



School of Engineering and Digital Sciences

**Bachelor of Engineering in
Mechanical and Aerospace Engineering**

**Manufacturing Process Optimization via Jigs
Development: Improving Safety and Efficiency in
Locomotive Assembly**

(Final Capstone Project Report)

by

Alisher Sovetkazin

Bekzat Adilbek

Kamilla Beshpalinova

Nursat Khobdabayev

Principal Supervisor: Professor Yerkin Abdildin

April 2025

Declaration

We, Nursat Khobdabayev, Kamilla Bespalinova, Bekzat Adilbek, and Alisher Sovetkazin, hereby declare that this report entitled “Manufacturing Process Optimization via Jigs Development: Improving Safety and Efficiency in Locomotive Assembly” is the result of our own project work except for quotations and citations that have been duly acknowledged. We also declare that it has not been previously or concurrently submitted for any other degree at Nazarbayev University.



Name: Nursat Khobdabayev



Name: Kamilla Bespalinova



Name: Bekzat Adilbek



Name: Alisher Sovetkazin

Date: April 28, 2025

Acknowledgment

We would like to express our deepest gratitude to our supervisor, Professor Yerkin Abdildin, for his active support, constant encouragement, and guidance throughout the process.

We would also like to mention our field supervisors, Adilbek Kabylbekov and Shaimerden Kuanganov, whose practical experience and continuous assistance in the field have significantly contributed to the success of this project. Their mentorship has helped us tackle the complexities of the manufacturing environment.

This project would not have been possible without the collective efforts and encouragement of everyone mentioned above.

Abstract

This capstone project addresses inefficiencies and safety concerns in the industry of locomotive assembly by developing custom jigs and fixtures. Current methods of aligning components are inefficient and mostly have been performed by cranes, resulting in time delays and safety hazards. In this frame, this project is dedicated to designing and integrating jigs that optimize alignment precision, workflow efficiency, and operator safety. The methodology includes conventional workflow analysis, application of ergonomic principles, and advanced manufacturing techniques in designing along with developing jig and fixture prototypes. It is argued that designed products are expected to minimize manual effort and reduce reliance on cranes, leading to improved assembly and prevented risks of downtime. Beyond improving assembly efficiency, it redefines traditional manufacturing concepts through integrating new design and applying engineering principles. These findings contribute to not only advancements in locomotive manufacturing but also can be applicable for other industries that may require efficient and safe assembly of large components.

Table of Contents

Declaration.....	i
Acknowledgment.....	ii
Abstract.....	iii
Table of Contents.....	iv
List of Figures.....	vi
List of Tables.....	viii
1 Introduction.....	1
1.1 Problem Statement.....	2
1.2 Aim and Objectives.....	3
1.3 Hypothesis.....	3
2 Literature Review.....	4
2.1 The Role of Jigs and Fixtures in Manufacturing.....	4
2.2 Ergonomics and Safety.....	6
2.3 Research Gap.....	6
3 Methodology.....	7
3.1 Overview of Methodology.....	7
3.2 Data Collection.....	8
3.3 Decision-Making Framework.....	9
3.4 Design Process.....	11
3.4.1 Initial Prototype.....	11
3.4.2 Limitations.....	12
3.4.3 Further Simplification of the Design.....	12
3.5 Calendar Plan.....	13
4 Results.....	14
4.1 Evolution of the Design: From the Initial to the Second Prototype.....	14
4.2 Key Features of the Second Prototype.....	15
4.3 Alignment and Precision Considerations.....	19
4.4 Justifying the Design Process.....	21

4.5 Changes to the Current Setup.....	22
4.6 Cost Analysis.....	23
5 Discussion.....	24
5.1 Technical Soundness.....	24
5.2 Limitations.....	31
5.3 Further improvements.....	32
6 Additional Jigs.....	32
6.1 Jig for Wheel Inspection.....	33
6.2 Brake Pipe Stand.....	35
6.3 Shaft Removal Handle.....	36
6.4 Shaft Stand.....	37
6.5 Adhered Spring Pusher.....	39
6.6 Table for Pressuring System.....	40
6.7 Table for Furnace.....	41
7 Conclusion.....	43
References.....	44
Appendix A: Technical specifications.....	45

List of Figures

Figure 1. Bogie frame and gearbox-motor assembly components.....	1
Figure 2. Bogie frame and gearbox-motor assembly inspection scheme.....	4
Figure 3. A jig system for a bogie frame and gearbox-motor assembly.....	5
Figure 4. Methodology Flowchart.....	8
Figure 5. Old process.....	8
Figure 6. Decision matrix of suggested solutions.....	10
Figure 7. The initial design of the jig.....	11
Figure 8. Gantt Chart.....	13
Figure 9. Sketch of the Initial Prototype Design.....	14
Figure 10. Second sketch of the second prototype design with key features.....	15
Figure 11. CAD model of the second prototype.....	16
Figure 12. CAD model of the second prototype (side view).....	17
Figure 13. CAD model of the second prototype (one part).....	17
Figure 14. Isometric view of Worm Gear Screw Jack.....	18
Figure 15. The drawing of a Worm Gear Screw Jack.....	18
Figure 16. The Process of Measuring the Bearing Clearance.....	20
Figure 17. Worm gear screw jack drawing.....	22
Figure 18. Selected rails assembly and dimensions.....	23
Figure 19. Special ergonomic analysis by the company's standards.....	27
Figure 20. Boundary conditions.....	28

Figure 21. Equivalent stress for the Dynamic Frame and Gearbox Stand.....	29
Figure 22. Results of analysis: Total deformation.	29
Figure 23. Max total deformation vs number of node elements.....	30
Figure 24. Optimized process of the engine gearbox assembly.....	30
Figure 25. Schematic map of Alstom Boogie-Centre with the location of additional jigs.	33
Figure 26. Jig for the wheel inspection: in real life and a 3D model.....	34
Figure 27. Assembly drawing of the wheel inspection jig.....	34
Figure 28. The current Brake Pipe Stand.....	36
Figure 29. New design for the Brake Pipe Stand.....	36
Figure 30. The operation before the handle.....	37
Figure 31. The handle's technical drawing.....	37
Figure 32. Shaft stand drawing.....	38
Figure 33. Manufactured shaft stand.....	38
Figure 34. Assembly pusher drawing.....	39
Figure 35. Welding pusher drawing.....	39
Figure 36. Assembly of the pusher with Wheel Motor Block.....	40
Figure 37. Pressurization table drawing.....	41
Figure 38. 3D Model of the Table for Furnace.....	42

List of Tables

Table 1. Stages of motor block assembly.....	9
Table 2. Improved process.....	31

1 Introduction

Manufacturing has been the backbone of industrial progress, which forced technological changes that have reshaped many societies and economies worldwide. Modern manufacturing has evolved into various processes prioritizing efficiency and safety in assembling complicated components into functional machinery. As industries continue to evolve, so do the challenges that come along with assembly processes, especially those involving the precise integration of large and complex components. Locomotive manufacturing is an important part of the transport industry. In this respect, locomotives represent the lifeblood of transportation networks all over the world and, therefore, need to be reliable to cope with the demanding conditions of heavy freight and passenger services. The primary focus of railway companies is to increase locomotive production. For this reason, engineers conduct workflow process assessments to identify inefficiencies. Among the many critical processes within the industry, gearbox and motor block assembly shows how precision and efficiency go hand in hand.

The gearbox is the major unit in locomotives that transmits mechanical power from the engine to the wheels. Seamless integration with the motor block yields operational efficiency and long-term reliability. Therefore, gearbox-motor assembly is a significant driving and structural part of the whole locomotive, located on the bogie frame, which serves as a chassis of the train (Fig. 1). However, the traditional assembly of these components is dependent on crane operations. Although cranes are necessary due to the substantial weight of the gearbox and motor block handling, their overuse brings major challenges. Manual positioning of the gearbox requires operators to place the gearbox physically, hence making it very difficult, error-prone, and unsafe. Furthermore, the dependency on cranes is directly responsible for production delays.

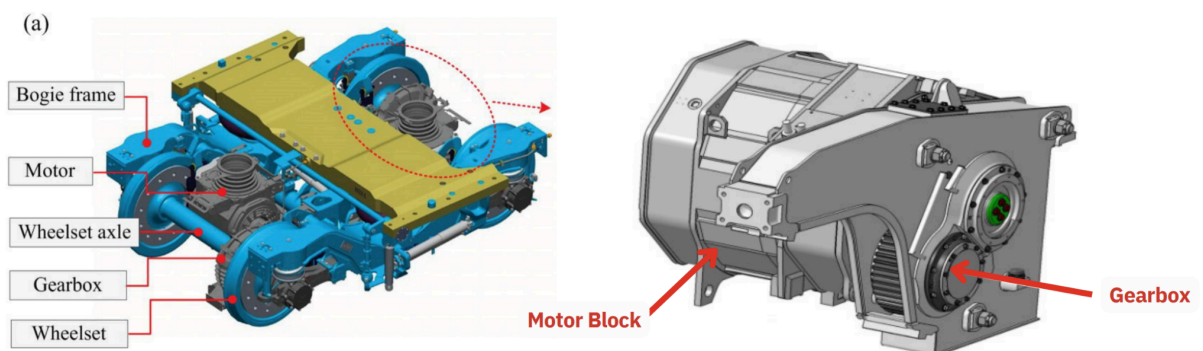


Figure 1. Bogie frame and gearbox-motor assembly.

The requirement for innovation in locomotive manufacturing is growing. These challenges can only be overcome with new-age solutions that focus on safety, streamlining workflow, and reducing dependency on cranes. Rigidity during the assembly can be provided by jigs and fixtures, which are tools that guide, provide precision, and repeatability. Jigs and fixtures have been used successfully in the aerospace to automotive industries to eliminate manual adjustments and increase efficiency. However, their application in locomotive assembly, especially in the integration of gearboxes and motor blocks, has rarely been explored.

To address these challenges, the use of **jigs and fixtures** was developed as a transformative solution across various manufacturing sectors. Jigs are tools that guide components into precise positions during assembly, ensuring alignment and repeatability. Fixtures, in contrast, hold components securely in place, providing stability and preventing movement during operations like welding, machining, or fastening. Together, these tools enable manufacturers to achieve the precision and consistency required for high-stakes applications.

1.1 Problem Statement

The assembly of gearboxes and motor blocks in locomotive manufacturing impacts not only safety and efficiency, but also overall productivity. The current process relies heavily on cranes, lifting and aligning the gearbox with the motor block. Manual control of the gearbox transportation across the plant and its placement onto the motor block via crank causes several issues related to the high risk of misalignment and the need for qualified operators. Additionally, the manual nature of the process also raises concerns about ergonomic risks.

Despite the advancements in manufacturing technology, the gearbox assembly process in locomotive manufacturing remains inefficient and fraught with several key challenges. Firstly, manual handling during crane operations exposes operators to potential hazards, including physical strain and accidental component misalignment. Secondly, reliance on cranes for positioning and alignment results in production delays, particularly when crane availability is limited. Thirdly, over-dependence on cranes introduces workflow rigidity, as assembly progress is dictated by the availability and capacity of this equipment.

These issues require a novel solution to optimize the assembly process, reduce crane usage, and improve safety and precision.

1.2 Aim and Objectives

Aim:

To design and implement a customized jig system that optimizes the gearbox and motor block assembly process (and reassemble), particularly minimizing crane usage and improving safety.

Objectives:

1. Conduct a detailed problem analysis of the current gearbox. Identify inefficiencies and safety concerns.
2. Develop a custom jig system with an ergonomic design that reduces manual handling. Prevent potential safety hazards for employees handling heavy components.
3. Ensure consistent and accurate alignment of the gearbox and motor block
4. Ensure the jig system aligns with industry safety standards
5. Improve workflow efficiency. Assess the system in terms of minimizing delays and ensuring smooth operations.
6. Document the findings, design, and outcomes of the project.

