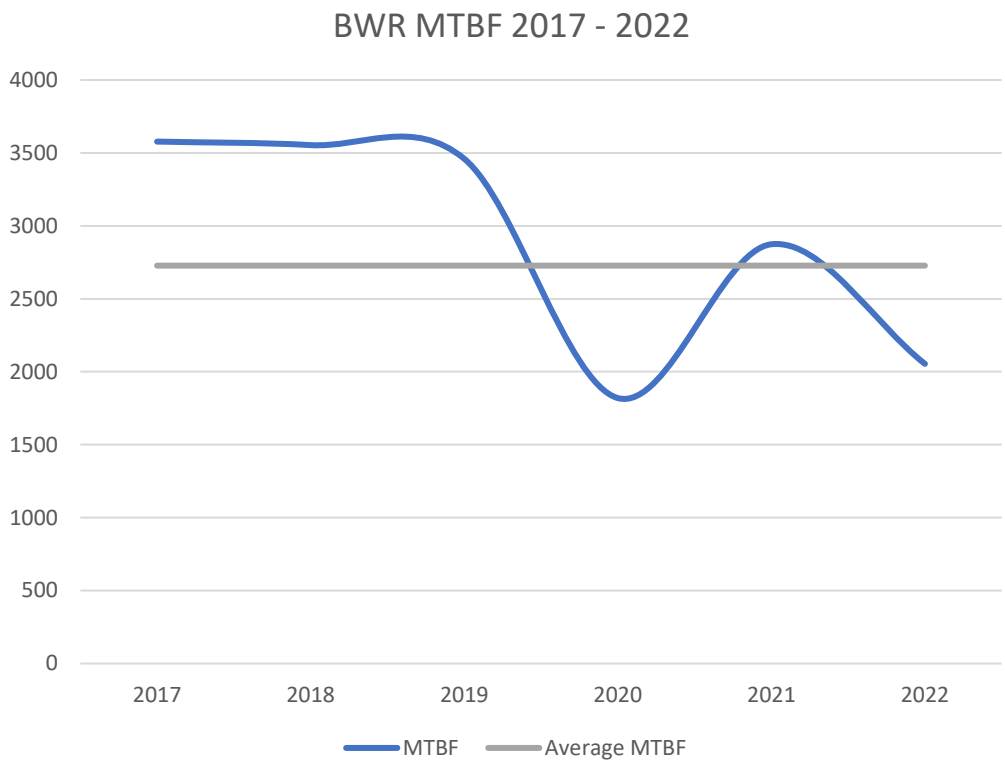


Figure 15 - MTBF

11.1.2. Maintenance Costs

Maintenance costs were analysed to understand the financial impact of maintaining the current gearbox system and identify trends. Financial records and CMMS data as shown in Table 7 provides insights into annual maintenance costs and the cost per failure. The analysis of Figure 16 and Figure 17 reveals the following trends:

1. There was a significant increase in annual maintenance costs over the years. For example, repair costs increased dramatically from £29,971 in 2017 to £325,216.50 in 2022.
2. The increasing cost per failure reflects the growing complexity and severity of repairs needed as the gearbox components wear out and also the sparsity of spare or replacement parts.

These escalating maintenance costs underscore the financial burden of maintaining an aging system. (Dhillon, 2008) argues the increasing trend in maintenance expenses, coupled with frequent and unpredictable failures, supports the conclusion that the gearbox is in its “End-of-Life” phase.

Table 7 - Maintenance Cost Data

Year	Repair Cost		Lead Time (Weeks)
2015	£	5,552.00	4
2017	£	29,971.00	14
2018	£	28,176.00	20
2019	£	98,694.00	22
2021	£	117,880.00	35
2022	£	325,216.50	67

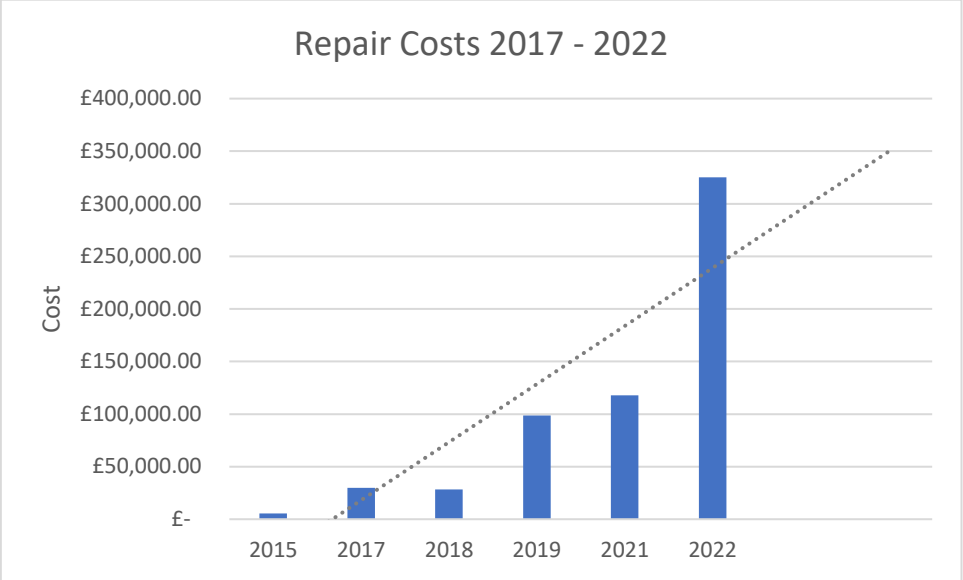


Figure 16 - Repair Costs

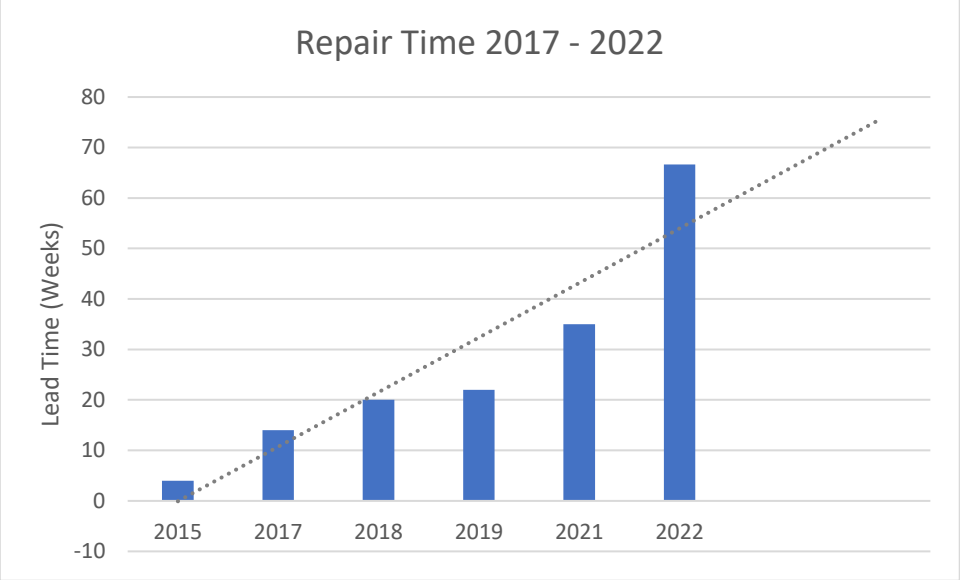


Figure 17 - Repair Times

11.1.3. Energy Consumption

Energy consumption data was analysed to evaluate the energy efficiency of the current gearbox system. The data shown in Table 8 was collected from the SCADA system and energy meters, focusing on metrics such as energy usage and running costs.

The analysis in Figure 18 shows an increasing trend in energy consumption, indicating a decline in energy efficiency. This is likely due to the deteriorating condition of the

gearbox, which (Petrecca, 2012) argues requires more power to operate efficiently as components wear out. The energy efficiency metrics, when compared to industry standards, highlighted that the current system is performing below expectations, suggesting potential for significant improvements.

The increasing energy consumption not only impacts operational costs as shown in Figure 19 but also Co2 production as shown in Figure 20. This highlights inefficiencies that could be mitigated by upgrading to a more efficient system. This analysis reinforces the need for a new, more energy-efficient hydraulic drive system.

Table 8 - Energy Data

Year	Annual Energy Usage [kWh]	Annual Running Cost [£]	Annual CO2 [kg]
2017	986,992	£ 148,048.80	229,969
2018	1,042,904	£ 156,435.60	242,997
2019	1,120,891	£ 168,133.65	261,168
2020	1,219,864	£ 182,979.60	284,228
2021	1,418,205	£ 212,730.75	330,442
2022	1,987,128	£ 298,069.20	463,001

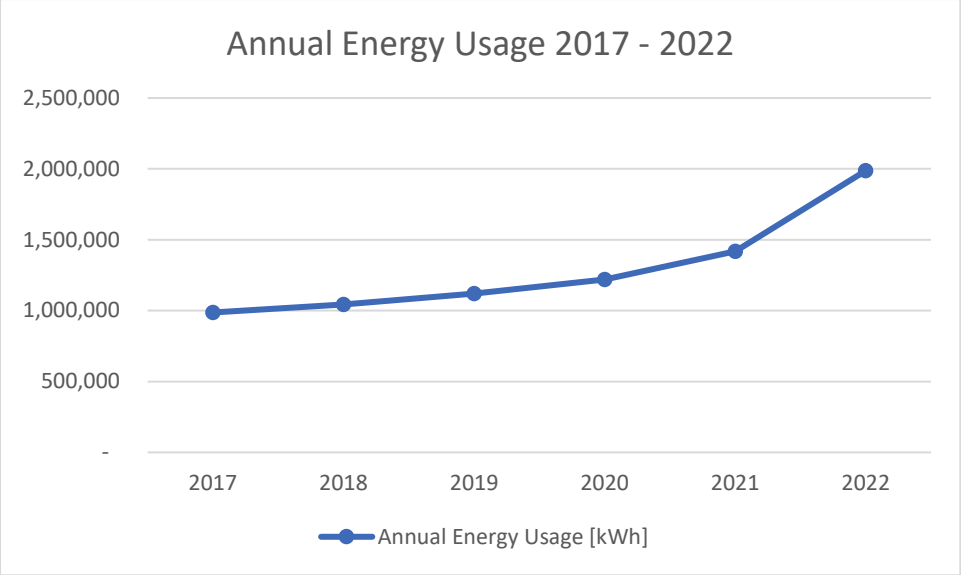


Figure 18 – Annual Energy Usage

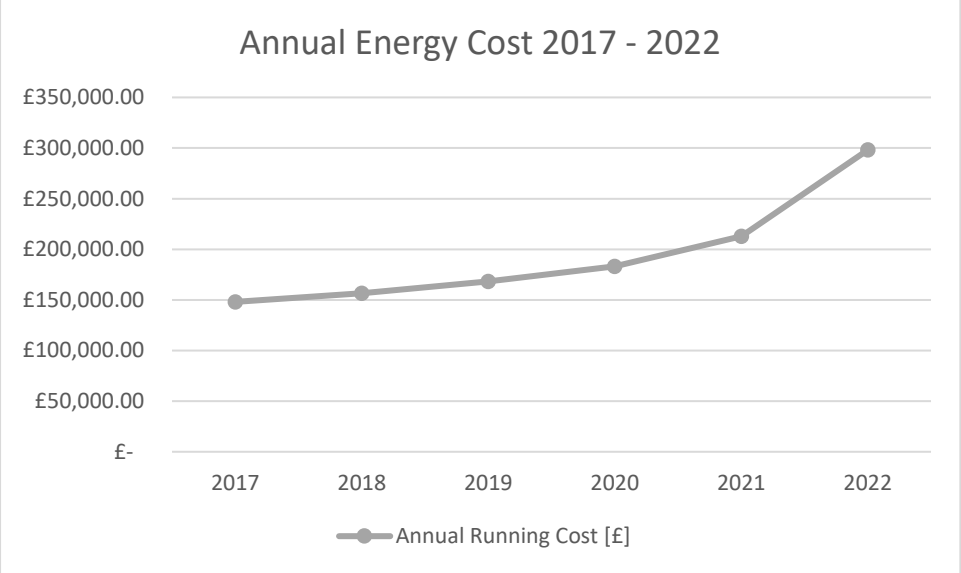


Figure 19 - Annual Energy Costs

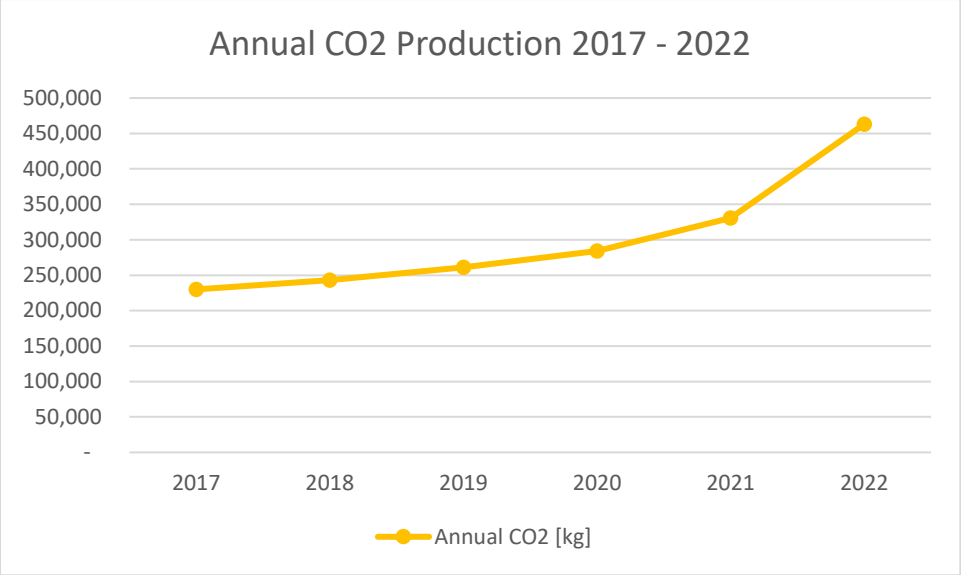


Figure 20 - Annual CO2 Production

11.1.4. Operational Downtime

Operational downtime was quantified to assess the impact of gearbox failures on production efficiency. Unplanned downtime hours and the frequency of downtime events were analysed using operational logs and CMMS data.

The data in Table 6 reveals a significant increase in downtime hours over the past few years, directly impacting production efficiency. The high frequency of unplanned downtime events further exacerbates this issue, highlighting the unreliability of the current gearbox system.

The data in Table 6 also shows, in 2020, there were 289 downtime events, significantly higher than previous years, reflecting the increasing instability of the system.

The substantial operational downtime emphasises the critical need for a more reliable system that can minimise disruptions and maintain consistent production levels.

11.1.5. Stakeholder Insights

To gather qualitative data on perceived reliability issues and maintenance challenges, structured interviews and surveys were conducted with operators and maintenance staff. This feedback provided valuable insights into the day-to-day experiences and challenges faced by those directly interacting with the gearbox.

Stakeholder feedback revealed several common issues, including the difficulty of accessing the gearbox for lubrication and the lack of real-time condition monitoring systems. Operators reported frequent failures that were difficult to predict, leading to significant operational disruptions. Maintenance staff highlighted the challenges of performing adequate lubrication and preventive maintenance due to the gearbox's location and design.

The feedback from stakeholders aligns with the quantitative data, reinforcing the need for improvements in maintenance accessibility and predictive monitoring capabilities. (Dhillon, 2008) argues that feedback and suggestions from operators and maintenance staff, such as implementing advanced PCM systems and improving lubrication access, are critical for enhancing the reliability of the system.

11.1.6. Condition Monitoring

Condition monitoring practices were assessed to determine their effectiveness and identify areas for improvement. Data on vibration levels, temperature hotspots, and oil contamination indicators were collected using condition monitoring tools such as vibration analysis equipment, thermal cameras, and oil analysis kits.

Trend analysis of condition monitoring data showed increasing vibration levels and temperature hotspots, indicating wear and tear on the gearbox components. Oil analysis revealed high levels of contamination, suggesting that lubrication practices are insufficient to maintain optimal operating conditions.

The correlation between condition monitoring data and failure events as discussed by (Nelson, 2004) indicates that advanced monitoring systems could have predicted some of the catastrophic failures, allowing for proactive maintenance. The lack of real-time PCM systems was identified as a significant gap in the current maintenance strategy, (Mobley, 2002) states this limits the ability to predict and prevent failures effectively.

11.2. Analytical Tools

Tools like Pareto analysis, fishbone diagrams, and the 5 Whys are employed to pinpoint the root causes of system inefficiencies and failures. Statistical techniques are used to validate data accuracy and ensure that insights drawn are reliable and actionable.

11.2.1. Pareto Analysis

Pareto analysis is a powerful tool used to identify and prioritise the most significant issues affecting the BWR. By illustrating the cumulative impact of various failure modes, the Pareto chart helps to focus attention on the areas that will yield the greatest improvement when addressed.

The Pareto chart in Figure 21 , shows that Gearbox Failure is by far the most significant issue, accounting for the majority of downtime minutes from 2017 to 2023. This is evident as the first bar, representing Gearbox failure, dwarfs all other causes of delays. The cumulative percentage line (red) confirms that addressing this single issue would significantly impact overall downtime reduction, as it constitutes the bulk of the total downtime.

Secondary issues such as Opportunity Maintenance Stop, Cable Damaged, and Cleaning, contribute relatively minor amounts of downtime in comparison. The steep initial rise in the cumulative percentage curve indicates that a small number of issues (primarily the gearbox failures) are responsible for the majority of the downtime. This aligns with the Pareto principle, often referred to as the 80/20 rule, which in this case suggests that focusing on the gearbox failures could resolve a substantial portion of the overall problem.

In conclusion, the Pareto chart clearly highlights the gearbox failure as the primary target for improvement efforts. Concentrating on resolving the failures associated with the gearbox, would achieve significant reductions in downtime and enhance the operational reliability of the BWR.

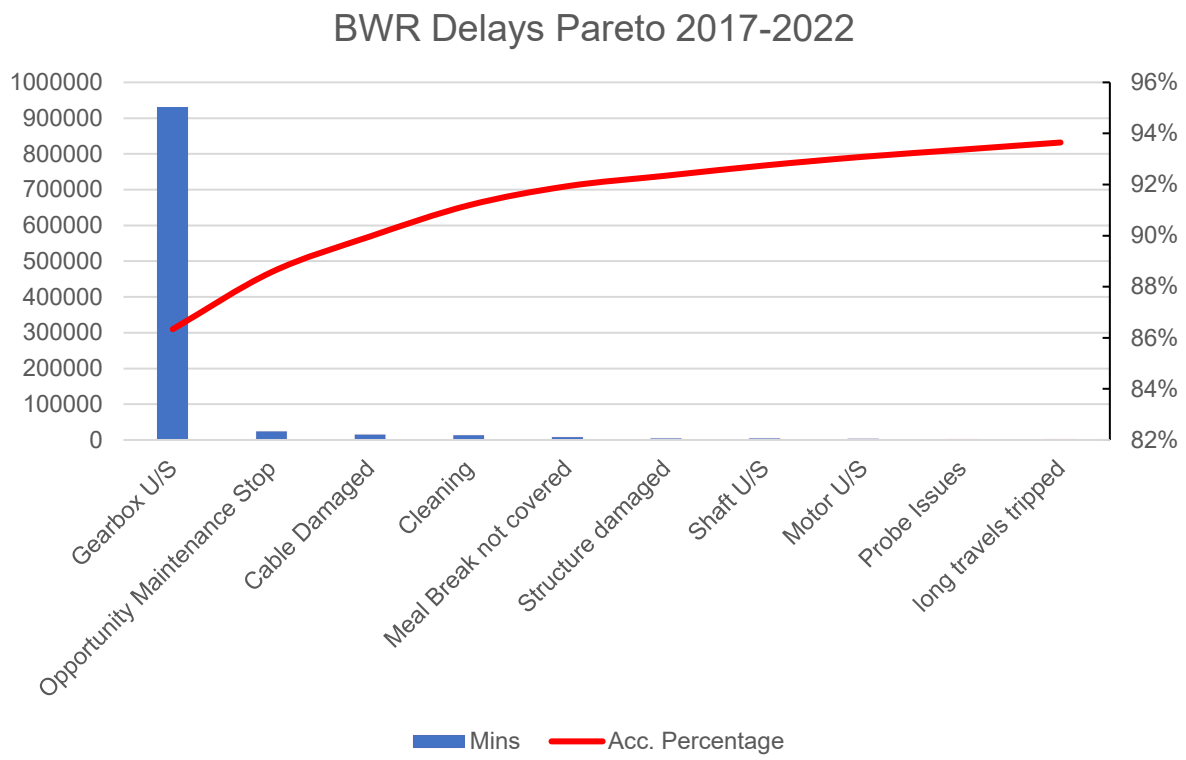


Figure 21 - PARETO Chart

11.2.2. 5 Why Analysis

The 5 Whys analysis was completed to systematically identify and understand the root causes of key issues affecting the reliability and operational efficiency of the bucket wheel reclaimer's gearbox system. (Serrat, 2017) argues that the 5 Whys technique, a fundamental tool in root cause analysis, helps to drill down into the underlying reasons behind each problem by repeatedly asking "Why?" until the core issue is revealed. This method not only uncovers the immediate causes but also highlights systemic issues that contribute to the failures.

The following analysis address three critical problem areas; High Mean Time to Repair (MTTR), Frequent Gearbox Planetary Carrier Failures, and Gearbox Bearing Failures, each of which significantly impacts the operational performance and maintenance efforts. By identifying these root causes, we aimed to develop targeted strategies to mitigate these issues and enhance the overall reliability of the BWR.

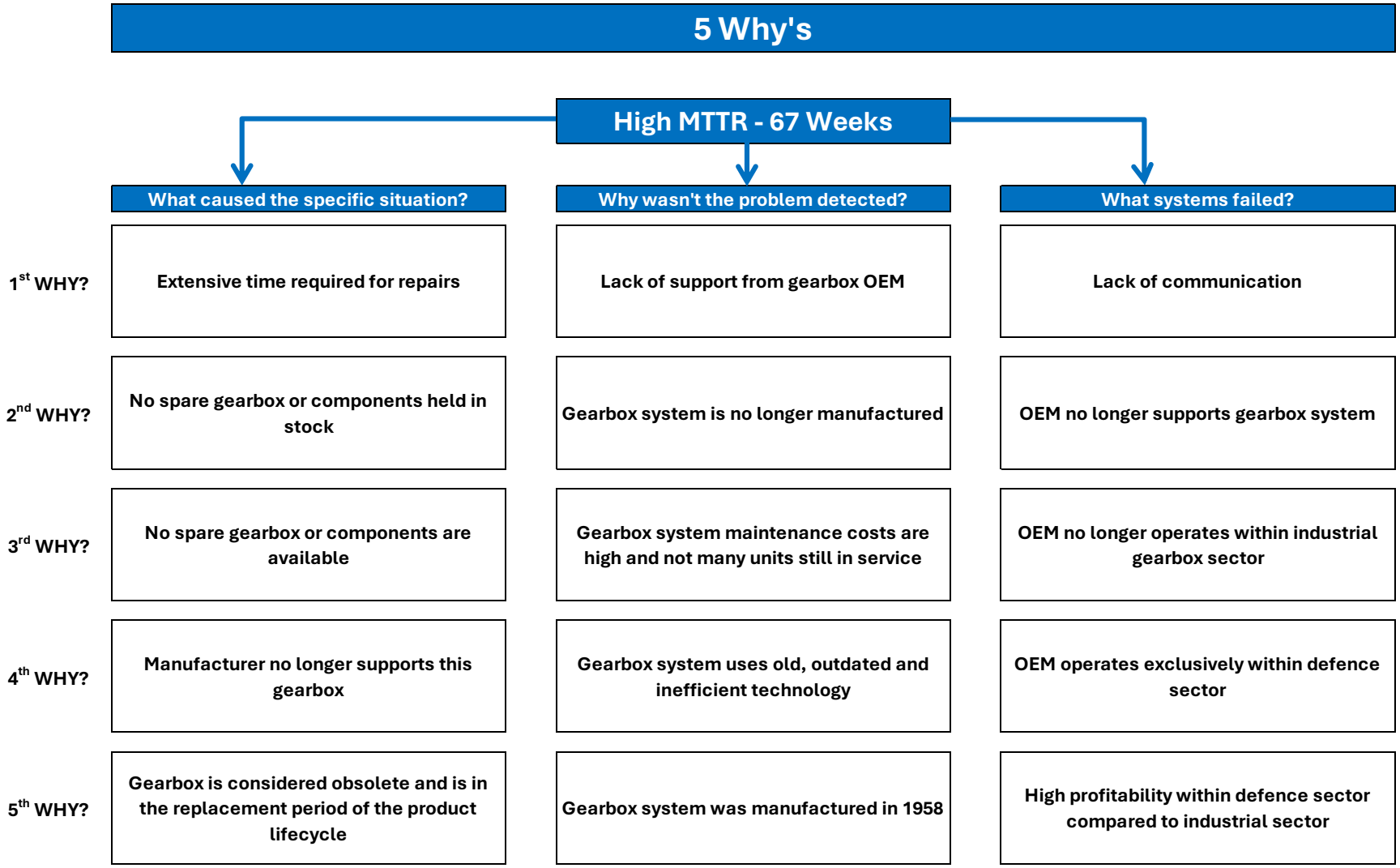


Figure 22 - High MTTR 5 why diagram

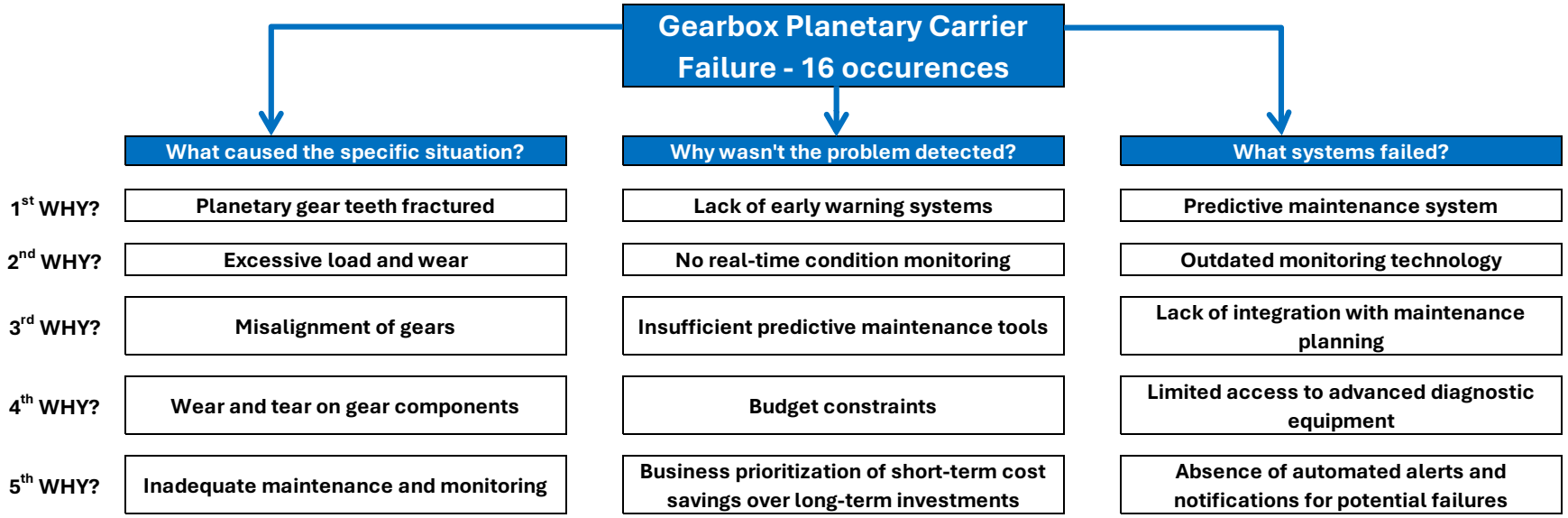


Figure 23 - Gearbox planetary carrier failure 5 why diagram

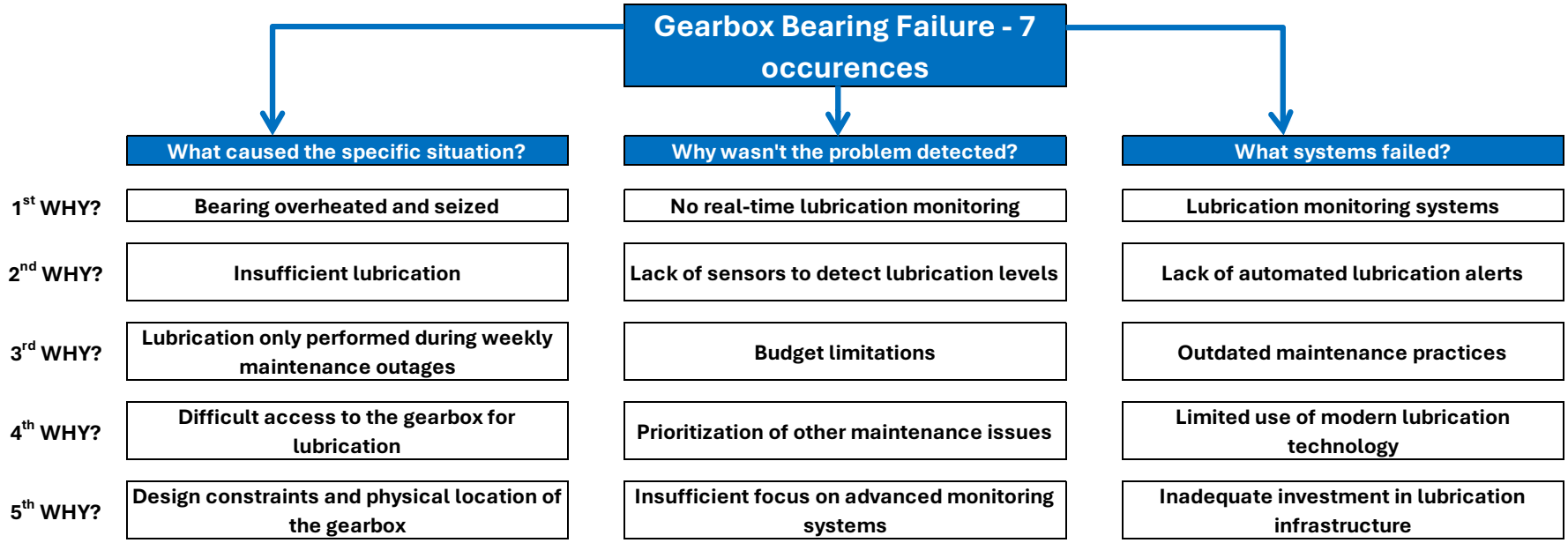


Figure 24 - Gearbox bearing failure 5 why diagram

11.2.2.1. Mean time to repair (MTTR) analysis

Figure 22 shows the long period of downtime following gearbox failures is primarily due to the extensive time required for repairs. This is exacerbated by the fact that no spare gearbox or components are held in stock. Without readily available spare parts, repairs are significantly delayed as parts need to be sourced, which is further complicated by the unavailability of spare gearboxes or components. This situation leads to prolonged downtime, severely impacting productivity and operational efficiency.

The issue of no spare gearbox or components being held in stock is a critical factor. This unavailability is since the gearbox system is no longer manufactured. As a result, even if a failure occurs, the time required to source obsolete parts from limited suppliers increases the overall repair time. This lack of spares in stock necessitates finding alternative sources, further delaying repairs and increasing downtime.

The unavailability of spare gearbox or components is a major concern. The high maintenance costs and the fact that not many units are still in service make it uneconomical for suppliers to stock these parts. This situation results in longer lead times for acquiring necessary components, further extending the repair period and downtime.

The manufacturer's decision to no longer support this gearbox exacerbates the problem. The gearbox system uses old, outdated, and inefficient technology, and the OEM has shifted focus away from this product line. Without support from the OEM, acquiring technical assistance and parts becomes challenging, further complicating the repair process and extending downtime.

The gearbox is considered obsolete and is in the replacement period of its product lifecycle, having been manufactured in 1958. As a result, it is no longer economically viable to maintain this equipment, and more efficient systems are available. However, the transition to new systems involves significant investments and planning, which have not yet been implemented, leading to continued reliance on an outdated and unreliable system.

11.2.2.2. Gearbox planetary carrier failure analysis

Figure 23 shows the planetary gear teeth fractured due to excessive load and wear. The gears were subjected to loads beyond their design capacity, leading to premature wear and failure. This situation is exacerbated by operational demands and inadequate maintenance practices, which do not address the root causes of gear stress and misalignment.

The excessive load and wear on the planetary gears result from misalignment and continuous operation under suboptimal conditions. The lack of real-time condition monitoring means that these issues go unnoticed until a failure occurs. This situation highlights the need for better load management and regular maintenance to prevent excessive wear.

Misalignment of gears causes uneven stress distribution, leading to premature failure. The misalignment can result from improper installation, wear and tear, or operational stresses. Without sufficient predictive maintenance tools, these issues are not detected early, leading to unexpected failures and increased downtime.

Continuous operation without adequate maintenance leads to significant wear and tear on gear components. Budget constraints prevent the implementation of comprehensive maintenance practices, resulting in reactive rather than proactive maintenance. This lack of preventive measures accelerates the degradation of critical components.

Inadequate maintenance and monitoring are key contributors to the frequent failures of the planetary carrier. The business prioritisation of short-term cost savings over long-term investments has led to insufficient focus on maintaining and upgrading the gearbox. This approach results in the failure to implement advanced monitoring systems and regular maintenance schedules, exacerbating the problem.

11.2.2.3. Gearbox bearing failure analysis

Figure 24 shows the bearing overheated and seized due to insufficient lubrication. Without adequate lubrication, friction increases, causing the bearing to overheat and eventually seize. This situation highlights the importance of regular lubrication and real-time monitoring to prevent overheating.

The insufficient lubrication was a result of lubrication only being performed during weekly maintenance outages. The lubrication schedule was inadequate for the operating

conditions, leading to increased friction and wear. This points to the need for more frequent lubrication and better access for maintenance.

Lubrication was only performed during scheduled maintenance, which was insufficient for the gearbox's operating conditions. Difficult access to the gearbox for lubrication further complicates regular maintenance efforts, necessitating design modifications to improve access and lubrication practices.

The gearbox's design and physical location made it challenging to perform regular lubrication. Design constraints and the physical location of the gearbox restricted access, making it difficult to perform timely and adequate lubrication, contributing to bearing failures.

The design and physical location of the gearbox limited the ability to perform regular and effective maintenance. Insufficient focus on advanced monitoring systems and modern lubrication technology further exacerbated the problem, leading to frequent bearing failures and increased downtime.

11.2.3. Fishbone Diagram (Ishikawa)

A Fishbone diagram, as shown in Figure 25, was used to systematically identify the root causes of the frequent and costly failures of the existing gearbox and electric motor. This diagram facilitated a structured brainstorming session with key stakeholders, including maintenance staff, operations personnel, and project engineers. The Fishbone diagram categorized potential causes into major groups: Machinery, Methods, Materials, Manpower, Measurement, and Environment. Under each category, specific issues were identified, such as worn-out planetary components, inadequate lubrication practices, lack of real-time condition monitoring, difficult access for maintenance, and environmental factors affecting gearbox performance. (Gijo, et al., 2011) suggests that by visualizing the complex interrelationships between these factors, a Fishbone diagram helps to pinpoint the most critical underlying issues that needed to be addressed. This comprehensive analysis confirmed that upgrading to a hydraulic system would mitigate these root causes, thereby enhancing system reliability and reducing maintenance costs. The clarity provided by the Fishbone diagram ensured that all relevant aspects were considered, leading to more targeted and effective improvement strategies.

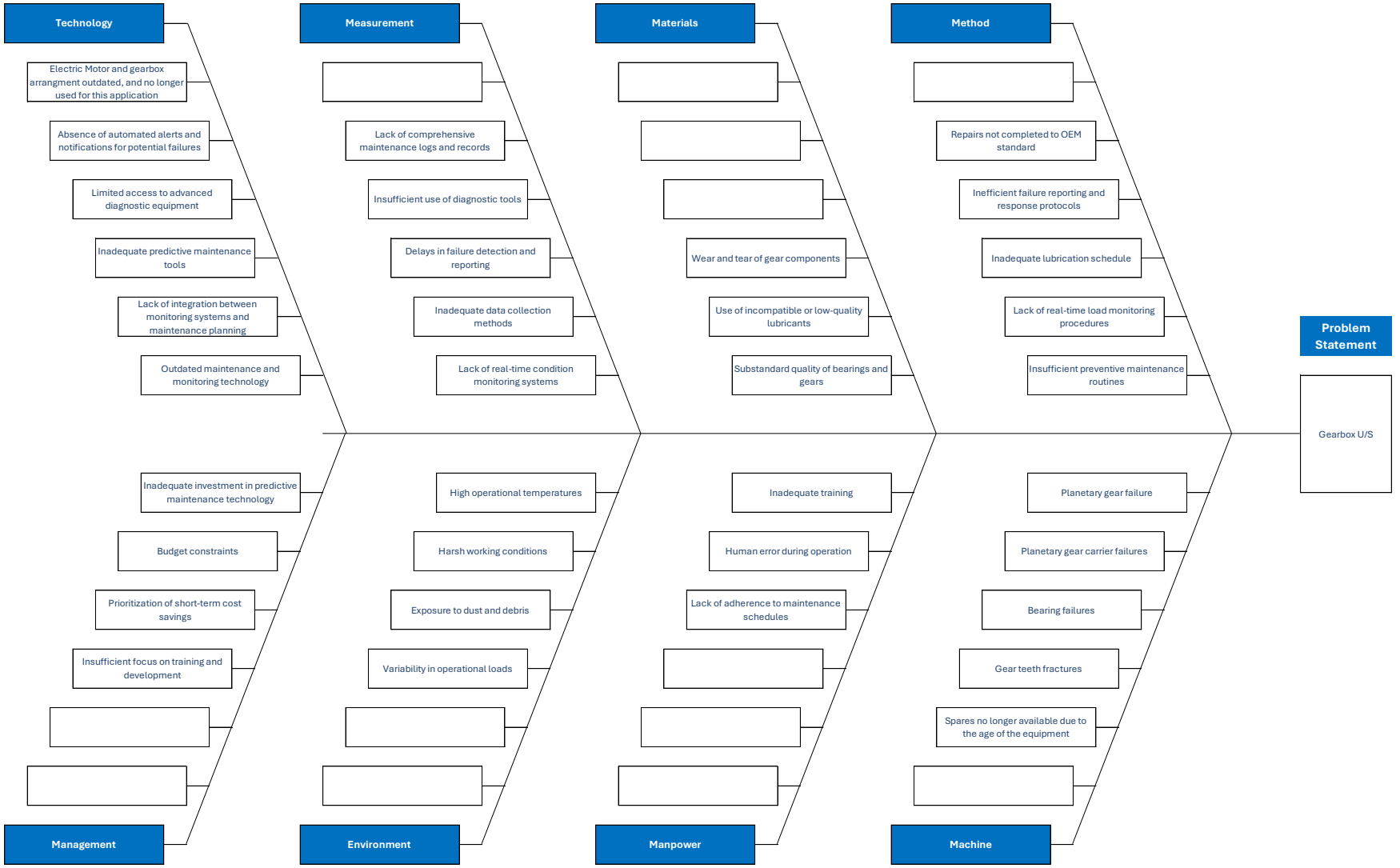


Figure 25 - Fishbone (ISHIKAWA) Diagram

11.2.4. Current Failure Modes and Effects Analysis (FMEA)

The FMEA in Table 9 was conducted to assess current potential failure modes of the entire bucket wheel reclaimer and prioritise them based on their impact on performance. The analysis focused on critical components, including the gearbox, bearings, gears, and hydraulic systems.

The FMEA highlighted planetary gear failure as the highest priority issue due to its high severity and occurrence rates. Bearing failures and gear teeth fractures also had high RPN scores, indicating the need for advanced monitoring and preventive maintenance. The lubrication challenges were also identified as a significant issue, requiring improvements in both access and frequency.

Table 9 - Current System FMEA

Process Step	Potential Failure Mode	Potential Effect	Severity (S)	Potential Causes	Occurrence (O)	Current Controls	Detection (D)	RPN	Recommended Actions
Gearbox	Gear tooth wear	Reduced efficiency, breakdown	8	Poor lubrication, wear and tear	6	Regular maintenance, lubrication schedules	4	192	Improve lubrication, use high-quality lubricants
Gearbox	Bearing failure	Overheating, mechanical failure	9	Contamination, inadequate lubrication	5	Vibration analysis, temperature monitoring	5	225	Install real-time condition monitoring systems
Gearbox	Seal failure	Oil leakage	7	Aging seals, high pressure	4	Visual inspections, scheduled replacements	3	84	Upgrade seals, increase inspection frequency
Gearbox	Misalignment	Vibration, increased wear	8	Improper installation, operational stresses	5	Alignment checks, vibration monitoring	4	160	Improve installation procedures, frequent alignment checks
Electric Motor	Overheating	Motor damage, fire risk	10	Overload, inadequate cooling	4	Thermal protection, regular maintenance	4	160	Install improved cooling systems, conduct load analysis
Electric Motor	Insulation failure	Short circuits, fire	9	Aging insulation, electrical stress	3	Insulation testing, maintenance schedules	3	81	Use higher quality insulation, increase testing frequency

Electric Motor	Bearing failure	Motor seizure, operational halt	8	Inadequate lubrication, contamination	5	Regular lubrication, vibration monitoring	4	160	Improve lubrication practices, install better seals
Conveyor Belt	Tear or rip	Material spillage, downtime	8	Overloading, material impact	5	Regular inspections, belt tension checks	4	160	Use stronger materials, implement impact protection
Conveyor Belt	Misalignment	Reduced efficiency, belt damage	7	Improper installation, wear	6	Alignment checks, tension maintenance	3	126	Improve installation procedures, frequent alignment checks
Conveyor Belt	Slippage	Reduced material throughput	7	Insufficient tension, drive issues	5	Tension monitoring, drive maintenance	4	140	Enhance tensioning systems, improve drive maintenance
Hydraulic System	Hose leakage	Hydraulic fluid loss, pressure drop	6	Aging hoses, high pressure	4	Regular inspections, pressure monitoring	4	96	Upgrade hoses, increase inspection frequency
Hydraulic System	Pump failure	Loss of hydraulic power	9	Wear and tear, contamination	4	Vibration monitoring, pressure checks	5	180	Install real-time condition monitoring systems
Hydraulic System	Valve sticking	Loss of control, operational inefficiency	7	Contamination, wear	4	Regular maintenance, filtration systems	4	112	Improve filtration, increase maintenance frequency
Slewing Mechanism	Bearing failure	Reduced manoeuvrability, breakdown	8	Contamination, inadequate lubrication	5	Vibration analysis,	5	200	Install real-time condition

						lubrication schedules			monitoring systems
Slewing Mechanism	Gear wear	Reduced efficiency, breakdown	8	Poor lubrication, wear and tear	5	Regular maintenance, lubrication schedules	4	160	Improve lubrication, use high-quality lubricants
Structural Frame	Cracks	Structural failure, safety hazard	10	Fatigue, overloading	3	Visual inspections, load analysis	3	90	Conduct regular structural assessments, strengthen design
Structural Frame	Corrosion	Reduced structural integrity	8	Environmental exposure, poor maintenance	4	Regular inspections, protective coatings	4	128	Apply corrosion-resistant coatings, improve maintenance
Boom	Buckets wear	Reduced material handling efficiency	7	Abrasive materials, improper use	6	Regular inspections, maintenance schedules	4	168	Use wear-resistant materials, increase inspection frequency
Boom	Structural damage	Failure, safety hazard	10	Overloading, impact	3	Visual inspections, load monitoring	3	90	Conduct regular structural assessments, strengthen design
Electrical System	Short circuit	Equipment damage, fire	9	Aging wiring, insulation failure	4	Insulation testing, regular maintenance	4	144	Upgrade wiring, increase testing frequency
Electrical System	Power loss	Operational downtime	8	Electrical faults, power supply issues	5	Redundant power systems,	3	120	Improve power supply infrastructure,

						regular maintenance			conduct load analysis
Electrical System	Component failure	Loss of functionality	7	Aging components, stress	4	Regular testing, scheduled replacements	4	112	Use higher quality components, increase testing frequency
Control System	PLC failure	Loss of control, operational halt	9	Software bugs, hardware failure	3	Software updates, hardware testing	3	81	Implement redundant PLC systems, increase testing frequency
Control System	Sensor failure	Incorrect readings, operational errors	7	Contamination, wear	4	Calibration schedules, regular maintenance	4	112	Use higher quality sensors, increase calibration frequency
Control System	Network failure	Loss of communication	8	Cable damage, signal interference	3	Regular inspections, signal testing	4	96	Improve cable protection, enhance signal integrity testing
Dust Suppression System	Nozzle blockage	Ineffective dust control	6	Contamination, wear	4	Regular cleaning, filtration systems	4	96	Improve filtration, increase maintenance frequency
Dust Suppression System	Pump failure	Loss of dust suppression capability	8	Wear and tear, contamination	3	Vibration monitoring, pressure checks	4	96	Install real-time condition monitoring systems

11.2.5. Analysis Findings

The systematic analysis of various data sets confirms that the gearbox is experiencing rapid onset and unpredictable catastrophic failures, primarily due to planetary component failures. These issues are exacerbated by the lack of real-time predictive condition monitoring and challenges in accessing the gearbox for lubrication. The frequent failures, difficulty in sourcing spare or replacement parts and high maintenance costs support the conclusion that the gearbox is in its End-of-Life phase and should be replaced with another system.

11.2.6. Recommendations

11.2.6.1. Immediate Actions

Implement real-time monitoring systems and increase preventative maintenance to help mitigate further catastrophic failures.

11.2.6.2. Long-term Solution

Replace the current gearbox with a new system to improve reliability, reduce downtime, and lower overall maintenance expenses.

Continue to monitor performance metrics post-implementation to ensure the new system meets the desired objectives.

12. Improve Phase

The improve phase of the project focused on enhancing the system's design, reliability, and performance. This phase involved a literature review, vendor selection, design reviews, and design improvements. It also included addressing weight distribution challenges due to load dynamics changes, and incorporating safety features like lockable ball valves for safe isolation and immobilization of the hydraulic system during maintenance.

A crucial part of this phase was the detailed engineering analysis conducted by Ingleside Engineering, which designed the new walkway assemblies and performed extensive calculations to ensure the structural integrity of the upgraded system. This analysis considered both the operational loads and the temporary loads during the installation phase, in compliance with legislative requirements. Temporary works were carefully planned to manage the removal of the existing gearbox and the installation of the new system.

The improve phase also included rigorous validation of BOSCH's hydraulic conversion calculations and component selections to ensure the system's compatibility and performance. The project's success hinged on addressing these technical challenges, aligning with safety and operational standards, and utilising the expertise of all stakeholders. This collaborative approach ensured that the improvements made were robust, sustainable, and aligned with the project's overall objectives of reducing downtime, improving efficiency, and enhancing safety.

12.1. Pre-planning

The pre-planning phase focused on laying the groundwork for the project engineering by conducting a thorough literature review, exploring possible solutions, and engaging with potential vendors. This phase was critical for understanding the scope of the problem, evaluating technological advancements, and identifying the best possible solution for upgrading the gearbox system.

12.1.1. Literature Review

Conducting a literature review aimed to identify the latest advancements in gearbox and drive system technologies for heavy duty or mining applications. Hydraulic systems became a primary focus due to their reliability and efficiency in heavy machinery applications. From the literature, (Nicholas, et al., 2008) suggests that upgrading the bucket drive system to a hydraulic system offer multiple advantages over traditional mechanical or electric drive systems, they also suggest hydraulic systems are also inherently more reliable and easier to maintain, as they have fewer moving parts subject to wear. Additionally, (Nicholas, et al., 2008) argues that hydraulic systems can be more energy-efficient, particularly in applications requiring variable speed and torque. Upgrading to a hydraulic drive can lead to significant improvements in reliability and operational efficiency, lower maintenance costs, and reduced energy consumption. The initial investment in upgrading can be offset by the extended equipment lifecycle and the operational savings achieved through improved efficiency and reduced downtime

In a case study, a large mining operation decided to upgrade its conveyor system by replacing the mechanical drives with hydraulic drive systems. The hydraulic drives offered better control and efficiency under variable load conditions and were more reliable and easier to maintain than the mechanical systems. (Kruczek, et al., 2019) describes how after the upgrade to hydraulic drives, the mining operation experienced a 30% reduction in energy consumption due to the higher efficiency of the hydraulic system. Additionally, maintenance costs dropped by 20% due to the increased reliability and lower wear and tear on the system. The operation also benefited from improved operational flexibility, allowing for smoother and more efficient handling of different materials.

12.1.2. Potential Solutions

Based on the literature review, several potential solutions were identified, including:

1. Replacing the Existing Electric Drive System with a new AC drive, motor and gearbox. These systems offer precise control and improved energy efficiency but would require frequent maintenance.
2. Replace the existing drive system with a Hydraulic drive system.

Hydraulic systems have improved robustness and lower maintenance requirements. They offer improved operational efficiency and reliability.

3. Replace complete Bucket Wheel Reclaimer with new, this would involve replacing the entire BWR, providing the latest technology and potentially the highest reliability and efficiency, however this would incur the greatest investment.

12.1.3. Vendor Consultation

To evaluate these solutions further, we invited market-leading vendors ABB, Bosch, and Thyssen-Krupp, for initial consultations. Each vendor was selected based on their expertise and proven track record in providing advanced solutions and retrofits for mining equipment and bucket wheel reclaimers. Each vendor provided a detailed technical presentation, outlining their proposed solutions and highlighting key benefits.

12.1.3.1. ABB

ABB proposed replacing the existing electric drive system with a new AC drive, motor and gearbox assembly, emphasising the benefits of high efficiency, precise control, and advanced diagnostics. Appendix A: ABB Proposal highlighted case studies where their systems improved operational efficiency and reduced downtime in similar applications. One of the primary advantages of ABB's solution is the energy efficiency improvement and the precise control it offers. AC Electric drives can be finely tuned to match the operational demands, potentially leading to lower operational costs and improved performance. ABB's systems are also well-integrated with modern control systems, providing advanced diagnostics and integration with existing infrastructure.

However, there are some drawbacks to this solution. AC Electric drive systems, while efficient, often require complex and more frequent maintenance. This could lead to higher long-term maintenance costs and potential downtime. Additionally, the implementation timeline for ABB's solution is moderate, which means that any operational interruptions during the upgrade could be more prolonged than with some other solutions.

12.1.3.2. BOSCH

BOSCH proposed a hydraulic system known for its reliability, robustness, and lower maintenance requirements. Appendix B: BOSCH Proposal included detailed technical

specifications and demonstrated lower maintenance costs and higher uptime through case studies in previous mining projects and specifically Bucket Wheel Reclaimers.

Hydraulic systems are particularly suited to heavy-duty operations, making them an ideal choice for the bucket wheel reclaimer. The primary benefit of their solution includes high reliability and robustness. Hydraulic systems can handle substantial operational loads and harsh working conditions with less frequent maintenance. This reliability translates into higher uptime and lower long-term maintenance costs. Additionally, the implementation timeline for BOSCH's solution is shorter compared to the electric drive option, as they utilise standardised and readily available (off the shelf) components, thus minimising operational interruptions during the upgrade and providing a high degree of support and serviceability going forward.

Despite these advantages, there are some potential drawbacks to consider such as the overall footprint and weight of the hydraulic system being considerably different and therefore would require structural modifications to accommodate. Additionally, Hydraulic systems require careful management of hydraulic fluids to prevent leaks and maintain system safety and efficiency. This necessitates a robust maintenance program to monitor and manage fluid levels and quality. However, BOSCH's extensive support services and expertise in hydraulic systems mitigate this concern significantly.

12.1.3.3. Thyssen-Krupp

Thyssen-Krupp proposed a completely new bucket wheel reclaimer at a cost of around £2M. Appendix C: Thyssen-Krupp Proposal showcased a previous project delivery of a bucket wheel reclaimer in a major mining operation alongside other case studies. This solution would provide the latest technology, highest potential reliability, and efficiency, and ongoing support from the OEM.

The primary benefit of this solution is the comprehensive upgrade on offer. By replacing the entire system, we can leverage the latest technological advancements, resulting in potentially the highest reliability and operational efficiency. Thyssen-Krupp's new reclaimer would come with state-of-the-art features and capabilities, setting a new standard for performance and productivity.

However, this solution involves the highest initial investment, which would be a significant financial burden. The cost is substantially higher than the other options,

making it a less attractive choice from a financial perspective. Additionally, the implementation timeline is much longer, which means more extended operational interruptions prior to and during the installation phase. While the long-term benefits are substantial, the immediate financial and operational impacts are considerable.

12.1.4. Vendor Selection

To objectively assess each proposal, a vendor selection criteria document was developed. The criteria includes factors such as technical capability, cost, implementation timeline, support services, and past performance. A weighted Decision Matrix as shown in Table 10 was used to evaluate each vendor against these criteria. The weights assigned to each criterion reflect their relative importance to the project.

1. Technical Capability – 30% - Evaluation of the proposed solution's technical merits and its suitability for our specific application.
2. Cost – 25% - Total cost of ownership (TCO), including initial implementation costs and long-term maintenance expenses.
3. Implementation Timeline – 20% - Estimated time required to implement the solution, including any potential downtime.
4. Spares/ Support Services – 15% - Availability of technical support, spares and after-sales service.
5. Past Performance – 10% - Track record of successful implementation of similar projects.

Table 10 - Vendor Assessment

Criteria	Weight	ABB Weighted Score	BOSCH Weighted Score	Thyssen-Krup Weighted Score
Technical Capability	30%	2.4	2.7	2.7
Cost	25%	1.75	2.0	1.25
Implementation Timeline	20%	1.2	1.8	1.0

Spares/ Support Services	15%	1.2	1.35	1.2
Past Performance	10%	0.8	0.9	0.8
Total	100%	7.35	8.75	7.0

12.1.5. Evaluation Outcome

Based on the comprehensive and structured evaluation, ensuring fairness and transparency, BOSCH emerged as the preferred vendor. BOSCH's proposal was deemed the best fit for the project, as the hydraulic system not only meets the technical requirements but also offers significant advantages in terms of TCO, ROI, reliability, maintenance, and support services compared to the other proposals.

12.2. Design Phase

Once the Vendor selection has been completed, it is then possible, to focus on refining the chosen solution, finalising technical specifications (engaging key stakeholders for input and validation), creating an impact assessment and preparing for implementation. This phase is critical to ensure that the solution meets all operational requirements and integrates seamlessly into the existing system. As the project manager, my role was pivotal to effectively manage the project, provide technical expertise, and ensure compliance with all regulatory and business requirements.

12.2.1. Finalising Technical Specifications

After selecting BOSCH as the preferred vendor, the next step involved working closely with their hydraulic experts to finalise the technical specifications of the hydraulic system. This included detailed costs, engineering drawings, system schematics, and specifications for components such as pumps, valves, power units, oil coolers, and control systems. Appendix D: BOSCH Specifications and Quotation provide specific details of the proposed hydraulic system specifications including costs.

12.2.1.1. Hydraulic calculations

Verification of BOSCH's component selections was a critical aspect of this phase. The independent calculations, shown in Appendix E: Hydraulic Calculations for torque

requirements, power ratings, and operational pressures, were completed and verified by consultant design engineers at Ingleside Engineering to ensure they met the performance criteria for our bucket wheel reclaimer. This involved confirming the anticipated running pressures and ensuring the maximum torque capability would safely meet operational demands.

12.2.1.2. Access requirements

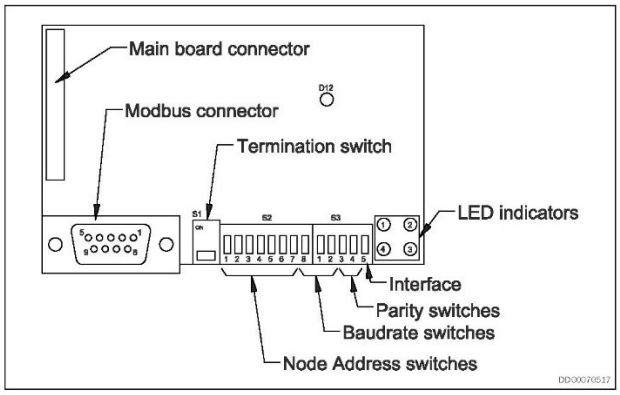
The implementation of a hydraulic system necessitated several structural modifications to the bucket wheel reclaimer. Appendix F: Design Brief, shows that Ingleside Engineering were engaged to design the necessary steelwork, including walkways and support structures. The design process involved detailed engineering drawings and structural calculations to ensure that the walkways would support the necessary loads and provide safe access for maintenance personnel. The design included features such as anti-slip surfaces, guardrails, and interlocked safety gates to enhance worker safety. Due to previous issues with maintainability and accessibility, it was a key requirement to ensure sufficient access for monitoring and maintenance. The initial design had poor access provisions, however after an initial design review, we incorporated features such as a new walkway system, with strategically placed access points and monitoring interfaces to facilitate easy inspection, maintenance, and real-time condition monitoring. These improvements aimed to minimise downtime and enhance the reliability of the system, whilst improving health and safety performance and minimising risk to personnel. The design shown in Appendix G: Walkway Design was completed by Ingleside Engineering, with input and feedback from the maintenance team to ensure maximum effectiveness. The tender document in Appendix H: Walkway Tender Document was then sent to MII Engineering Ltd, and Appendix I: Walkway Quotation was received in return and the contract awarded for manufacture.

12.2.1.3. Control Systems Requirements

The control systems requirements for the new hydraulic system were a significant part of the design phase. This involved ensuring compatibility between the existing control systems of the Bucket Wheel Reclaimer (BWR) and the new hydraulic components. The integration of the MODBUS system with the PROFIBUS and PROFISAFE systems presented several challenges due to differences in communication standards, data

formats, and safety protocols. The BWR's existing control system operates on MODBUS protocol, whereas the new hydraulic system from BOSCH usually uses PROFIBUS and PROFISAFE protocols. Integrating these systems required meticulous planning and the use of a special MODBUS card from a different BOSCH system as shown in Figure 26.

4.3.2 Modbus RTU



4.3.2.1 Indicators

Indicator name	Description	Function	Information
D1	Processing	Green flashing	Receiving Query and building response
		Off	No Query.
D2	Bus error	Red	Bus error
		Off	Normal operation
D3	Offline	Red	Module is Off-Line.
		Off	Module is not Off-Line.
D4	HW settings status	Green	Bus ready. Normal operation.
		Red	Bus timeout error.
		Off	Bus not initialized correctly.
D12	Watchdog	Green flashing 1Hz	Initialized and running OK.
		Green flashing 2Hz	Not initialised.
		Red	Unspecified internal error or running in boot loader mode.
		Red flashing 1 Hz	RAM failure.
		Red flashing 2 Hz	ASIC or FLASH failure.
		Red flashing 4 Hz	DPRAM failure.

Bosch Rexroth Mellansel AB, User manual, Hägglunds Spider2 , RE 15330-WA/03.2015

36/68 Main boards, Jumpers & Terminals

4.3.2.2 Switches

Indicator name	Function	Settings	Information
S1	Terminating switch	On	Enabled (if first or last in a network)
		Off	Disabled
S2:1-7	Node Adress Switch:	Binary value: 1234567	
		0000000	Not valid
		0000001	1
		0000010	2
		0000011	3
		...	...
		...	...
		1111111	127
S2:8 S3:1-2	Baud rate Switch:	Binary value 812	Not valid
		000	1200
		001	2400
		010	4800
		011	9600
		100	19200 (Default)
		101	38400
		110	57600
		111	
S3:3-4	Parity	Binary value 34	Not valid
		00	None(Default)
		01	Even
		10	Odd
		11	
S3:5	Physical interface	0 = RS-485 1 = RS-232	

4.3.2.3 Modbus connector (Female 9-pin D-sub)

Pin	Function	Information
Housing	Shield	Connected to PE
1	Not connected	
2	RS232-TX	Transmit signal
3	RS232-RX	Recive signal
4	Not connected	
5	GND Bus	Signal grund
6	+5V Bus	
7	RS485D0	
8	RS485D0	
9	Not connected	

RE 15330-WA/03.2015, User manual, Hägglunds Spider2, **Bosch Rexroth Mellansel AB**

Figure 26 - MODBUS Card

12.2.1.4. Electrical and Control System Cable Modifications

Modifying the power supplies and control system cabling was a critical aspect of the installation. This involved connecting the BWR's Programmable Logic Controller (PLC) on the slew deck area to the hydraulic controller located at the end of the boom. Detailed plans were developed to run new cabling that meets the BS5467:2016 (British Standards Institute, 2016),and BS EN 50288-7:2005 (British Standards Institute, 2005) specifications. Control systems engineers configured the PLC and spider systems to ensure that the software and hardware interfaces were compatible.

12.2.1.5. Collaboration and Testing

Close collaboration between the TATA and BOSCH teams was essential. Regular coordination meetings and technical reviews were conducted to address issues and ensure that the integration progressed smoothly. On-site testing was performed prior to design finalisation using a dummy control unit which was shipped to site from BOSCH and connected to the BWR PLC system to verify that the systems communicated correctly and that all safety protocols were in place before the design was finalised.

12.2.2. Structural Changes and Steelwork Requirements

12.2.2.1. Impact on Load Dynamics

The transition from an electric drive system to a hydraulic system affects the load dynamics of the machine. The removal of the existing motor and gearbox and the installation of the new hydraulic components and walkways as shown in Figure 27, alters the weight distribution and load paths significantly. Ingleside Engineering conducted a detailed analysis to understand these changes and designed counterbalances and reinforcements as needed. Appendix J: Load Dynamic Calculations shows the calculation of the Tonnes per metre for the existing and proposed systems to simulate the load conditions and determine what modifications would be required at the counterbalance to maintain the machine's stability and not compromise the structural integrity of the slewing and luffing arrangements.



Figure 27 - Hydraulic Bucket Drive System (BOSCH REXROTH, 2023)

12.2.2.2. Temporary Works During Installation

Given the significant structural changes required, temporary works are necessary to support the machine during the installation phase. This includes thickness testing of the existing structure in specific locations as per Appendix K: Thickness Testing Plan prior to the installation of temporary bracing and supports to maintain structural integrity while the old system is removed, and the new system installed. These temporary works as shown in Appendix L: Temporary Works Design are designed by Ingleside Engineering in accordance with the CDM: Construction Design and Management Regulations 2015 (Health and Safety Executive, 2015) and independently verified by Tata Consultant Engineers (TCE) based in India. This verification process ensures independent compliance with CDM legislative requirements.

12.2.3. Impact Assessment

Evaluating the impact of the proposed improvements on the reclaimer's reliability performance, including reductions in operation and maintenance costs, and overall productivity improvements is crucial before finalising the project route.

12.2.3.1. Benefits of implementing Hydraulic Drives

1. Hydraulic drive systems offer superior control and efficiency, especially for variable speed and load applications. This can lead to energy savings and improved operational performance. (Meehan, 2012)
2. Hydraulic systems have fewer moving parts and are less prone to wear and tear, resulting in lower maintenance costs and higher reliability. (Rydberg, 2015)
3. Hydraulic drives can be more easily adjusted or reconfigured for different operational needs, providing greater flexibility in mining-type operations. (Meehan, 2012)

12.2.3.2. Costs of implementing hydraulic drives

1. Upgrading to hydraulic drives involves capital expenditure for new equipment and installation. (Norton, 2019) However, this cost is offset by the long-term savings and operational benefits.
2. There may be a transition period during which productivity is impacted as the new system is installed and commissioned.
3. While the initial investment for hydraulic drive systems is higher than some alternative solutions, the long-term savings in maintenance and operational efficiencies, as well as potential increases in production capacity, contribute to a favourable ROI. (Rydberg, 2015) states case studies have reported payback periods of 2-5 years following the upgrade to hydraulic systems.

12.2.4. Lifecycle Analysis

A comprehensive analysis considering the entire lifecycle of the BWR will demonstrate the long-term benefits and cost savings resulting from the proposed upgrades and different maintenance strategies. (Sonnemann & Margni, 2015)

12.2.4.1. Objectives and Scope

To evaluate the environmental, economic, and social impacts of completing a hydraulic drive upgrade on the BWR during Implementation, Operation and Maintenance phases.

12.2.4.2. Environmental Analysis

1. Using Equation 1 , and the values found in Table 11 it is possible to calculate the current Annual Energy Usage for both Materials reclaimed.

   $Current\ Annual\ Energy\ Usage\ (Material\ A) = 7800\ x\ 132\ x\ 0.95 = 978{,}120 kWh.$

   $Current\ Annual\ Energy\ Usage\ (Material\ B) = 7800\ x\ 132\ x\ 0.98 = 1{,}009{,}008\ kWh.$

2. Using Equation 2, a CO2 emission factor of 0.233 kgCO2/kWh (Department for Energy, Security and Net Zero, 2023), and the values in Table 11, it is possible to calculate the Current CO2 Emissions.

   $Current\ CO2\ Emissions\ (Material\ A) = 978120\ x\ 0.233 = 227{,}901.96\ kg$

   $Current\ CO2\ Emissions\ (Material\ B) = 1009008\ x\ 0.233 = 235{,}098.66\ kg$

3. Using Equation 1 , and the values in Table 12, it is possible to calculate the Future Annual Energy Usage.

   $Future\ Annual\ Energy\ Usage\ (Material\ A) = 8712\ x\ 132\ x\ 0.50 = 574{,}992\ kWh.$

   $Future\ Annual\ Energy\ Usage\ (Material\ B) = 8712\ x\ 132\ x\ 0.55 = 632{,}491.20\ kWh.$

4. Using Equation 2, and the values in Table 12, it is possible to calculate the future CO2 Emissions.

   $Future\ CO2\ Emissions\ (Material\ A) = 574992\ x\ 0.233 = 133{,}973.14\ kg$

   $Future\ CO2\ Emissions\ (Material\ B) = 632491.20\ x\ 0.233 = 147{,}370.45\ kg$

Table 11 – Current Operating Parameters

Material	Runtime (T) [h]	Power rating (P) [kW]	Load Factor (X) [%]	Annual Energy	Annual Running Cost [£]	Annual Co2 [kg]

				Usage [kWh]		
A	7800	132	0.95	978,120.00	146,718.00	227,901.96
B	7800	132	0.98	1,009,008.00	151,351.20	235,098.86

This is the current operating parameters for the electric bucket drive motor, for our two different material bulk-densities, with 12 hours maintenance per week and 168-hour maintenance period every 6 months.

Table 12 - Future Operating Parameters

Material	Runtime (T) [h]	Power rating (P) [kW]	Load Factor (X) [%]	Annual Energy Usage [kWh]	Annual Running Cost [£]	Annual Co2 [kg]
A	8712	132	0.50	574,992.00	86,248.80	133,973.14
B	8712	132	0.55	632,491.20	94,873.68	147,370.45

This is the proposed operating parameters for the hydraulic bucket drive, for our two different material bulk-densities, with 24-hour maintenance period every 6 months (the increased runtime due to increased reliability)

Equation 1 (Beaty, 2000)

$$Annual\ Energy\ Usage\ [kwh] = Power\ Rating\ (\mathrm{P}) \times Load\ Factor(X) \times Runtime\ (T)$$

Equation 2 (Beaty, 2000)

$$CO2\ Emissions\ [kg] = Energy\ Usage\ [kWh] \times CO2\ Emission\ Factor\ [kgCO2\ /\ kWh]$$

Equation 3

$$Estimated\ Energy\ Savings[kWh] = Current\ Energy\ Usage\ [kWh] - Future\ energy\ usage[kWh]$$

Equation 4

$$CO2\ Emission\ \text{Reduction}[kg] = Current\ CO2\ Emissions\ [\text{kg}] - Future\ CO2\ Emissions[kg]$$

Equation 5

$$Estimated\ Cost\ Savings[£] = Current\ Energy\ Costs[£] - Future\ energy\ Costs[£]$$

12.2.4.3. Economic Analysis

1. Initial Investment = £180,000 (Hydraulic System Upgrade = £140,000 + Steelwork Modifications = £30,000 + Design Consultants = £10,000). Appendix D: BOSCH Specifications and Quotation, Appendix I: Walkway Quotation
2. Using the Equation 3, the anticipated energy savings between Table 11 and Table 12, and the average UK energy cost of £0.15 per kWh. (Office of Gas and Electricity Markets, 2024).

$$Annual\ Energy\ Cost\ Savings\ (Material\ A) = 146{,}718.00 - 86{,}248.80 = £60{,}470$$

$$Annual\ Energy\ Cost\ Savings\ (Material\ B) = 151{,}351.20 - 94{,}873.68 = £56{,}477.52$$

3. Maintenance Cost Savings = (Marquez, et al., 2008) suggests 20% - 40% reduction in maintenance costs between electro-mechanical systems and hydraulic systems. A conservative estimate of a 20% reduction in 2023 maintenance costs of £1.6m, leads to savings of £320,000 per annum.
4. Operational Cost Savings = By avoiding 1 incident of unplanned downtime per year, costing £50,000 in mobile plant equipment alone, savings amount to at least £50,000 annually.

12.2.4.4. Social Analysis

(Davies, 2012) states the workforce requires training on the new systems, software, and procedures. Thus, enhancing skills but requiring upfront time and resource investment.

12.2.4.5. Environmental Impact Assessment

The implementation significantly reduces energy consumption and CO2 emissions, contributing positively to environmental sustainability goals.