1.3 Hypothesis

The integration of a custom-designed jig system will significantly improve the efficiency of the assembly process. This approach is expected to minimize production delays, decrease error rates, and establish a practice that can be extended to other rail industries.

2 Literature Review

2.1 The Role of Jigs and Fixtures in Manufacturing

Jigs and fixtures are essential components in manufacturing. Being one of the fundamental parts of the whole bogie development process, jig development plays a significant part in both the pre- and final assemblies through the finishing and inspection operation (Fig. 2).

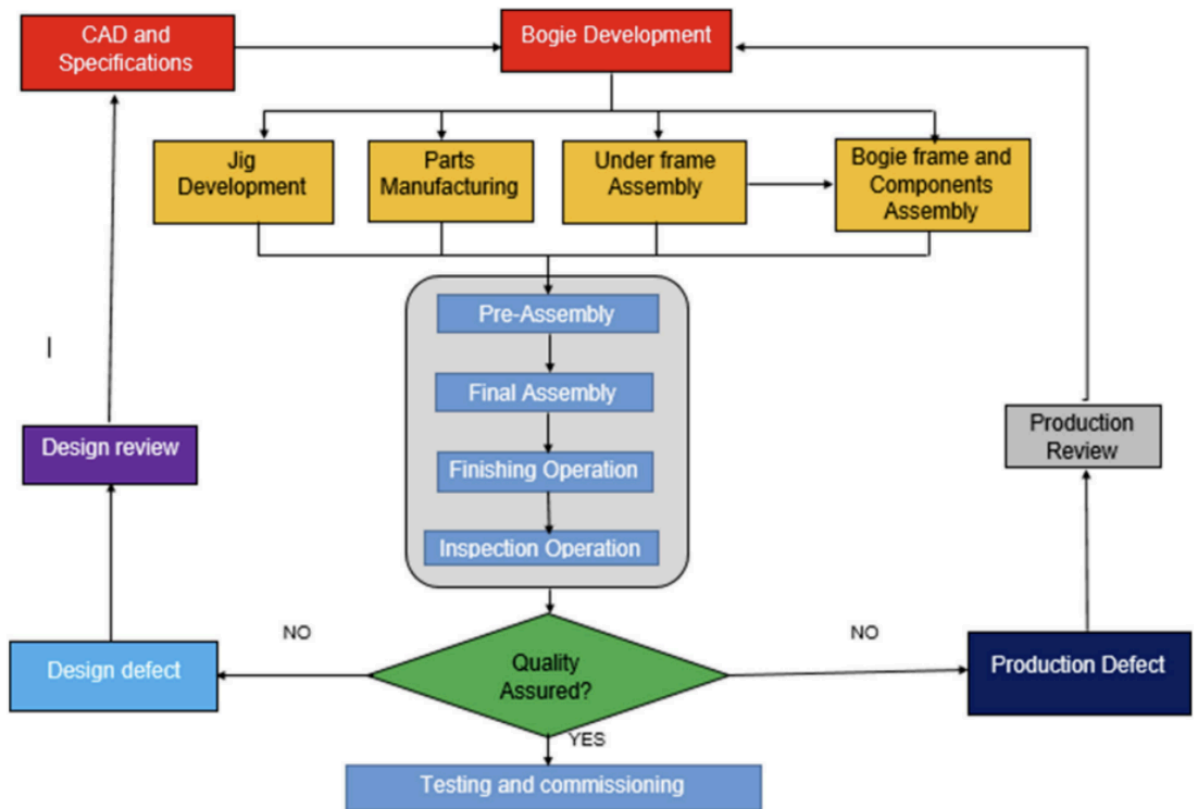


Figure 2. Bogie frame and gearbox-motor assembly inspection scheme.

A fixture can be defined as manufacturing equipment that secures workpieces in specific positions [1] (Fig. 3). There are many types of fixtures depending on the geometry, such as modular, dedicated, and hybrid systems, with modular flexible fixture systems (MFFS) and singular flexible fixture systems (SFFS). Overall, these tools account for up to 29% of total investment costs in production systems, as observed in automotive body shops.

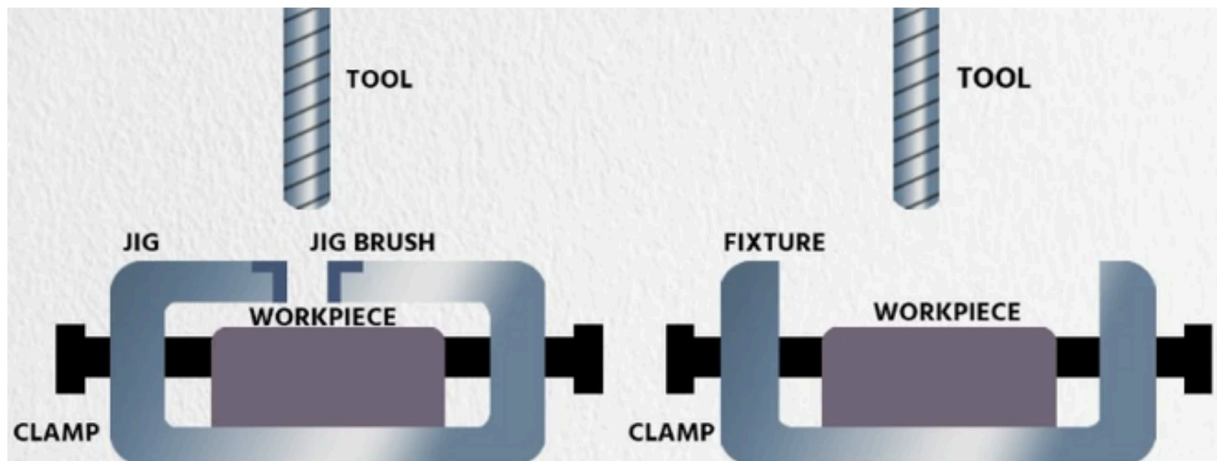


Figure 3. A jig system for a bogie frame and gearbox-motor assembly.

Some studies report a 30% to 50% reduction in manufacturing costs and up to 40% to 90% shorter ramp-up times [1]. For instance, BMW uses AM for producing approximately 200,000 components annually, including grippers and fixture elements for industrial robots. Research has also demonstrated the use of digital twin technology and its profound impact on locomotive assembly [2]. For example, the Internet of Things (IoT) provides real-time data through sensors and connected devices installed on mechanical systems. In gearbox assembly, IoT devices can provide continuous monitoring of important parameters such as alignment, torque, and vibration. Besides IoT, the combination of big data technologies and machine learning algorithms can be used to foresee potential issues for effective maintenance [2].

Jigs are particularly important in high-volume production. A high-quality system typically requires jig bushings and support locating pins [3]. Jig bushings are critical for guiding cutting tools (such as drills, reamers, and taps) during machining operations. They “must be wear-resistant, interchangeable, and precise [4]. The pins are used to support coarse or rough surfaces during machining. Finally, the time spent by a single operator using a rectangular jig in a sitting position was recorded: an average assembly time accounted for 18.36 seconds per product [5].

One of the common practices in optimising production is lean manufacturing. Lean manufacturing includes Total Quality Management (TQM), Just-In-Time (JIT) production, Total Productive Maintenance (TPM), organizational performance and Enterprise Resource Planning (ERP) [6]. One of the papers shows that lean culture develops the relationship between suppliers. Environmental and financial sustainability are significant considerations in lean manufacturing as well.

2.2 Ergonomics and Safety

Safety in manufacturing environments is of paramount importance, especially when dealing with heavy components such as gearboxes. Poorly designed workflows can compromise operator well-being and lead to inefficiencies. Jigs and fixtures play a pivotal role in improving both ergonomics and safety by minimizing manual handling and ensuring precision during operations. Incorporating semi-automated jigs significantly reduces operator fatigue and the risk of injury by eliminating repetitive manual tasks [7]. Their study demonstrates how replacing manual processes with ergonomic jigs streamlined the insertion of components, reducing workplace injuries and improving productivity.

The ergonomic principles in jig design focus on optimizing handling efficiency, reducing physical strain, and ensuring proper positioning of workpieces. Radhwan et al. emphasize that well-designed jigs can provide rigid support, ensure accurate alignment, and provides easy loading and unloading of components. These features not only improve the safety of the operator but also enhance the overall productivity of the manufacturing process.

In the context of gearbox assembly and disassembly, ergonomic considerations include the reduction of crane dependency and the implementation of controlled mechanisms such as screw jacks to minimize manual intervention. This approach ensures a safer working environment by addressing risks associated with heavy lifting and imprecise manual operations. As highlighted in Radhwan et al.'s findings, incorporating ergonomic designs into jigs enhances operator comfort and efficiency, leading to a more streamlined manufacturing process.

2.3 Research Gap

While the benefits of jigs and fixtures are well-documented in aerospace and automotive industries, their application in locomotive gearbox assembly remains underexplored. Most existing studies focus on general manufacturing advantages without addressing the specific challenges of aligning and integrating heavy components like gearboxes. This gap highlights the need for targeted research to develop solutions tailored to the unique demands of locomotive manufacturing.

What makes this problem particularly unique is the lack of a direct, universal solution that addresses the specific needs of locomotive gearbox assembly. Unlike standardized processes in other manufacturing sectors, the problem requires a highly customized approach based on the design constraints of the company. It is common for industrial engineers to design

bespoke solutions that address the specific requirements of their organization in accordance with existing workflows, equipment, and production goals. In other words, every company tackles this issue differently.

3 Methodology

3.1 Overview of Methodology

The methodology described for this project was selected and modified to address the safety concerns and inefficiencies associated with the locomotive assembly, according to the Methodology Flowchart (Fig. 4). It started with a data collection, where detailed observation of the assembly workflow was conducted to identify current methods and correlated issues with assembling. Then, a process analysis was carried out to establish inefficiencies and areas for improvement, which served as a foundation for further steps. The gathered information was interpreted, and potential solutions that meet the project objectives were brainstormed.

Following the design concept phase, it consisted of several steps, starting with the generation of some design ideas for jigs and fixtures, considering factors such as precision, ease of integration, and operator safety. After developing these concepts, they were systematically evaluated using a decision matrix focusing on precision, cost-effectiveness, and ease of maintenance, which led to the selection of the final concept. The selected design was then improved and further developed.

The next phase involved design analysis that ensures the suggested solution meets the project requirements. It included FEA to validate the structural strength of the design under loads, estimating durability, and reliability. Ergonomic analysis assessed the design's impact on operator safety and comfort. Additionally, a cost analysis was conducted to evaluate the economic feasibility of the proposed solution, and a time analysis was conducted to compare the assembly process with the new jig against the conventional method.

The iterative approach of this methodology allows constant improvement of the design, relying on analysis results and ensuring that the final solution meets project goals, particularly in terms of safety, efficiency, and precision. The methodology ended with the documentation of the design that serves as a detailed guide for integrating the custom jigs and fixtures into the workflow.

Table 1. Stages of motor block assembly.

Step	Description
1	Prepare the motor block, ensuring all clamping surfaces are absolutely clean and ready for assembly.
2	Install the seal on the engine housing and lubricate the inner bore of the gearbox with silicone grease.
3	Attach the lifting equipment (crane) to the gearbox so that it maintains maximum balance.
4	Using the crane, connect the gearbox and the engine drive shaft. Avoid damage and ensure proper adjustment. Since the reductor is heavy, it must be lifted and lowered carefully. Multiple skilled workers are needed to operate the crane, including ground staff to guide the load. Aligning the inductor with the motor block requires several small, manual adjustments to achieve the proper fit, making the process time-consuming.
5	Manual assembly. Secure and fasten other parts according to specifications.
6	Disassembly with a crowbar.