12.2.4.6. Economic Impact Assessment

1. Using Equation 6 it is possible to calculate the total annual savings.
   $Total\ annual\ savings\ =\ £56{,}477.52\ +\ £320{,}000\ +\ £50{,}000\ =\ £426{,}477.52$
2. Using Equation 7 it is possible to calculate a Return on Investment (ROI)
   $Return\ on\ Investment\ (ROI)\ =\ £426{,}477.52\ /\ £180{,}000\ \times\ 100\ =\ \mathbf{236.93}\%$
   This ROI value indicates a payback period of less than 6 months.

Equation 6

$$Total\ Annual\ Savings\ =\ Energy\ Cost\ Savings\ +\ Maintenance\ Cost\ Savings\ +\ Downtime\ Cost\ Savings$$

Equation 7

$$Return\ on\ Investment\ (ROI) = (Total\ Annual\ Savings)/(Initial\ Investement)\ \times 100$$

12.2.4.7. Social Impact Assessment

The introduction of new technologies and systems enhances workforce capabilities, promoting a culture of continuous learning and adaptation. (Davies, 2012)

12.2.4.8. Interpretation

The integration of predictive maintenance and hydraulic drive upgrades presents a comprehensive approach to improving the lifecycle performance of the equipment. (Schmidt, 2014) argues that this strategy not only enhances operational efficiency and reliability but also makes significant strides towards environmental sustainability and economic savings. The synergy between these improvements maximises potential benefits, making a strong case for their adoption.

12.2.5. Role as Project Manager

As the project manager, my role was critical in coordinating these activities and ensuring the project stayed on track during the design phase. Effective project management tools, such as Gantt charts and regular review meetings, were used to plan and track the project's progress. These tools helped in identifying critical tasks, managing dependencies, and ensuring that the project stayed on schedule. Regular project

meetings, updates, site visits and feedback sessions were conducted to ensure understanding and to address any concerns promptly.

My technical expertise were also essential in addressing the isolation and immobilisation requirements. Ensuring that the hydraulic system could be safely isolated for maintenance, required a deep understanding of both the mechanical and operational aspects of the system. This involved working closely with BOSCH's engineers to design the isolation mechanisms and verifying that they met not only legislative safety standards but also company safety standards and protocols.

12.3. Implementation Phase

12.3.1. Planning

The planning phase is a crucial step in ensuring that the implementation of the hydraulic system upgrade is executed smoothly and efficiently. This phase involves finalising the project timeline, securing resources, coordinating with all stakeholders, and preparing detailed plans for each subsequent phase.

12.3.1.1. Project Timeline and Coordination

A detailed project timeline was developed using Gantt charts and the Critical Path Method (CPM) to identify critical tasks, manage dependencies, and ensure that the project stayed on schedule. Key milestones include the completion of the design phase, procurement of materials, manufacturing, installation, and commissioning. Regular project meetings were scheduled to provide updates, address any issues, and ensure alignment among all stakeholders.

12.3.1.2. Resource Allocation

Securing the necessary resources, both financial and human, is critical to the success of the project. This involved finalising the budget, ensuring that funds were allocated for each phase, and assembling a team of skilled professionals, including project engineers, consultants, technicians, and safety officers. Coordination with the procurement department was essential to ensure timely acquisition of materials and components.

12.3.1.3. Stakeholder Engagement

Engaging stakeholders early and maintaining open lines of communication is a priority. This includes regular updates to senior management, involvement of the maintenance and operations teams in planning and decision-making processes and ensuring compliance with safety regulations through consultations with safety officers. Effective stakeholder management helps in addressing concerns, obtaining buy-in, and ensuring smooth execution of the project.

12.3.2. Manufacturing

The manufacturing phase involves the production and assembly of the hydraulic system components and the new access walkways, ensuring they meet the required specifications and quality standards.

12.3.2.1. Hydraulic System

The hydraulic system components were manufactured by BOSCH according to the finalised technical specifications. This included the CB840-680 direct drive hydraulic motor complete with shrink disc coupling, DUC-LS2-132-250+000-0-A-Y-S-E-400/50 HPU with integrated oil cooler, TC A 0840 2 0 00 Torque arm complete with pivot attachment and SPDC CB—0 01856 00 00 speed sensor, and spider control systems. BOSCH's expertise in hydraulic systems ensured that the components were of the highest quality and adhered to (European Commission, 2014) CE marking standards.

12.3.2.2. Access Walkways

In parallel with the hydraulic system, new walkway assemblies were manufactured to facilitate access for installation and future maintenance. The fabrication of the walkway assembly was carried out by MII Engineering Ltd, a specialised manufacturing facility with expertise in producing industrial walkways and platforms. MII Engineering Ltd manufactured the walkways according to the detailed drawings created by Ingleside Engineering as shown in Appendix G: Walkway Design.

Once fabricated, the walkway assemblies underwent thorough quality assurance and testing procedures. This included paint finishes, alignment, stability, and compliance with the design specifications. Any discrepancies were addressed promptly to maintain the highest quality standards.

The completed walkway assemblies were transported to the project site in modular sections, designed for easy on-site assembly. Detailed installation plans were developed to coordinate the installation of the walkways with the hydraulic system installation

12.3.2.3. Quality Assurance

Quality assurance processes were implemented to verify that all components met the required standards. This included rigorous testing of the individual hydraulic components and the overall hydraulic system assembly to ensure functionality, durability, and safety at the BOSCH Factory. It also included auditing the CE documentation which accompanies the assemblies.

12.3.2.3.1. Factory Acceptance Testing (FAT)

As project manager, it was my responsibility to witness the factory testing in person at the BOSCH factory, ensuring any deviations from specifications were addressed promptly to maintain the success of the project. I then signed the FAT document as shown in Appendix M: Factory Acceptance Document, to accept the systems performance meets the specifications and to authorise the shipping of the system to site, ready for installation shown in Figure 28.



Figure 28 - Delivered System

12.3.3. Installation

The installation phase involves the installation of temporary works, removal of the existing electric drive system, installation of the new hydraulic system, and implementation of structural modifications to support the new system before temporary works removals. This phase is meticulously planned and must be executed accordingly to ensure safety and efficiency.

12.3.3.1. Temporary Works

Temporary works are an essential aspect of the installation phase for the hydraulic system upgrade. Given the complexity and weight of the systems involved, temporary supports, bracing, and safety measures are necessary to maintain structural integrity and ensure the safety of personnel during removal and fitting of components. In addition to the Ingleside Engineering modelling and design as shown in Appendix L: Temporary Works Design - A coordination plan is required to ensure the structural integrity of the BWR during the installation phase, to provide safe working conditions for all personnel

involved in the installation phase and comply with all relevant safety regulations, including the Construction (Design and Management) Regulations 2015 (Health and Safety Executive, 2015)

12.3.3.1.1. Roles and Responsibilities

The project manager has overall responsibility for coordinating the temporary works, ensuring compliance with project timelines. The temporary works coordinator is a dedicated person responsible and accountable for overseeing the design, installation, monitoring, and removal of temporary works, in accordance with safety standards, and regulatory requirements. The engineering team (Ingleside Engineering) are responsible for designing the temporary works, conducting site surveys, and providing technical support throughout the project. The safety officers monitor compliance with safety protocols, conduct regular inspections, and address any safety concerns related to the temporary works. The temporary works installation teams execute the installation and removal of temporary works according to the approved design and procedures.

12.3.3.1.2. Temporary Works Procedure

1. Mobilise the necessary equipment and materials to the site, ensuring all components are in good condition and meet safety standards.
2. Implement safety barriers and signage to designate restricted areas and protect personnel from potential hazards.
3. Implement measures to control dust, noise, and other environmental impacts during the temporary works.
4. Ensure proper waste management and disposal procedures are in place to minimise environmental footprint.
5. Provide access platforms and walkways to facilitate safe movement and working conditions for installation teams.
6. Erect temporary supports and bracing according to the approved design, following the manufacturer's instructions and industry best practices.
7. Install guardrails, harness points, and fall protection systems to prevent accidents and injuries.
8. Conduct initial inspections and load tests to verify the integrity and stability of the temporary works.

9. Dedicated temporary works coordinator to implement a regular inspection schedule to monitor the condition of the temporary works throughout the installation phase and address any issues to ensure compliance with safety protocols. They must also maintain a detailed log of all inspections, maintenance activities, and any modifications to the temporary works.
10. Once the hydraulic system installation and structural modifications are complete, safely dismantle and remove the temporary works.
11. Ensure all temporary works components are removed without causing damage to the permanent structures or newly installed equipment.
12. Remove safe access equipment and signage
13. Conduct a final site inspection to ensure all temporary works have been properly removed and the site is restored to its original condition.

12.3.3.1.3. Compliance and Verification

- Ensure all temporary works comply with the (Health and Safety Executive, 2015), including risk assessments, method statements, and safety plans.
- Tata Consultant Engineers (TCE) to provide independent verification of the temporary works design and implementation. TCE will conduct independent inspections and audits to ensure compliance with safety and structural standards.
- Maintain comprehensive documentation of all temporary works activities, including design approvals, inspection reports, and compliance audits. Provide regular updates to project stakeholders and regulatory authorities as required.

12.3.3.2. Removal of Existing System

After the temporary works are installed, the safe removal of the existing electric drive system can begin. This will involve disconnecting electrical components, dismantling the gearbox, motor assemblies, and safely disposing of obsolete parts. Careful planning and execution are required to ensure that this process does not cause any damage to the existing structure or surrounding equipment.

12.3.3.2.1. Detailed Lifting Plan

The installation phase of the hydraulic system upgrade requires the use of an 80-tonne mobile crane to safely handle and install the heavy components of the hydraulic system.

Appendix N: Detailed Lifting Plan outlines the lift details, specifying the procedures, equipment, and safety measures required to ensure safe and efficient lifting operations. The plan includes specific steps for pre-lift planning, lift coordination, execution, and post-lift procedures, with a focus on safety and precision at every stage.

12.3.3.3. Installation of Hydraulic System

The installation of the hydraulic system will be carried out in several stages as shown in the detailed plan Gantt chart shown in Figure 29 - Gantt Chart.

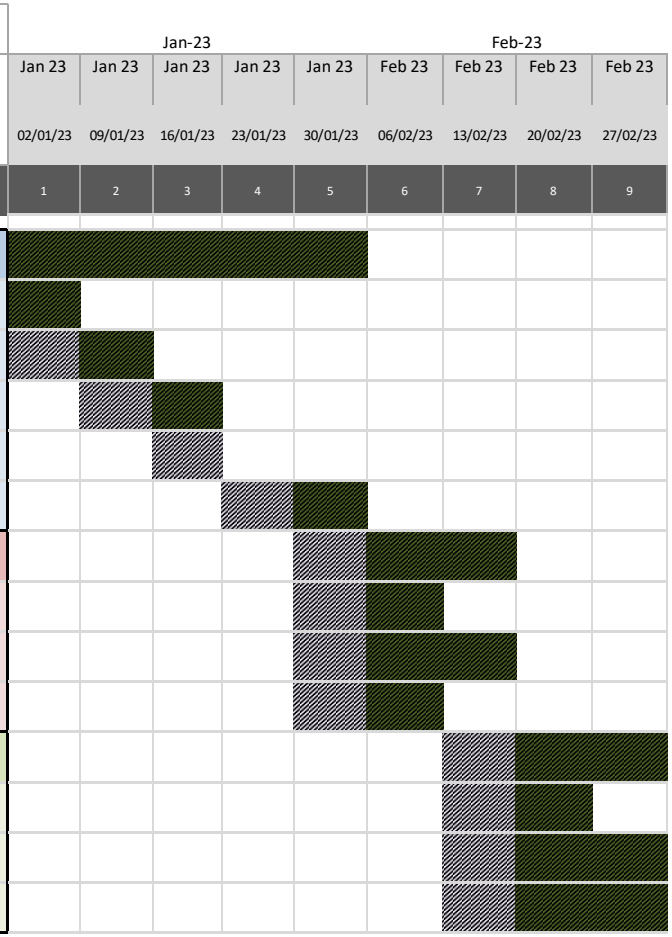
1. Structural Modifications: Implement the necessary structural changes, including the installation of new walkways, support structures and counterbalance weights.
2. Installing the hydraulic motor, pumps, valves, pipework, cabling and control systems according to the detailed engineering drawings. This will involve precise alignment and secure mounting to ensure optimal performance and safety.
3. Filling the system with hydraulic fluid, ensuring proper filtration, and conducting leak tests to verify the integrity of the system. This step will be crucial to prevent any contamination and ensure smooth operation.

BWR Gearbox Failures

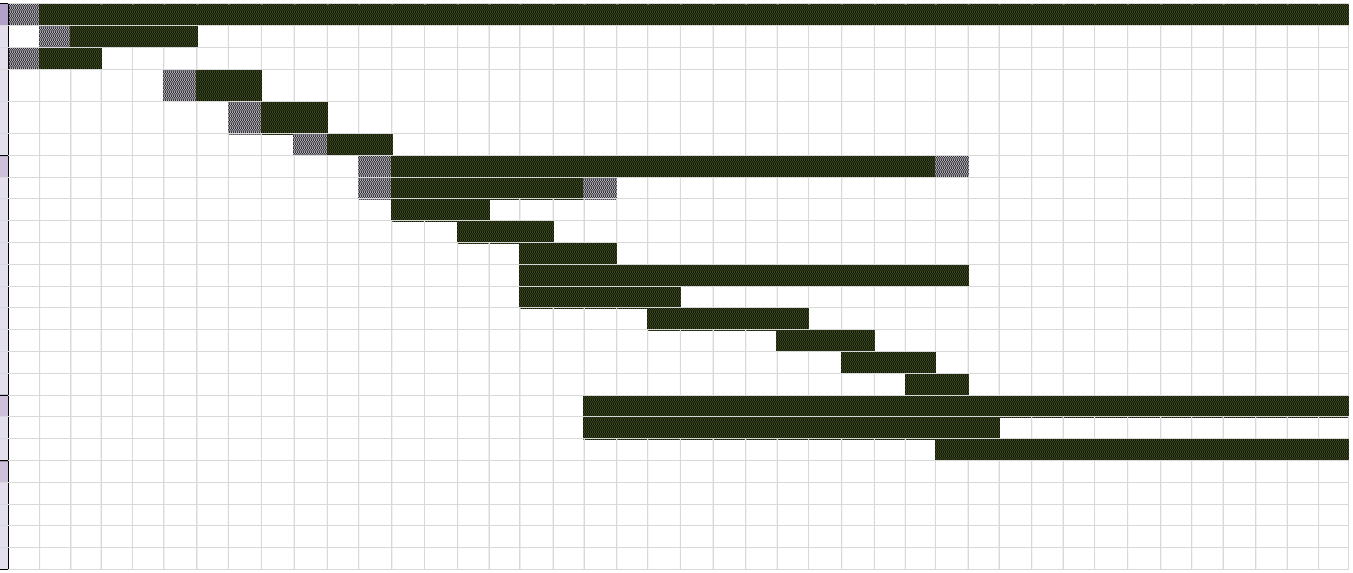
Tata Steel UK
David Adams

Project Start: Mon, 02/01/2023
Display Week: 1

TASK	OWNER	PROGRESS	START	DURATION (WEEKS)	END
Define		**100%**	**2/1/23**	**4.071428571**	**30/1/23**
Kick-off meeting	Project Manager	100%	2/1/23	0.5	5/1/23
VoC analysis	Project Manager	100%	6/1/23	1	13/1/23
Create project charter	Project Manager	100%	14/1/23	0.5	18/1/23
Develop SIPOC diagram	Project Manager	100%	19/1/23	0.5	22/1/23
Map current process	Engineering Team	100%	23/1/23	1	30/1/23
Measure		**100%**	**30/1/23**	**2**	**13/2/23**
Develop data collection plan	Data Analyst	100%	30/1/23	1	6/2/23
Collect baseline data	Maintenance Team	100%	30/1/23	2	13/2/23
Conduct Gage R&R study	Data Analyst	100%	30/1/23	1	6/2/23
Analyse		**100%**	**13/2/23**	**2**	**27/2/23**
Perform root cause analysis	Engineering Team	100%	13/2/23	1	20/2/23
Conduct statistical analysis	Data Analyst	100%	13/2/23	2	27/2/23
Validate hypotheses	Engineering Team	100%	13/2/23	2	27/2/23



Improve		**79%**	**20/2/23**	**56**	**21/3/24**
Brainstorm and evaluate solutions	Engineering Team	100%	27/2/23	4	27/3/23
Project outline sent to vendors for quotation	Project Manager	100%	20/2/23	2	6/3/23
Site visits to finalise contract scope	External Vendors	100%	27/3/23	2	10/4/23
Quotations Received and Vendor Selection	External Vendors	100%	10/4/23	2	24/4/23
CAPEX Funding Application	Project Manager	100%	24/4/23	2	8/5/23
Design Phase		**100%**	**8/5/23**	**18**	**11/9/23**
Hydraulic System Design	**External Vendors**	**100%**	**8/5/23**	**7**	**26/6/23**
Hydraulic Design Review #1	Project Manager	100%	15/5/23	2	29/5/23
Hydraulic Design Review #2	Project Manager	100%	29/5/23	2	12/6/23
Hydraulic Design Buy-off	Project Manager	100%	12/6/23	2	26/6/23
Structural Design	**External Vendors**	**100%**	**12/6/23**	**13**	**11/9/23**
Structure Design Review #1	Project Manager	100%	12/6/23	4	10/7/23
Structure Design Review #2	Project Manager	100%	10/7/23	4	7/8/23
Structure Design Buy-off	Project Manager	100%	7/8/23	2	21/8/23
Structural Manufacture Tender Documentation	Project Manager	100%	21/8/23	2	4/9/23
Structural Manufacture Vendor Selection	Project Manager	100%	4/9/23	1	11/9/23
Manufacture Phase		**100%**	**26/6/23**	**23**	**4/12/23**
Hydraulic System Manufacture	External Vendors	100%	26/6/23	12	18/9/23
Sturctural Steelwork Manufacture	External Vendors	100%	11/9/23	12	4/12/23
Installation Phase		**0%**	**1/2/24**	**7**	**21/3/24**
Removal of Redundant gearbox	Maintenance Team	0%	1/2/24	1	8/2/24
Removal of existing steelwork	External Vendors	0%	8/2/24	1	15/2/24
Installation of new structural steelwork	External Vendors	0%	15/2/24	3	7/3/24
Installation of new hydraulic drive system	External Vendors	0%	7/3/24	2	21/3/24



Control		0%	21/3/24	11	2/6/24
Develop control plan	Project Manager	0%	21/3/24	0.5	24/3/24
Testing under 0% load	External Vendors	0%	21/3/24	0.5	24/3/24
Testing under coal load	External Vendors	0%	24/3/24	0.5	28/3/24
Testing under ore load	External Vendors	0%	28/3/24	0.5	31/3/24
Conduct training sessions	Training Provider	0%	31/3/24	1	7/4/24
Update documentation and SOPs	Engineering Team	0%	7/4/24	2	21/4/24
Validation of improvements against KPI	Project Manager	0%	21/4/24	4	19/5/24
Communicate Project Findings and close project	Project Manager	0%	19/5/24	2	2/6/24
University		70%	4/9/23	41	17/6/24
Proposal	David Adams	100%	4/9/23	1	11/9/23
Viva 1	David Adams	100%	12/12/23	1	19/12/23
Report	David Adams	80%	20/5/24	1	27/5/24
Viva 2	David Adams	0%	10/6/24	1	17/6/24

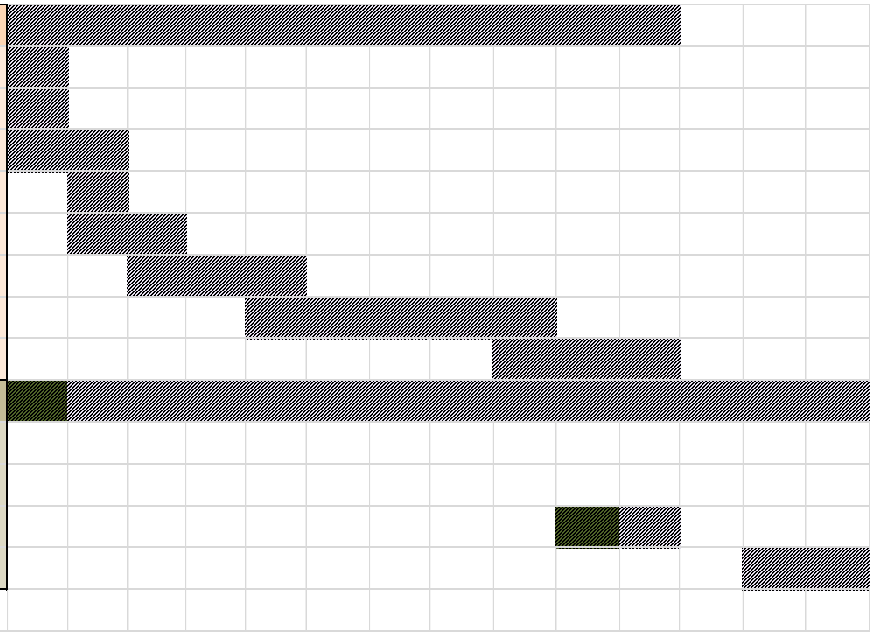


Figure 29 - Gantt Chart

12.3.4. Commissioning

The commissioning period will ensure thorough testing and validation of the new system to ensure it meets all performance and safety requirements.

12.3.4.1. System Testing

Comprehensive testing will be conducted to verify the functionality and performance of the hydraulic system. This includes ensuring all safety features, such as the lockable ball valves for safe isolation, and the pressure relief valves are operating correctly, to comply with Pressure Systems Safety Regulations 2000 (PSSR) (Health and Safety Executive, 2000). Conducting incremental hydraulic pressure tests to ensure the system can operate at the required pressures without any leaks or failures is crucial before running the system under various load conditions, to verify its performance and reliability. Running the system under various load conditions requires substantial quantities of the different materials processed. This requires careful planning to ensure the materials are on site prior to the project start date and are available for reclaim during the commissioning phase. This involves consulting with the operations team and the raw materials purchasing team regularly to inform them of project progress and any timeline variations.

12.3.5. Training and Handover

Training sessions will be conducted for the maintenance team to ensure they are familiar with the new system and its maintenance requirements and how to safely complete them. This training will be essential to ensure the long-term success and reliability of the hydraulic system. There is also a series of training sessions for the operations teams, to familiarise them with the new system and how to correctly set the reclaim rates based on the materials. This training will be delivered by BOSCH, who will supply copies of training materials for record keeping purposes.

13. Control Phase

The control phase of a DMAIC project is crucial for maintaining the long-term success of the project. This phase involves the collation and storage of all project documentation, integrating maintenance schedules into the CMMS software, conducting a project close-out meeting, and establishing continuous monitoring and review processes.

13.1. Project Documentation

A comprehensive approach to documentation collation and storage is crucial for maintaining the long-term integrity and operability of the hydraulic system. The project will use the CMMS package SAP to store all relevant documents securely. This system will ensure that installation records, training materials, OEM manuals, and detailed maintenance schedules, maintenance guides, and troubleshooting procedures are easily accessible to authorised personnel.

The Installation records, including detailed lift plans, structural modifications, and component placements, provide a thorough reference for future maintenance, troubleshooting and further projects.

Training records will be meticulously documented, including content, attendance records, and assessments to ensure that all personnel have received adequate training. These records will facilitate the scheduling of refresher courses as needed.

To comply with the Provision and Use of Work Equipment Regulations 1998 (PUWER), (Health and Safety Executive, 2018) Pressure Systems Safety Regulations 2000 (PSSR) (Health and Safety Executive, 2000) and the Data Protection Act 2018 (UK Government, 2018), all records will be maintained in a manner that meets legal and regulatory standards. Regular audits and updates to documentation will reflect any changes in regulations or operational procedures, ensuring ongoing compliance. Furthermore, the ISO 55000 series of standards (International Standards Organisation, 2014) emphasise the importance of maintaining detailed records for effective asset management These records support informed decision-making, risk management, and continuous improvement throughout the asset's lifecycle.

The integration of maintenance schedules and documentation into the Computerised Maintenance Management System (CMMS) software SAP is a critical step for ensuring that maintenance activities are performed on schedule and recorded accurately. This integration allows for automated scheduling of maintenance tasks, real-time tracking of maintenance activities, and centralised storage of maintenance records.

By using CMMS software, we ensure that maintenance is performed on schedule, reducing the risk of unplanned downtime and extending the lifecycle of the hydraulic system. Automated alerts will notify maintenance personnel of upcoming tasks, ensuring that routine inspections and preventive maintenance are conducted in a timely manner. The further integration with system feedback sensors, can predict pre-cursors to failures and generate maintenance work orders for intervention before failures occur. This proactive approach to maintenance management minimises the risk of equipment failure and optimises system performance.

The CMMS will also provide real-time tracking of maintenance activities, offering visibility into ongoing tasks and identifying any overdue actions. This real-time data will facilitate effective planning and resource allocation, enabling maintenance teams to address issues promptly and efficiently. Furthermore, centralised storage of maintenance records in the CMMS ensures that all relevant information is easily accessible for analysis and decision-making. Maintenance history, completed work orders, and inspection reports will be stored in the system, providing a comprehensive view of the hydraulic system's performance and maintenance needs. The use of CMMS software aligns with best practices in asset management, as outlined in the ISO 55000 series of standards (International Standards Organisation, 2018)., which emphasise the importance of maintaining accurate and comprehensive maintenance records for effective asset management.

13.2. Project Close Out

A project close-out meeting will be conducted to formally conclude the hydraulic system upgrade project and review the lessons learned. This meeting will involve all key stakeholders, including project team members, representatives from TATA and BOSCH, as well as maintenance and operations staff. The purpose of this meeting is to ensure

that the project objectives have been met and to gather insights that can improve future projects.

During the close-out meeting, the project team will conduct a detailed review of the initial objectives, evaluating whether they have been achieved. This includes assessing performance metrics such as system reliability, energy efficiency, and operational cost savings. Cost targets will be analysed to ensure that the project stayed within budget, and project timelines will be reviewed to confirm that the upgrade was completed on schedule.

13.2.1. Lessons Learned

Documenting lessons learned is a critical component of the project close-out process. The team will identify what aspects of the project worked well and which areas could be improved. This information will be categorised into technical, operational, and managerial insights. Technical lessons might involve specific engineering challenges and solutions, while operational lessons could focus on maintenance procedures or system performance. Managerial insights may address project planning, stakeholder engagement, and resource allocation.

The lessons learned will be integrated into the business's continuous improvement processes. This closed-loop feedback system ensures that the organisation benefits from the project experience and applies these insights to future initiatives. Regular reviews and updates to project management methodologies will incorporate the lessons learned, enhancing the efficiency and effectiveness of future projects.

13.3. Bathtub Curve Analysis

The bathtub curve as shown in Figure 30 is an essential model in reliability engineering, depicting the failure rates of a system over its lifecycle. It consists of three distinct phases: early failures (infant mortality), constant failures (useful life), and increasing failures (wear-out). Understanding and managing these phases are critical for ensuring the reliability and longevity of the hydraulic system upgrade.

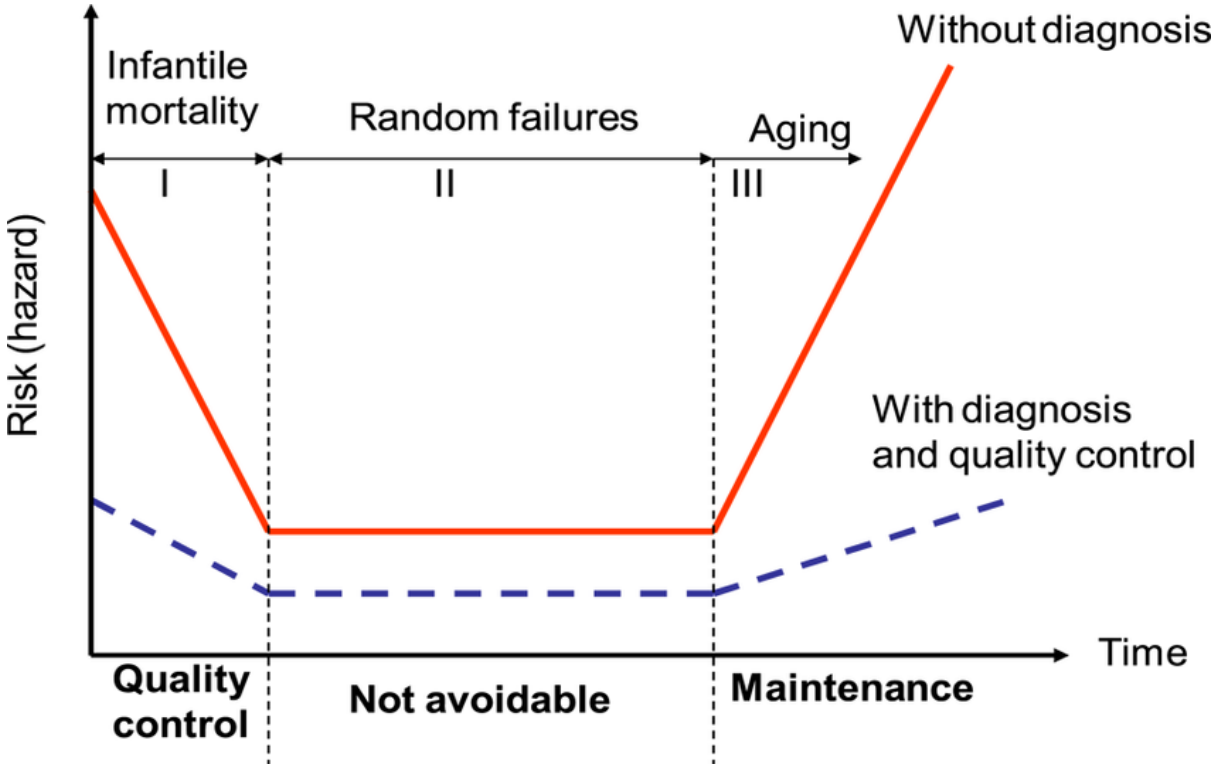


Figure 30 - Bathtub curve (Montanari, et al., 2020)

13.3.1. Pre-Upgrade Condition

Before the upgrade, the electric motor and gearbox system of the bucket wheel reclaimer were in the wear-out phase of the bathtub curve. This phase is characterised by a high frequency of failures due to aging components, which often lead to catastrophic failures and long, expensive repairs. The frequent unplanned maintenance - Low MTBF value, high repair times – High MTTR, and high costs indicates that the system has surpassed its useful life, necessitating the upgrade to a more reliable solution.

13.3.2. Post-Upgrade Expectations

Following the upgrade to the hydraulic system, the equipment is expected to initially enter the infant mortality phase of the bathtub curve. This phase typically sees a higher rate of failures due to installation errors, early-life component failures, or unforeseen integration challenges. To manage this phase effectively, rigorous initial testing and validation during the commissioning stage will be conducted. This involves comprehensive performance tests, system diagnostics, and operational simulations to identify and rectify potential issues early.

Frequent inspections and monitoring during the initial months of operation will help detect and address any early-life failures promptly. A dedicated rapid response team will be established for the first 2 weeks, consisting of a BOSCH technician and TATA maintenance technicians, to respond quickly to any failures, minimising downtime and ensuring a smooth transition to the useful life phase. This proactive approach aims to stabilise the system as quickly as possible, reducing the duration of the infant mortality phase. These issues will be documented and investigated thoroughly by the project team to ensure that they are not a pre-cursor to more serious issues or issues that are likely to reoccur.

13.3.3. Useful Life Phase

Once the system stabilises, it will enter the useful life phase, characterised by lower and more predictable failure rates. During this phase, the system is expected to perform reliably with regular maintenance and monitoring. Adherence to the maintenance schedules uploaded in the CMMS will ensure consistent and reliable operation. Real-time condition monitoring will be implemented to detect any anomalies early and prevent unexpected failures. This phase represents the optimal operating period where the system delivers consistent performance with minimal interruptions.

13.3.4. Planning for Wear-Out Phase

As the system approaches the end of its useful life, proactive planning for the wear-out phase will be essential. This involves anticipating increased failure rates and preparing for component replacements or upgrades to avoid extended downtimes. Proactive replacement planning, informed by continuous monitoring data and maintenance histories, will help maintain operational efficiency and reliability as the system ages.

13.4. Change Management

Effective change management is crucial for the successful implementation of the hydraulic system upgrade. This involves managing the transition, addressing resistance to change, and ensuring compliance with legal requirements. Properly managing these aspects helps ensure a smooth transition to the new system while maintaining operational continuity and safety standards.

13.4.1. Stakeholder Engagement

Engaging stakeholders early and maintaining open lines of communication are essential strategies in change management. Regular meetings and updates will be conducted to keep all parties informed and involved. By involving key stakeholders such as maintenance personnel, operations staff, and senior management throughout the process, the project team can address concerns, gather input, and foster buy-in. This approach helps mitigate resistance to change and promotes a collaborative environment.

13.4.2. Comprehensive Training

Providing comprehensive training and ongoing support ensures that all personnel are comfortable with the new system and understand its operation and maintenance requirements. Training sessions will cover the technical aspects of the hydraulic system, safety procedures, and maintenance protocols. Training materials, including manuals and video tutorials, will be made available to personnel for reference. Ongoing support will be provided through refresher courses and troubleshooting assistance, ensuring that staff remains proficient in using and maintaining the new system.

13.4.3. Compliance with Legal Requirements

Under UK health and safety legislation, any significant changes to machinery and equipment must comply with the Provision and Use of Work Equipment Regulations 1998 (PUWER) (Health and Safety Executive, 2018). These regulations require that equipment is suitable for its intended use, maintained in safe condition, and operated by trained personnel. Compliance with these regulations is paramount to ensuring the safety of all personnel and the proper functioning of the hydraulic system.

Additionally, ISO standards such as ISO 9001 (International Standards Organisation, 2015) for quality management and ISO 45001 (International Standards Organisation, 2018) for occupational health and safety provide frameworks for managing change effectively. ISO 9001 emphasises the need for documented procedures and records to ensure consistent quality, while ISO 45001 focuses on risk management and the involvement of workers in health and safety processes. Ensuring that the hydraulic

system upgrade complies with these standards will enhance the project's credibility and demonstrate a commitment to maintaining high safety and quality standards.
By following these strategies and adhering to legal requirements and industry standards, it is possible to achieve a successful and compliant transition to the new hydraulic system, maintaining operational efficiency and safety.

13.5. Continuous Improvement

Continuous monitoring and regular reviews are integral to validating the project's success and driving continuous improvement. This process involves tracking various performance metrics, quality metrics, and other key indicators to ensure that the hydraulic system upgrade delivers the expected benefits.

13.5.1. Performance Metrics

Monitoring energy consumption and system performance compared to the previous electric drive system is crucial for evaluating efficiency improvements. Improved efficiency will indicate reduced operational costs and environmental impact. Monthly data collection and analysis will track trends and identify any deviations from expected performance. Real-time monitoring systems will be employed to provide continuous data, enabling immediate responses to any anomalies.