3.3 Decision-Making Framework

To identify the most effective solution for improving efficiency in motor and gearbox assembly, a thorough evaluation of five potential systems: hydraulic lift, pneumatic lift, scissor lift, and an actuator system, was conducted using a decision matrix. Additionally, the previous method that the company used in the matrix, the crane, has been included as a benchmark to assess how the proposed solutions compare. The design concepts were assessed based on five key criteria: safety, cost, precision, operation, and maintenance, and scores for each criterion varied from 0 (the lowest) to 5 (the highest). Weights were assigned to reflect their importance, which was determined in consultation with the company's engineers. Safety and cost were prioritized with a weight of 25% each, followed by precision (20%), operation (15%), and maintenance (15%).

The company's existing approach usage of the crane scored a total of 2.95 in the evaluation (Fig. 6). While it demonstrated reasonable safety and ease of operation, its high cost and maintenance requirements highlighted significant limitations. Among the alternatives, the hydraulic system was expected to face similar cost and maintenance challenges, but scored a

3.40 because of good marks for precision. These scores were slightly higher for the pneumatic system, 3.65, due to some advantages in safety and cost. However, its moderate precision and maintenance requirements reduced its overall score.

Thus, the scissor lift system was considered a favorable design that achieved a score of 3.90. It was a reasonable option for the company due to its low cost and ease of maintenance, with adequate performance in other categories. Initially, the actuator system seemed to be the most valid option with achieving the highest score of 3.95. Due to the alternatives' high safety, precision, and operational ease. However, its low cost score, which reflects its expense, is a significant disadvantage. In further discussions with the company's lead engineers, the actuator system's cost was considered a critical concern. Moreover, the fact that the difference in scores between the actuator system and the scissor lift system by 0.05 points is considered significantly small, and the actuator's favorability was further diminished.

The recommendation by the company manager was for the scissor lift system. While the actuator system had excelled in many criteria, the scissor lift offered a more balanced solution which met the financial and operational priorities given by the company. The analysis also highlighted considerable benefits of the proposed design concepts over the current crane system. The scissor lift was a practical, functional solution to the problem.

DECISION MATRIX

	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	
CRITERIA DESCRIPTION	Safety	Cost	Prcecision	Operation	Maintenance	
	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	WEIGHTED SCORE
WEIGHT	5	5	4	3	3	20
	25%	25%	20%	15%	15%	100%
OPTIONS	Criteria 1 SCORES	Criteria 2 SCORES	Criteria 3 SCORES	Criteria 4 SCORES	Criteria 5 SCORES	
Crane	3	2	4	4	2	2.95
Hydraulic System	3	3	5	4	2	3.40
Pneumatic System	4	4	3	3	4	3.65
Scissor's Lift System	4	5	3	3	4	3.90
Actuator System	5	2	5	5	3	3.95

Figure 6. Decision matrix of suggested solutions

3.4 Design Process

3.4.1 Initial Prototype

After selecting the final concept, the jig design was initiated. The initial prototype was developed using Computer-Aided Design (CAD) (Fig. 7).

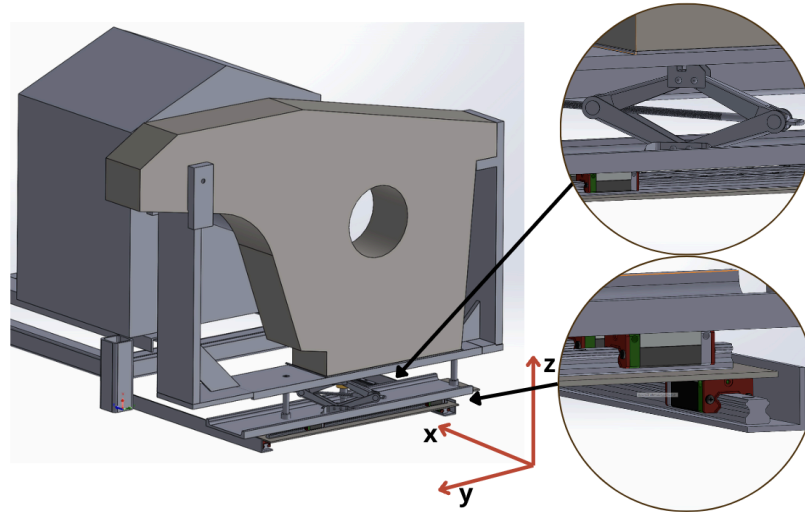


Figure 7. The initial design of the jig

The main components of the jig are:

1. **Scissor Jack:** Supplies z-axis (vertical motion) to precisely place the gearbox.
2. **Sliding Rollers:** Allow horizontal movement on the x- and y-axes, with ease of positioning.
3. **Gearbox Fixtures:** Fix the gearbox securely in place to provide stability to it on assembly and disassembly.

During a review with the supervisors at Alstom, it was noted that the current disassembly process for the motor block and gearbox posed challenges. Specifically, the components were tightly fitted, requiring significant force to separate them. Presently, operators use hammers to remove the gearbox from the assembly, which is both unsafe and prone to causing damage to the parts.

Based on feedback from Alstom's lead engineers, it was recommended to integrate a safer and more efficient disassembly mechanism into the jig design. This would eliminate the need for hammering and reduce the risk of defects. Following a thorough and iterative design process, the final design, addressing these concerns, is detailed in the Results section.

3.4.2 Limitations

The proposed jig system, while addressing key inefficiencies and safety concerns in locomotive assembly, has certain limitations. It requires manual operation by an operator, which can result in lower precision compared to systems equipped with electronic control units. In addition, the design lacks ergonomic considerations, often necessitating workers to sit or bend over during use. This could lead to discomfort or fatigue over time, potentially affecting productivity and overall operator well-being. These limitations highlight areas for potential improvement in future iterations of the jig, including the integration of automated controls and ergonomic enhancements to ensure greater precision, ease of use, and operator comfort.

3.4.3 Further Simplification of the Design

After carefully reviewing the supervisors' feedback, a new approach was proposed for the jig design. Since the jig will be used exclusively to assemble and disassemble the same motor block and gearbox components, which all share identical dimensions (height, weight, length, etc.), the design has been simplified by removing the scissor jack mechanism and one pair of sliding rollers.

The rationale behind this decision includes several key points. Firstly, the analysis of the setup has shown that with the small modifications to the current setup of the motor stand and the rails mechanism as the fixed positioning walls for the engine and gearbox allows neglecting the need of the upwards and sideways translation. So, with consistent dimensions across all assemblies, there is no need for vertical (z-axis) or lateral (y-axis) movement of the gearbox; only horizontal (x-axis) movement is required for proper alignment (Fig. 7). Secondly, the low positioning of the scissor system raised ergonomic concerns, making it uncomfortable for operators to use over extended periods. Thirdly, reducing the number of components enhances the reliability of the jig by simplifying its design and lowering maintenance requirements.

Additionally, to address the challenge of disassembling the gearbox when it is tightly fitted, a specialized mechanism has been integrated into the jig - the worm gear screw jack provides controlled force application during disassembly. This system eliminates the need for manual hammering, and provides a safer and more efficient method for separating the components without risking damage. This enhancement not only improves usability but also ensures greater safety and precision during disassembly.

4 Results

4.1 Evolution of the Design: From the Initial to the Second Prototype

As the project progressed, it became evident that the initial jig design, while effective for basic gearbox alignment, faced limitations when applied to more complex operations like disassembly. The existing design lacked the stability required for handling the added mechanical stresses involved in separating the gearbox from the motor assembly. Additionally, the initial model combined components such as scissor jacks and sliding rollers, which, while functional, increased manufacturing costs and maintenance requirements.

Recognizing these limitations, the team introduced a **second prototype** (Fig. 9), developed to address these challenges while maintaining operational simplicity. The new model integrated a worm gear screw jack mechanism, specifically designed to ease the disassembly process. This mechanism operated in compression, enabling the controlled extraction of the gearbox from the motorblock assembly without causing damage or requiring manual hammering. This adjustment significantly improves safety and ensures the integrity of both components (Fig. 10).

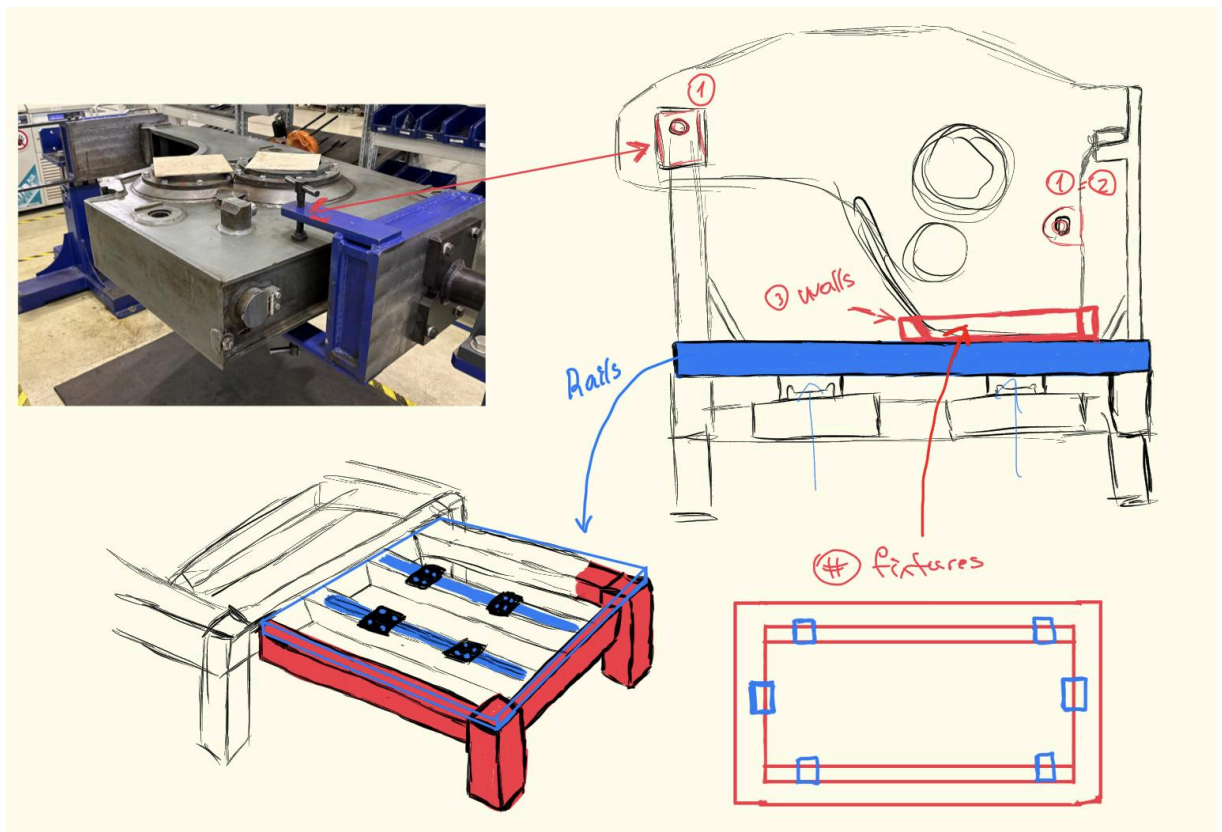


Figure 9. Sketch of the Initial Prototype Design.

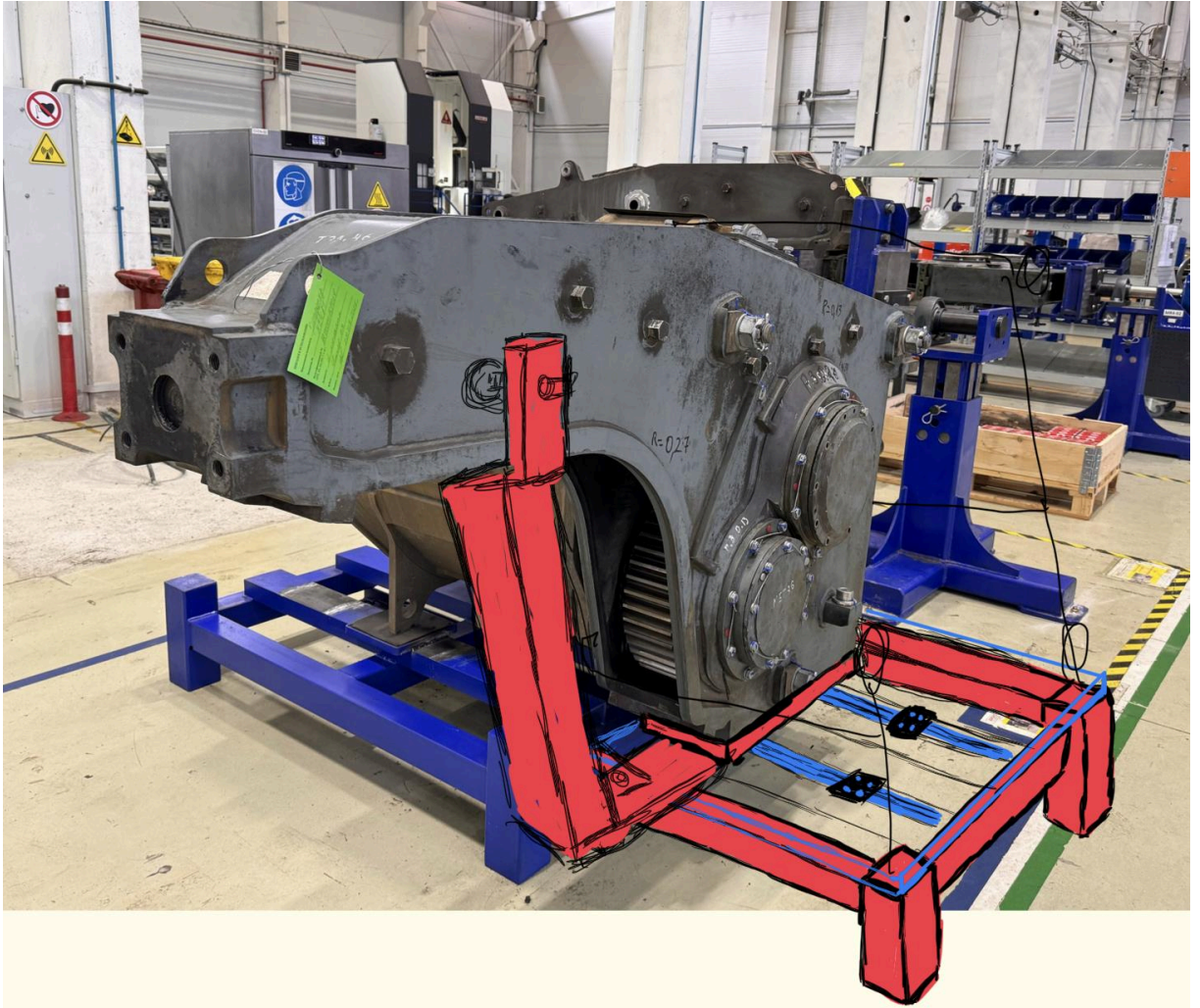


Figure 10. Second sketch of the second prototype design with key features.

4.2 Key Features of the Second Prototype

The second prototype reflected significant advancements in design and functionality (Fig. 11-15):

1. **Motion mechanics was simplified.** The new jig limited movement to the x-axis, directly targeting the required assembly field. It reduced complexity, enhanced precision, and removed the need for z-axis adjustments, which were redundant given the consistent dimensions of the components.
2. **Enhanced Disassembly Capability.** The addition of the worm gear screw jack provides controlled force application during disassembly. This mechanism replaced unsafe manual practices, such as hammering, to prevent the risk of operator injury and component damage.

3. **Improved Stability.** The redesigned jig improved stability by introducing a robust framework and simplifying structural components. These changes led to better performance during assembly and disassembly operations, especially under high-stress conditions.
4. **Cost Optimization.** By removing the scissor jack and one pair of sliding rollers, the new prototype reduced material and machining costs. This leaner design was more cost-effective without compromising functionality.

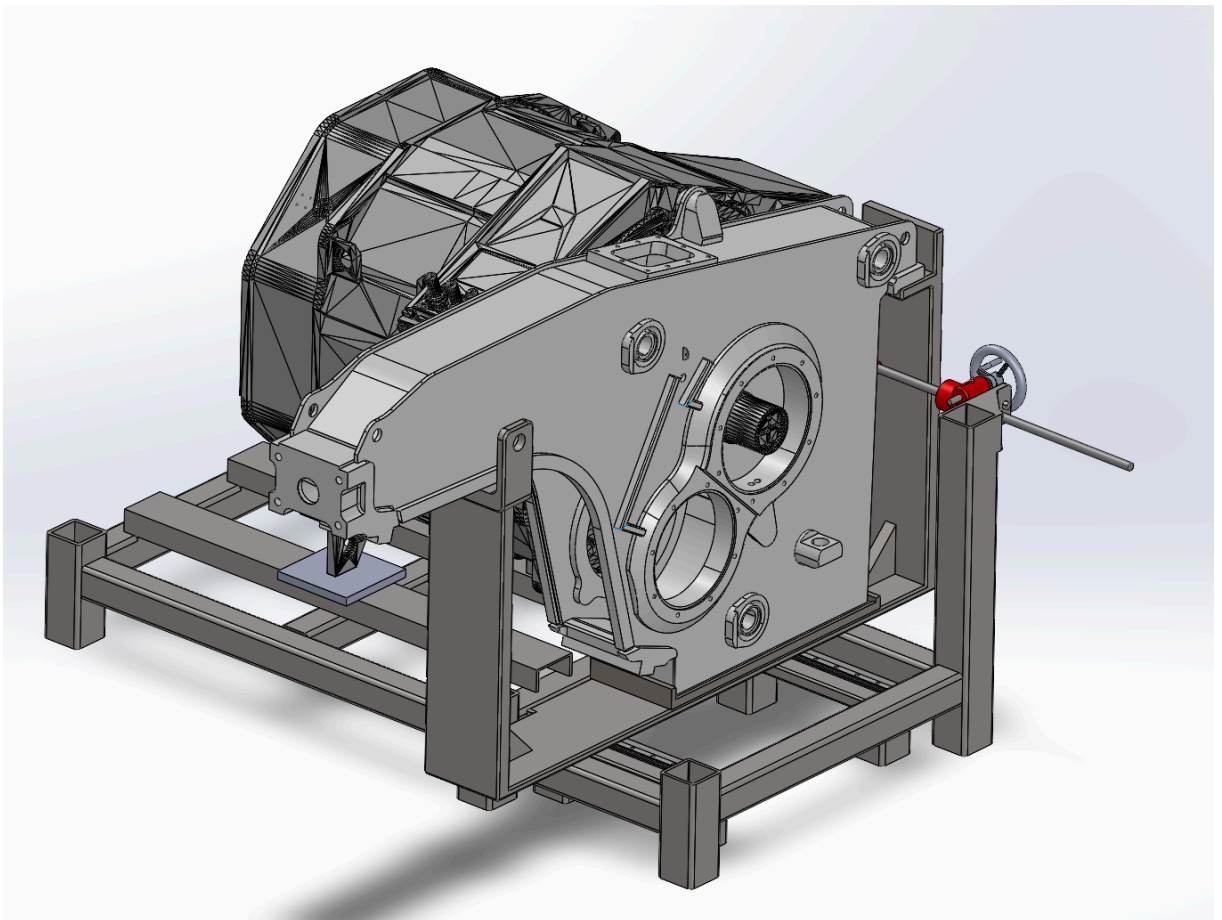


Figure 11. CAD model of the second prototype.

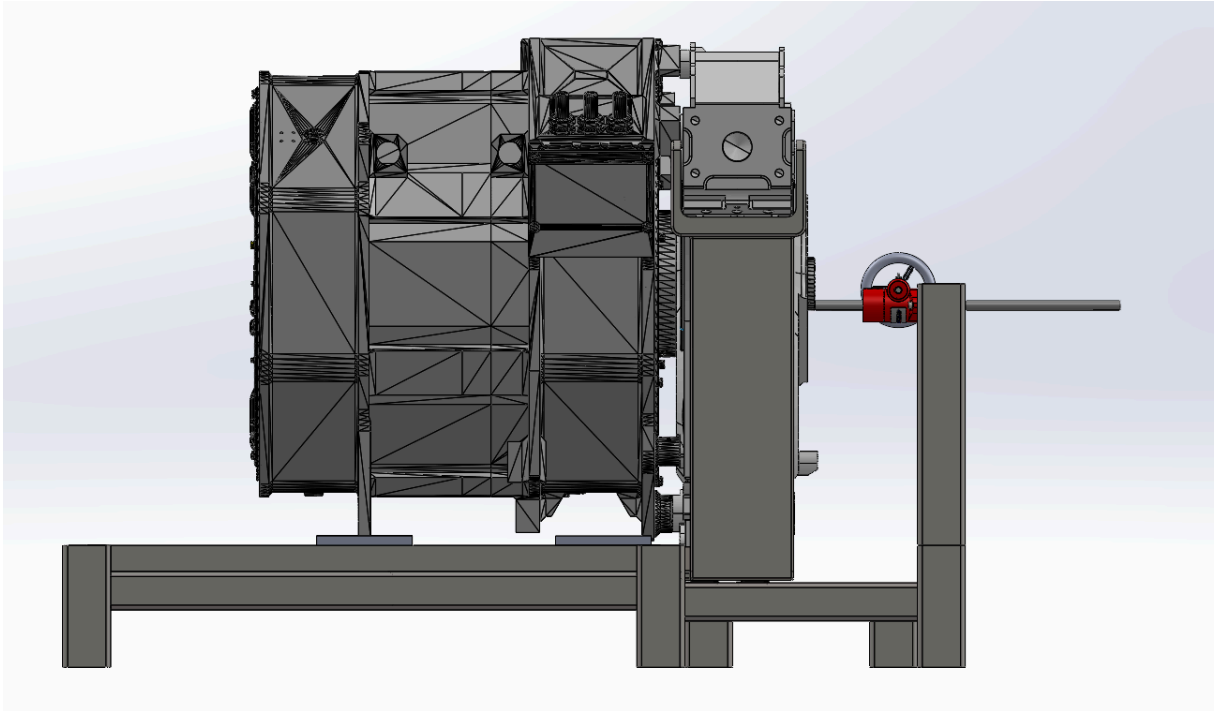


Figure 12. CAD model of the second prototype (side view).