13.5.2. Quality Metrics

Tracking the frequency and severity of defects provides insights into the reliability and quality of the system. Lower defect rates indicate higher reliability. Quality audits will be conducted quarterly to ensure compliance with standards and identify areas for improvement. These audits will review maintenance logs, inspection reports, and operator feedback to identify any recurring issues and develop corrective actions.

13.5.3. Adaptability

Evaluating the system’s adaptability involves assessing its ability to adapt to different operational demands and material types without significant reconfiguration. This will be assessed through performance reviews and operator feedback. The hydraulic system's

flexibility in handling varying loads and operating conditions will be tested periodically to ensure it meets operational requirements.

13.5.4. Reliability Metrics

Reliability metrics, such as Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR), will be measured using the CMMS. These metrics provide a measure of system reliability and maintenance efficiency. Regular reviews of maintenance records will help identify trends and potential issues, enabling proactive maintenance planning.

13.5.5. Maintenance Metrics

Monitoring planned and unplanned maintenance times involves tracking the duration and frequency of maintenance activities to ensure they are completed efficiently and to identify any areas for improvement. The CMMS will generate reports on maintenance activities, highlighting any deviations from scheduled maintenance and providing insights into the causes of unplanned maintenance.

13.5.6. Cost Metrics

Comparing maintenance and operational costs before and after the upgrade provides insights into cost savings and the effectiveness of the new system. Detailed analysis will be conducted after 12 months to assess the overall financial impact of the upgrade. This analysis will include a review of energy costs, maintenance expenses, and operational efficiencies.

13.5.7. Environmental Impact

Monitoring changes in emissions and waste generation resulting from the new hydraulic system will be part of the environmental impact assessment. The improved energy efficiency and reduced environmental footprint will align with the ISO 50001 standard for energy management, demonstrating the upgrade's contribution to achieving higher sustainability standards. Regular environmental audits will assess compliance with these standards and identify opportunities for further improvements.

13.5.8. Stakeholder Feedback

Collecting stakeholder feedback from operators and maintenance staff helps identify areas for improvement and ensures the system meets their needs. This will involve regular surveys and interviews, as well as reviewing performance data to validate the feedback. Both qualitative feedback through interviews and surveys and quantitative data from performance metrics will be used to validate the project's success. Stakeholder feedback sessions will be held bi-annually to gather insights and suggestions for continuous improvement.

13.5.9. Validating ROI Calculations

Validating the return on investment (ROI) calculations is essential to confirm that the financial benefits projected at the start of the project are being realised. This involves comparing the actual cost savings, efficiency improvements, and operational performance with the initial projections. The ROI validation will be conducted 6 months following project completion. This validation process will involve detailed financial analysis, including a comparison of pre- and post-upgrade costs related to maintenance, operations, and energy consumption. The goal is to ensure that the projected savings and efficiency gains are being realised in practice, providing a clear measure of the project's success.

13.6. PFMEA Review

Reviewing the Process Failure Modes and Effects Analysis (PFMEA) documentation is essential to ensure accuracy and comprehensiveness in identifying potential failure modes and their impacts on the new hydraulic system. The PFMEA is updated to reflect the changes brought by the new hydraulic drive system, considering factors such as new components, operational conditions, and maintenance requirements. This proactive approach helps in identifying and mitigating risks, ensuring the system's reliability and safety.

13.6.1. Updated FMEA

The updated FMEA shown in Table 13 contains a detailed analysis of potential failure modes across the entire bucket wheel reclaimer, with a focus on the hydraulic bucket drive system. This includes identifying possible causes of failure, assessing the severity, occurrence, and detection of each failure mode, and implementing corrective actions to mitigate risks. This document will serve as a living document, continuously updated based on new insights and operational data.

Table 13 - Updated FMEA

Process Step	Potential Failure Mode	Potential Effect	Severity (S)	Potential Causes	Occurrence (O)	Current Controls	Detection (D)	RPN	Recommended Actions
Hydraulic Motor	Overheating	Motor damage, reduced efficiency	9	Inadequate cooling, excessive load	4	Thermal sensors, load monitoring	4	144	Enhance cooling system, improve load distribution
Hydraulic Motor	Seal failure	Hydraulic fluid leakage, pressure drop	8	High pressure, seal wear	4	Regular inspections, scheduled replacements	3	96	Use high-quality seals, increase inspection frequency
Hydraulic Pump	Cavitation	Reduced efficiency, noise	7	Air in fluid, high fluid temperature	4	Pressure monitoring, fluid temperature control	4	112	Improve fluid management, install anti-cavitation devices
Hydraulic Pump	Bearing failure	Pump seizure, loss of hydraulic power	9	Contamination, inadequate lubrication	3	Vibration monitoring, fluid cleanliness	4	108	Improve filtration, increase lubrication checks
Valves	Sticking	Loss of control, operational inefficiency	7	Contamination, wear	4	Regular maintenance, filtration systems	4	112	Improve filtration, increase maintenance frequency
Valves	Leakage	Hydraulic fluid loss, reduced pressure	8	Seal wear, improper installation	3	Regular inspections, pressure monitoring	3	72	Improve installation procedures, use high-quality seals

Hydraulic Lines	Rupture	Loss of hydraulic fluid, pressure drop	9	Mechanical damage, aging hoses	4	Protective sheathing, regular inspections	4	144	Upgrade hose material, enhance protective measures
Hydraulic Lines	Blockage	Reduced flow, loss of efficiency	7	Contamination, improper maintenance	3	Regular inspections, filtration systems	3	63	Improve filtration, implement regular cleaning routines
Control System	PLC failure	Loss of control, operational halt	9	Software bugs, hardware failure	3	Software updates, hardware testing	3	81	Implement redundant PLC systems, increase testing frequency
Control System	Sensor failure	Incorrect readings, operational errors	7	Contamination, wear	4	Calibration schedules, regular maintenance	4	112	Use higher quality sensors, increase calibration frequency
Control System	Communication failure	Loss of control, data errors	8	Network issues, signal interference	3	Regular signal testing, redundant systems	3	72	Improve network infrastructure, enhance signal integrity
Hydraulic Reservoir	Fluid contamination	Reduced efficiency, component wear	7	Poor maintenance, environmental exposure	4	Filtration systems, regular fluid checks	4	112	Improve fluid handling procedures, enhance filtration
Hydraulic Reservoir	Overheating	Degraded fluid, reduced efficiency	8	Inadequate cooling, excessive use	3	Temperature monitoring, cooling systems	3	72	Upgrade cooling systems, implement better temperature control
Slewing Mechanism	Bearing failure	Reduced manoeuvrability, breakdown	8	Contamination, inadequate lubrication	5	Vibration analysis,	5	200	Install real-time condition

						lubrication schedules			monitoring systems
Slewing Mechanism	Gear wear	Reduced efficiency, breakdown	8	Poor lubrication, wear and tear	5	Regular maintenance, lubrication schedules	4	160	Improve lubrication, use high-quality lubricants
Structural Frame	Cracks	Structural failure, safety hazard	10	Fatigue, overloading	3	Visual inspections, load analysis	3	90	Conduct regular structural assessments, strengthen design
Structural Frame	Corrosion	Reduced structural integrity	8	Environmental exposure, poor maintenance	4	Regular inspections, protective coatings	4	128	Apply corrosion-resistant coatings, improve maintenance
Boom	Buckets wear	Reduced material handling efficiency	7	Abrasive materials, improper use	6	Regular inspections, maintenance schedules	4	168	Use wear-resistant materials, increase inspection frequency
Boom	Structural damage	Failure, safety hazard	10	Overloading, impact	3	Visual inspections, load monitoring	3	90	Conduct regular structural assessments, strengthen design
Electrical System	Short circuit	Equipment damage, fire	9	Aging wiring, insulation failure	4	Insulation testing, regular maintenance	4	144	Upgrade wiring, increase testing frequency
Electrical System	Power loss	Operational downtime	8	Electrical faults, power supply issues	5	Redundant power systems,	3	120	Improve power supply infrastructure,

						regular maintenance			conduct load analysis
Electrical System	Component failure	Loss of functionality	7	Aging components, stress	4	Regular testing, scheduled replacements	4	112	Use higher quality components, increase testing frequency
Dust Suppression System	Nozzle blockage	Ineffective dust control	6	Contamination, wear	4	Regular cleaning, filtration systems	4	96	Improve filtration, increase maintenance frequency
Dust Suppression System	Pump failure	Loss of dust suppression capability	8	Wear and tear, contamination	3	Vibration monitoring, pressure checks	4	96	Install real-time condition monitoring systems
Walkway Assemblies	Structural failure	Safety hazard, operational downtime	9	Overloading, improper maintenance	3	Visual inspections, load testing	4	108	Regular inspections, enhance maintenance protocols
Walkway Assemblies	Corrosion	Structural integrity compromised	7	Environmental exposure, poor maintenance	4	Regular inspections, protective coatings	4	112	Apply corrosion-resistant coatings, improve maintenance
Walkway Assemblies	Fastener failure	Safety hazard, operational inefficiency	8	Vibration, improper installation	4	Regular inspections, torque checks	4	128	Use high-quality fasteners, improve installation procedures
Emergency Stop System	Failure to activate	Safety hazard, operational risk	10	Electrical fault, mechanical failure	3	Regular testing, redundancy systems	3	90	Improve system design, increase testing frequency

Emergency Stop System	False activation	Unnecessary downtime	7	Sensitivity issues, improper calibration	3	Regular calibration, system checks	3	63	Improve calibration procedures, enhance system checks

14. Conclusion

The Six Sigma (DMAIC) methodology has been instrumental in guiding the hydraulic system upgrade project for the bucket wheel reclaimer (BWR). This project aimed to improve the BWR reliability and reduce operation and maintenance costs through replacement of the outdated and unreliable electric drive system. Despite significant progress and meticulous planning, the project has been temporarily halted due to unforeseen circumstances within the business. This conclusion provides a detailed reflection on the project's achievements up to the installation and testing phases and discusses the implications of the current suspension of activities.

14.1. Define Phase

In the Define phase, we established the project's scope, objectives, and deliverables. The primary goal was to address the frequent and costly failures of the BWR's gearbox and electric motor, which had reached the end of their lifecycle. We aimed to enhance system reliability, reduce maintenance costs, and improve operational efficiency by upgrading to a new drive system. Key stakeholders, including maintenance staff, operations personnel, and senior management, were engaged early in the project to ensure their buy-in and support. A detailed project charter was developed, outlining the project's goals, timelines, and responsibilities, providing a clear roadmap for the project team.

14.2. Measure Phase

During the Measure phase, we collected and analysed baseline data on the performance and reliability of the existing system. Key performance indicators (KPIs) such as Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), maintenance costs, and energy consumption were measured to provide a comprehensive understanding of the current state of the equipment. The collected data were validated through Gage R&R studies to ensure accuracy and reliability. This data highlighted the critical areas needing improvement and provided a solid foundation for the subsequent analysis phase.

14.3. Analyse Phase

The Analyse phase focused on identifying the root causes of the frequent failures and high maintenance costs associated with the existing system. Techniques such as the Fishbone diagram and the 5 Whys analysis were employed to systematically explore potential failure modes. Our analysis revealed that the gearbox was experiencing rapid onset and unpredictable catastrophic failures due to worn-out planetary components and inadequate lubrication. The lack of real-time condition monitoring and difficult access for maintenance exacerbated these issues. This comprehensive analysis confirmed that upgrading to a hydraulic system would mitigate these problems and provide a more reliable solution.

14.4. Improve Phase

In the Improve phase, we embarked on the design and implementation of the new drive system. A thorough literature review and consultations with vendors such as ABB, BOSCH, and Thyssen-Krupp were conducted to explore available technologies and solutions. The decision to proceed with BOSCH's hydraulic system was strongly based on their previous successes, and the superior reliability and performance characteristics of hydraulic systems in this application. Detailed design reviews were conducted, incorporating input from key stakeholders to ensure that the new system met all operational and maintenance requirements.

14.4.1. Integration and Coordination Challenges

A critical aspect of the project involved integrating the new hydraulic system with the existing control systems. This required careful coordination between TATA and BOSCH engineers to address the challenges of connecting MODBUS, PROFIBUS, and PROFISAFE protocols. Detailed planning and expert knowledge were necessary to design and install new cabling and modules, configure the PLCs, and ensure compatibility between the software and hardware interfaces. Regular coordination meetings and technical reviews were conducted to address any issues and ensure smooth integration. Testing was performed at each stage to verify that the systems communicated correctly and that all safety protocols were in place.

14.5. Control Phase

The Control phase aimed to ensure the long-term success and sustainability of the hydraulic system upgrade. All project documentation, including installation records, training materials, OEM manuals, and maintenance schedules, was collated and stored securely. These documents were integrated into the CMMS software SAP to automate maintenance scheduling and real-time tracking of maintenance activities. This approach facilitated proactive management and timely interventions, enhancing the overall efficiency and reliability of the hydraulic system.

A comprehensive project close-out meeting was planned to review the project's objectives and document lessons learned. The system's performance was to be continuously monitored using real-time condition monitoring and regular reviews of performance metrics, quality metrics, and maintenance records. The Bathtub Curve model was employed to track the system's lifecycle and plan for proactive maintenance and component replacements. Continuous improvement processes were to be driven by stakeholder feedback and ongoing performance assessments.

14.6. Project Suspension

Despite the significant progress made, the project faced an unexpected suspension due to unforeseen circumstances within the business. As a result, all projects were held at their current stage, with the hydraulic system and walkways delivered to the site but not yet installed. The remainder of the work, including installation and commissioning, is on hold and will only be executed if there is another catastrophic failure of the BWR gearbox. At that point, the business will assess whether to complete the upgrade or scrap the asset entirely.

This suspension is particularly disappointing as the project manager. Having invested considerable effort and resources into planning, designing, and preparing for the installation, it is disheartening not to see the project through to completion. The hydraulic system upgrade was poised to significantly improve the reliability and efficiency of the BWR, and I was eager to demonstrate the benefits of this solution fully.

14.7. Reflection and Future Considerations

The decision to halt the project is understandable given the broader business context, but it underscores the challenges of managing large-scale projects in dynamic environments. As project manager, I remain hopeful that the business will recognise the value of completing the upgrade should another failure occur or prior. The groundwork has been laid, and the systems are ready for installation, which positions us well for a swift response if needed.

Reflecting on the project, it is clear that the Six Sigma (DMAIC) methodology provided a robust framework for identifying issues, developing solutions, and planning for implementation. Each phase of the process was critical in ensuring that the project was well-conceived and executed up to the point of suspension. The lessons learned from this project will undoubtedly inform future initiatives, emphasising the importance of flexibility, thorough planning, and stakeholder engagement.

In conclusion, while the hydraulic system upgrade project has not yet reached its final stage, the work completed thus far has laid a strong foundation for future success. Should the project resume, the preparation and planning undertaken will facilitate a smooth and efficient completion. As project manager, I am committed to seeing this project through and demonstrating its value to the business. This experience has reinforced the importance of resilience and adaptability in project management, and I look forward to applying these lessons in future endeavours.

15. Bibliography

1. ABB, 1996. *Modernization of a Bucket-Wheel Excavator*. s.l.:ABB.
2. Agustiady, . & Cudney, ., 2016. *Total Productive Maintenance: Strategies and Implementation Guide*. United States: CRC Press.
3. Beaty, ., 2000. *Handbook of Electric Power Calculations*. United Kingdom: McGraw-Hill Education.
4. BOSCH REXROTH, 2023. *Factory Acceptance Document*. Wakefield: BOSCH REXROTH.
5. BOSCH REXROTH, 2023. *Reliable Performance for Mining and Materials Handling*. s.l.:BOSCH REXROTH.
6. BOSCH REXROTH, 2023. *Systems and Engineering Quotation*. s.l.:BOSCH REXROTH.
7. British Standards Institute, 2005. *BS EN 50288-7:2005 Multi-element metallic cables used in analogue and digital communication and control - Sectional specification for instrumentation and control cables*. s.l.:BSI.
8. British Standards Institute, 2016. *BS5467:2016 Electric cables. Thermosetting insulated, armoured cables of rated voltages of 600/1 000 V and 1 900/3 300 V for fixed installations. Specification*. s.l.:BSI.
9. Bryson, J., 2004. What to Do When Stakeholders Matter. *Public Management Review,* Volume 6, pp. 21-53.
10. Capehart, ., Turner, . & Kennedy, ., 2008. *Guide to Energy Management*. United States: Fairmont Press.
11. Davies, A., 2012. *Handbook of Condition Monitoring: Techniques and Methodology*. Cardiff: Springer.
12. Davim, J. P., 2011. *Tribology for Engineers: A practical guide*. s.l.:Elsevier Science.
13. Department for Energy, Security and Net Zero, 2023. *Digest of UK Energy Statistics*. [Online]
    Available at:
    https://assets.publishing.service.gov.uk/media/64f1fcba9ee0f2000db7bdd8/D

UKES_2023_Chapters_1-7.pdf
[Accessed 2024].

14. Dhillon, B. S., 2008. *Engineering Maintenance: A Modern Approach*. s.l.:CRC Press.
15. European Commission, 2014. *The EU Declaration of Conformity*. [Online] Available at: https://single-market-economy.ec.europa.eu/single-market/ce-marking/manufacturers_en
16. FreeWordCloudGenerator.com, 2024. *Word Cloud Generator*. [Online] Available at: https://www.freewordcloudgenerator.com/generatewordcloud
17. Gijo, E. V., Scaria, J. & Antony, J., 2011. Application of six sigma methodology to reduce defects of a grinding process. *Quality and Reliability Engineering International,* 27(8), pp. 1221-1234.
18. Gregory, A. & Parsa, H., 2013. Kano's Model: An Integrative Review of Theory and Applications to the Field of Hospitality and Tourism. *Journal of Hospitality Marketing & Management,* Volume 22, pp. 25-46.
19. Griffin, A. & Hauser, J., 1991. The Voice of the Customer. *Marketing Science,* Volume 12.
20. Gulati, R. & Smith, ., 2009. *Maintenance and Reliability Best Practices*. United States: Industrial Press.
21. Hauser, J. R., Clausing, D. P. & Garvin, D., 1988. The House of Quality. *Harvard Business Review,* pp. 63-73.
22. Health and Safety Executive, 2000. *PSSR: Pressure Systems Safety Regulations 2000*. United Kingdom: HSE.
23. Health and Safety Executive, 2015. *CDM: Construction Design and Management Regulations*. United Kingdom: s.n.
24. Health and Safety Executive, 2018. *PUWER 1998: Provision and Use of Work Equipment Regulations 1998*. London: HSE.
25. Heimerl, F., Lohmann, S., Lange, S. & Ertl, T., 2014. *Word Cloud Explorer: Text Analytics Based on Word Clouds*. 47th Hawaii International Conference on System Sciences, IEEE.
26. Higgins, L. R., Mobely, R. K. & Wikoff, D. J., 2008. *Maintenance Engineering Handbook*. s.l.:McGraw-Hill Education.

27. Imbarrato, ., 2021. *The Project Roadmap: Your Hands-On Guide to Initiating, Planning, Executing and Completing Projects*. s.l.:MBI Consulting, LLC.
28. Ingleside Engineering, 2023. *Design Brief*. Port Talbot: Ingleside Engineering.
29. Ingleside Engineering, 2023. *Hydraulic Calculations*. Port Talbot: Ingleside Engineering.
30. Ingleside Engineering, 2023. *Temporary Works Design*. Port Talbot: Ingleside Engineering.
31. Ingleside Engineering, 2023. *Thicknes test locations*. Port Talbot: Ingleside Engineering.
32. Ingleside Engineering, 2023. *Weight Calculations*. Port Talbot: Ingleside Engineering.
33. Inglside Engineering, 2023. *Proposed walkway layout*. Port Talbot: Ingleside Engineering.
34. International Standards Organisation, 2014. *ISO55001:2014 Asset Management - Management Systems Requirements*. [Online] Available at: https://www.iso.org/obp/ui/en/#iso:std:iso:55001:ed-1:v1:en [Accessed 2024].
35. International Standards Organisation, 2015. *ISO9001:2015 - Quality Mangement System Requirements*. [Online] Available at: https://www.iso.org/obp/ui/en/#iso:std:iso:9001:ed-5:v1:en [Accessed 2024].
36. International Standards Organisation, 2018. *ISO 45001:2018 - Occupational health and safety managment systems requirments*. [Online] Available at: https://www.iso.org/obp/ui/en/#iso:std:iso:45001:ed-1:v1:en [Accessed 2024].
37. International Standards Organisation, 2018. *ISO50001:2018 Energy Management Systems*. [Online] Available at: https://www.iso.org/obp/ui/en/#iso:std:iso:50001:ed-2:v1:en [Accessed 2024].
38. International Standards Organisation, 2018. *ISO55002:2018 Asset Management - Management Systems Guidance*. [Online]

Available at: https://www.iso.org/obp/ui/en/#iso:std:iso:55002:ed-2:v1:en [Accessed 2024].

39. Jardine, A. K. S., McGlynn, J. & Campbell, J. D., 2016. *Asset Management Excellence: Optimizing Equipment Life-Cycle Decisions*. 2nd ed. United States: CRC Press.
40. Jardine, A. K. & Tsang, A. H., 2021. *Maintenance, Replacement, and Reliability Theory and Applications*. United States: CRC Press.
41. Kennedy, ., 2017. *Understanding, Measuring, and Improving Overall Equipment Effectiveness: How to Use OEE to Drive Significant Process Improvement*. s.l.:Taylor & Francis.
42. Kerzner, H., 2017. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*. s.l.:Wiley.
43. Kruczek, P. et al., 2019. *Predictive Maintenance of Mining Machines Using Advanced Data Analysis System Based on the Cloud Technology*. s.l., Springer International Publishing.
44. Levitt, ., 2009. *The Handbook of Maintenance Management*. United States: Industrial Press, Incorporated.
45. Manring, N., 2013. *Fluid Power Pumps and Motors: Analysis, Design and Control*. United States: McGraw-Hill.
46. Marquez, P. G., Lewis, R. W., Tobias, A. M. & Roberts, C., 2008. Life cycle costs for railway condition monitoring. *Transportation Research Part E: Logistics and Transportation Review,* 44(6), pp. 1175-1187.
47. Meehan, J., 2012. *Hydraulic Power System Analysis*. New York: CRC Press.
48. MII Engineering Ltd., 2023. *Walkway Quotation*. Port Talbot: MII Engineering Ltd.
49. Mobley, R. K., 2001. *Plant Engineers Handbook*. s.l.:Elsevier Science.
50. Mobley, R. K., 2002. *An Introduction to Predictive Maintenance*. 2nd ed. s.l.:Elsevier.
51. Montanari, G., Seri, P. & Ghosh, R., 2020. Testing cable system reliability after commissioning and during operation life: in medio stat virtus?. *High Voltage,* Volume 6.
52. Moubray, J., 2001. *Reliability-Centred Maintenance*. 2nd ed. s.l.:Industrial Press Inc..

53. Nelson, W. B., 2004. *Accelerated Testing: Statistical Models, Test Plans, and Data Analysis*. s.l.:Wiley.
54. Nicholas, ., Young, . & Anzalone, ., 2008. *Predictive Maintenance Management*. 3rd ed. United States: s.n.
55. Norton, ., 2019. *Design of Machinery*. 6th ed. United States: McGraw-Hill Education.
56. Office of Gas and Electricity Markets, 2024. *Energy Policy and Regulation*. [Online]
Available at: https://www.ofgem.gov.uk/
57. Petrecca, ., 2012. *Industrial Energy Management: Principles and Applications*. Switzerland: Springer US.
58. Project Management Institute, 2021. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide) – Seventh Edition and The Standard for Project Management*. s.l.:Project Management Institute.
59. Pyzdek, T. & Keller, P., 2014. *The Six Sigma Handbook*. 4th ed. s.l.:McGraw Hill LLC.
60. QFD Online, 2007. *Free QFD Templates*. [Online]
Available at: https://www.qfdonline.com/templates/
61. Rydberg, K. A., 2015. *Energy Efficient Hydraulics – System Solutions for Minimizing Losses*. Linköping, Sweden, National Conference on Fluid Power, "Hydraulikdagar'15.
62. Sachs, N. W., 2019. *Practical Plant Failure Analysis: A guide to understanding deterioration and improving equipment reliability*. 2nd ed. Boca Raton: CRC Press.
63. Schmidt, ., 2014. *Business Case Essentials: A Guide to Struture and Content*. United States: Solution Matrix Limited.
64. Serrat, O., 2017. The Five Whys Technique. In: *Knowledge Solutions*. s.l.:Springer, pp. 307-310.
65. Smith, . & Hinchcliffe, ., 2003. *RCM-Gateway to World Class Maintenance*. Netherlands: Elsevier Science.
66. Sonnemann, G. & Margni, M., 2015. *Life Cycle Management*. Germany: Springer.

67. Suhanda, R. & Pratami, D., 2021. RACI Matrix Design for Managing Stakeholders in Project. *International Journal of Innovation in Enterprise System,* Volume 5, pp. 122-133.
68. Swanson, L., 2001. Linking maintenance strategies to performance. *International Journal of Production Economics,* 70(3), pp. 237-244.
69. Tata Steel Europe, 2022. *At a glance*. [Online] Available at: https://www.tatasteeleurope.com/about-us/at-a-glance
70. Tata Steel UK, 2020. *Project Charter Template*. s.l.:s.n.
71. Tata Steel UK, 2022. *Corporate Guidelines on Project Management*. s.l.:s.n.
72. Thumann, . & Younger, ., 2008. *Handbook of Energy Audits*. Switzerland: Fairmont Press.
73. Thyssen-Krupp, 2023. *Bucket Wheel and Drum Reclaimers*. s.l.:Thyssen-Krup.
74. Turner, J., 2008. *The Handbook of Project-based Management: Leading Strategic Change in Organizations*. United Kingdom: McGraw-Hill Education.
75. UK Government, 2018. *The Data Protection Act 2018*. London: GOV.UK.
76. Wireman, ., 2004. *Total Productive Maintenance*.. United States: Industrial Press.

16. Appendices

16.1. Appendix A: ABB Proposal (ABB, 1996)

Open-pit mining Project report

Modernisation of a Bucket-Wheel Excavator
at the Welzow-South lignite mine, Lausitzer Braunkohle AG, Germany (1996)



ABB

The task

An SRs 6300.50/15.0+VR bucket-wheel excavator used for overburden removal at the Welzow-South lignite mine in Germany had been in operation since 1981. An electrical rehabilitation became necessary in 1997, due to the long years of operation under extreme mining conditions. The job was given to ABB Cottbus with the target to enable the machine to work, under the geological and operational conditions of the mine, for another fifteen to twenty years and to achieve a marked reduction of electrical maintenance costs.

This paper describes the major elements of that rehabilitation.

Variable-speed drives

The main drives of the conveying system consisted of slipring motors with rheostatic starters that did not allow, because of their fixed speeds, any optimisation by adapting performances to varying operational requirements.

The introduction of variable-speed drives for the 4 belt conveyors, in addition to the main drives and the bucket-wheel drive, laid the basis for a complex automation of material conveying.

The new solution yields essential operational advantages:

- Squirrel-cage motors can be used.
- Starting and slip resistors that caused high losses are no longer needed.
- Performance is adapted by speed reduction (power saving).
- Motors can be run at crawling speed (for removing large rocks in the overburden).
- Starting and stopping torques can be controlled.
- Mechanical maintenance is reduced.
- The noise level decreases.

ABB Cottbus has chosen the reliable ABB frequency converters ACV 700 Multidrive, and for smaller drives the model ACS 600. The incoming supplies of the main drives in the superstructure of the excavator work as self-commutated grid inverters.

The system is characterised by the following features:

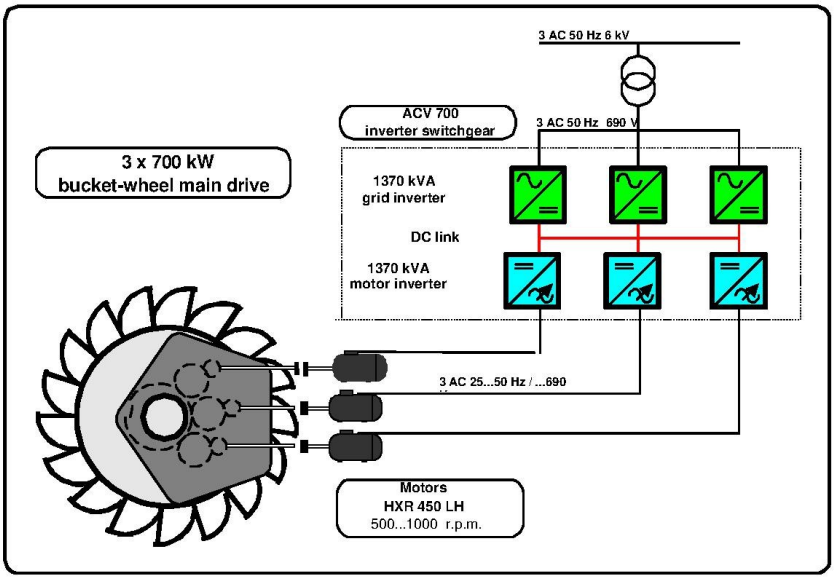
- high overall efficiency of >94.5 %
- regenerative braking at minimum system perturbation (distortion factor of <3%)
- improved power factor
- high availability through parallel power supply
- fully digitalised power electronics
- powerful optical-fibre interfaces for diagnostic routines

The control of drive speeds is based on active vector regulation, with the application control (APC) implementing torque setpoints.

Moreover, the application control serves to visualise all inverter signals for each drive on a local display.

Modernisation of a Bucket-Wheel Excavator

Technical Data of the Conveying System		Technical Data of the Main Drives	
Bucket wheel	3 x 700 kW / 690 V	Bucket-wheel hoist	2 x 620 kW / 690 V
Bucket-wheel conveyor	2 x 1120 kW / 690 V	Slewing	4 x 75 kW / 500 V
Intermediate conveyor	630 kW / 690 V	Travelling (excavator)	12 x 132 kW / 500 V
Receiving conveyor	2 x 1120 kW / 690 V	Travelling (loading section)	6 x 132 kW / 500 V
Loading conveyor	630 kW / 690 V	Conveyor hoist	1 x 15 kW / 500 V
		Loading-boom hoist	1 x 22 kW / 500 V
		Loading-boom slewing	1 x 15 kW / 500 V
		Cable reel	1 x 4 kW / 500 V
		Cable carriage	1 x 0,15 kW / 500 V



Control System and Process Management

The machine is controlled and supervised from the control room of the excavator that has been designed according to modern ergonomic principles. The installation consists of an OS 520 operator station from the ABB Advant Open Control System and three powerful AdvantController 450 processing stations of the same family. Those controllers have a high processing capacity, a comprehensive process periphery, a wide range of different process input and output devices as well as a large number of communication interfaces. All process data is stored fully configurably in databases.
The Advant process control stations and the controllers are connected to a Master-Bus 300 network. The MasterBus 300 is based on the connection-free data circuit service protocol according to IEEE 802.2, class 1, and the access protocol as to IEEE 802.3 CSMA/CD. The process level uses the sensor-actor bus INTERBUS-S specified by the customer.

ABB, Open-pit mining, Cottbus/Germany 3

Communication Infrastructure

Signal transmission within the excavator complex as well as to and from a central control station is based on a powerful communication structure using most modern components, such as optical-fibre connections for data communication and signal exchanges between the individual sections of the system. A wide-band communication system (OTN) makes it possible to print out signalisation, fault and operation records at any point of the excavator. All data can be received at the central control station via Ethernet.

Automation functions

The modernised excavator features a high degree of automation:

- automatic positioning of the loading conveyor over the hopper
- optimisation of starting and stopping the conveyor
  - accelerated start
  - control of belt speed
- operational cycles and programmed control moves for
  - slewing angle limitation
  - cutting depth control
  - slice thickness
  - slice height
  - formation of even surfaces
  - $1/\cos\varphi$ control
  - lateral slope formation
  - front slope formation
  - deep cutting
  - performance control
- excavation and transport of rocks
- automatic transmission of specified values (setpoint and limit values)

System diagnosis

For the first time a comprehensive diagnostic programme has been introduced in order to support maintenance and repair measures. All necessary software modules and communication interfaces have been concentrated at a diagnosis desk located in the substructure of the excavator. That desk can be remote-controlled via TCP/IP network connection.

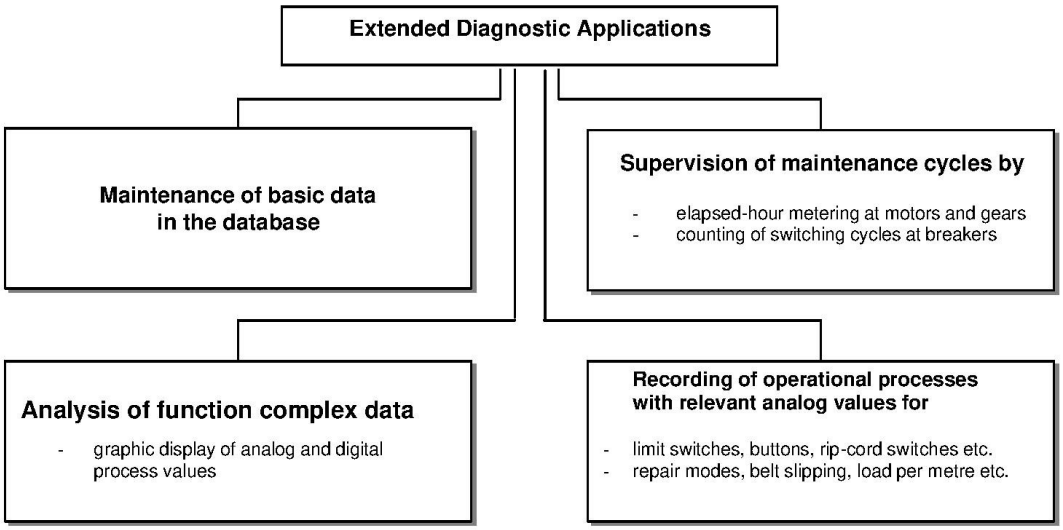
The programme breaks up into “operative diagnosis” and “extended diagnosis”.

“Operative diagnosis” covers the examination of individual system components for faults and maintenance status. That is done by means of the tailor-made diagnostic tools the manufacturers provide for their devices as well as on the basis of the information gathered in the central control system.

"Extended diagnosis" means the longer-term supervision of wear and tear by means of

- relevant control data
- a central data library kept on a database server
- evaluation of specific applications.

New technological possibilities such as client server databases and INTRANET have been utilised to implement that function.



Summary

The project has been implemented in close cooperation with the customer, Lausitzer Braunkohle Aktiengesellschaft. In part, new ways have been opened up, particularly with regard to installing speed control for all main drives, which has made the excavator the only one of its kind with all main drives controlled. Thus it has become clearly more efficient than comparable machines without control, because the innovative design produces savings in the field of variable costs.