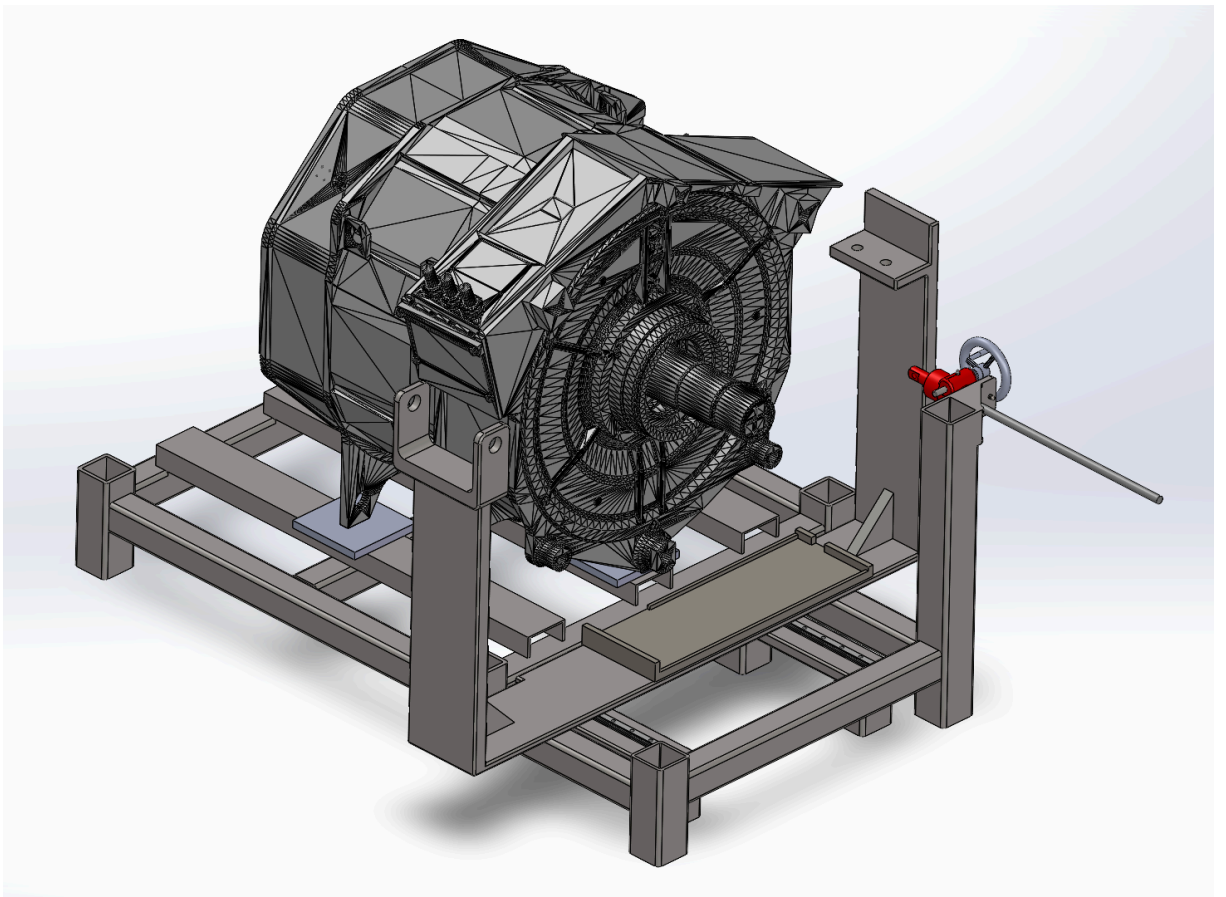


Figure 13. CAD model of the second prototype (one part).

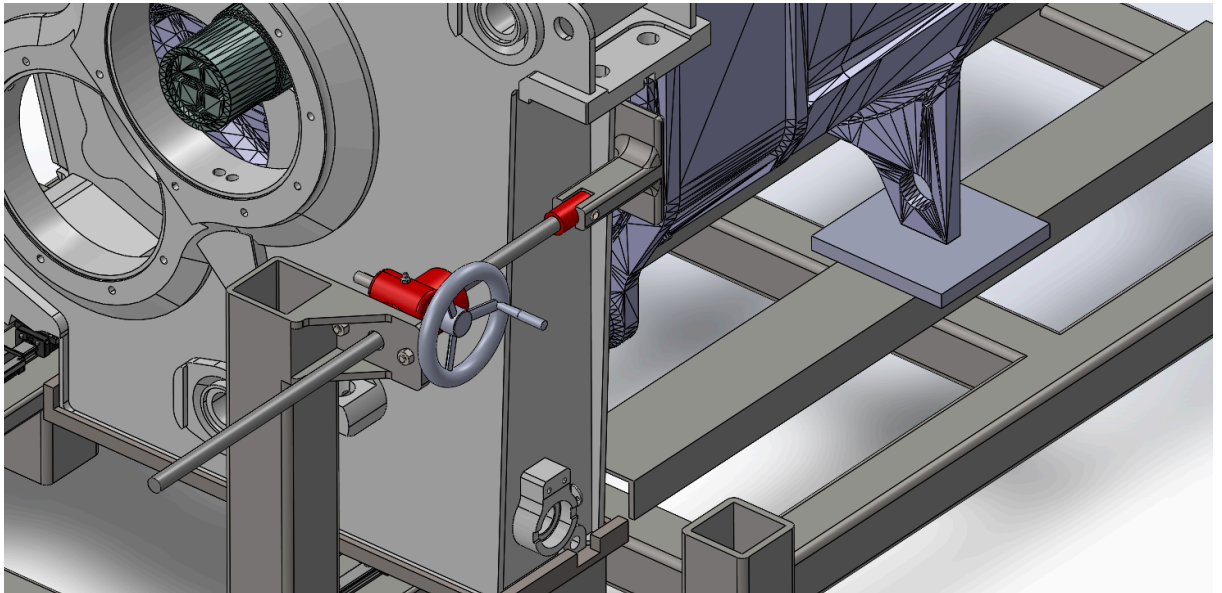


Figure 14. Isometric view of Worm Gear Screw Jack.

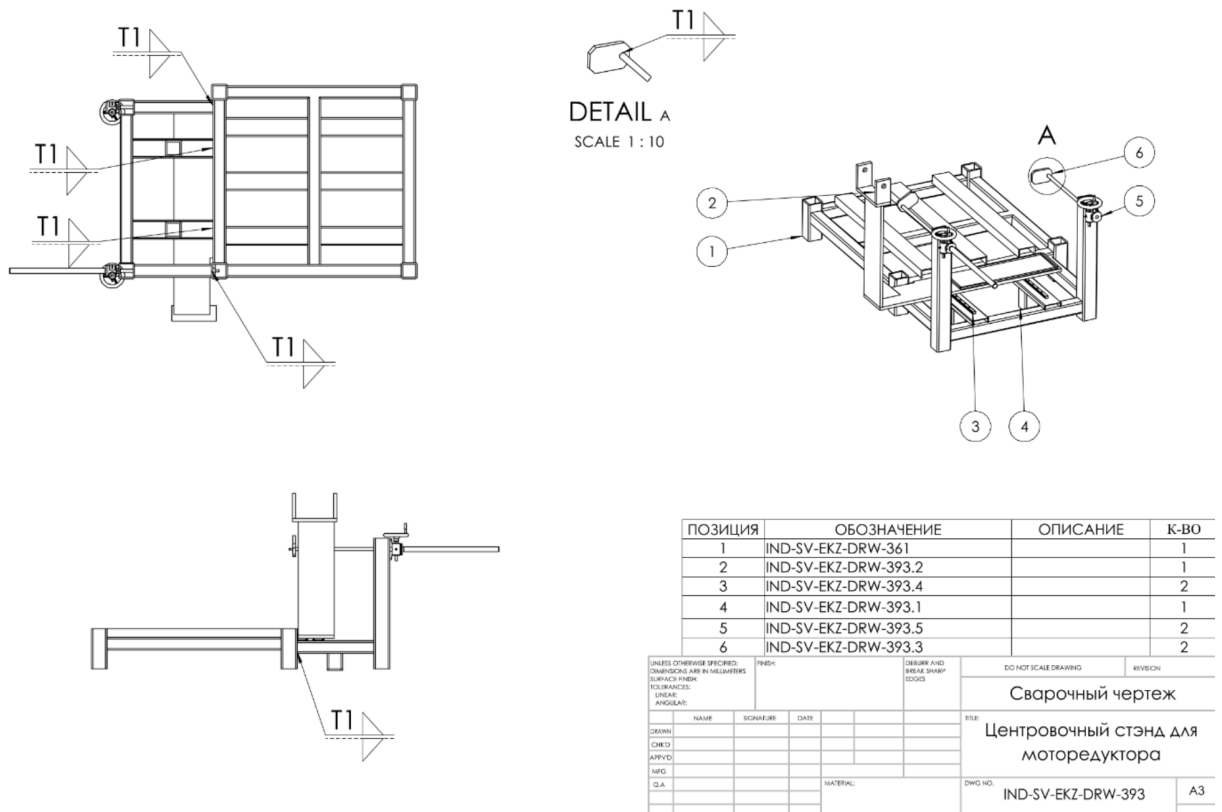


Figure 15. The drawing of a Worm Gear Screw Jack.

4.3 Alignment and Precision Considerations

Translational movement along the y-axis (lateral) and z-axis (vertical) was avoided in the final jig system design. Translational movement was allowed only along the x-axis (longitudinal) direction. The restriction posed a fundamental problem of how the motor block and the reductor would be aligned. Since x-axis translation alone was allowed by the jig, the motor block mounting as well as the mounting of the reductor need to have good initial accuracy.

To ensure the level of fit required, the other geometric tolerances were specified on the technical drawings and specifications provided to the potential manufacturers. The tolerances specified the most significant aspects of the flatness, the parallelism, and the consistency of the height of the mounting surfaces.

4.3.1 Flatness of the Mounting Surfaces

Since the proper positioning of the motor block and the reductor depends immediately on the quality of the seating surfaces, the latter needed to be machined to satisfactory flatness. Flatness ensured that each individual surface lacks surface waviness, bulges, or undulations that might have a negative impact on the alignment status of components.

Knowing that ideal flatness under theoretical conditions cannot be achieved and that ultra-flat machining would be prohibitively expensive, a limit of 0.02 mm of flatness on each surface was called for. It had a very tight and difficult tolerance on heavy mechanical components and was justified by the serious application of shaft and bearing alignment within the assembly.

Although keeping in mind the production by a contractor or external firm that could have varying machinability or cost factors, a contingency was provided. Where required due to cost or machinability constraints, the maximum deviation of the flats could be relaxed up to a value of 0.05 mm while the quality of the assembly remains adequate.

4.3.2 Parallelism of the Mounting Surfaces

Along with flatness, parallelism of the surfaces on which the motor block was mounted relative to each other is of the highest significance. Although a tight fit on both surfaces inherently promotes good parallelism, a certain amount of parallelism tolerance was deliberately established to prevent total error due to buildup.

A 0.02-mm parallelism tolerance was required, meaning the second surface of the fixture (reductor) has to be within 0.02 mm of the referenced surface (motor block). That aligned the

motor block and reductor axes correctly while keeping the bearing loads, the misalignment of the gears, and the mechanical stresses minimal.

Just like the situation of flatness, if the closer tolerancing could not be obtained by the manufacturer, the tolerancing of the parallelism could be reduced to 0.05 mm. However, one should maintain the closer specification as much as possible due to its impact on the assembly's operation.

4.3.3 Height tolerances

The motor block shaft should fit very accurately into the inner ring of the bearing (FAG NU2322-E-MPA-H67C-R210-240) mounted on the housing of the reductor. Precise height matching between the shaft and bearing centers was therefore critical to prevent binding, excessive assembly forces, or misalignment stresses.

The internal radial clearance of the bearing was verified using a feeler gauge (Fig. 16) and was approximately 0.12 mm as per the manufacturer's tolerances of this type of bearing (nominal clearance range: 0.10–0.15 mm). For the reason that the radial clearance should provide room for small deviations without creating unwanted overloading, the maximum admissible height deviation of the motor block shaft and the center of the bearing was determined.



Figure 16. The Process of Measuring the Bearing Clearance

Specifically, in order to achieve a centered location without preloading of the bearing, the difference of relative height between the two surfaces of the fixture was set at ± 0.05 mm. It was a more conservative estimate than the theoretical split clearance ($0.12 \text{ mm} / 2 = 0.06 \text{ mm}$) as a means of creating a small margin for uneven small machining and assembly. Consequently, the consistency of the reductor fixture and motor block height has strictly been managed for the effective operation of bearings and long-term reliability of the drivetrain assembly.

4.4 Justifying the Design Process

The development of the second prototype was driven by the realization that the initial design, while functional for basic gearbox assembly, could not adequately address the added complexities introduced by the disassembly process. During the initial phase, the primary goal was to conceptualize a foundational design that streamlined alignment and assembly. Given the simplicity of the initial prototype's purpose, detailed sketches and process illustrations were deemed unnecessary, as the model was focused on addressing fundamental issues with crane dependency and alignment.

However, as the project evolved, the scope expanded to include the disassembly process. This required a deeper understanding of the operational forces and mechanical stresses involved. The second prototype introduced critical new features, such as a worm gear screw jack mechanism (Fig. 17), that are designed specifically for controlled disassembly. This added complexity led to the creation of sketches and process illustrations to improve the model and address its functional requirements.

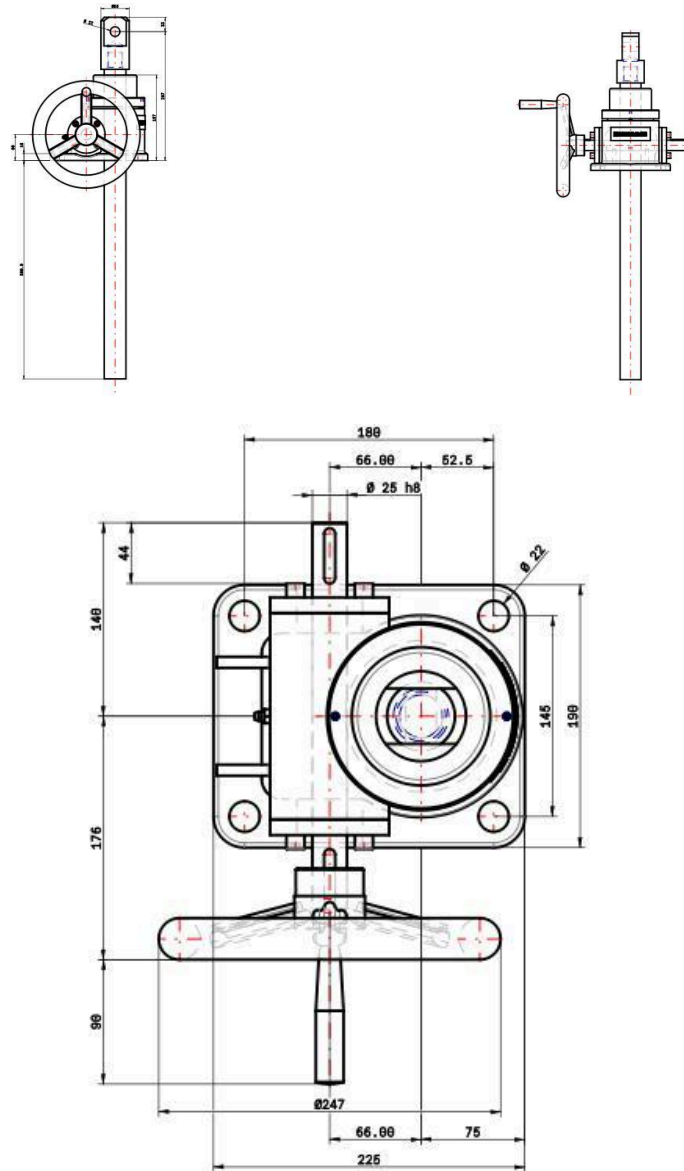


Figure 17. Worm gear screw jack drawing.

These illustrations played a pivotal role in visualizing the design concepts, identifying potential weaknesses, and iterating on the structural and functional aspects of the jig. By mapping out the integration of the worm gear screw jack and its role in the disassembly workflow, the team was able to improve the model's stability and improve its efficiency. The process simulations derived from these sketches not only justified the modifications but also provided a clear roadmap for implementing the new design elements.

4.5 Changes to the Current Setup

The implementation of the second prototype introduces significant changes to the gearbox assembly and disassembly workflow. By addressing the shortcomings of the initial model, the new design fundamentally reshapes the process. The enhanced stability of the jig ensures that

the gearbox remains secure during both assembly and disassembly, reducing the reliance on cranes. This change alleviates one of the primary inefficiencies in the existing setup and improves workflow flexibility.

The safety standards of the operation are also greatly improved. The controlled compression mechanism of the worm gear screw jack replaces the need for manual hammering, which not only reduces risks to operators but also ensures that the gearbox and motorblock are protected from potential damage during disassembly.

Operational efficiency has been streamlined through the simplified motion mechanics of the jig. By reducing unnecessary movements and focusing on a single axis for assembly, the prototype minimizes time losses and ensures consistent alignment. Additionally, the precision of the new jig design eliminates errors and rework, enhancing the overall reliability of the workflow.

4.6 Cost Analysis

The cost of the jig is fully covered by the company, and while there are no budget constraints, the expenses must remain reasonable to align with the objectives. Relying on preliminary estimates, the final design consists of two rail assemblies (441N20A0) priced approximately at \$350 [8] (Fig. 18), for a total of \$700 and a screw jack, which is estimated at around \$500.

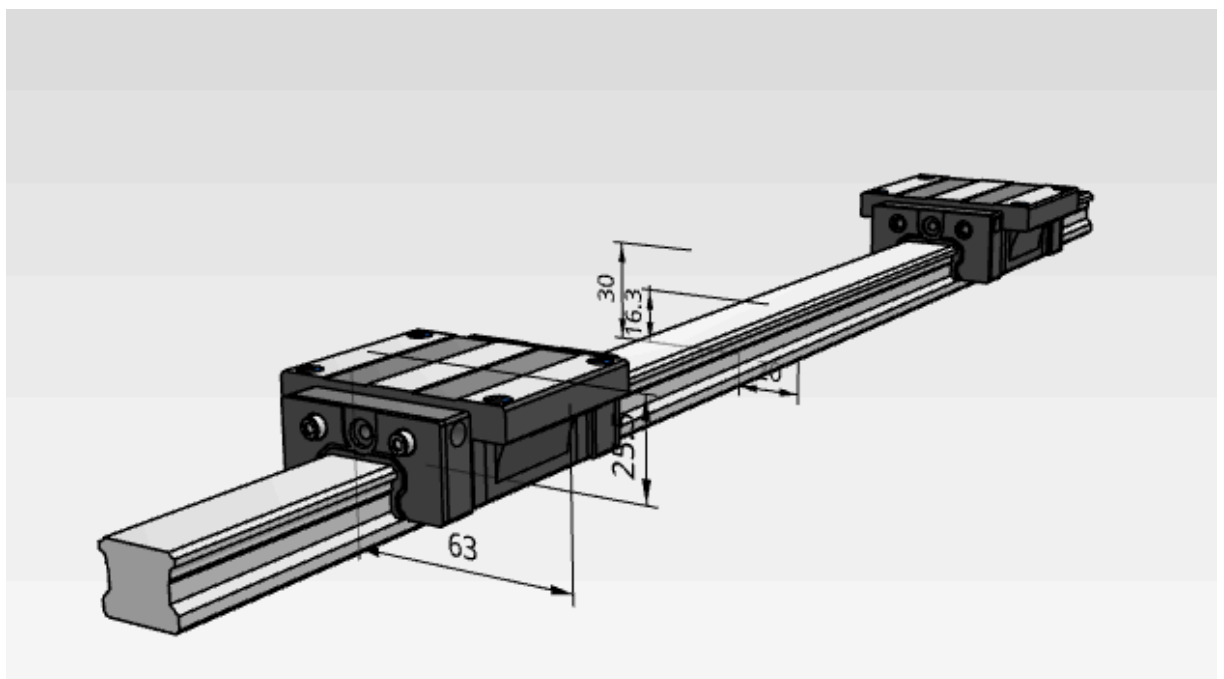


Figure 18. Selected rails assembly and dimensions.

The material and machining costs for the fixtures are expected to be \$400. As a result overall cost for the **components of the jig** was accounted for approximately \$1600. Although these cost evaluations are approximate, they have significantly varied since the company handled the entire purchase process.

It was necessary to request clarification from the Alstom supervisors to identify the total cost that includes both manufacturing and maintaining the jig, rather than solely the component costs. The main parameters considered during the cost analysis were as follows;

Main parameters considered during the cost analysis were as follows;

1. **Supplier management & procurement.** One person is usually responsible for the supply and ordering of 10 jigs per month. While the jigs' drawings were sent to the manufacturing company, the procurement of the main equipment took 3 months.
2. Manufacturing cost. Defined by the supplying company.
3. Shipping & transportation, packaging fees.
4. Installation cost (labour, equipment, and downtime). The supplier has established the price that includes materials, machining, labor, shipping, and setup. The cost is 6,000,000 tenge.
5. Maintenance cost. One engineer ensures periodic inspection, lubrication, and repairs. It is assumed that he spends 10% of the time and does monthly checks for the following 5 years with an average wage rate of 400,000 ₺.

$$C_{\text{Total}} = C_{\text{Procurement}} + (C_{\text{Manufacturing}} + C_{\text{Transportation}} + C_{\text{Setup}}) + C_{\text{Maintenance}}$$

$$C_{\text{Total}} = \frac{1 \cdot 400,000 \cdot 3}{10} + 6,000,000 + 1 * 400,000 * 0,10 * 12 * 5$$

$$C_{\text{Total}} = 8,520,000 \text{ ₺}$$

5 Discussion

5.1 Technical Soundness

The technical soundness of the jig system design addressed the primary challenges associated with the assembly and disassembly of the motor block and gearbox while maintaining simplicity and reliability. The design combined fundamental engineering principles, ensuring structural integrity, operational efficiency, and safety.

5.1.1 Structural Integrity and Reliability

The jig system was developed with a focus on stability and durability, using robust materials and precise manufacturing techniques. The removal of the scissor jack and one set of sliding rollers simplified the structure while maintaining functionality, reducing potential points of failure. Moreover, the jig system achieves greater reliability and ease of maintenance, reducing long-term costs associated with repairs and upkeep.

5.1.2 Precision and Alignment

By limiting movement to the x-axis, the design uses the consistent dimensions of the components to achieve precise alignment during both assembly and disassembly. The addition of a specialized mechanism for separating tightly fitted parts further enhances precision, eliminating the risk of misalignment or damage caused by manual interventions such as hammering.

5.1.3 Safety and Ergonomics

There was an ergonomic evaluation of the design of the jig system conducted using the company standards for work within the field. The resultant Ergo Global Score was 90% (Fig. 19), which is extremely high according to the company scoring scales. 80–100% scores are scored as very low risk levels and safe work conditions, while lesser scores would necessitate redesigns from an ergonomic point of view. Even with the resultant high rating, however, the assessment determined there were moderate ergonomic risks.

The rating was obtained from a weighted model with two significant constituents: 70% rating of biomechanical elements and 30% rating of criteria-based elements of force application, complexity of tasks, and repetitiveness. It was determined through biomechanical assessment that 62% of the movements and postures of work performed were rated as correct at a biomechanical level. Another 28% were rated under acceptable but non-ideal criteria, while 8% were rated as having incorrect biomechanical posture, of which 2% was rated as deviating from standard work procedures under general ergonomic criteria.

The physical stress pattern against body areas indicated that the shoulders and the wrists were the most stressed body areas involved in jig operations. Moderate stress was borne by the neck and the elbows, perhaps due to the occasional bending forward as well as the reach involved in handling as well as aligning the parts. Surprisingly, the lower body areas of the ankles, knees, and hips were under very little stress, indicating that much of the ergonomics of the jig system is concentrated within the upper body.

These were confirmed through physical solicitations analyses. Shoulders and wrists were proven to move fully within the safe zone of safety, demonstrating appropriate postural control as well as minimized musculoskeletal stress within the same. Torso had a moderate level of physical solicitation, with 67% safe movements against 33% needing improvement under mild forward-leaning postures. Elbows had equal division of acceptable versus moderate levels of risk, equaling manual handling as well as fine adjustment operations. The neck had 58% of movements as safe but involved 42% with mild ergonomic concern, especially with prolonged upward or downward gazes while performing work with the jig.