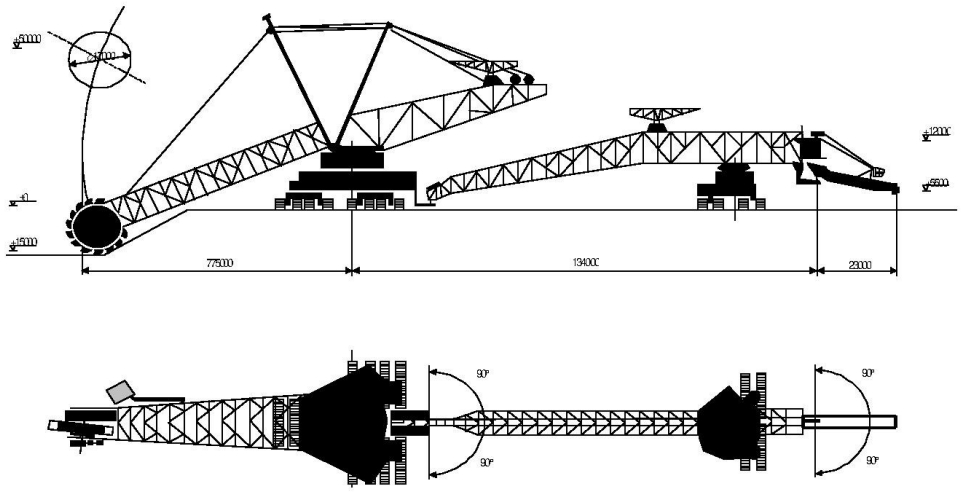


ABB Process Industries GmbH
Open-pit Mining
Gaglower Straße 17/18
03048 Cottbus
GERMANY
Phone: +49 (0) 355 596-225
Fax: +49 (0) 355 596-832
E-Mail: cottbus.deasy@de.abb.com
www.abb.com/mining

IN/BF 0907 EN

Bucket wheel excavator

Reliable electrification and automation solutions

ABB, a market leader in efficiency systems, has more than 60 years of experience with bucket wheel excavators. Our solutions help raise productivity, increase equipment reliability, increase safety, and significantly improve energy efficiency.

Are you looking for support or purchase information?

Contact us

Our offering



Programmed excavator control

The conventional programmed excavator control (BPS) is used to automate bucket-wheel and bucket-chain excavators. The BPS consists of up to 6 functional units which can be used separately, or in any combination.

The following functional units (FU) are provided:

1. Cutting depth
2. Slice length
3. Slewing angle control
4. Cost control
5. Cut-off at vmax.
6. Lateral slope design

This state-of-the-art BPS technology not only ensures reliability, it also keeps both workers and equipment safer. ABB's BPS has been used in a variety of open-pit mines around the world and has a long and proven track record of reliable performance.



It's critical that dump devices be positioned correctly on both the uptake and dump spot to ensure the quality of material. Sensors are used to exactly measure the position of the devices, relative to other facilities and open areas, to ensure complete control. Our methodology includes four areas for positioning:

1. Absolute encoder to measure the position (travel drive, slewing drive, boom angle
2. RFID (Radio Frequency Identification) to locate position or verify and calibrate absolute encoder positioning values
3. Barcode positioning meter
4. GPS applications



Power supply and electrification

Major mechanical and electrical installations impact the efficiency of a mine. Our engineers ensure that the right technologies and products are used to offer maximum energy savings. Based on decades of experience, we select the correct cable dimensions, and plan the layout for seemless commissioning. Our goal is to reduce your energy consumption, savings that will continue over the life of your plant.



Instrumentation

Machines operate in tough conditions, and require instrumentation solutions that are certified to international standards. ABB's field-proven sensor technology meets those standards and is specifically designed to perform in harsh environments. Our highly accurate sensor technology provides exact measurement values, consistently delivering the right data to the operational system.



Cabin design

Our customized driver cabs can be found in mining machines all over the world. Our goal is to provide the operator with an ergonomic workplace to prevent tiredness and incorrect operations. The most up-to-date

We offer air conditioning and heating, windscreen demisting and airborne dust blowers, screen wipers and washers, and fixed or movable ergonomic operator desks. Our philosophy is to install the respective computer technology separately from the operator station if possible, for operating convenience.



Motors and drive systems

A bucket wheel excavator is a complex machine with many movable parts, including a boom that has to slew and raise, crawlers to move the excavator forward, and a bucket wheel that turns. All of these movements require motors and drives. Our experts ensure that both of these products are sized correctly to provide the power and control required for the application.



Fire warning, intercom and lighting concepts

With increasing emphasis on safety and environmental issues, large equipment needs more than just automation. That's why ABB is offering energy efficient light concepts, as well as fire warning and firefighting systems, which can include all equipment (video, radio and speaker systems) on the machine.

Downloads and multimedia

Brochure

We set your business in motion

Automation solutions and electrical equipment for open-pit mining and bulk-material handling

Press Release

ABB retrofit to reduce energy consumption of mining equipment by 20%

ABB's AC drives retrofit will enhance life cycle and increase energy efficiency of an electric mining shovel

Baden, Switzerland, September 24, 2012 - ABB, the leading power and automation technology group, jointly with Joy Global, the leading mining equipment supplier, have been awarded a shovel retrofit project from the largest merchant coke producer in the US. The rebuild will boost the life expectancy of the electric mining shovel and significantly reduce its energy consumption, up to 20% after the retrofit.

The mechanical components of open-pit mining machinery often remain in good shape for more than 20 years. But the life span of the associated electrical equipment is usually exhausted by that time. ABB's drives and controls retrofit can enhance the operating time of the BE395BI shovel for about 10 years. To achieve these results, ABB will replace the obsolete drives system and relay controls of the shovel with a highly efficient solution utilizing ACS800 drives for mining, operator controls and an AC800M controller.

The project was awarded thanks to the state-of-the-art technology from ABB, the mining machinery field expertise from Joy Global Services as well as the ability to execute the engineering and delivery of the equipment within a tight timeframe.

The new drives system will lead to significantly higher productivity through the use of ABB's sophisticated Direct Torque Control (DTC) that provides best-in-class drive dynamics and torque control to reach a more responsive operation. Additionally, the original drive system with large brake choppers will be replaced with modern regenerative drives.

"We are very pleased to work with ABB on this project," said Scott Ottesen, Joy Global. "Our cooperation is efficient and smooth and the state-of-the-art solutions deliver impressive results to our customer. We are convinced that retrofits are a very cost effective way to maintain the life cycle and productivity of our mining equipment."

The coal industry faces a lot of challenges today. Due to the increasing environmental awareness and the request for alternative sources coal producers have to improve and optimize their processes. This is one of the reasons why retrofits of mining equipment are requested more frequently. Joy Global choose the cooperation with ABB since ABB's retrofit solutions are among the best in the market. Its solution for the BE395BI shovel will increase productivity and achieve a reduction of energy consumption up to 20%.

ABB (www.abb.com) is a leader in power and automation technologies that enable utility and industry customers to improve their performance while lowering environmental impact. The ABB Group of companies operates in around 100 countries and employs about 145,000 people.

For help with any technical terms in this release, please go to: www.abb.com/glossary

Press Release





ABB's retrofit will increase productivity of an electric mining shovel.

For more information please contact:

ABB Switzerland Ltd.
Marion Kaufmann Hug
Marketing Communications
Minerals business unit
(Baden/Switzerland)
Tel: +41 58 586 71 33
e-mail: marion.hug@ch.abb.com

Reprint from World Coal, September 2012

A powerful retrofit
ABB drive retrofits extend life cycle of shovels and draglines



Shovel excavators and draglines are mechanically robust and can have a life cycle of up to 30 years. However, regular upgrades of the electrical equipment are recommended to improve reliability and reduce maintenance costs. Such an upgrade only makes up about 10–12% of the total costs for a new machine — making retrofits a powerful and efficient tool to extend the life cycle of your mining equipment for another 10–15 years.

Power and productivity for a better world™ ABB



A POWERFUL RETROFIT

Boris Rathmann, ABB, Germany, describes how AC drive retrofits for shovels and draglines can be a cost-efficient alternative.

Coal has been the key to a reliable energy supply and has fuelled the world's industrial development over more than a century. A pressing question today concerns the role of coal in power generation in the near and mid-term future. US coal production, for example, increased slightly during 2011 for the second year in a row, rising about 0.4% from its 2010 level, after falling sharply during 2009, according to the US Energy Information Administration (EIA). This made total production for 2011 around 1.1 billion short t (997 million t). Increasing environmental awareness, and the desire to tap into alternative sources, such as shale gas and renewables, has sharpened the problems around coal.

Numerous claims have been made by US mining and power generating companies about the industry struggles to co-operate with the US Environmental Protection Agency (EPA).

Nevertheless, in developed countries such as Germany, coal still remains an important power generating source, accounting for about 43% of electricity generation in 2011. This is in a similar range to North America. In combination with the shutdown of nuclear power plants after the Fukushima disaster in March 2011, the role of the domestic coal-fired power plants has increased. Germany is the top lignite mining country in the world. All of the country's lignite production is used domestically for power generation and is increasingly important for the baseload energy generation.

Does Germany face different environmental and economical challenges than North America, or the rest of the world? Most likely not: the answer lies in technology development and cost-efficient processes. Coal mining will remain a profitable business over a long time period as it was in the past.

In last two decades, state-of-the-art technology developments around the globe have founded a solid base for the coal mining industry. Highly automated overburden removal systems, coal blending and energy-efficient mining machines are commonly found at large-scale operation and brownfield investments. In particular, the retrofit and upgrade of existing mining equipment is an important market for a turnkey supplier of electrical equipment such as ABB.

Electric rope shovel with AC drives

ABB mining drives have provided benefits for customers of one of the market leaders for electric rope shovels, Joy Global (P&H Mining Equipment). More and more mine operators have decided to employ advanced AC drive technology to achieve a higher level of productivity (10%) and significant energy savings (7%), as evaluated in a comparison between conventional DC shovels and the new AC type 4100 XPC in the Canadian coal industry.

The North American coal industry is looking for the most productive and efficient equipment to attain results for the lowest operational cost. The first 4100 shovels with AC drives began operation in US and Canadian coal mines. A higher performance of AC drive systems is achieved through the use of a highly efficient motor design, excellent dynamic response time behaviour of the direct torque control (DTC) and the multidrive design with a common DC-bus regenerative motor-to-motor energy usage. Further, the use of individual crowd and propel motion AC drives helps the shovel to quickly achieve an optimal position to the bank and increase the bucket payload. The new AC drives system is more reliable and needs no electrical maintenance for motors.



Electric rope shovel operating with ABB ACS800 multi-drive.

Shovel and dragline motion drives technology

Over several decades different technologies have been used for motion drives. The most common for shovels is the DC motor with static converter in analogue and digital control.

Today, a typical drives application for shovels is the AC multi-drive concept, in which one supply unit feeds several motor inverters over a common DC bus-bar. The common DC bus allows energy sharing between the motors. Usually a regenerative insulated gate bipolar transistor-based (IGBT-based) supply unit is used, which enables the return of excessive braking energy back to the grid. Regenerative VFD supply units usually have a better power factor and lower total harmonic distortion (THD) levels. In weak grid conditions the drive is also better protected against voltage dips, or even short blackouts. The modern IGBT supply units have an adjustable leading or lagging power factor, and can be used for reactive power compensation.

For draglines, motor-generator sets have been the most popular drive systems and new draglines are still delivered with motor-generator sets. The majority of the operational draglines were built between 1960 and 1990, with Ward-Leonard motor-generator sets and DC motion motors. New draglines are now offered with conventional or gearless AC drive systems. The advantages with new motion drive solutions are almost maintenance-free AC motors, and higher efficiency of the overall drive system, as well as better drive controls and diagnostics compared to DC



ABB ACS800 drives module.

drives. The higher overall availability of the dragline with an AC drive system will provide significant productivity improvements to the mine operation and the operating cost of the machine.

AC drives retrofit extending the shovel life cycle

Rope shovel excavators are mechanically robust and can have a life cycle of up to 30 years – around two to three times the life cycle of a hydraulic mining shovel. After a certain period of operation, it is recommended to upgrade the electrical equipment to improve reliability and reduce maintenance costs. Decreasing availability, obsolete technology and increasing difficulty in acquiring the necessary spare parts make many users think about alternatives. The capital costs of the entire electrical equipment is about 10 – 12% of a new rope shovel. That means a retrofit of an existing shovel can be an efficient way to extend the life cycle for another 10 – 15 years. Usually, it requires a 5 – 6 week period to replace the electrical equipment, including commissioning. Today, most operators appreciate the advantages of AC technology because of a robust motor and reliable power electronic with digital drives control.

An ABB order in June 2012 for a shovel AC retrofit in co-operation with Joy Global MinePro Services to Drummond Coal underlines the need for upgrades in the coal industry. This BE395B shovel was built in 1987 and is planned to be in operation for at least another 10 years. This is an example in which the operator is convinced that a retrofit can be a cost-efficient alternative to a new shovel.

In addition to the successful AC technology applications, ABB has equipped two smaller shovels with modern DCS800 DC converters with reactive power compensation systems at a quarry in Germany. The upgrade was necessary due to frequent unscheduled downtime and to improve the functional reliability and safety of the dated analog electrical system. The new fully-digital converter and new drive control have helped to provide a high degree of functional reliability and reduce overall maintenance costs. Torque control and a backlash protection system for the new drives also helped to reduce the stress factors affecting the machine during operation. With the installed AC reactive power compensation, based upon the ACS800 AC drive, the high surge current of the DC load could be reduced by 25%, further optimising the drive system solution. After a direct comparison of the new shovel with the conventional motor-generator-set solution, a measured energy savings of about 15% was realised. This was calculated using 5000 operating hours/year as a basis with a resultant cost savings of US$ 17,500/year for this application (5 m³ shovel and an industry price of US$ 0.08/kWh).

For dragline retrofits the situation is similar. An upgrade of an existing machine can be cost-effective and would be available for a short-term mine planning consideration. A new dragline excavator needs a lead time of about two years from the planning to the startup and often requires investment approval at the board level. For that reason, in the North American coal mining industry various tenders have been offered in 2012 for dragline retrofits that focus AC motion drives. ABB offers recent experience in this area from a number of AC retrofits for continuous mining machines, and from two draglines equipped with AC drives.

Service and life cycle management

The mining industries face a common goal of maximising their production output at the lowest possible operational costs, with a focus on safety. Increasing uptime requires proper equipment maintenance to ensure the optimum lifetime and performance. This requires a professional engineered and predictive approach for service from the beginning of the equipment's life cycle or after certain operational period to optimise mining operation.

An available system service from ABB is designed to be performed onsite as simply a diagnostic audit of the mining system and has value in measuring the process. With this service, the company analyses the performance of the system and identifies the relevant key performance indicators (KPIs), which results in a benchmark study. This study will be the basis from which to value the financial impact and to consider measures to improve the system. The components that make up a system service are designed to capture opportunities that impact return on investment (ROI) to the operator. The ROI portion attempts to quantify the performance gap in terms of financial return to a specific measure. For this analysis ABB, together with the University RWTH Aachen, developed a Payback Calculator for shovel and dragline applications. After the evaluation of the payback time by the operator, ABB will offer service solutions with an implementation plan.

ABB follows a four-phase model for product life cycle management:

- Active.
- Classic.
- Limited.
- Obsolete.

The company can provide a customised service concept, which covers different areas from global product support to life cycle management, specific operator training or full service concepts.

16.2. Appendix B: BOSCH Proposal (BOSCH REXROTH, 2023)

Rexroth
Bosch Group

Reliable Performance for Mining and Materials Handling





From strength to strength

When it comes to reliable performance in demanding environments all over the world, we know all about providing the right movement, power, control and function regardless of technology or location. Flexible system solutions for a wide range of applications help you to optimize performance and productivity, wherever you are.

Providing excellence

If you really need to get things moving it's all about Bosch Rexroth solutions. The scope of our solutions for heavy engineering projects is unrivaled and with our expertise in applications engineering we provide a unique service to help you optimize performance and productivity.

It doesn't matter if it's about bringing the right speed to your ship unloader, bringing excellent power and controllability to your conveyor, or providing shock load protection to your bucket wheel drive.



Powerful flexibility

If there is one thing we know how to do, it is how to get things moving. We have the solution, regardless of technology and environment. Solutions that provide you with the drive and control you need to gain maximum benefit from your investment. The best part? If your needs change, the solutions can be easily adjusted and upgraded, providing a versatile asset towards competitive advantage.

Bucket wheel drive – features

- built-in overload protection that eliminates trip-outs and minimizes production losses in the event of a stall
- low inertia and weight, reduces stresses on your boom and slewing gear
- full torque at an infinite range of speeds, letting you adjust to all types of materials and conditions

Slewing and luffing drives – features

- compact arrangements
- shock load protection
- excellent controllability

Long travel drive – features

- perfectly balanced load sharing on the wheels
- excellent controllability
- low maintenance


Bucket wheel drive


Luffing drive


Luffing drive


Long travel drive



Bucket wheel reclaimer

Doing a good turn



Kilns and drums

Twisting, turning and crushing. Material processing can be a tough job with high demands on reliability, flexibility and speed options. Bosch Rexroth offers reliable system solutions for smooth operations that make the most of the material processed.

Kilns and drums – features

- perfect load sharing
- High torque providing starting torque for an unlimited period of time
- enabling trouble free inching with the main drive
- flexible system solution offering reliability through redundancy

Ball mills – features

- weight and space saving
- Infinitely variable speed enables optimization of processes
- enabling trouble free inching

Crushers – features

- built-in overload protection eliminating trip-outs, minimising production losses in the event of a stall
- easy start, stops and reversals
- extending life of wear components


Crushers


Ball mills

Always on the move

Slow or fast, backwards or forwards – the speed requirements and directions don't really matter. With our powerful and flexible solutions you get reliable transportation solutions tailored to your needs. Solutions enabling you to optimize you performance, bringing material to where you need it - when you need it

Conveyors – features
- torque control protects the belt from overloads
- soft starts and stops keep belt stress to a minimum
- low speeds can be used for easy inspection
- high starting torque that can be maintained for an unlimited period of time

Ship unloaders – features
- excellent controllability
- forward and reverse in both driving and braking mode without limitations

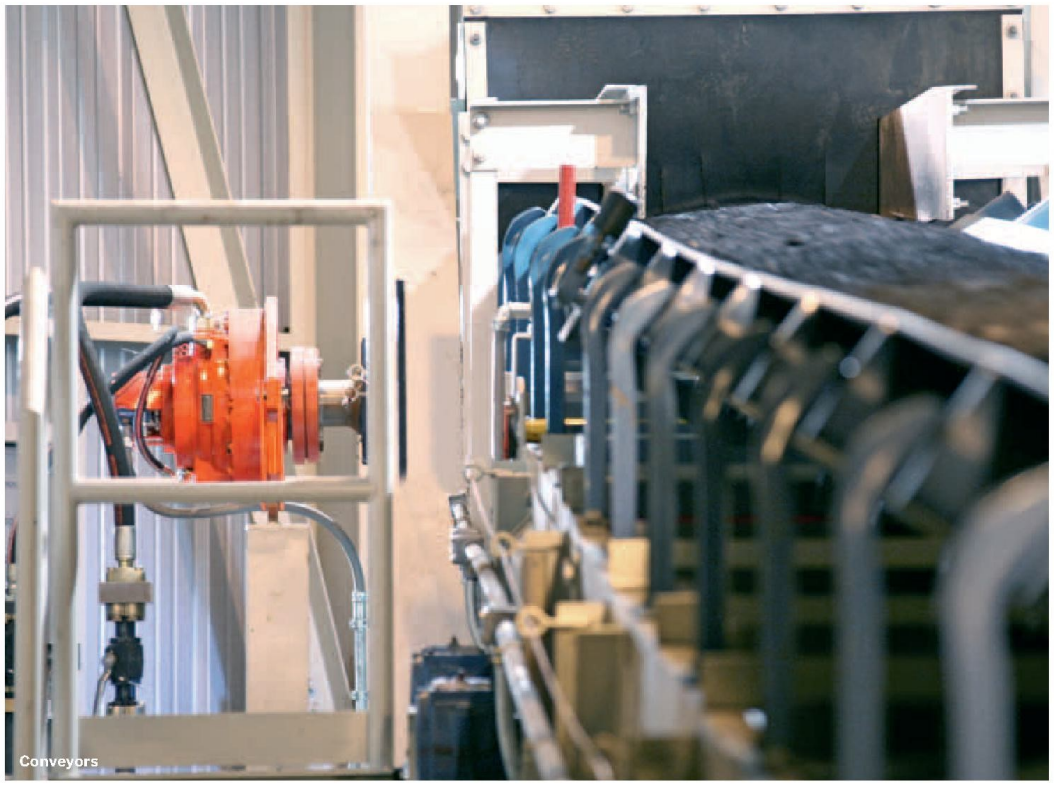
Car handling – features
- excellent controllability
- high reliability for optimized capactiy
- all functions from one supplier

Feeders – features
- provides full starting torque for an unlimited time
- built-in overload protection
- easy handling of frequent starts and stops
- variable speed enabling process optimisation




Apron feeder


Car handling system


Conveyors

Reliability all the way

Our drive is to make sure that our customers get the most out of their processes and work through great solutions and services. To facilitate and enhance their operations by being an active long-term partner sharing our experience, know-how and technological solutions.

A long-term partner

Wherever you are, we are right there with you. With our global network of knowledge and service, we offer local support that goes well beyond the ordinary. Our experienced engineers are not only experts in our own solutions, but also specialists in your applications.

With our own local service personnel who understand our products and your situation, we have the capacity to take care of the system solutions so that you can concentrate on the most important aspect of all – your core business.



The Drive & Control Company Rexroth Bosch Group

Turnkey solutions for bucket wheel reclaimers



Making good even better

Bosch Rexroth offers an easy path for new machines and for modifying or upgrading existing machines with the best system solutions for total performance. Our expertise and systems ensure that any and all relevant requirements are taken into account to achieve a complete and efficient solution.

Our solutions provide the highest possible flexibility in design and installation. Our systems are modular and engineered for heavy-duty performance. A hydraulic system has the advantage of allowing installation of the electric motor/pump, regardless of where it functions. In many cases, this feature provides a real benefit. For example, in the bucket wheel drive system only the relatively lightweight hydraulic motor needs to be attached to the bucket wheel, at the end of the boom, while the heavy electric motors and pumps can be positioned near the center of the machine.

Save weight and energy
On a performance-to-weight basis, our solutions were already best in class. With our new CBM motors, we have taken the next step. Compared with our previous standard motor, Marathon, our CBM motors are smaller yet more powerful, with higher performance at about 25-30% less weight.

Less weight at the end of the boom means lighter counterweights, leading to a lower slewing torque and therefore a leaner slew drive system. The weight savings offered by a CBM bucket wheel installation allows the entire machine to have a considerably lighter and less costly design.

Take full advantage of the flexibility, modularity and unique features of Bosch Rexroth systems solutions to optimize the design and productivity of your bucket wheel reclaimer – both for new machines and for existing machine upgrades.



1. Belt Conveyors
▲ Torque control protects the belt from overloads
▲ Soft starts and stops keep belt stress to a minimum
▲ Low speeds can be used for easy inspection
▲ High starting torque that can be maintained for an unlimited period of time
2. Bucket Wheel Drives
▲ Built-in overload protection that eliminates trip-outs and minimizes production losses in the event of a stall
▲ Low inertia and weight, reduces stresses on your boom and slewing gear
▲ Full torque at an infinite range of speeds, letting you adjust to all types of materials and conditions
3. Slewing and Luffing Drives
▲ Compact arrangements
▲ Shock load protection
▲ Excellent controllability
4. Long Travel Drives
▲ Perfectly balanced load sharing on the wheels
▲ Excellent controllability
▲ Low maintenance
1
2
3
3
4

Invest smart and boost performance with Bosch Rexroth

Our high-performance solutions ensure quick payback and minimal maintenance for your bucket wheel reclaimer. They are ideal for both new machines and existing equipment upgrades. Many customers have already taken advantage of our extensive application knowledge, comprehensive portfolio and familiarity with optimizing performance and productivity in the industry.

We offer outstanding solutions for every bucket wheel reclaimer application. Our direct hydraulic drives are ideal in key positions such as bucket wheel, slewing, and long-travelling, as well as for intermediate conveyors and boom conveyors. We also offer excellent solutions for tasks such as luffing and auxiliary linear functions.

When you use our solutions for any of your bucket wheel reclaimer functions, you can be confident that you are getting a complete fully integrated and optimized system solution. Bosch Rexroth is your guarantee for these turnkey solutions.

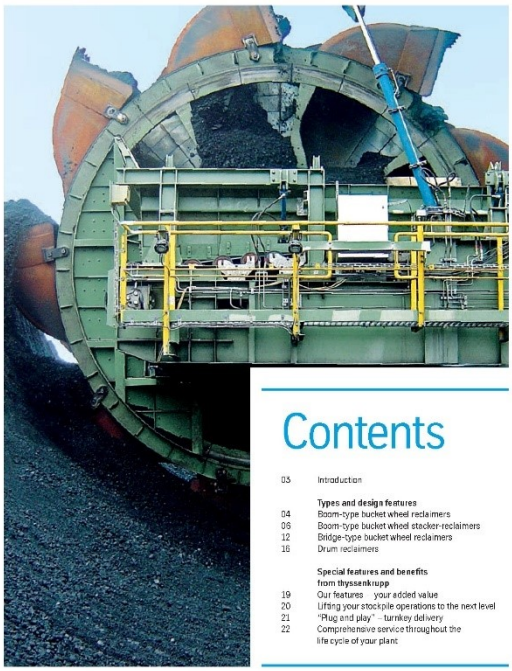
Close to you – personally and geographically
Bosch Rexroth is your guarantee of quality assurance and a one-stop solution from a single supplier. Our worldwide organization provides support for engineering, installation and service, regardless of location. This translates into quick and well-coordinated global support for quotations, installation and on-site service or assistance, when needed.

We consider every aspect
For more than 30 years we have supplied and installed drive systems based on Hägglunds solutions for bucket wheel reclaimers. Our cumulative experience through the years has given us a solid understanding of how to configure each function on the machine for optimal results. For example, we know that it is important to adapt and optimize the speed of the bucket wheel to suit different materials and conditions.

Density, shape, moisture content and temperature all affect the speed appropriate for maximum handling capacity. A change in any of these factors requires a compensatory adjustment in speed. The unique speed and torque control provided by our systems enable you to achieve maximum efficiency in every situation.

16.3. Appendix C: Thyssen-Krupp Proposal (Thyssen-Krupp, 2023)





Contents

05 Introduction

Types and design features
04 Boom-type bucket wheel reclaimers
06 Boom-type bucket wheel stacker-reclaimers
12 Bridge-type bucket wheel reclaimers
16 Drum reclaimers

Special features and benefits from thyssenkrupp
19 Our features – your added value
20 Lifting your stockpile operations to the next level
21 "Plug and play" – turnkey delivery
22 Comprehensive service throughout the life cycle of your plant

Advanced technology for stockpile management

Bucket wheel reclaimers are the ideal means of handling and moving large amounts of bulk materials in the shortest possible time. They can be designed as reclaimers or combined stacker-reclaimers for handling huge volumes of coal, ores and other materials in ports, power plants, stockyards or steel plants. High throughputs need optimum handling technology. The system components must be matched up with one another to ensure smooth transport flows. And that is where these types of machines provide ideal solutions.

thyssenkrupp's bucket wheel reclaimers combine robustness, high speed and high throughputs. They are the result of decades of experience and technical competence, proven in many special configurations and new developments, such as the lightweight bucket wheel design.

Drum reclaimers offer the highest possible homogenization at a constant reclaiming rate combined with low maintenance costs for optimum blending of materials.

Following a lengthy standstill in Europe's drum reclaimer business, thyssenkrupp Industrial Solutions has again set the precedent for high-capacity, high-performance and highly reliable blending machines operating in steelworks and in iron ore and coal mines. Thanks to specific design improvements the new drum reclaimers combine reduced wear, weight and power consumption, while still achieving the optimum homogenization and reclaiming process.

Proven technology tailored to your needs
thyssenkrupp refines proven technologies and tailors them to your capacity requirements and intended use, regardless of whether you require a boom-type bucket wheel reclaimer, a combined stacker-reclaimer, a bridge-type bucket wheel reclaimer or a drum reclaimer.

A tradition of innovation

thyssenkrupp Industrial Solutions has fully integrated the know-how of PWH Anlagen & Systeme and DEMAG Lauchhammer, companies with over a century of history that were known worldwide for their excellent bucket wheel and drum reclaimer solutions.

This tradition, combined with consistent innovative strength, ensures our proven bucket wheel and drum reclaimers will continue to set standards in quality and cost effectiveness under the thyssenkrupp label. Our vast experience in building all types of bucket wheel and drum reclaimers guarantees the ideal solution to meet all your needs.

Boom-type bucket wheel reclaimers

Boom-type bucket wheel reclaimers are designed to reclaim stockpiles on both sides of their rail track. Changing between stockpiles arranged in line is also possible through luffing/slewing of the boom and subsequent long travelling.

In combination with a seperate stacker, this type of machine provides the highest possible flexibility for stockyard management, along with the possibility of simultaneous stacking and reclaiming operations.

Bucket wheel reclaimers for ore applications:
- Ore mines
- Steel mills
- Export terminals



Rocker type machine with luffing cylinder on the rear side

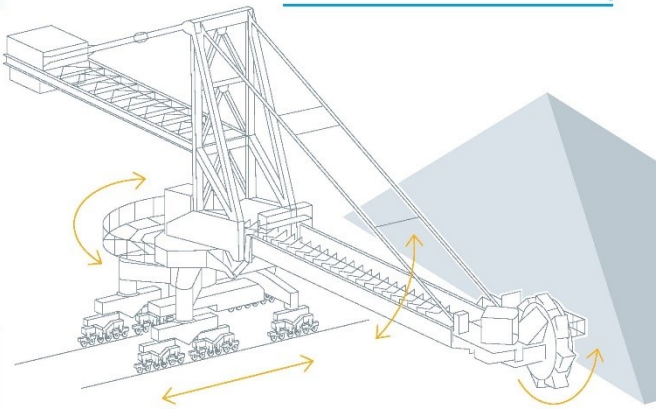
Location
Saim, Mauritania
Material
Iron ore and pellets
Reclaiming capacity
3,700 t/h
Boom length
40 m

High capacity bucket wheel reclaimers for iron ore mines



Typical machine design of Australian bucket wheel reclaimers

Location
BHP, Australia
Material
Iron ore
Reclaiming capacity
15,000 t/h
Boom length
60 m



Bucket wheel reclaimers for coal applications:
- Coal-fired power plants, coking plants and steel mills
- Coal export terminals



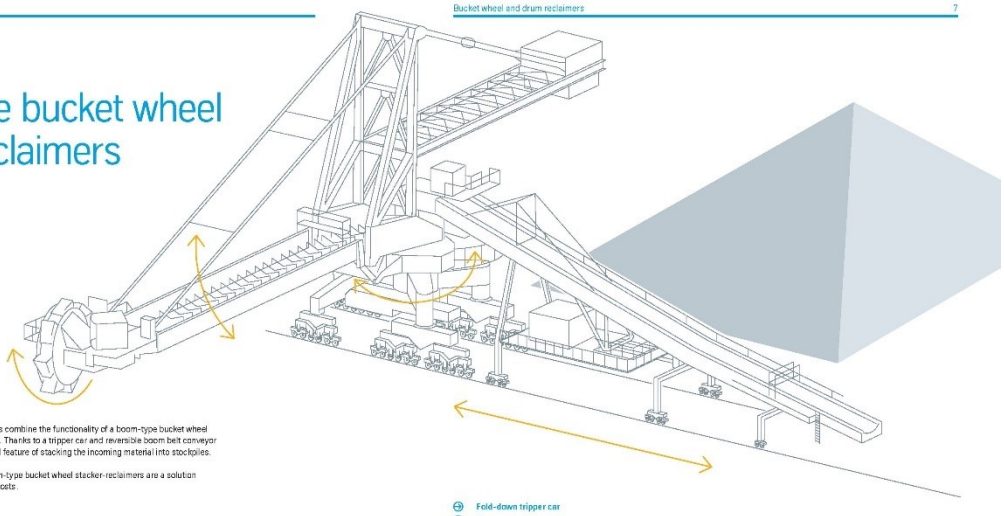
Rocker type machine with luffing cylinder on the rear side

Location
Muuga, Estonia
Material
Coal
Reclaiming capacity
2,200 t/h
Boom length
55 m

6

Bucket wheel and drum reclaimers 7

Boom-type bucket wheel stacker-reclaimers



Boom-type bucket wheel stacker-reclaimers combine the functionality of a boom-type bucket wheel reclaimer and a stacker in a single machine. Thanks to a tripper car and reversible boom belt conveyor this type of machine provides the additional feature of stacking the incoming material into stockpiles.

This functional integration means that boom-type bucket wheel stacker-reclaimers are a solution characterized by relatively low investment costs.

Rigid tripper car



Rocker type machine with luffing cylinder on the front side and rigid tripper car

Location
Jiaxing, China
Material
Coal
Stacking capacity
3,600 t/h
Reclaiming capacity
1,200 t/h
Boom length
50 m

Fold-down tripper car
No central chute



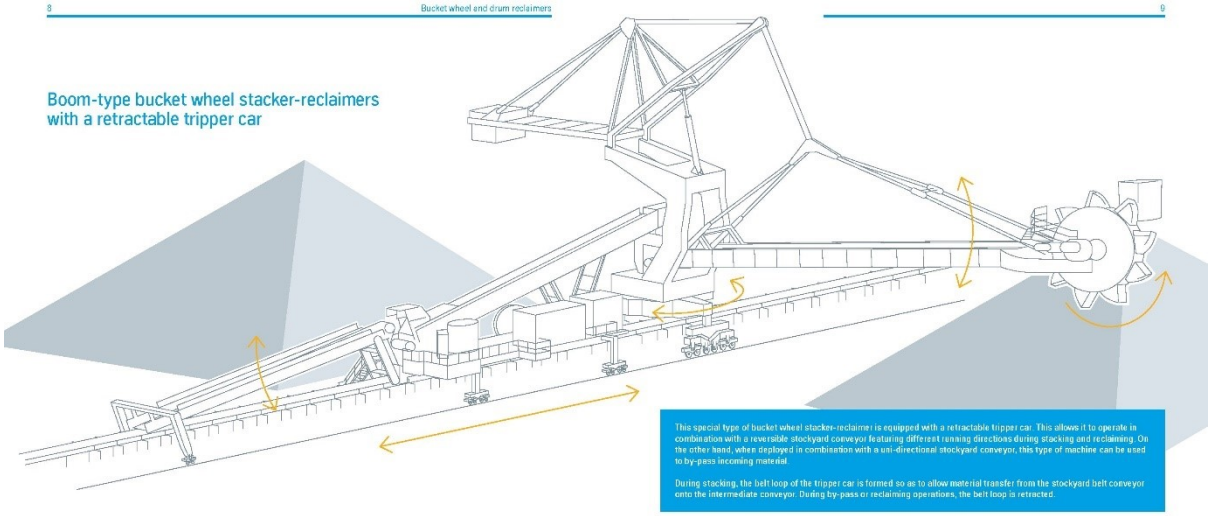
Special design with foldable tripper car for stacking or reclaiming operation – no central chute needed for reclaiming

Location
EECV L3, Netherlands
Material
Iron Ore / Pellets
Stacking capacity
5,600 t/h
Reclaiming capacity
5,600 t/h
Boom length
40 m

8

Bucket wheel and drum reclaimers 9

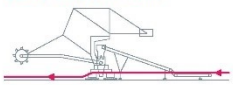
Boom-type bucket wheel stacker-reclaimers with a retractable tripper car



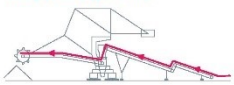
This special type of bucket wheel stacker-reclaimer is equipped with a retractable tripper car. This allows it to operate in combination with a reversible stockyard conveyor featuring different running directions during stacking and reclaiming. On the other hand, when deployed in combination with a uni-directional stockyard conveyor, this type of machine can be used to by-pass incoming material.