More work dynamic analyses indicated a low level of repetitiveness with tasks spread over nearly one hour with sufficient recovery time spent between repeating movements. Lifting, pushing, and pulling tasks were looked at separately, where lifting took up 17% of work time, and despite a marginal overload of lifting duration levels (approximately 10 minutes), it remained within levels of work acceptability. Regarding body position, workers spent most worktime standing for 67% of work time and sitting for the other 33%, without using the floor, bending, or lying down, which are mostly associated with more ergonomic risks. To conclude, while the ergonomical review reinstated the design of the jig as ergonomically compliant with the company requirements for operator safety and comfort, a minor risk of torso and neck strain was indicated. These risks are noncritical though they can be minimized through some minor improvements, such as through minor adjustments of the working height of the jig or with the reconfigured location of often-used tools to avoid frequent forward leaning. The results overall reaffirm the design of the jig as being safe ergonomically, for safe effectiveness, as well as efficient operations for prolonged application within the locomotive assembly environment.

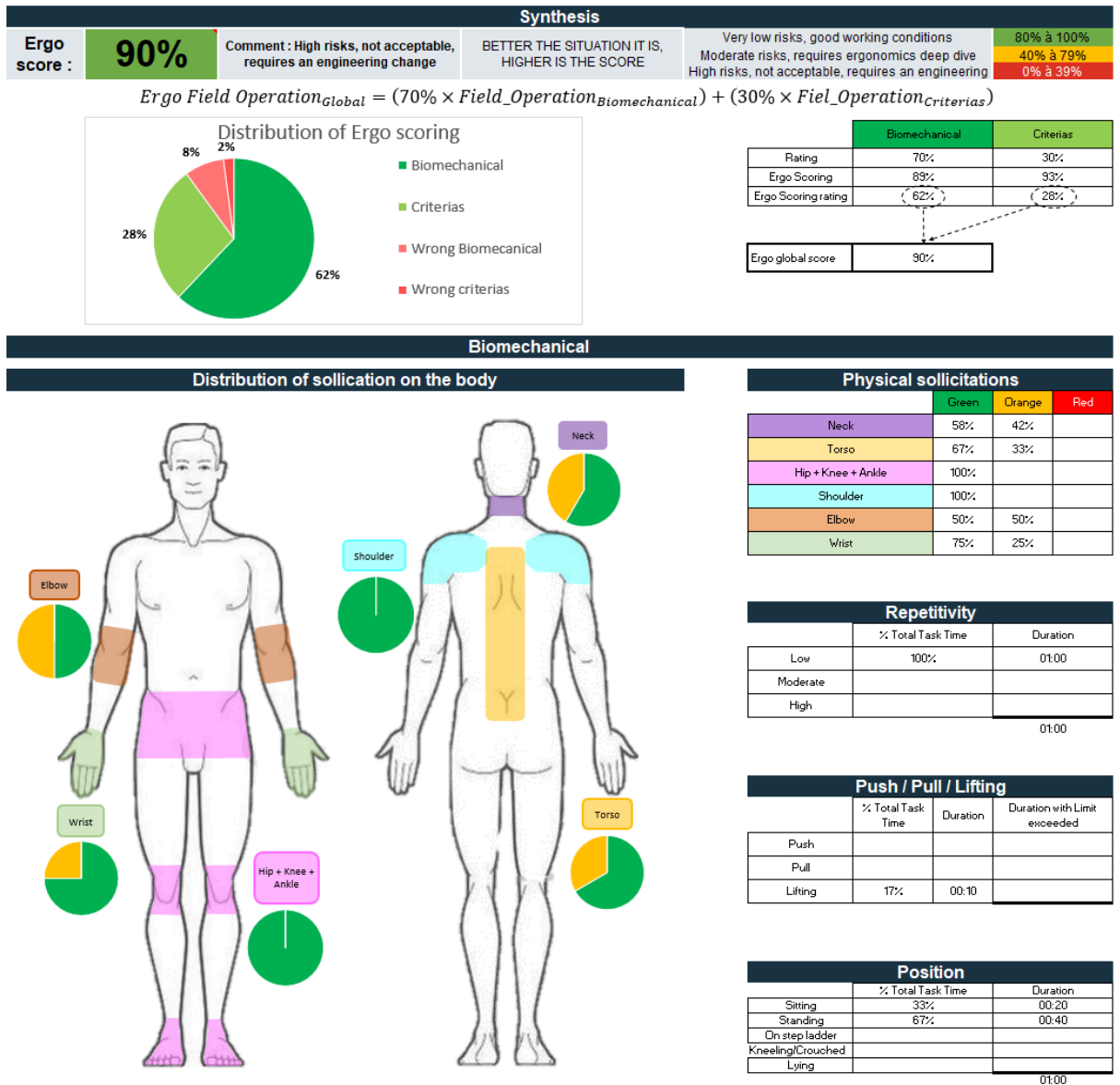


Figure 19. Special ergonomic analysis by the company's standards.

5.1.4 Ansys Simulations

In order to ensure the reliability of the customized jig, a Static Structural Finite Element Analysis was conducted using ANSYS. However, due to computational constraints, simulating the entire assembly with a sufficient mesh, particularly those areas where the stands were connected through rails, were complicated. Hence, the analysis was focused on custom-fabricated components: Dynamic Frame and the Gearbox Stand separately. Other components of the jig such as the rails that will be purchased instead of manufactured, are considered reliable, withstanding up to 3000 kg, according to supplier information. The stand for motor is already in use by the industry and does not require further validation.

Structural Steel was selected as the material of the designed jig with material properties of Young's modulus (200 GPa) and Tensile Yield Strength (250 MPa) in ANSYS. Boundary

conditions were applied as follows: for the Dynamic Frame, fixed supports were applied where rail attachments are expected, while for the Gearbox Stand, fixed supports were assigned to the base surfaces simulating connection to the floor. The loads were estimated using the gearbox mass of 500 kg (approximately 4905 N) and this weight was assumed to be distributed with the ratio of $\frac{1}{3}$ and $\frac{2}{3}$ on the Dynamic Stand, resulting in forces of 1635 N and 3270 N. The $\frac{2}{3}$ load component (3270 N) was applied as a direct force. For the $\frac{1}{3}$ of the weight, which is transferred by fixtures was implemented in terms of moments of 196.2 N.m. The load of 6000 N on the Gearbox Stand, represented the weight of the Dynamic Frame (approximately 80 kg) and gearbox (500 kg) and distributed evenly of 3000 N onto each plate (Fig. 20).

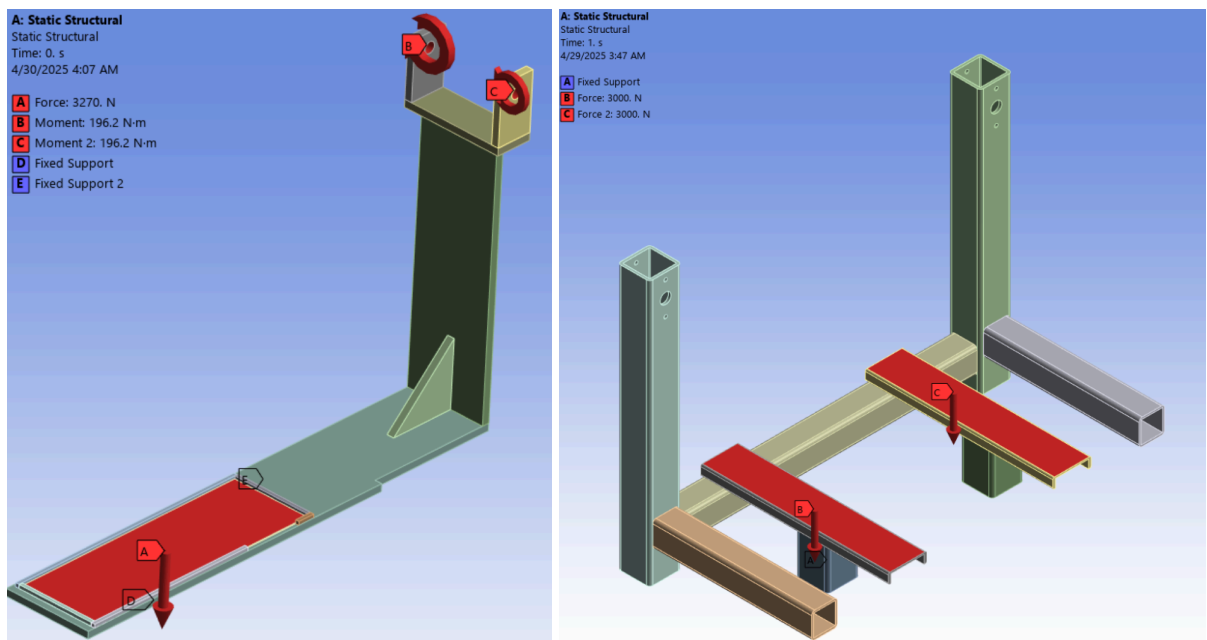


Figure 20. Boundary conditions

The static structural FEA results demonstrated the highest equivalent stresses of 65.8 MPa in the Dynamic Frame and 52.4 MPa in the Gearbox Stand (Fig. 21). These stresses significantly below the material's yield strength (250MPa) indicating that the jig will operate under its elastic limit under these loads.

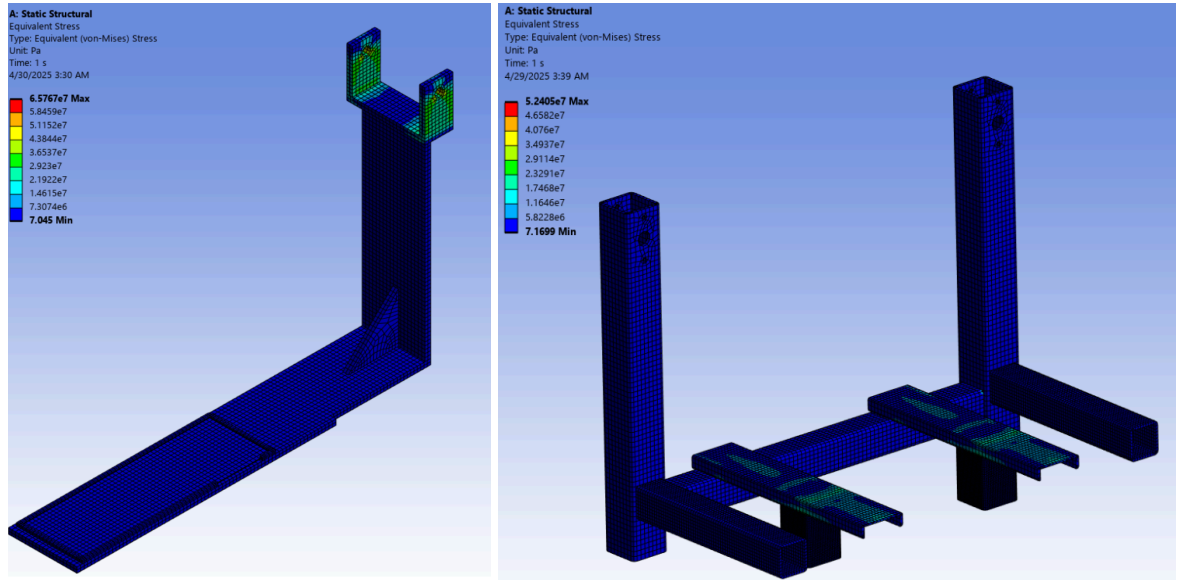


Figure 21. Equivalent stress for the Dynamic Frame and Gearbox Stand

The total deformation was computed to be approximately 0.318 mm for the Dynamic Frame and 0.165 mm for the Gearbox Stand (Fig. 22). The maximum deformations occurred at points on the Dynamic Frame where securing connections and where Gearbox Stand meets Motor Stand. These deformations are within acceptable design limits, ensuring the structural stiffness.