During stacking, the belt loop of the tripper car is formed so as to allow material transfer from the stockyard belt conveyor onto the intermediate conveyor. During by-pass or reclaiming operations, the belt loop is retracted.

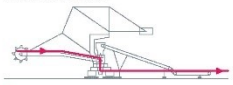
By-pass operation (tripper car retracted)

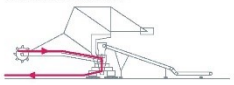


Stacking operation (tripper car lifted)



Reclaiming operation (tripper car retracted)





Bucket wheel stacker-reclaimers for coal and ore handling at export terminals



C-frame type machine (pantograph type) with intermediate conveyor and retractable tripper car

Location
EMO KB6, Netherlands
Material
Iron ore and coal
Stacking capacity
6,000 t/h
Reclaiming capacity
4,600 t/h
Boom length
60 m

Bucket wheel stacker-reclaimers for coal handling at export terminals and steel mills



C-frame type machine (pantograph type) with intermediate conveyor and retractable tripper car

Location: EECV LT, Netherlands
Material: Coal
Stacking capacity: 4,000 t/h
Reclaiming capacity: 3,400 t/h
Boom length: 47.5 m

Bucket wheel stacker-reclaimers for coal handling at export terminals and steel mills



C-frame type machine (pantograph type) with intermediate conveyor and retractable tripper car

Location: CSA, Brazil
Material: Coal and coke
Stacking capacity: 4,400 t/h
Reclaiming capacity: 1,100 t/h
Boom length: 53.4 m

Boom-type bucket wheel stacker-reclaimers with a shiftable tripper car



C-frame type machine with intermediate conveyor and shiftable tripper car with two-way chute for stacking or by-pass operation

Location: Kamsar, Guinea
Material: Bauxite
Stacking capacity: 4,600 t/h
Reclaiming capacity: 4,500 t/h
Boom length: 45 m

Boom-type bucket wheel stacker-reclaimers with a counter directional tripper car



Rocker type machine with intermediate conveyor, transverse conveyor and counterdirectional tripper car

Location: Jimah, Malaysia
Material: Coal
Stacking capacity: 3,800 t/h
Reclaiming capacity: 2,250 t/h
Boom length: 41.2 m

Drum reclaimers for coal handling



Drum reclaimer for bi-directional operation

Location: Ekibastuz, Kazakhstan
Material: Coal
Capacity: 4,000 t/h
Rail gauge: 43.5 m

Drum reclaimers for coal handling



Drum reclaimer for bi-directional operation

Location: Eskom Medupi, South Africa
Material: Coal
Capacity: 3,400 t/h
Rail gauge: 43.5 m

Our features – your added value

Sophisticated state-of-the-art features make our bucket reclaiming machines eco-friendly and ensure both reliable and user-friendly operation that avoids downtime and facilitates day-to-day processes.

Environmental design
To meet today's environmental requirements, thyssenkrupp's bucket reclaiming machines are generally equipped with all the necessary precautionary equipment and systems to minimize the impact of noise, dust emissions, etc. on the surroundings. In order to reduce dust emissions to a significant extent, an on-board water spraying system can be provided for our bucket reclaiming machines, if required and specified. In addition, the bucket wheel transfer point and the conveyors of our boom-type bucket wheel reclaimers and stacker-reclaimers can be covered by hoods.

Maintenance assistant system (MAS)
As a maintenance support tool, MAS helps to ensure maintenance takes place at regular intervals. Every time maintenance activities are completed, they are recorded and documented in the system logbook. By adhering to the preset maintenance schedule, operators can avoid expensive repairs caused by a lack of maintenance and ensure minimum downtimes.

Local analyzer interface (LAI)
As part of the standard equipment, the LAI is installed on each bucket reclaiming machine. This device collects and stores different kinds of data, e.g. measuring signals. As a benefit for the customer, the LAI provides access to this large set of historical data from the machine, which is useful for early recognition of possible upcoming defects or for subsequent analysis of failures or damage.

Automation-ready design
All bucket reclaiming machines built by thyssenkrupp are characterized by their automation-ready design, which is a prerequisite for a fully automated reclaimer. Our automation-ready reclaimers not only give you, as a standard feature, state-of-the-art integrated drive and operational safety control via a PLC system (operating in local, manual and semi-automatic mode) as a standard, they are also equipped with the specially configured control system required for the optional upgrade to an autonomously operating machine.







Lifting your stockpile operations to the next level

After mechanically optimizing your reclaimers, automation and digitalization is the next logical step to take your operations to the next level. By combining our mechanical know-how and operating experience with state-of-the-art sensor technology we can fully exploit the potential of our customers' assets. From smaller process improvements or assistance modules to fully autonomous reclaimers, we offer our customers a wide range of smart automation and digitalization solutions.

Collision avoidance (risk reduction)

- Safe operation through our anti-collision management system
- Ensuring operations under the highest safety standards as the first step towards fully automated operations

Stockyard management (inventory transparency and advanced stockyard planning)

- 3D volume measurement of stockpiles for an overview of your stockyard at any given time
- Intelligent stockyard management for efficient utilization of available space and stocktaking material

Autonomous operation (productivity growth & optimizing machine lifetime)

- Productivity growth through our adaptive controller – optimal material flow by constantly measuring the stockpile surface
- Unmanned operation through fully automatic positioning
- Reducing peak loads that would otherwise lead to a shorter machine lifetime, higher maintenance costs and downtimes

Your added value

- Higher productivity
- Operational safety improvement & risk reduction
- Lower operational costs
- Less machine stress
- Inventory transparency



"Plug and play" – turnkey delivery

Through the turnkey delivery of tested, preassembled bucket reclaiming machines we supply a ready-to-use solution for your stockyard. This gives you an immediate economic benefit with minimum on-site construction work.

How you benefit from turnkey delivery

- Time-saving erection on the manufacturer's pre-assembly yard where tools, lifting equipment and a workshop are always available
- Pre-commissioned bucket reclaiming machines mean only small adjustments are necessary at your site
- Minimized downtime on the stockyard, also when replacing an existing machine







Comprehensive service throughout the life cycle of your plant

With thyssenkrupp Industrial Solutions you can count on cost efficiency right from the start. Through the turnkey delivery of tested, preassembled bucket reclaiming machines, we ensure that on-site construction work is kept to a minimum. And even after commissioning, we remain a partner you can trust for all your needs.

Always there when you need us

Our portfolio includes a full range of services for your bucket reclaiming machines – throughout their entire life cycle. thyssenkrupp Industrial Solutions provides its customers all over the world with a reliable and extensive customer service. The scope of customer services ranges from maintenance and engineering support, advisory services and spare parts, trainings for operation and maintenance to plant optimization, repair and refurbishment. On top of this, thyssenkrupp Industrial Solutions offers a range of tailor-made services to meet the requirements of today's customers.

One-stop-shop service

360° Service

- Parts & supply management
- Field & workshop services
- Revamps & outages
- Asset management



16.4. Appendix D: BOSCH Specifications and Quotation (BOSCH REXROTH, 2023)

DC-Form

Systems and Engineering Quotation

Systems and Engineering (DCEN/EPU2-GB)

rexroth
A Bosch Company

Tata Steel UK Ltd
Port Talbot Works
Port Talbot
SA13 2NG

Bosch Rexroth Limited
15 Cromwell Road
St Neots
PE19 2ES
Tel. +44 (0)345 604 4106
E-mail: sales@boschrexroth.co.uk
www.boschrexroth.co.uk

For the attention of David Adams

Customer Ref:	Quotation Ref:	Rev:
Blending Plant BWR	1103941045	

Dear David,

Project: Replacement Drive System for Blending Plant BWR .

Quotation Type: **Fixed**

Please find attached our quotation in relation to your enquiry referenced above. The technical information we have is based on the information provided by Tata Steel and that obtained during the site visit.

Please refer to document "BWR Drive Selection"

The equipment selected is based on the use of standard industrial components, in accordance with Bosch Rexroth and European standards covering electrical and mechanical standards. Any deviation to comply with local standards or any other standards will require further assessment and may be subject to a price increase.

The environmental conditions are based on those of a UK installation associated with metal recycling industry. The intended location is within the existing hydraulic room.

In the event of selecting Bosch Rexroth as your supplier, please send your purchase orders to **sales@boschrexroth.co.uk** with a copy of the Bosch Rexroth quotation to ensure the most expedient processing and acknowledgement.

We trust that our offer is of interest and look forward to your further instructions. If you have any queries regarding our offer please do not hesitate to contact us.

For and On Behalf of
Bosch Rexroth Limited
DCEN/GB-HD/SAL-UK

pki, BOSCH, EMEA, J, O, john.berry
Digitally signed by pki, BOSCH, EMEA, J, O, john.berry
Date: 2023.03.17 10:45:47 Z

John Berry
Sales HD UK DC-HD/SAL-UK

cc: XX
Attachments: XX

© Bosch Rexroth Ltd. 2021

DCFR72155-880_FOR_N_EN_2021-02-17.docx

rexroth
A Bosch Company

About Bosch Rexroth



Drawing on our own technologically advanced component inventory and a dedicated network of experienced engineers, we are able to provide optimised, drive and control solutions to industry. Affording enhanced precision, combined with full connectivity with our digital world, from which efficiency, durability and thru life reliability can be realised.

Having subjected our technology to the extremes of the freezing arctic, the depths of our oceans and the heat radiated from steel making furnaces; our engineered solutions continue to perform and impress. With performance matched to capture the smallest movement under the most significant loads, the ability to bring precise motion to almost any structure is possible.

As a **global partner, Bosch Rexroth** supports mechanical and plant engineering efforts around the world with its cutting-edge technology and unique industry knowledge. More than **38,000 associates across the globe** are developing tailored, safe and resource-friendly solutions. Our innovations deliver multi-dimensional enhancements for machine manufacturers and end users. For example, they help to reduce harmful carbon dioxide emissions while simultaneously raising productivity.



Above all, we make it easy to use **cross-technology solutions** by means of predefined functions and integrated engineering tools.

rexroth
A Bosch Company

Bosch Rexroth Applications & Engineering


Civil Engineering


Offshore


Materials Handling


Automotive


Entertainment


Metallurgy


Mining and General Mech. Engineering


Transport Technology


Machine Tools


Testing and Simulation Technology


Aerospace Technology


Energy Technology


Printing and Converting


General Automation


Food and Packaging


Tightening and Press Fit


Special Technology


Naval Technology


Resistance Welding


Motion Systems


Mounting and Handling


Research Technology


Wind power


Tidal Power

rexroth
A Bosch Company

Quote Line Items

Item	Description	Qty	List Each	Line Total
10	***Bosch Rexroth Hagglunds DUc Half*** cabinet style of hydraulic power unit, complete with a ***132kW*** electrical motor mounted to a closed loop axial piston pump which shall be supplied from a stainless-steel oil reservoir that comes with the system health monitoring sensors. these include a reservoir PT100 temperature sensor, system pressure transmitter, boost pressure transmitter, oil level sensor, suction valve isolation switch, 1 off return and 1 off drain filters with blocked indication switches. Also fitted are an air oil breather, oil level sight glass, oil sample point, oil reservoir drain down valve, oil tank heater and an oil filler point through a quick release coupling. Maximum system pressure is 350 bar giving a maximum torque from the CB840-680 drive motor of 221kNm. Maximum output flow will give a maximum shaft speed of 8 rpm. (Please note that the maximum torque and maximum speed are not achievable simultaneously due to the installed power) An air oil cooler is included which is mounted to the cabinet in which the interconnecting hoses are included. Fully variable speed of the feeder is via our "Spider" control unit, which is wired and mounted to the power unit. Speed input signal can be ±10vdc or 4-20mA. Health monitoring indication is displayed on the front screen showing the warnings and alarms. Electrical voltages are based on 400v-3ph-50hz and 110/220vac-1ph-50hz. All electrical motors are to IEC specifications. Electrical Motors are IP55 rated Spider Control Unit is IP65 rated Instrumentation is IP65 / IP67 rated Documentation includes: - Electronic copy in a pdf format of the Installation & Maintenance" manual. **Type : DUC-LS2-132-250+000-0-A-Y-S-E-400/50**	**1**		
20	***Bosch Rexroth Hagglunds CB 840 680*** direct drive motor complete with shrink disc coupling. **Type : CB 840 680 CA0N00 00 00**	**1**		
30	***Bosch Rexroth Hagglunds*** torque arm complete with pivot attachment and mounting bolts. **Type : TC A 0840 2 0 00**	**1**		
40	***Bosch Rexroth Hagglunds*** speed sensor to mount directly to the drive motor. **Type : SPDC CB—0 01856 00 00**	**1**		

50	***Bosch Rexroth Hagglunds*** harsh environment kit to mount directly to the drive motor. **Type : HEK 26 CRN 00 00**	**1**

Total List Price	
Discount :	
Nett Price	**£136,585.37**
Material Surcharge @ 2.5%	**£3,414.63**
Total Nett Price	**£140,000.00**

Options

Item	Description	Qty	Budget Each	Line Total
OP10	Profibus Card	**1**	**£964.73**	
OP20	Hydraulic Oil can be quoted if requested.	**1**	**TBC**	
OP30	Assistance with installation & commissioning can be quoted if requested. Price shown is budgetary and based on 2 engineers for 5 days using Monday to Friday day rates.	**1**	**£6,000.00**	
OP40	Supply of interconnecting flexible hoses based on a 5m run	**1**	**£3,000.00**	

Note: Price is exclusive of the UK rate of Value Added Tax (VAT)
Exclusions apply: Please refer to section "Technical Notes".

Rev.	Date	Name	Changes
AA	XX	XX	XX
AB			
AC			

rexroth
A Bosch Company



rexroth
A Bosch Company

Terms and Conditions

Terms and Conditions of Sale, Systems and Engineering in accordance with DCPD 72061-000-AN2.

Supply Condition

Our price is offered FCA Our Works Wakefield for delivery to a UK destination by road transportation. Packaging and delivery would be charged extra, dependent on destination within the UK and any applicable packing specification (Incoterms 2010 apply).

Delivery

Delivery would be **17** working weeks from receipt of order and agreement of all commercial and technical conditions.

The above delivery is also based upon achieving a design freeze (circuit approval) within 2-3 weeks from an order placement.

Any changes requested after the design freeze date may impact on the delivery programme and incur costs. Please refer to Section 3 of our Terms and Conditions of Sales, Systems and Engineering (DCPD 72061-000-AN2).

Payment Terms

30% with order, payment due immediately.
40% before despatch of goods.
30% nett cash account 30 days.

Any delay in payment to Bosch Rexroth Ltd. may affect the delivery date and / or the contract conditions.

Please note that the above terms, or mutually agreed terms, must be clearly stated on any order before it can be processed.

Payment

Please refer to Section 11 of our Terms and Conditions of Sale, Systems and Engineering (DCPD 72061-000-AN2).

Quotation Validity

Quotation valid till the 25th March 2023.

Warranty

Standard warranty terms apply. Please refer to Section 7 of our Terms and Conditions of Sale, Systems and Engineering (DCPD 72061-000-AN2).

Intellectual Property and Software

Definitions and rights considering use, please refer to Section 13 of our Terms and Conditions of Sale, Systems and Engineering (DCPD 72061-000-AN2).

Quotation Type

Under cover of this letter, the offer is identified as a quotation type. These types are defined under Section 2 of our Terms and Conditions of Sale Systems and Engineering (DCPD 72061-000-AN2); and draw your attention to the restrictions placed on 'Non-Binding Quotations'.

The information within this document is proprietary and confidential and must not be disseminated to, or used by, third parties without Bosch's written consent.

rexroth
A Bosch Company

For and On Behalf of
Bosch Rexroth Limited
DCEN/sector

Richard Bates DCGB/SVE pki, BOSCH, EMEA, R, I, richard.bates 2023.03.17 11:10:37 Z

Name (authoriser 2)
Job Description or Title

For and On Behalf of
Bosch Rexroth Limited
DCEN/sector

pki, BOSCH, EMEA, J, O, john.berry Digitally signed by pki, BOSCH, EMEA, J, O, john.berry Date: 2023.03.17 10:46:18 Z

Name (authoriser 1)
Job Description or Title

For and On Behalf of
Bosch Rexroth Limited
DCEN/sector

Name (authoriser 3)
Job Description or Title

For and On Behalf of
Bosch Rexroth Limited
DCEN/sector

Name (authoriser 4)
Job Description or Title

rexroth
A Bosch Company

Technical Notes System Solutions

Operating Environment

Equipment Location:	Indoor
Ambient Temperature:	0°C to +35°C
Humidity Level:	up to 85% maximum
Height Above Sea Level:	Max 1000m
Corrosive Atmosphere:	None / Dusty environment
Special Considerations:	None
Hazardous Zone Rating:	N/A

Customer Incoming Electrical Supply

Electrical Supply - 3 Phase:	400VAC 3Ph 50Hz
Electrical Supply - 1 Phase:	110/240VAC
Electrical Supply – DC:	24VDC

Duty Cycle

Continuous

Hydraulic Fluid

The equipment offered is suitable for use on Shell Tellus SMX VG68 (or equivalent, depending on ambient temperature, viscosity curve and cleanliness levels according to the product datasheets).

General System Operating Description

Metal recycling infeed conveyor which feeds the scrap metal into the shredder. The conveyor is a continuous duty cycle with constant stops and starts while feeding the scrap metal into the shredder.

Layout

The system layout shall generally be as follows:

- Cabinet design vertical mounted
- Fork pockets
- Lifting points
- Pump sets shall be mounted vertically and have a positive head of oil from the reservoir.

Fluid Pipe and Fittings

The fluid pipework shall be designed to optimise the transmission of fluid, with consideration to address pressure drop, turbulence, cavitation and sound attenuation according to the environmental operability, duty cycle and fluid identified.

The pipe shall be sized to suit the applicable pressure and flow rate in each section, with consideration to oil velocities and pressure drops. Pipes shall be clamped to provide adequate support, typically with polypropylene jaws mounted to a carbon steel base.

Hydraulic Hoses

- Hose Material: Rubber (suitable for oil type)
- Hose End Fittings: DKOL & DKOS / ISO 6162 (SAE3000 & SAE6000)
- Hose End Materials: Carbon steel, plated

Pump Set Details

Main Pump Set - Electric Motor
Electric Motor Voltage: 400V / 3Ph / 50Hz

- Electric Motor Power: 75kW
- Efficiency Rating: IE2
- IP Rating: IP55
- Anti Condensation Heater: None
- Thermistors: None
- Nominal Speed: 1500 rpm
- Special Considerations: None

Main Pump Set

- Pump Type: Closed Loop Axial Piston pump, controller type EPG
- Nominal Flow Rate: 265 l/min max at 50Hz
- Max Working Pressure: 350 bar
- Construction: Close coupled via bellhousing and drive coupling, with anti-vibration mounts
- Protection Measures: Pump Compensator and integrated cross line relief valves
- Special Considerations: None

Hydraulic Fluid Reservoir

The hydraulic fluid reservoir would be designed to optimise fluid movement and conditioning with consideration toward de-aeration, thermal balance, and contamination control. The capacity and construction would be matched to the operating cycle and fluid draw-off, with consideration to the operating environment and operating hydraulic fluid identified.

The reservoir would consist of the following major features:

- Style: Rectangular
- Total Volume: 130L
- Material of Construction: Stainless Steel
- Removable Lid: Yes
- Inspection Covers: None
- Sight Glass: Standard
- Immersion Heaters: Included
- Anti-syphon Features: None
- Drain & Oil Sample Valve: Included
- Suction Valves: Included
- Additional Features: None

Filtration

The design of the filtration system has been made to optimise the serviceability of the equipment, taking into consideration the environment, duty, hydraulic fluid and cleanliness levels demanded by the component inventory and system. With a view to target cleanliness in sensitive areas and those susceptible to contamination ingress, the following principles apply:

- Pressure Filtration: None
- Return Filtration: Qty 1off, Nominal Rating 10 micron, Bypass
- Drain Filtration: Qty 1off, Nominal Rating 10 micron, Bypass
- Offline Filtration: None
- Specific Filtration: None
- Suction Strainer: None
- Reservoir Breather: Qty 1off, Nominal Rating 10 micron, Standard

Hydraulic Fluid Cooling

The system has been designed to optimise cooling considering the environment and duty defined and the specific characteristics of the hydraulic fluid identified. The resulting cooling has been based on the natural convection of free air around the hydraulic reservoir and component inventory aiding cooling to electrical parts (solenoids, electric motors, electrical apparatus including amplifiers, transformers, and inverters (without restrictions)).

To aid the cooling capacity of the hydraulic fluid reservoir, additional cooling equipment has been provided as per the details below. Based on the maximum ambient temperature detailed above, this would result in a maximum system temperature of approximately 60°C measured at the hydraulic fluid reservoir. Note - some areas may exceed this temperature locally, for example pump case drains.

- Cooler Heat Dissipation: TBA kW
- Cooler Type: Air Blast Cooler
- Cooling Source: Return Oil
- Cooling Source Flow Rate: N/A
- Cooling Medium: Air
- Cooling Medium Temperature: Maximum 35°C
- Cooling Medium Flow Rate: N/A
- Cooling Medium Pressure: N/A

Cooler Electric Motor Details:

- Electric Motor Voltage: 400V / 3Ph / 50Hz
- Electric Motor Power: 2.2 kW
- Efficiency Rating: IE2
- IP Rating: IP55
- Anti Condensation Heater: None
- Thermistors: None
- Nominal Speed: 1500 rpm
- Special Considerations: N/A

Hydraulic Fluid Heating

The performance of the system is reliant on achieving an operable temperature under all conditions, adverse conditions or low temperatures may warrant consideration to a heating cycle during equipment start-up. This requirement has been met as noted below and takes into consideration both the operating environment, duty and hydraulic fluid identified.

It should be noted that the optimum performance of a hydraulic system will only be realised when it is brought to an operational mean average temperature of approximately 40°C.

- Hydraulic Fluid Heating Source: Immersion Heater
- Hydraulic Fluid Heater Power: 1.0 kW
- Hydraulic Fluid Heater Voltage: 400V / 3Ph / 50Hz
- Hydraulic Fluid Heater Quantity: 1 off

Other specific details relating to heating, None

Manifold Blocks

In order to supply the most compact and efficient design, our engineered solution makes use of standard and bespoke manifold blocks, configured according to functional requirements. Using a range of matched hydraulic components, including surface mounted and cartridge valves, the resulting manifold assembly provides an optimised installation envelope in order to maximise performance capability.

- Material Type: N/A
- Material Grade: N/A
- Finish: N/A

Instrumentation

The unit will include the following instrumentation:-

- Oil level sensor to monitor low oil level warning and minimum oil level shutdown.
- Oil temperature sensor to monitor minimum oil temperature shutdown, cooler control, high oil temperature warning and maximum oil temperature shutdown.
- Pressure switch to indicate clogged oil filters.
- Pressure transmitter to monitor main system oil pressure (4-20mA) including digital display.
- Suction valve switches to indicate when the valve is not fully open.
- Speed encoder for the pan drive motor

Painting

- Frame C3 Black RAL 9017
- Panels C3 Orange RAL 2002
- Doors C3 Orange RAL 2002

Noise

No consideration for noise output has been made as part of this quotation. Should a specific noise level be required, please provide further details by return and we would provide revised quotation accordingly.

Electrical Panel / Junction Box

No electrical panel is included in the scope of supply.

An internal junction box is included in which all instrumentation is wired to.

Electrical Installation Wiring

No external electrical installation wiring is included in scope of supply.

Factory Acceptance Test & Inspection for UK Built Power Units.

The equipment shall be subjected to the standard factory test and inspection programme to validate the functional operability of the equipment. Both performance and endurance testing is specifically excluded. When tests are completed all pump control valves, pressure relief valves, flow control valves, pressure switches and temperature switches shall be left set as per the circuit drawing unless otherwise specified. Where settings are not defined, or a range is provided, these valves shall be set to the minimum setting.

Validation of construction, presentation and identification (labelling), in accordance with documentation forming the original scope of supply; General Arrangement Drawing / Circuit Drawing / Material Listing and Electrical Wiring Diagram associated with fully wired equipment.

Verification of pressure test, subjecting discreet circuits to test fluid to check pressure integrity. Verification of component functionality according to designated datasheet function (not performance / response characteristics).

Adjustments to final settings may be required during installation and commissioning as outlined in our data sheet RE07900 'Installation, commissioning, maintenance of hydraulic systems'.

Equipment shall be tested using mineral oil HM VG68 in accordance with fluid recommendations identified within our data sheet RE15414 'Hydraulic fluids based on mineral oils and related hydrocarbons', with fluid cleanliness levels to match the equipment specified.

Whilst the equipment is supplied 'visually clean' it must be appreciated that when put into service, the equipment shall attain its respective cleanliness class as the component inventory beds in.

The integrity and continuity of electrical equipment (including earth bonding) is subjected to test when the equipment is supplied with a junction box or control panel, including electrical installation by Bosch Rexroth.

An inspection and test report shall be completed for each assembly (or batch of), compromising the following information:

- General confirmation of correct assembly
- Major Component Serial Numbers
- Test Values (e.g. pressure / flow / current / temperature / noise)
- Oil cleanliness
- Labelling

A witness test programme has not been included.

Free Issue Equipment

- N/A

Packaging and Protection

Our offer excludes packaging and protection.
Our offer includes for packaging and protection suitable for standard road transport & limited storage:

- Cased ply construction (depending on equipment size).
- Suitable for storage not exceeding 6 months without explicit instruction considering frequency of inspection, storage to provide environmental control.

Operation and Maintenance Manual

The equipment shall be provided with general documentation to support the safe handling, use, service and maintenance including the following documents:

- General Product Information on Hydraulic Products, RE07008.
- Installation, Commissioning & Maintenance of Hydraulic Systems, RE07900.
- Installation, Commissioning & Servicing of Hydraulic Pumps & Motors, RE07080.
- Installation, Commissioning & Maintenance of Industrial Valves, RE07300.
- Installation, Commissioning & Maintenance of Electro-hydraulic Servo & High-Response Control Valves, RE07700
- Installation, Commissioning & Maintenance of Proportional Valves, RE07800.
- Operation & Maintenance of Filters in Hydraulic Systems, Notes (Hydraulic Trainer Vol. 3)

The equipment shall be provided with specific documentation to support the safe handling, use, service and maintenance including the following documents:

- Hydraulic / Electrical Circuits (including bills of material)
- Hydraulic / Electrical General Arrangement Drawings
- Major Component Datasheets
- Spare parts list (commissioning and consumables)

All documentation shall be provided in English Language, in electronic format (pdf), temporarily downloadable from our data exchange server (temporary login and password provided upon completion of manual).

Further details, including spare parts price lists, can be provided upon request.

Should a system specific manual including detailed maintenance and operations instructions be required then this can be offered at an additional cost.

rexroth
A Bosch Company

Technical Notes Site Work

Site work

Our offer excludes installation & Commissioning

The competency of site personnel shall be matched to the role to be undertaken. Correct PPE shall be provided and any site specific accreditation & certification shall be met, provided this has been brought to our attention and agreed by us.

The client shall provide full details of their site representatives, including their contact details and responsibilities, together with a nominated representative to facilitate the progressive sign off, to authorise site extras (see below), and qualify the acceptance of site acceptance certificates.

Details of all working conditions including access, communication, details considering health and safety & well-being applicable to your site are required with receipt of order. Any variations to those specified in your enquiry document may incur additional costs.

All civil works shall be undertaken by others. These include (but are not limited to) holes in walls, floors, trenching, trench covers, ramps and foundation holes.

Suitable safe and secure areas for site cabin(s)/container(s), storage, adjacent to the installation area to be available, free of charge. All light, heat, ventilation, electrical, water and personnel services to be available free of charge including operable power supplies for tooling.

Craneage, scaffolding and access towers related to the offloading, positioning, inspecting and or dismantling operations are excluded.

Installation

Positioning and mounting of equipment within the civil structure / machinery shall be by others. Fixings, fasteners and anchorage devices are excluded from our offer.

All guarding / screening required as a result of a customer risk assessment, are excluded from our offer.
To summarise the scope of the installation:-

Site Preparation:

- Method statements and risk assessments (solely Bosch Rexroth supply): Excluded
- Technical appraisal, specifications for anchor points & structural loadings: Excluded
- Technical specification, supply of fixings, fasteners & anchorage devices: Excluded
- Guarding & screening, barriers, protection and security: Excluded
- Marking & Signage, warnings & hazards / translation / languages: Excluded
- Greases & lubricants and supply of temporary preservation materials: Excluded
- Positioning & routing (inc supporting) of electrical power supplies: Excluded
- Termination & glanding of electrical power supplies: Excluded
- Transition spools, adaptors and fittings for hydraulic / cooling services: Excluded
- Termination & joining of hydraulic / cooling pipework: Excluded
- Hydraulic fluid: Excluded
- Filling and priming of equipment (excluding site pipe work): Excluded

Site Pressure Testing and Flushing

Not included in our offer

Site Cold Commissioning

Not included in our offer

Site Hot Commissioning

Not included in our offer

Site Acceptance Test (SAT) & Handover for UK built Power Units.

Upon completion of the above, your nominated representative will be invited to witness and sign an acceptance certificate which will be signed by both parties to indicate the completion of our site work provisions.

Site Extras to Contract

All extras to contract (including materials and man-hours) shall be recorded on our 'Daywork Sheet'. This shall be checked, agreed and signed for by your nominated site representative.

All extra costs including travel, hotel, lodge and subsistence shall be invoiced at our daywork rates against the recorded extras.

A copy of the relevant daywork sheet shall be forwarded with our invoice as proof that the work was carried out and the recorded times etc have been agreed by your representative as an extra to contract.

No additional work shall be carried out without a written variation order.

The signing of any daywork sheets by your nominated representatives constitutes an irrevocable agreement of payment to us against the terms above and the specified day work rates.

Exclusions

We wish to draw your attention to the following items, which unless specified otherwise within our offer are excluded.

- Hydraulic actuators and any line mounted items.
- Supply of Interconnecting site pipe work and hoses.
- Electrical installation wiring of junction boxes and ancillary equipment (e.g. valves, instrumentation, motors and heaters etc).
- Control cabinets, including PLC's, HMI's, signal conditioning devices and amplifier / driver cards.
- Software and control related programmes.
- Any additional certification not currently specified within the quotation.
- First fill of hydraulic fluid.
- Nitrogen pre-charge for accumulators.
- Spares and consumables.
- Site work, installation and / or commissioning including the offloading, storage or positioning of equipment or the putting to use / provision for services.

- Witness of our Factory Acceptance Test (FAT).
- Site Acceptance Tests (SAT's).
- Removal & disposal of packaging and waste materials.

rexroth
A Bosch Company

Health and Safety

The equipment offered in accordance with the EC Machinery Directive 2006/42/EC is defined as a 'partly completed machine' and shall be provided with a declaration of incorporation.

It is incumbent upon the 'Customer' who has contractual claim to the 'Goods' to responsibly perform their duties to address the essential health and safety requirements considering the integration of the partly completed machine. This shall be completed prior to putting the equipment in to use.

A declaration of incorporation shall be provided with the goods supplied.

Quality

The equipment offered shall be produced in accordance with our ISO 9001 accreditation and quality management systems. Having subjected our design and production processes to FMEA (Failure Mode Effect and Analysis), scrutiny, the resulting realisation of our engineered solutions is performed according to our standard quality plan covering order placement, design verification, receipt of goods, production, test validation, delivery together with reassurance toward outsourced supply.

Process reviews, documented risk assessments, environmental considerations together with appraisals toward our legal obligations defined within the Machinery Directive mitigate risk and address safety.

A summary of the Standard Control Plan is included below:

- Seamless steel **tubes**: certified considering form, properties – strength / grades and condition to EN 10204-3.1
- Inspection of **fabrications**; constructional compliance – dimensional accuracy, welded joints, finishes – coatings, correctness of threads / sealing faces / specific lifting provisions and cleanliness – presentation.
- Inspection of **pipework**; constructional compliance - dimensional accuracy, respective finish, integrity of welded joints – as applicable (radiographic examination of 10% of butt welded 'pressure' joints produced by certified welders / applicable weld procedures). Correctness of threads / sealing faces, cleanliness and presentation.
- **Manifold**: material certified considering form, properties – strength / grades and condition (NDT flaw detection), EN 10204-3.1 (2.2 for certain materials) and subject to inspection for constructional compliance – dimensional accuracy, respective finish, correctness of threads / sealing faces, cleanliness and presentation.
- **Proprietary components**: supply compliance - subject to visual inspection on receipt
- **Hydraulic hose assemblies**: certified conformity, considering form – and pressure test with traceability to unique indelible marking.
- All **equipment** representing engineered assemblies, shall be subject to **functional test and inspection:** constructional compliance, integrity and functional performance to design documents are validated, from which the appropriate document – either Declarations of Incorporation or Certificate of Compliance is provided.
- **Finish and Presentation**: compliance and overall quality is assessed: Colour, coverage and thickness of paint is verified, labelling, capping of termination points and integrity – correctness of packing / preservation undertaken, warning and cautionary marks are reviewed.
- **Delivery**: the equipment shall be subjected to a pre-delivery inspection.

rexroth
A Bosch Company

UK Site Locations



St Neots
Tel: +44 (0)1480 223200

UK Headquarters
Rexroth Service

Sales, engineering, design, assembly and service of hydraulic systems and components of Bosch Rexroth.



Cirencester
Tel: +44 (0)1285 863000

Sales, engineering, design, assembly and service of electro-mechanical drive solutions, drives, linear motion and assembly technology.



Wakefield
Tel: +44 (0)1924 220100

Power Unit Manufacture
Hagglunds Service

Sales, engineering, design, assembly and service of hydraulic systems and components of Bosch Rexroth.



Glenrothes
Tel: +44 (0)1592 631777

Hydraulic Motors Manufacture

Regional Sales Office.
Sales and service of hydraulic systems and components of Bosch Rexroth.



Blackburn
Tel +44 (0)345 604 4106

Area Sales Office - North



Newport, Wales
Tel: +44 (0)345 604 4106

Area Sales Office - South

Please click on this link for further information on our extensive range of products and services covering industrial hydraulics.
http://www.boschrexroth.com/en/xc/

16.5. Appendix E: Hydraulic Calculations (Ingleside Engineering, 2023)

Existing Drive System : 130kW, 3300v-3ph-50hz electrical motor through a fluid coupling and a David Brown speed reduction gear box (details unknown, could be worm type).

Note gear box rating is 93 kW from SAP data.

The reclaim rate typically does not exceed 900 tph due to the downstream capabilities.



The bucket wheel speed was timed at 9.15 secs per revolution, giving a shaft speed of 6.6 rpm.

Electrical motor shaft speed of 1480 rpm through the 224 : 1 reduction gear box is 6.6 rpm

Full load current to be advised by for the installed electrical motor, calculated value is 26.76 Amps on a 4-pole electrical motor rated for 3300 volts.

Reclaim material was on Sinter Fines which is classed as a light material, operators target is to maintain the reclaim rate at 12 amps. Reclaim material DRI is the heaviest material, and the target is to maintain the load between 20 and 22 amps, any higher than these values it starts to put the cylinder luffing forces into an amber warning mode.

We have assumed the following efficiencies for the various components in the drive

Component Efficiencies	100% Load	50% Load
Electrical Motor	94	93
Electric Motor Power Factor (Pf)	0.85	0.84
Fluid Coupling	98	98
Gear Box	94	90

For the assessment of the absorbed power when reclaiming **Sinter Fines,** we shall base this on the values shown at 50% in the above table. The drive torque shall then be calculated from the running speed of 6.6 rpm.

Absorbed Power (kW) = (V x I x Pf x $\sqrt{3}$ x Eff.) / 1000

Torque = (Absorbed Power x 9550) / rpm

Power = 3300 x **12** x 0.84 x 1.732 x (0.93 x 0.98 x 0.9) / 1000 = 47.26 kW

Torque = (47.26 x 9550) / 6.6 = 68,381 Nm

For the assessment of the absorbed power when reclaiming **DRI,** we shall base this on the values shown at 100% in the above table. The drive torque shall then be calculated from the running speed of 6.6 rpm.

Absorbed Power (kW) = (V x I x Pf x √3 x Eff.) / 1000

Torque = (Absorbed Power x 9550) / rpm

Power = 3300 x **20** x 0.85 x 1.732 x (0.94 x 0.98 x 0.94) / 1000 = 84.14 kW

Torque = (84.14 x 9550) / 6.6 = 121,745 Nm

Power = 3300 x **22** x 0.85 x 1.732 x (0.94 x 0.98 x 0.94) / 1000 = 92.55 kW

Torque = (92.55 x 9550) / 6.6 = 133,920 Nm

The operator also mentioned that sometimes they do hit 24 amps but this is rare and typically caused by avalanching onto the wheel, which would calculate to be 146,000 Nm

Drive Motor Selection.

Based on this information we can select a CB840-680 direct drive hydraulic motor complete with shrink disc coupling.

The anticipated running pressures on **DRI** would be 195 bar to 220 bar

The anticipated running pressures on **Sinter Fines** would be 120 bar.

The anticipated running pressure at peak load of 24 amps is 235 bar.

The drive system would have a maximum torque capability of 221kNm at 350 bar.

16.6. Appendix F: Design Brief (Ingleside Engineering, 2023)

DESIGN BRIEF

BUCKET WHEEL DRIVE UPGRADE AT TATA STEEL, PORT TALBOT

INGLESIDE ENGINEERING

2023

Ingleside Engineering Ltd.

CONTENTS

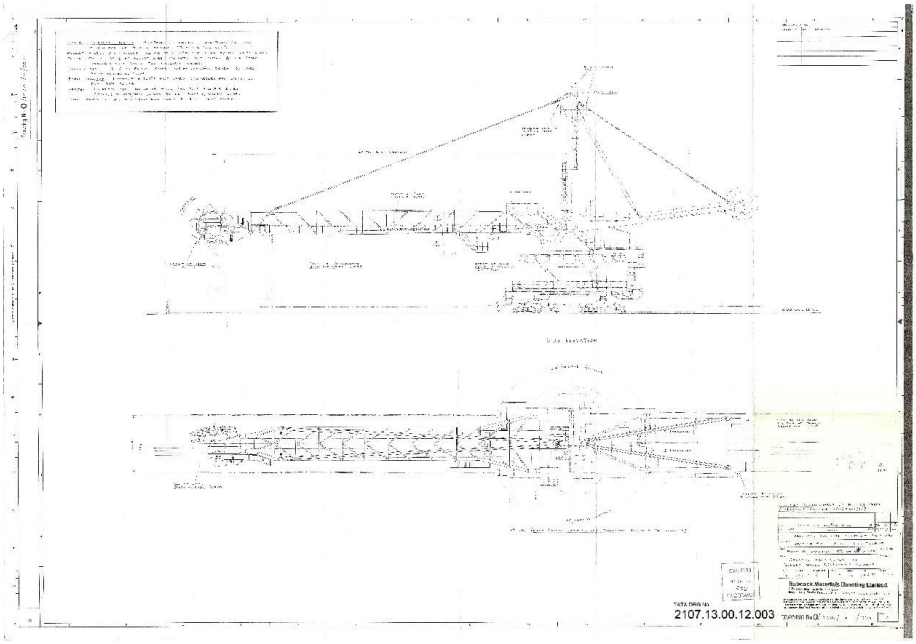
Section	Title	Page
1.0	INTRODUCTION	3
2.0	REFERENCE MATERIAL	5
3.0	APPENDIX	6

Ingleside Engineering Ltd.

1.0 INTRODUCTION

The harbour area, at the Tata Steel Port Talbot site, is the point where all raw materials are stored prior to transfer to other parts of the processing plants. After the raw materials have been stored in the harbour area, reclaim machines are used to collect the materials and discharge these onto belt conveyors for onward use. These bucket wheel reclaim (BWR) machines are utilised for this purpose.

The drawing below shows the existing #2 BWR:



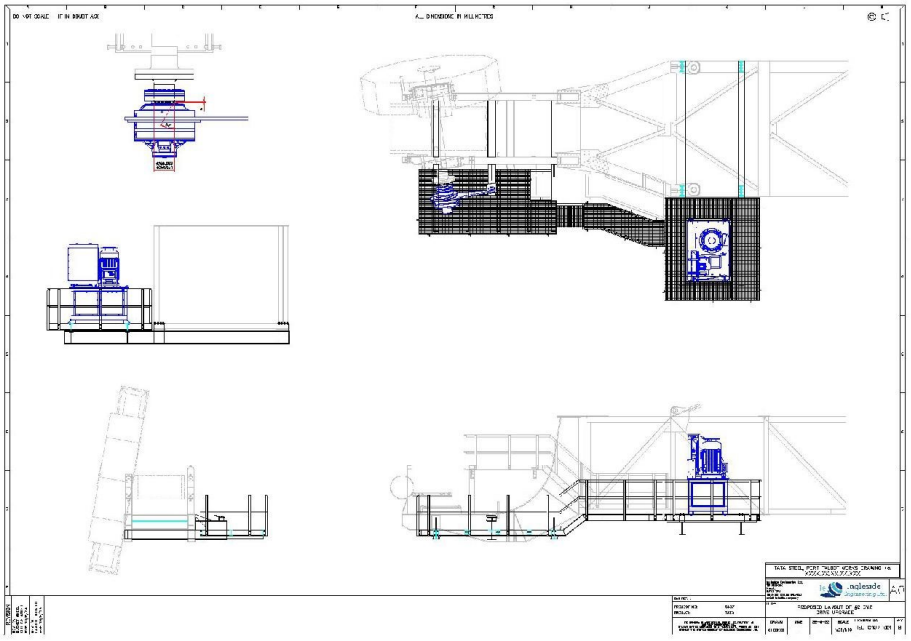
TATA Steel have decided to upgrade the existing gearbox type drive unit and replace this with a hydraulic motor (Hagglunds/Rexroth). To allow the new hydraulic drive system to be installed an additional supporting structure is required for the power pack unit. TATA Steel also requested that the new drive has a maintenance platform that is accessed from the current bucket wheel walkway.

The removal of the existing drive unit will affect the 'balance' of the overall machine. The addition of the new components and the supporting steelwork structure also affects the 'balance' of the machine.

A calculation has been completed to show the requirements for the counterweights and this is shown on drawing IEL-C407-002.

Ingleside Engineering Ltd.

The drawing below shows the proposed arrangement of the drive upgrade scheme:



These requirements have been the basis of the Ingleside Engineering Design Brief enabling us to provide an effective solution to meet the requirements and expectations of TATA Steel.

All drawings and design information for this design brief can be found in Section 3 (Appendix) of this document.

Ingleside Engineering Ltd.

2.0 REFERENCE MATERIAL

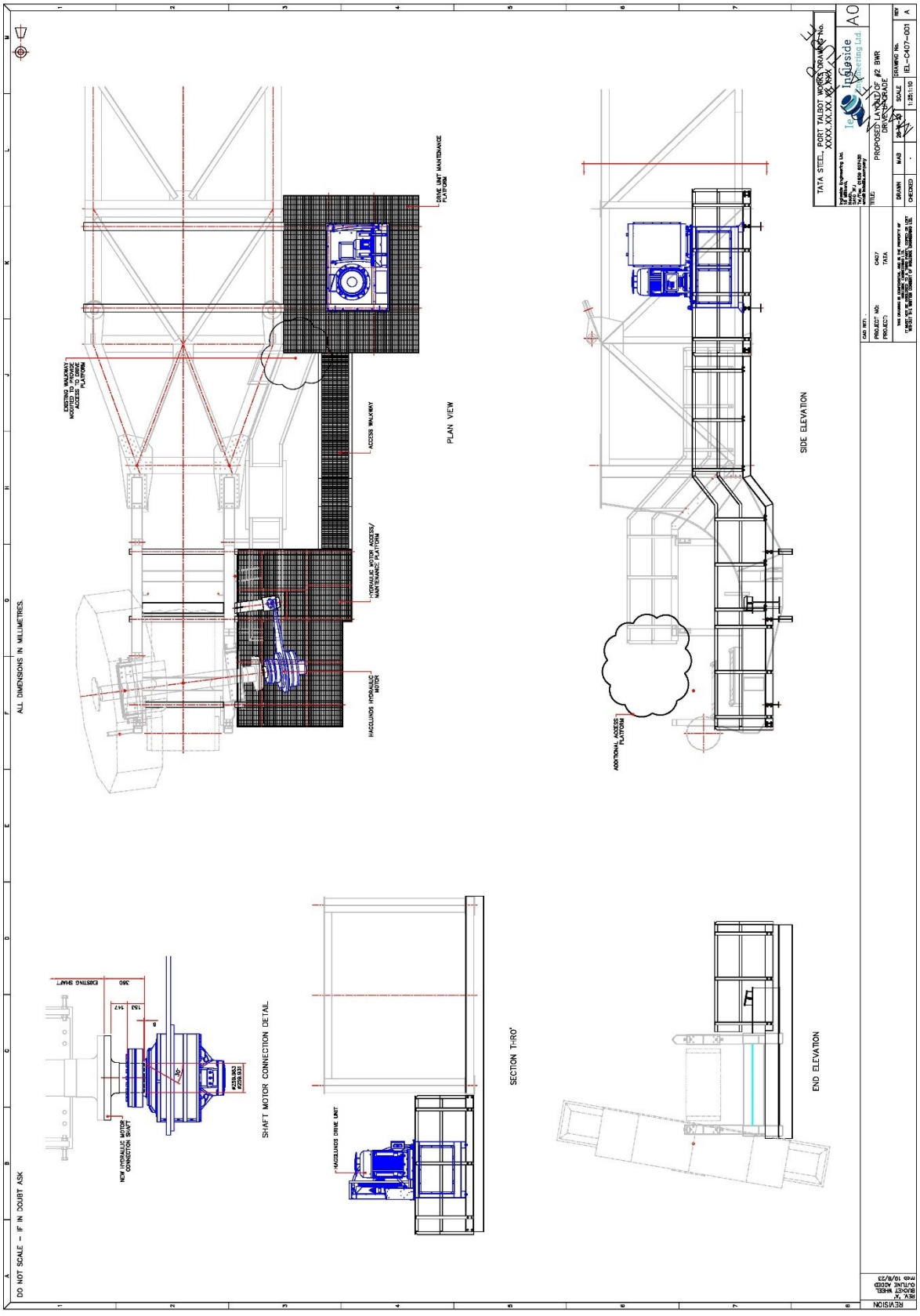
TATA Steel Information

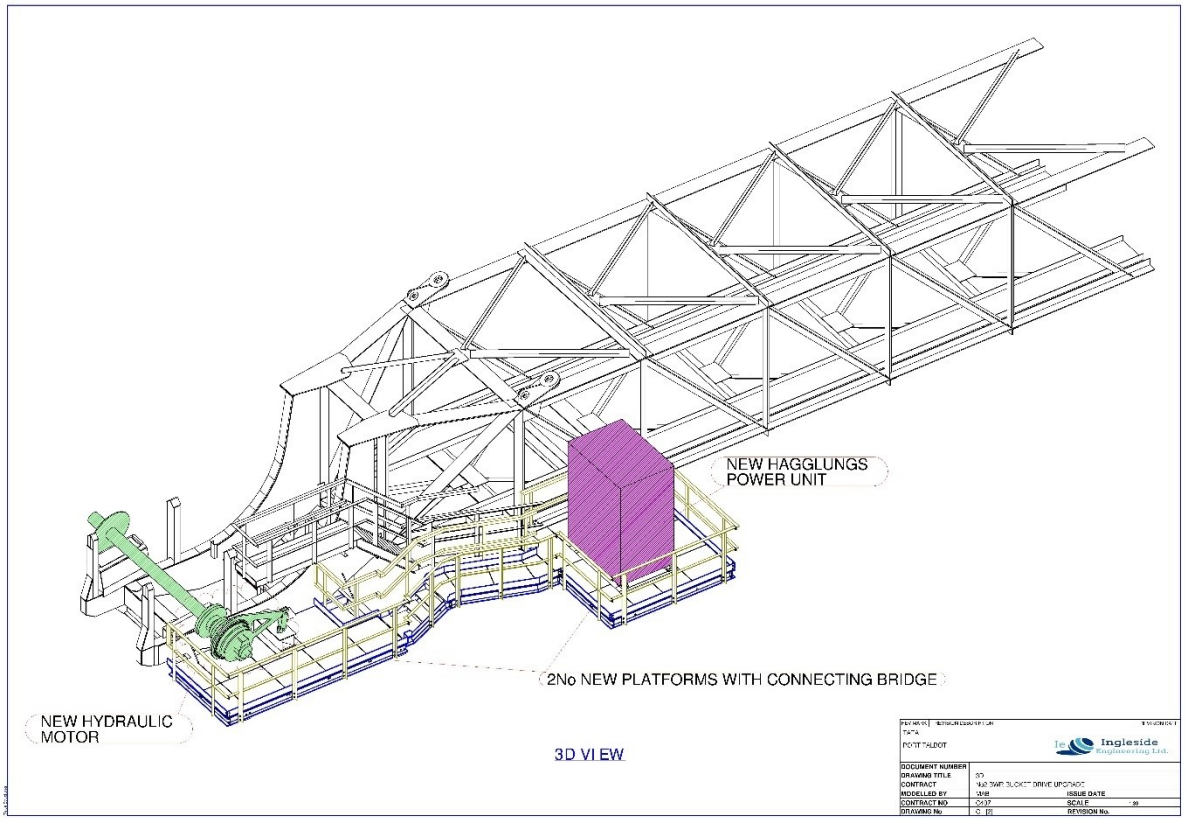
72030/BW/SD.71.B	Diagram Showing Loads & Position with Boom Horizontal
2107.13.00.12.003	General Arrangement of Bucket Wheel Reclaiming Machine
191001/A/004 B	Arrangement of Head End
191001/2/005 B	Details of Replacement Boom Middle Section Sheet 1
191001/2/006 A	Details of Replacement Boom Middle Section Sheet 2
191001/2/004 A	Details of Replacement Boom Middle Section Sheet 3
191001/2/015 A	Arrangement & Details of Boom Walkways – Front Section
191001/2/033 B	Details of Ballast Weights & Trimmers
191001/2/035 C	Modifications to Existing Cell Less Bucket Wheel 6m Body Type 'C'
191001/2/036 B	Details of Bucket Wheel Shaft & Hub
2100.09.02.12.003 A	Cell Less Bucket Wheel Inner Shaft Ref. 320
078 5005	CB840 Hydraulic Motor
278 5017	Torque Arm
R0024771	Drive Unit

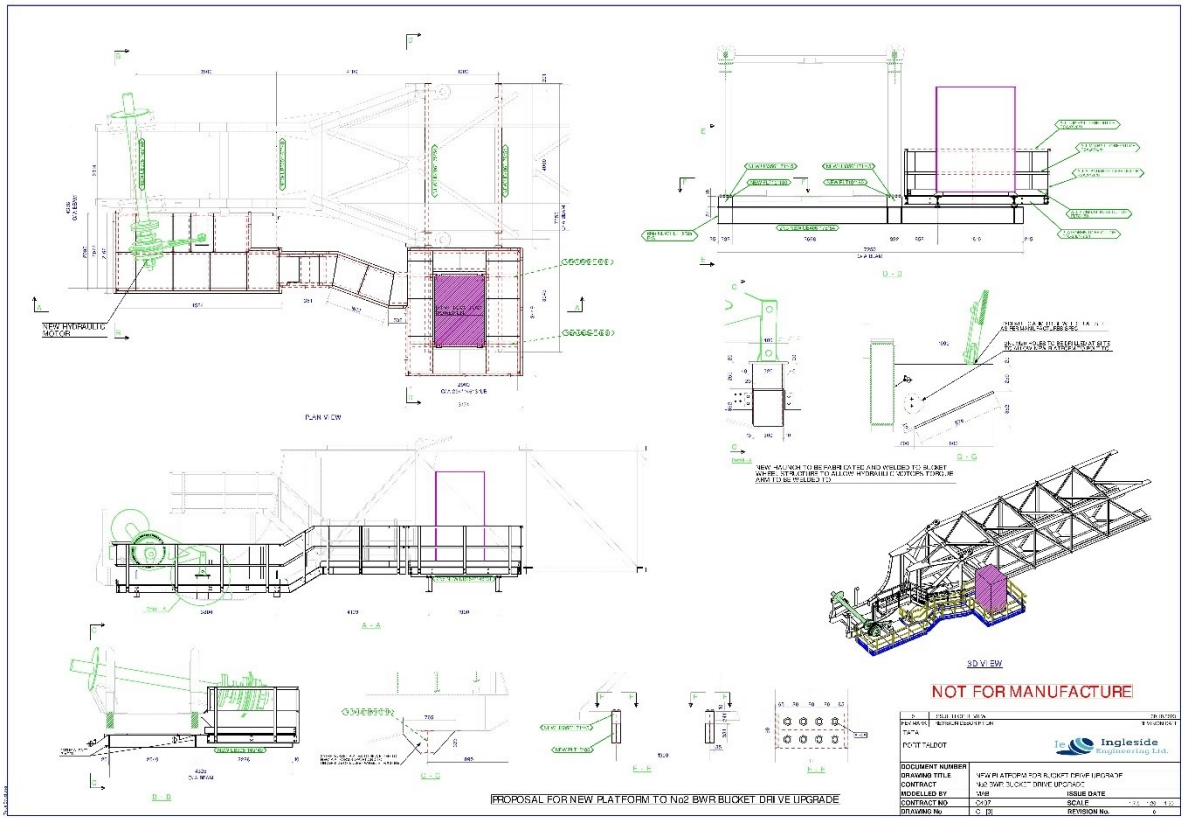
Ingleside Engineering Ltd. Information

IEL-C407-001	Proposed Layout of #2 BWR Drive Upgrade
IEL-C407-002	#2 BWR Drive Upgrade Counter Balance Calculation

16.7. Appendix G: Walkway Design (Inglside Engineering, 2023)




NEW HAGGLUNGS
POWER UNIT
2No NEW PLATFORMS WITH CONNECTING BRIDGE
NEW HYDRAULIC
MOTOR
3D VIEW
PORT TALBOT
Ingleside
Engineering Ltd.
DOCUMENT NUMBER
DRAWING TITLE
3D
CONTRACT
MODELLED BY
ISSUE DATE
CONTRACT NO
SCALE
DRAWING No
REVISION No.


NEW HYDRAULIC
MOTOR
PLAN VIEW
3D VIEW
NOT FOR MANUFACTURE
PROPOSAL FOR NEW PLATFORM TO No2 BWR BUCKET DRIVE UPGRADE
PORT TALBOT
Ingleside
Engineering Ltd.
DOCUMENT NUMBER
DRAWING TITLE
NEW PLATFORM FOR BUCKET DRIVE UPGRADE
CONTRACT
MODELLED BY
ISSUE DATE
CONTRACT NO
SCALE
DRAWING No
REVISION No.

16.8. Appendix H: Walkway Tender Document

Request for Quotation

Project Title:	BWR Drive Upgrade	Project Engineer:	David Adams
Specification No.:	TSE0130191-B	E-Mail:	d.adams@tatasteeleurope.com
Issue Date:	16/10/23	Desk Phone:	01639 603480
Tender Return Date:	30/10/23	Mobile:	N/A

Location:

Bucket Wheel Reclaimer, Harbour & Blending, Burdening Dept, Port Talbot Works, SA13 2NG

Purpose of Works:

Invitation to tender for the manufacture, supply, and installation of structural steelwork and a 3190kg counterweight for the Bucket Wheel Reclaimer Upgrade Project

Description of Works:

Manufacture, supply, and onsite installation of structural steelwork and a 3190kg counterweight as per the specifications detailed in Appendix 1 - Manufacturing drawing set.

Selected vendor will be notified by 6th November 2023, Installation of the structural steelwork and counterweight is scheduled to begin on 8th February 2024, the project is expected to be completed by 7th March 2024 or earlier.

Supporting Documents Supplied:

Appendix 1 – Manufacturing Drawing set

Contents of Tender

Your tender should be addressed as follows: David Adams, Harbour Engineer, Tata Steel Europe Ltd, Port Talbot Works, SA13 2NG

Your tender must include the following:

- Project title, specification no., tender reference and date
- Scope of supply and provision of service incl. quantities, options and variants
- Price ex tax of the labour per operation, number of hours * hourly rate
- Price ex tax of the supply per operation number * unit price
- Other if detailed in description of works
- Total price ex tax

If the Vendor considers it appropriate, they will send additional variants to the specification.

Tender Responsibilities

It is the responsibility of the vendor to gather all necessary data required to ensure that any equipment supplied will meet the system requirements & maintain or improve current levels of facility performance. The contractor should carry out a complete survey of the current installation for the benefit of their submission. Failure to identify any issues during the quoting period of the project will be rectified at the vendor's expense; TSE will accept no responsibility, financially or practically, for any issues arising from the vendor failing to carry out a full survey. Any data supplied by TSE is only information & a guide; the vendor should carry out all necessary actions to validate that information.

List of proposed equipment & materials should be contained within the quotation for TSE to review. As part of the quotation the vendor should present a list of all sub-contractors that may be used. TSE will review the proposed list of vendors & confirm the suitability of those companies submitted. The vendor is responsible for any sub-contractors they employ.

The tendering parties should at no stage in the development of the project discuss the project with any third parties other than their sub-contractors & they should ensure that their sub-contractors are also aware of this requirement.

Should any concessions or deviations be required, they must be requested in writing and clearly agreed between TSE & vendor prior to a contract award. The vendor, at their own expense, must rectify any failures of compliance.

The TSE non-production terms and conditions for the supply of goods and services are applicable: "TSE Non-Production Supply of Goods and Services Oct16.pdf".

Issue 5 05/08/2019 Retention AMIS 25.03 S+1 TSE-ME-FAC-0004-5 Page 1 of **2**

Request for Quotation

All installations must comply with the TSE Mechanical Specification and the TSE Colour Specification. For all lifting equipment, a LOLER certificate is required and the equipment must be marked with the Safe Working Load (SWL). All machinery must be CE marked and an EC declaration of conformity must be issued to TSE.

All electrical installations and software must comply with the TSE Controls Specification, Electrical Drawing Specification, ADDS PLC Specification and Label Standard Specification.

The chosen vendor will provide all as installed drawings, calculations, specifications & operating/maintenance manuals, the bill of materials, the spare & wear parts list, electrical drawings and software documentation within 2 weeks of the final acceptance of the facility. The documentation must be supplied in printed (single copy) in conjunction with an electronic form (USB stick) to the TSE engineer.

Any validation test data remains the property of TSE & may not be distributed without TSE permission. All design drawings, calculations & specifications, regarding this project, are the property of TSE.

Site visits must be arranged through the relevant TSE engineer. Facility installations and modifications must be planned with the TSE engineer, implemented around existing equipment and during normal production operating hours (where practicable). Where this is not practicable then non-production shift patterns must be agreed with no disruption to production quality or volume.

A permit to work will be issued before the commencement of any work on site. Additional permits are required for hot work, roof access, excavations, confined spaces and lifting operations. The vendor will be responsible for providing all risk assessment & methods statements, these should be provided at least 5 days prior to project commencement. All contractors working on site must attend the TSE induction prior carrying out any work on site. No pictures or videos are to be taken at any time.

Full H&S regulations apply whilst on site. CDM Regulations 2015 apply to all construction projects. The TSE statement of Health & Safety and Environmental policy must be respected. Both documents will be issued by the TSE engineer upon request.

Contractors should ensure that they provide all access equipment, lifting equipment & relevant PPE equipment that may be required to complete works in a safe & controlled manner. All relevant certification should accompany any equipment that arrives on the TSE site & be available for examination by relevant bodies at any time. Contractors should note that they are not to use TSE equipment unless they have permission from the person responsible for the particular piece of equipment.

It is the responsibility of the vendor to maintain their site in a safe & clean manner; site cleaning should be completed at the end of the working shift & the site should be secured.

The vendor will be responsible for ensuring that all their waste materials are removed from site & disposed of in a safe & responsible manner. A frequency for disposing of waste should be agreed with the responsible engineer.

16.9. Appendix I: Walkway Quotation (MII Engineering Ltd., 2023)

Tata Steel UK Ltd

Port Talbot Steel Works
Harbour & Blending
SA13 2NG

Your Reference:	Tenderdoc1029873
Our Reference:	MII-E-24-23901
FAO:	Mr David Adams
Subject:	Quotation for Manufacture and Supply of BWR Steelwork

Dear Sir,

We thank you for your valued enquiry and we now have pleasure in submitting our quotation for the work as described.

Quote to manufacture and deliver to site the structural steelwork and walkways as per drawings provided in Tender document pack ref: 1029873.

This quote is for the sum of **£28,968.11** *(Twenty eight thousand, nine hundred and sixty eight pounds and eleven pence.)*

Note: Quotation is not confirmation of resource allocation. Further planning meetings are being held weekly where TATA will confirm site wide priorities.

We hope to have interpreted your enquiry requirements correctly and look forward to being of service to you, assuring you of our best attention at all time, we remain,

Yours Faithfully

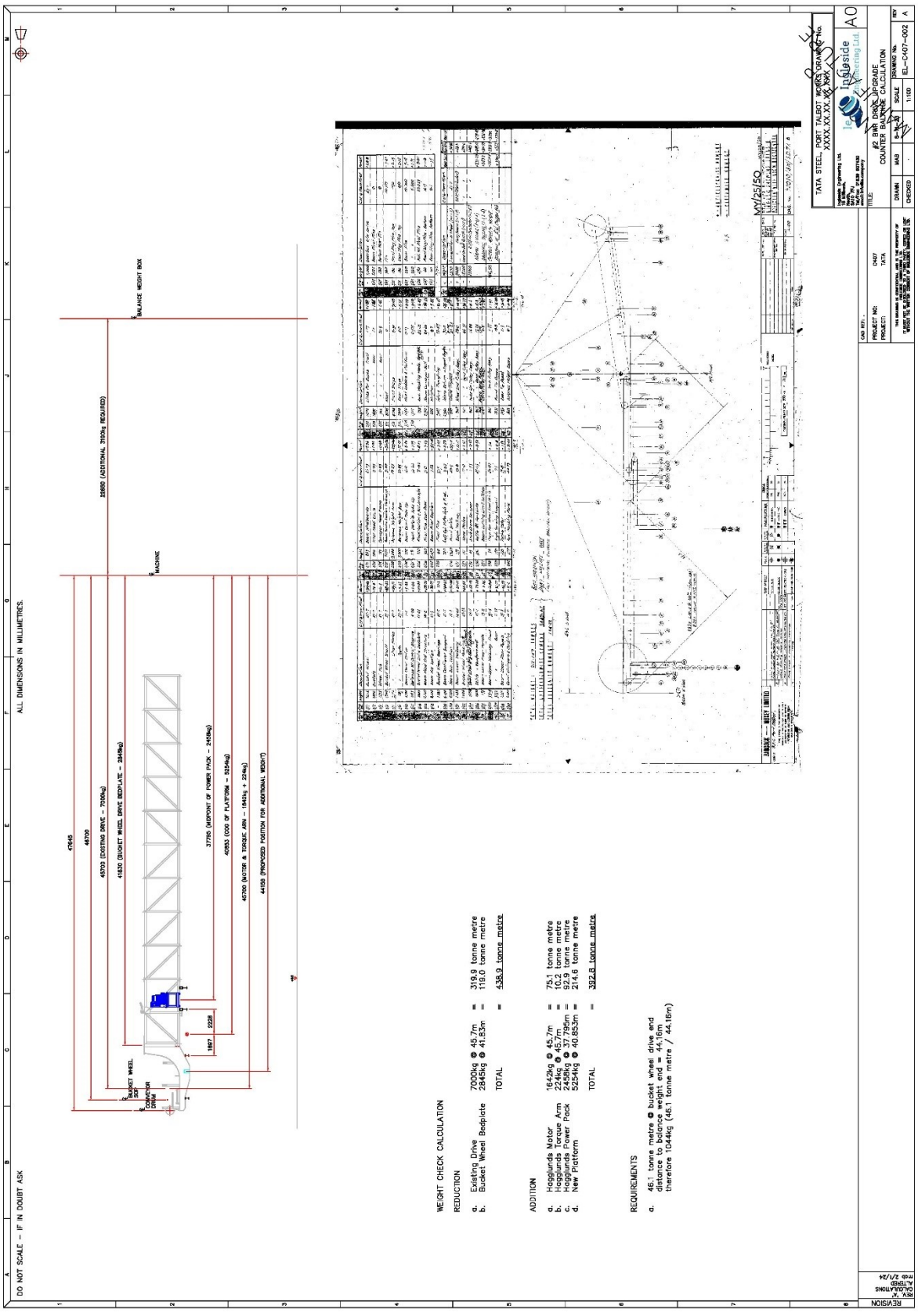
For and on behalf of
MII Engineering Ltd

Andrew Davies

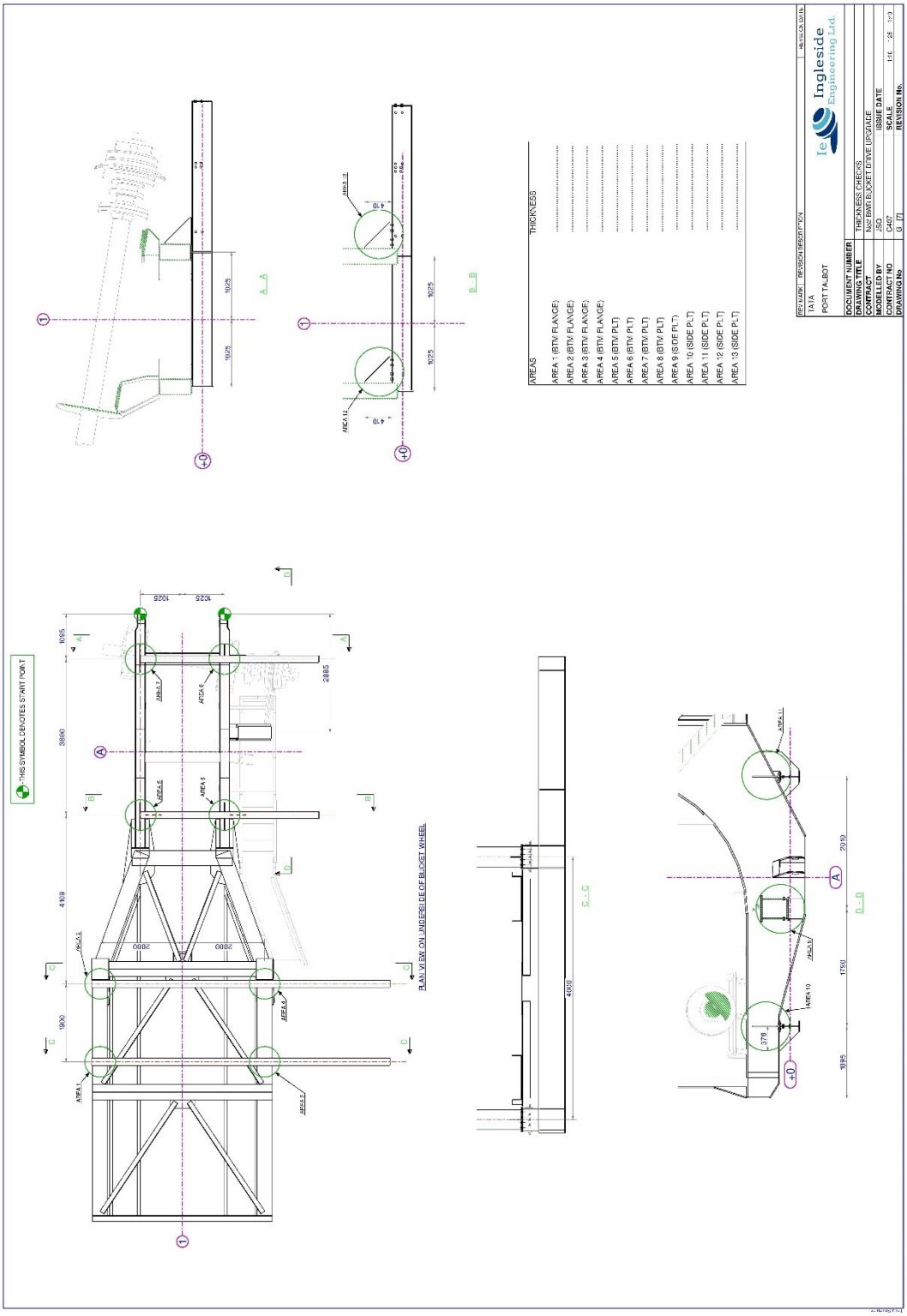
MII Engineering Ltd
Unit 20, Pant Glas Industrial Estate
Bedwas, Caerphilly, CF83 8DR Tel:
+44 (0) 2920 857800
Fax: +44 (0) 2920 857839
www.mii.co.uk

Directors: B R Arnesen, M J Moody, J A Brand
Company Registration No. 6806614 England

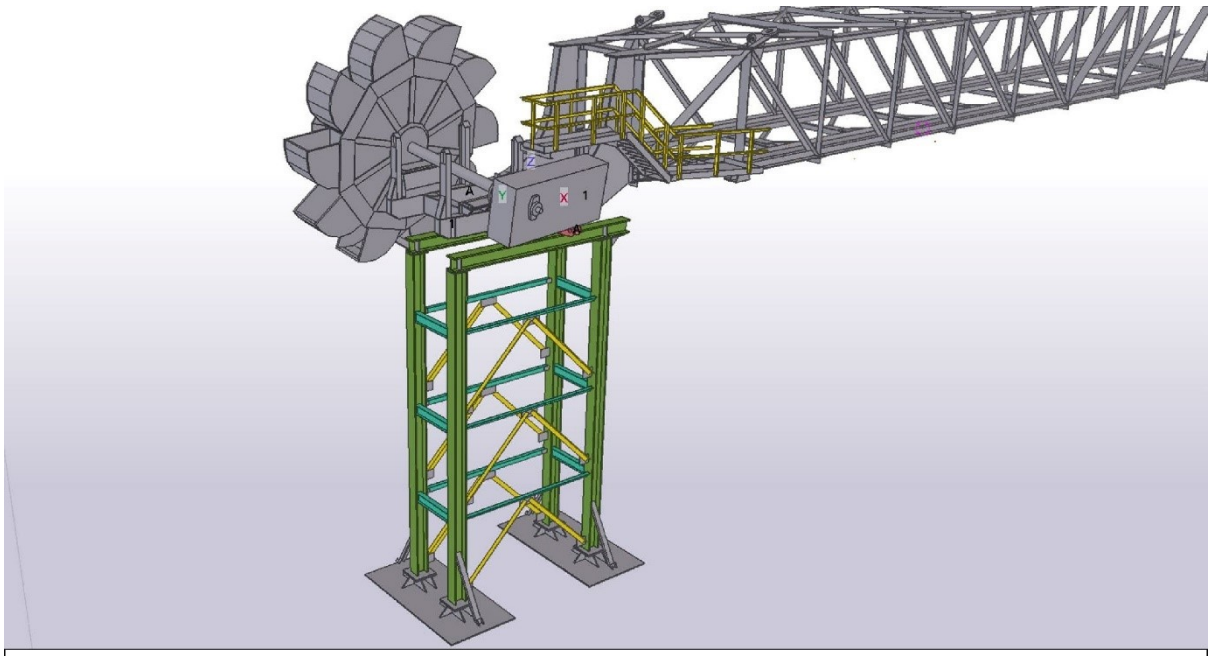
16.10. Appendix J: Load Dynamic Calculations (Ingleside Engineering, 2023)



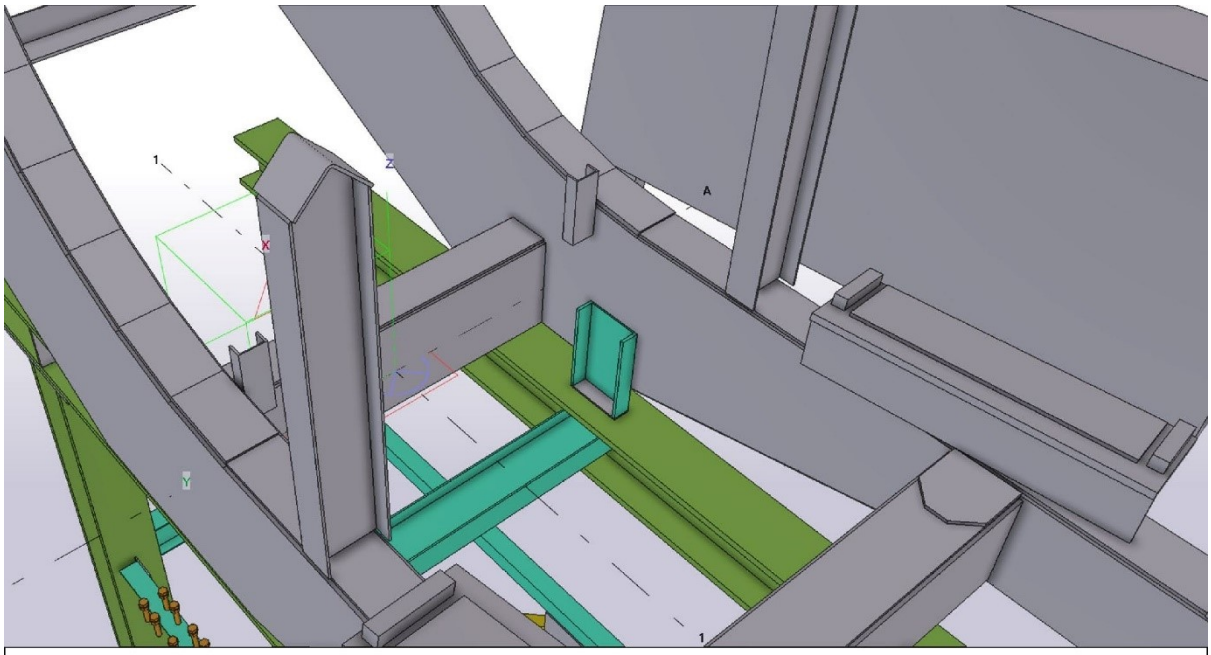
16.11. Appendix K: Thickness Testing Plan (Ingleside Engineering, 2023)



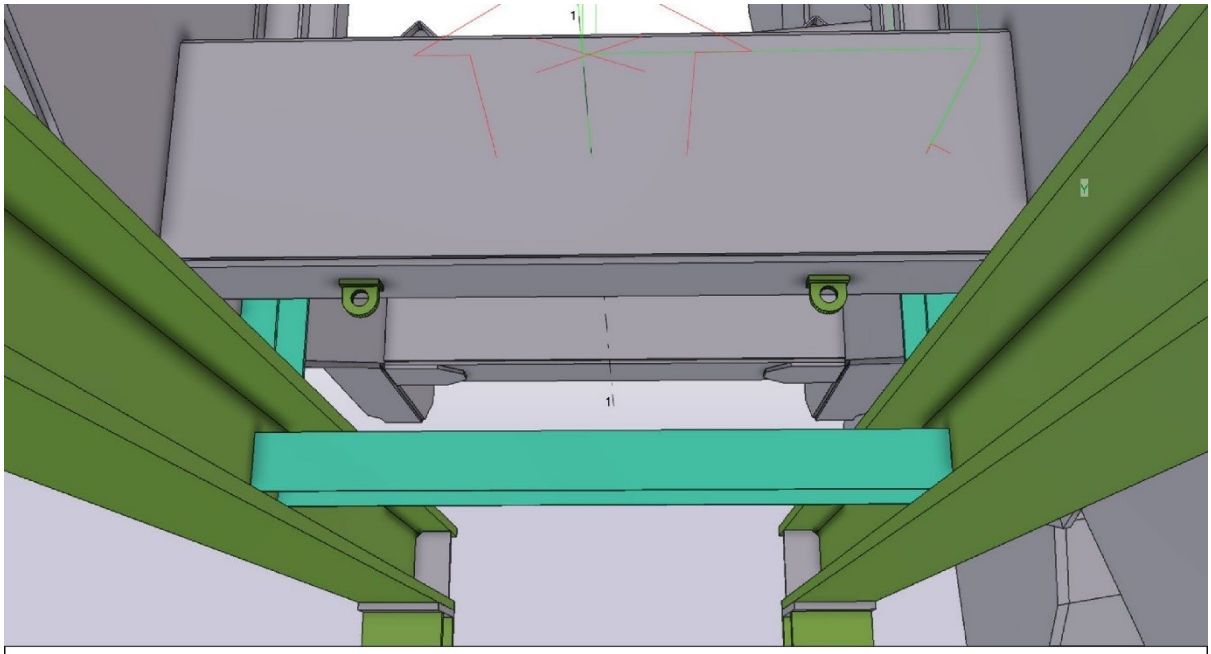
16.12. Appendix L: Temporary Works Design (Ingleside Engineering, 2023)



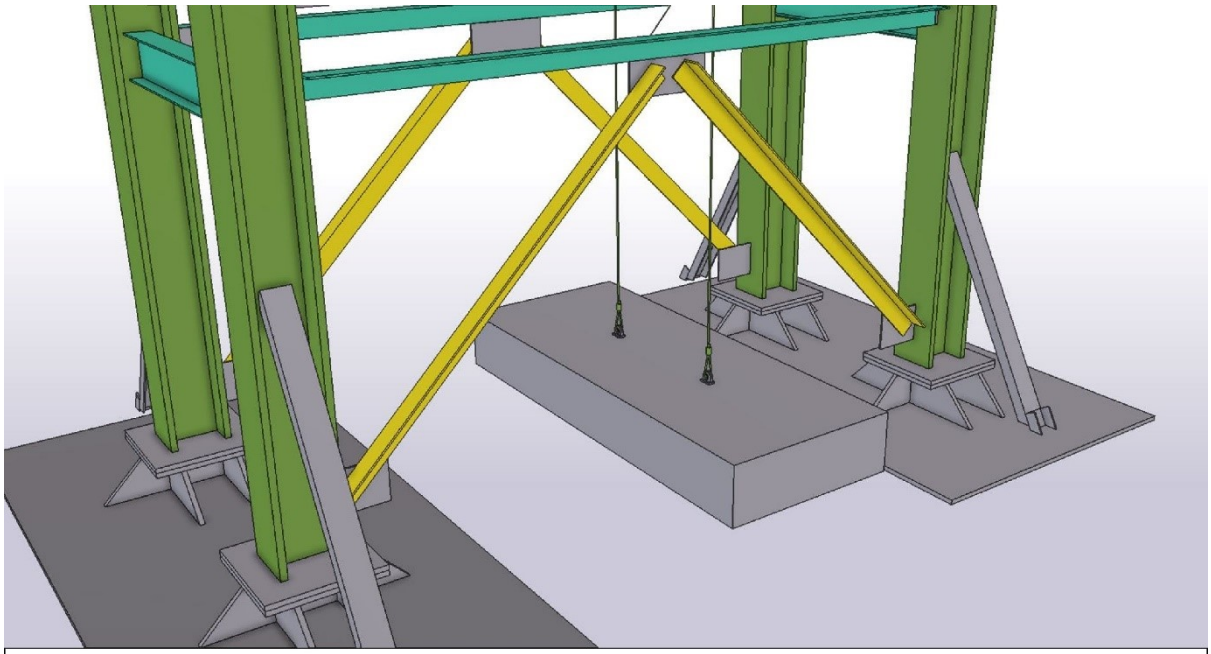
1. POSITION BWR OVER EXISTING ERECTED TRESTLE



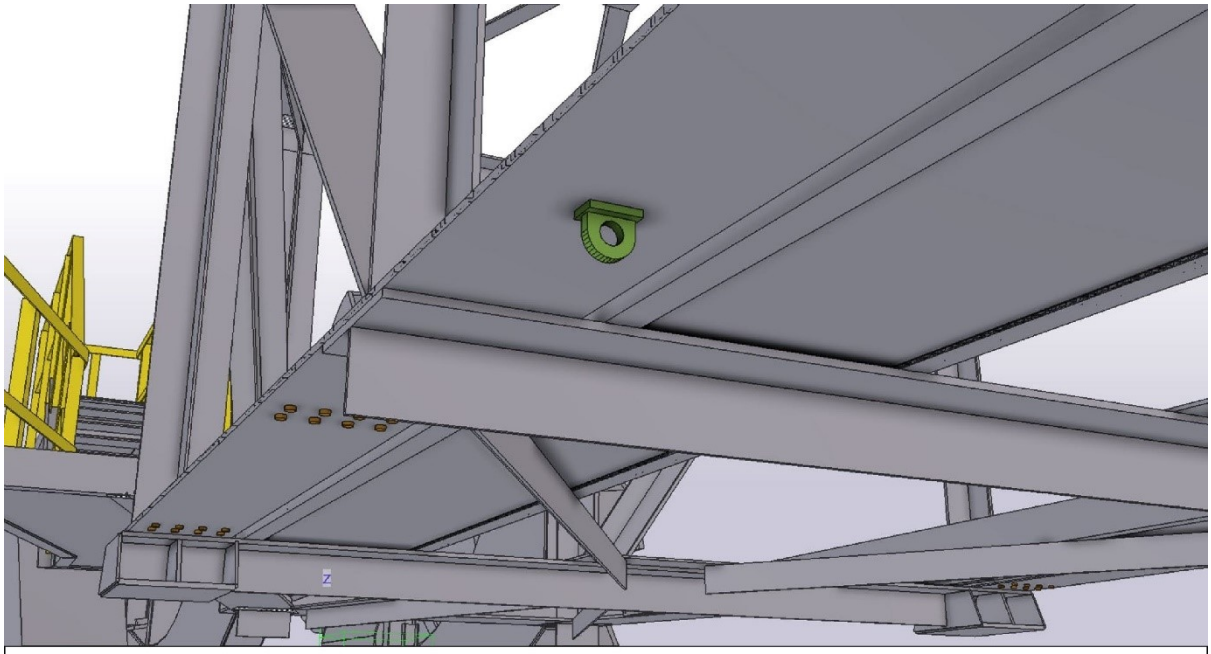
2. INSTALL 2no 300*90 PFC UPRIGHTS AND WELD TO THE INSIDE OF THE BOOM



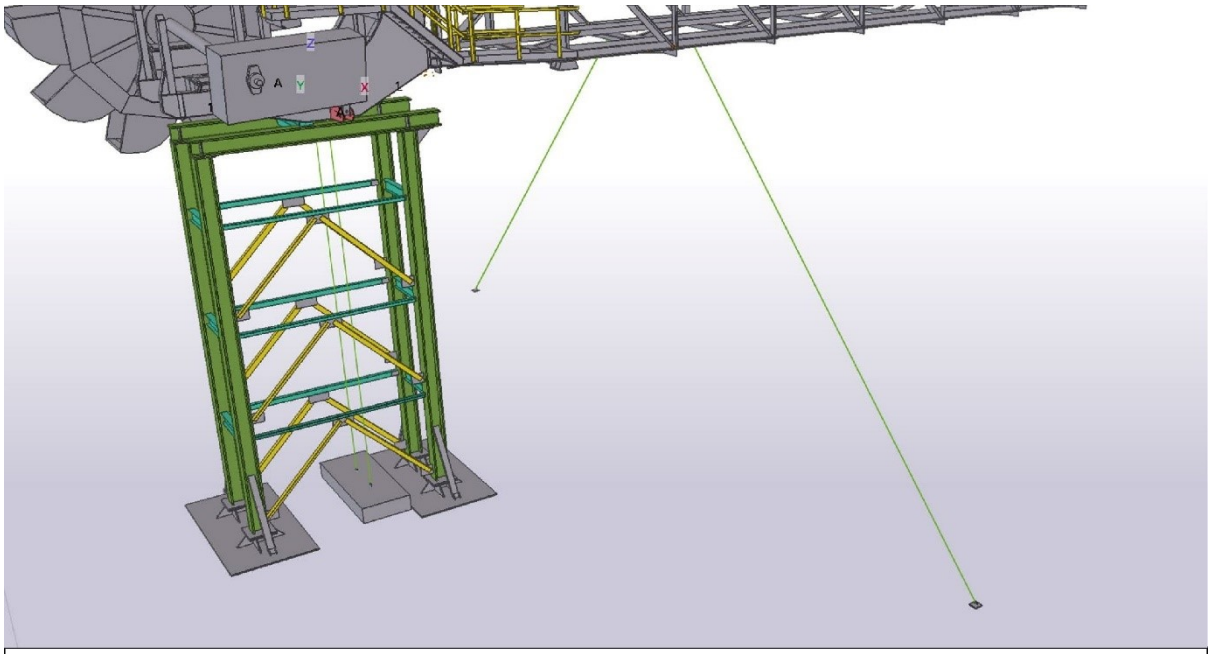
3a. INSTALL 2no LIFTING POINTS UNDERSIDE BRACE BEAM



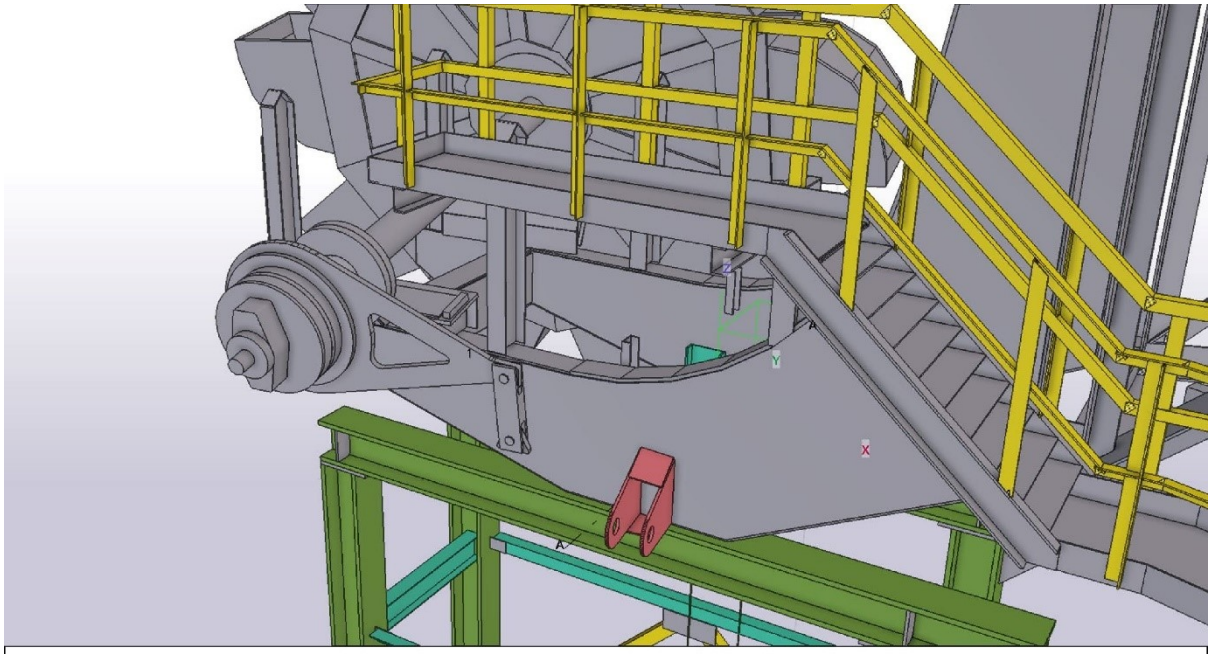
3b. RIG WEIGHT OFF LIFTING EYES PREVIOUSLY INSTALLED TO UNDERSIDE OF BRACE



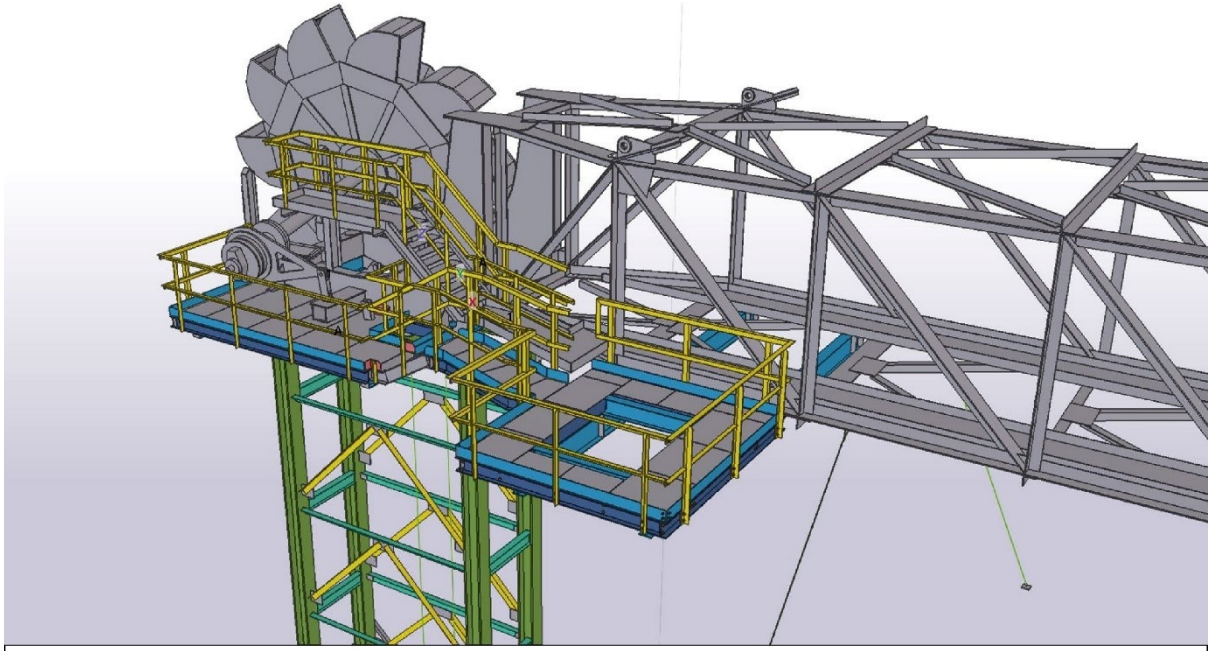
4a. INSTALL LIFTING POINTS ON BOOM AS SHOWN



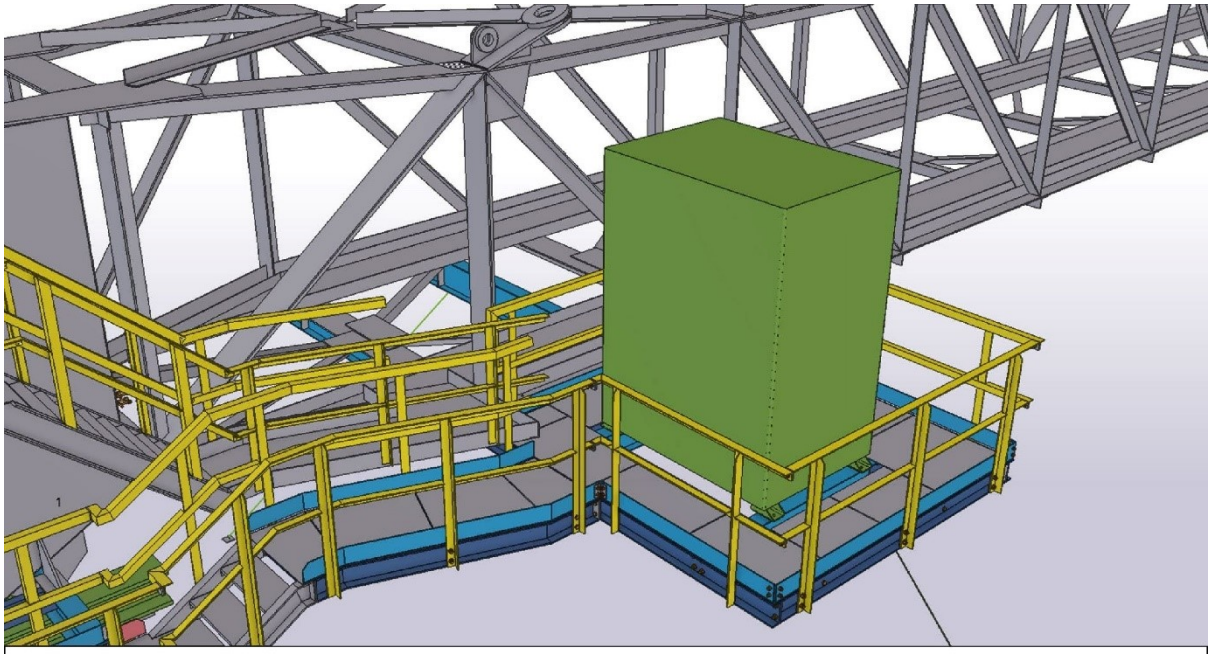
4b. INSTALL ANCHORS



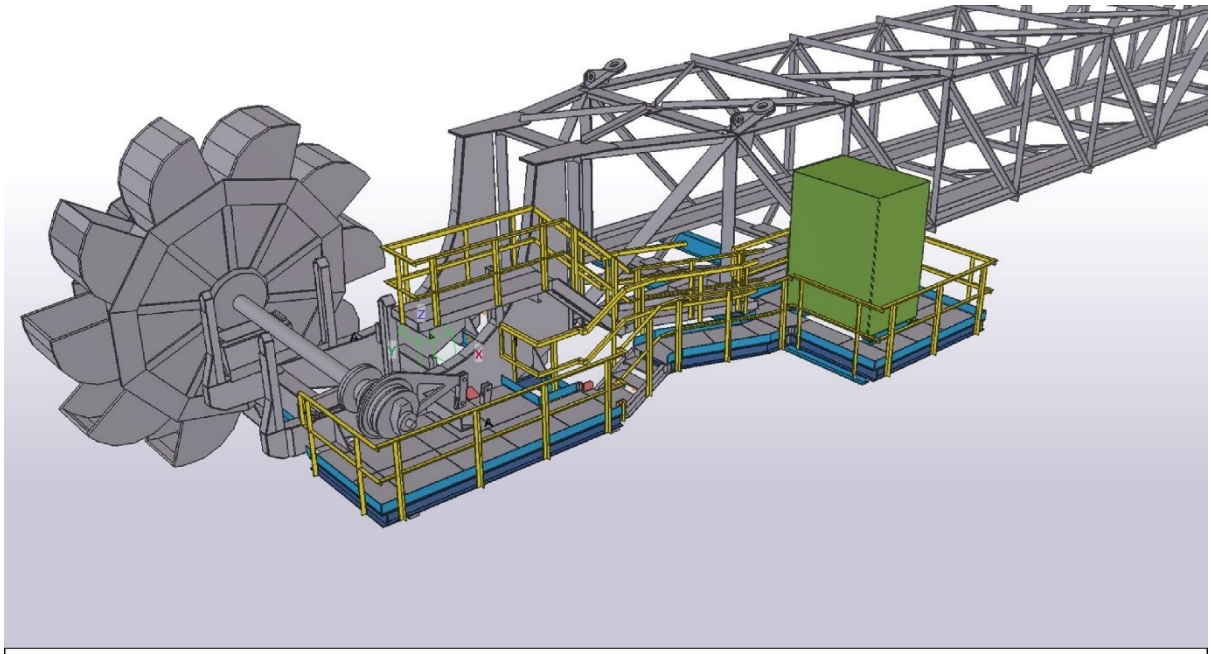
5. REMOVE EXISTING MOTOR



6. INSTALL NEW PLATFORM



7. INSTALL NEW HYDRAULIC MOTOR



8. REMOVE ALL TEMPORARY WORKS

16.13. Appendix M: Factory Acceptance Document (BOSCH REXROTH, 2023)

Factory Acceptance Test Document

Systems and Engineering (DCEN/EPU2-GB)

rexroth
A Bosch Company

Location of Factory Test:
BOSCH REXROTH, Wakefield
Tel: +44 (0)1924 220100

BOSCH REXROTH Representative:
John Berry

TATA Steel Representative:
David Adams

Date of Test Completion:
23/10/2023

Bosch Rexroth Limited
15 Cromwell Road
St Neots
PE19 2ES
Tel. +44 (0)345 604 4106
E-mail: sales@boschrexroth.co.uk
www.boschrexroth.co.uk

System Description:
TATA STEEL BWR Hydraulic system components including CB840-680 direct drive hydraulic motor complete with shrink disc coupling, DUC-LS2-132-250+000-0-A-Y-S-E-400/50 HPU with integrated oil cooler, TC A 0840 2 0 00 Torque arm complete with pivot attachment and SPDC CB—0 01856 00 00 speed sensor.

No.	Test Item	Test Description	Pass/Fail	Remarks
1	Visual Inspection	Check for physical damage, correct labelling, and component integrity.	Pass	*No physical damage, labels correct.*
2	Dimensional Check	Verify dimensions against design specifications.	Pass	*Dimensions within tolerance.*
3	Hydraulic Motor Functionality	Test motor for correct operation, including start-up and shutdown.	Pass	*Motor operates correctly.*
4	Pump Performance	Measure pump output against expected performance parameters.	Pass	*Output matches specifications.*
5	Valve Operation	Check for correct valve operation and response times.	Pass	*Valves operate within specified times.*

rexroth
A Bosch Company

6	Actuator Performance	Test actuators for correct operation under load.	**Pass**	*Actuators function as expected under load.*
7	Torque Reaction Arm	Verify correct installation and functionality.	**Pass**	*Proper installation confirmed.*
8	Oil Cooler Efficiency	Measure oil cooler performance and efficiency under operating conditions.	**Pass**	*Cooler maintains required temperature.*
9	Control System Integration	Test integration with spider control systems, including feedback loops.	**Pass**	*Control system integration successful.*
10	Pressure Testing	Conduct pressure tests to ensure no leaks and system integrity.	**Pass**	*No leaks detected; system holds pressure.*
11	Vibration Testing	Measure vibration levels during operation.	**Pass**	*Vibration levels within acceptable range.*
12	Noise Level Measurement	Measure noise levels during operation.	**Pass**	*Noise levels within acceptable range.*
13	Electrical Connections	Verify all electrical connections are secure and correctly labelled.	**Pass**	*All connections secure and labelled correctly.*
14	Functional Testing of Safety Features	Test all safety features, including emergency shutdown and alarms.	**Pass**	*All safety features function correctly.*
15	Software Functionality	Validate software functions and user interface.	**Pass**	*Software operates as expected.*
16	Documentation Verification	Check completeness and accuracy of documentation provided.	**Pass**	*Documentation complete and accurate.*
17	Final System Test	Run full system test to ensure overall	**Pass**	*System operates correctly under full load.*

		functionality and performance.		

This document certifies that the hydraulic system has passed all factory acceptance tests and inspections, confirming its readiness for installation and operation at TATA Steel Port Talbot, as per all terms and conditions previously stated.

BOSCH REXROTH Representative:
John Berry
(Signature: _____)

Date:
23/10/2023

TATA Steel Representative:
David Adams
(Signature: _____)

Date:
23/10/2023

16.14. Appendix N: Detailed Lifting Plan

LIFT PLAN

Crane Specifications	
Crane Type	DEMAG AC80-2
Lifting Capacity	80 Tonnes maximum (see diagram)
Boom Length	50 metres
Jib Length	15 metres
Maximum Reach	65 metres
Operator Certification	Certified crane operator with a valid license
Lift Classification	Category 2 – Tata PICOLO only (up to 100Te simple lift)
Safety Requirements	
Safety Zones	Establish safety zones around the lift area to keep unauthorized personnel at a safe distance. Use barriers and signage to mark these zones.
Weather Monitoring	Monitor weather conditions continuously. Suspend lifting operations if wind speeds exceed 8m/s as per regulations XXXX or if there are adverse weather conditions such as heavy rain or lightning.
Emergency Procedures	Develop and communicate emergency procedures for potential incidents such as load drops or crane malfunctions. Ensure the lift crew is trained on these procedures.
Lifting Plan Components	
1. Pre-Lift Planning	
Site Inspection	Conduct a thorough inspection of the site to identify potential hazards and ensure the ground is stable and capable of supporting the crane and its loads.
Load Assessment	Evaluate the weight, dimensions, and center of gravity of each component to be lifted. Ensure that all loads are within the crane's lifting capacity.
Rigging Equipment	Select appropriate rigging equipment, including slings, shackles, spreader bars, and lifting beams. Ensure all rigging equipment is inspected and certified.
2. Lift Coordination	
Person In Charge of Lifting Operations (PICOLO)	Appoint a PICOLO, responsible for overseeing the lifting operations and ensuring compliance with safety procedures.
Lifting Team	Assemble required lifting team, including riggers, signalers, and safety personnel. Conduct a pre-lift meeting to review the lift plan and assign roles.
Communication	Establish clear communication protocols, including hand signals to BSENXXXX and radio communication, to ensure coordination between the crane operator and PICOLO.
3. Lift Execution	
Stabilization	Position the crane on stable ground, using outrigger pads to distribute the load. Ensure the crane is level and secure.
Rigging Setup	Attach the rigging equipment to the load, ensuring proper alignment and secure attachment. Double-check all connections and load distribution.
Test Lift	Perform a test lift to verify the load is balanced and the rigging setup is secure. Make any necessary adjustments before proceeding with the full lift.
Lifting Procedure	Execute the lift slowly and steadily, avoiding sudden movements. Use tag lines to control the load and prevent swinging. Lift the load to the required height and maneuver it into position with precision.
Load Placement	Lower the load slowly into its final position, ensuring it is aligned correctly and securely placed. Disconnect the rigging equipment carefully.
4. Post-Lift Procedures	
Inspection	Conduct a post-lift inspection of the crane, rigging equipment, and the lifted components. Check for any signs of damage or wear.
Documentation	Record the details of the lift, including the weight of the load, lift height, and any issues encountered. Ensure all documentation is completed.

Detailed Lifting Procedure for Hydraulic Motor Installation
1. Pre-Lift Inspection
Verify the weight of the hydraulic motor using motor data plate
Inspect the lifting points on the hydraulic motor
Ensure the rigging equipment (slings, shackles, lifting beams) are rated for the load
2. Rigging Setup
Attach slings to the lifting points on the hydraulic motor using shackles and eye bolts
Secure the slings to the crane hook
3. Test Lift
Conduct a test lift to a height of 0.5 meters
Check the balance of the load and the integrity of the rigging setup
Make necessary adjustments
4. Main Lift
Slowly lift the hydraulic motor to the required height
Use tag lines to control the load and prevent swinging
Maneuver the motor into position above the mounting point
Lower the motor slowly into place
5. Post-Lift Inspection
Verify the hydraulic motor is securely positioned and aligned
Disconnect the rigging equipment
Inspect the crane and rigging equipment for any signs of wear or damage
Detailed Lifting Procedure for Hydraulic Pump Installation
1. Pre-Lift Inspection
Verify the weight of the hydraulic pump
Inspect the lifting points on the hydraulic pump
Ensure the rigging equipment (slings, shackles, lifting beams) is rated for the load
2. Rigging Setup
Attach slings to the lifting points on the hydraulic pump
Use a lifting beam to ensure stability
Secure the slings to the crane hook with shackles
3. Test Lift
Conduct a test lift to a height of 1 meter
Check the balance of the load and the integrity of the rigging setup
Make necessary adjustments
4. Main Lift
Slowly lift the hydraulic pump to the required height
Use tag lines to control the load and prevent swinging
Maneuver the pump into position above the mounting point
Lower the pump slowly into place
5. Post-Lift Inspection
Verify the hydraulic pump is securely positioned and aligned
Disconnect the rigging equipment
Inspect the crane and rigging equipment for any signs of wear or damage