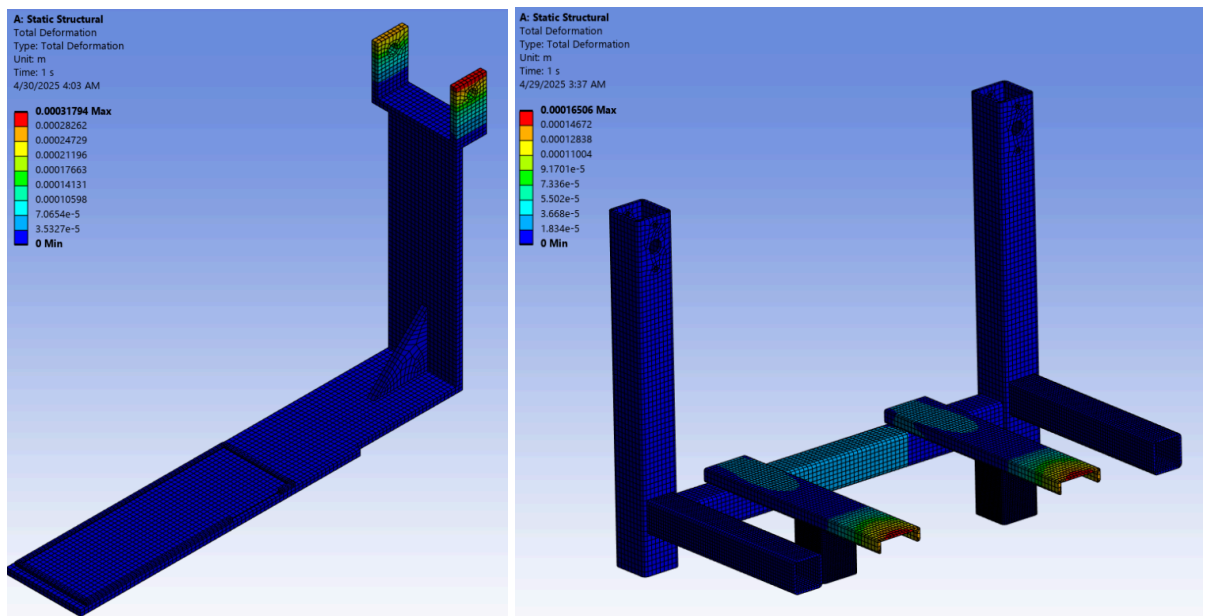


Figure 22. Results of analysis: Total deformation.

Based on these stresses the Factor of Safety (FoS = Yield strength/Max Equivalent stress) was estimated at 3.8 for the Dynamic Frame and 4.8 for Gearbox Standing. These FoS values ensure operational safety and can be interpreted as the overdesign. However, the priority was

placed on the high stiffness and minimal deformation critical for achieving the required tolerances.

To validate the accuracy of the analysis results, a mesh convergence study was performed, confirming that the results had converged (Fig. 23). The overall analysis confirms the structural integrity of the designed components for these static loadings.

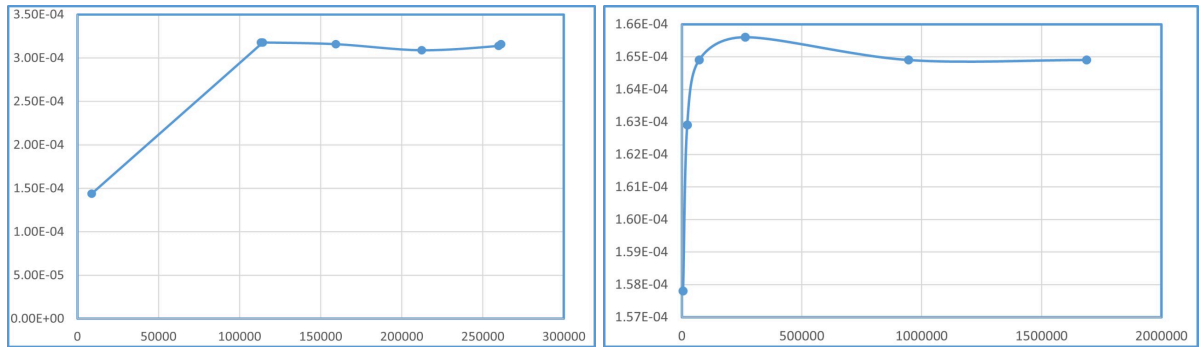


Figure 23. Max total deformation vs number of node elements.

5.1.4 Adaptability

While the jig system is tailored to specific components with consistent dimensions, its modular design allows for potential modifications to accommodate similar tasks in other assembly processes. This adaptability makes it a practical solution for a variety of manufacturing applications. Overall, the jig system demonstrates strong technical soundness, effectively addressing the challenges of the assembly process while balancing safety, precision, and simplicity. Its performance under real-world testing will provide further validation of its technical robustness

5.1.5 Workflow Efficiency

The utilization of the worm gear screw jack and simplified motion mechanics eliminates redundant movements, significantly reducing assembly and disassembly times. By focusing on horizontal movement, the jig enhances precision and streamlines the alignment process, minimizing errors and delays (Fig. 24).

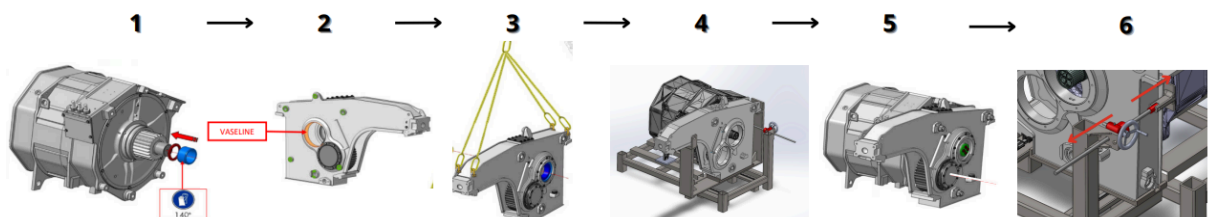


Figure 24. Optimized process of the engine gearbox assembly.

Table 2. Improved process.

Step	Description
1	Prepare the motor block, ensuring all clamping surfaces are absolutely clean and ready for assembly.
2	Install the seal on the engine housing and lubricate the inner bore of the gearbox with silicone grease.
3	Place the inductor on the jig using the crane. Use the jig for alignment. The jig aligns the inductor and motor block, ensuring perfect fitment without manual adjustments. The jig system reduces the need for multiple workers, speeds up the process, and minimizes errors and potential damage.
4	Instant connection. The gearbox installation is completed in one step.
5	Manual assembly. Secure and fasten other parts according to specifications.
6	Disassembly with a crowbar.

5.1.6 Operator Safety

The design addresses critical safety concerns, replacing unsafe practices like hammering with controlled force mechanisms and reducing crane dependency. This improvement not only reduces the risk of workplace injuries but also enhances component integrity by preventing damage during disassembly. Additionally, by minimizing crane dependency, the system fosters a safer, more flexible work environment.

5.1.7 Scalability

The modular nature of the jig system makes it adaptable to similar assembly and disassembly tasks in other manufacturing processes. Its versatility allows for potential applications in industries like aerospace and automotive, where the alignment and secure handling of heavy components are critical. The project's outcomes demonstrate a pathway for implementing cost-effective, efficient, and safer solutions across various industrial sectors.

5.2 Limitations

While the jig system offers notable improvements, there are still a few limitations:

5.2.1 Manual Operation

The system still requires significant manual intervention, which may result in lower precision compared to fully automated systems. Operators must be trained to handle the jig effectively to avoid operational inconsistencies.

5.2.2 Fixed Component Dimensions

The current design assumes consistent dimensions for the motor block and gearbox. Any deviation in component size or geometry would require modifications to the jig, limiting its flexibility.

5.2.3 Need for Real-Life Testing

The jig's effectiveness and safety metrics can only be fully validated through real-life testing in an operational environment. Such testing is necessary to evaluate its performance, identify unforeseen challenges, and improve the design based on practical feedback.

5.3 Further improvements

While the system significantly improves the assembly process, further advancements could be explored if budget constraints were lifted. For instance, the changes would focus on automation to eliminate manual intervention even more. In particular, an automated guidance system could be integrated into the jig. This system could use servo motors and precision actuators that automatically align the gearbox and motor block. Apart from that, position sensors could be integrated to detect improper positioning or any shifts.

Secondly, IoT could significantly affect the workflow. IoT sensors would display continuous tracking of stress and wear. Such predictive maintenance algorithms could inform operators of possible issues before anything leads to downtime. Detecting these patterns could reduce unexpected failures and extend the lifespan of the jig or other assembly equipment. Moreover, production delays would be minimized, which are usually caused by unplanned maintenance.

6 Additional Jigs

Once the main jig design was complete and off for manufacture, the remaining work was focused on helping streamline the processes for locomotive assembly. To best utilize the interim timeframe, meetings were conducted with the operators as well as engineers at Alstom. From their suggestions as well as from observed inefficiencies within the flow of

work, a second set of seven jigs was designed and prototyped, and a few of them have already been manufactured.

These new jigs were designed with the overall objectives of improving safety, promoting effectiveness of operations, and reducing ergonomic hazards. Each of them was designed to solve a specific assembly and maintenance problem. The details of the jigs, including functional rationale, technical specifications, and intended benefits are also provided. Each of the designs, including visual aids such as CAD drawings, technical models, as well as pictures, will accompany the final report.

A schematic map of the boogie center demonstrates the integration of these jigs into the assembly environment and illustrates the intended placement and functional zones of each additional jig (Fig. 25).

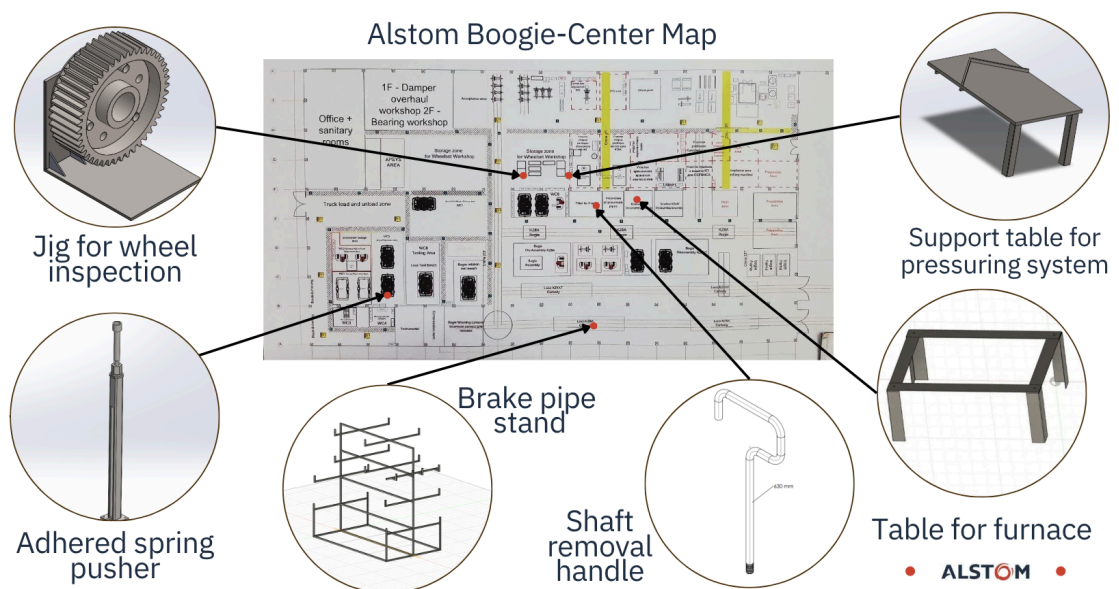


Figure 25. Schematic map of Alstom Boogie-Centre with the location of additional jigs.

6.1 Jig for Wheel Inspection

This jig was designed to improve the process of inspecting the gears locomotive wheelset (Fig. 26, 27). Its principal function is to support the mass of the 30 kg gear in a vertical position, reduce hazards of hand handling, and provide convenient access for optical check and mechanical measurement.

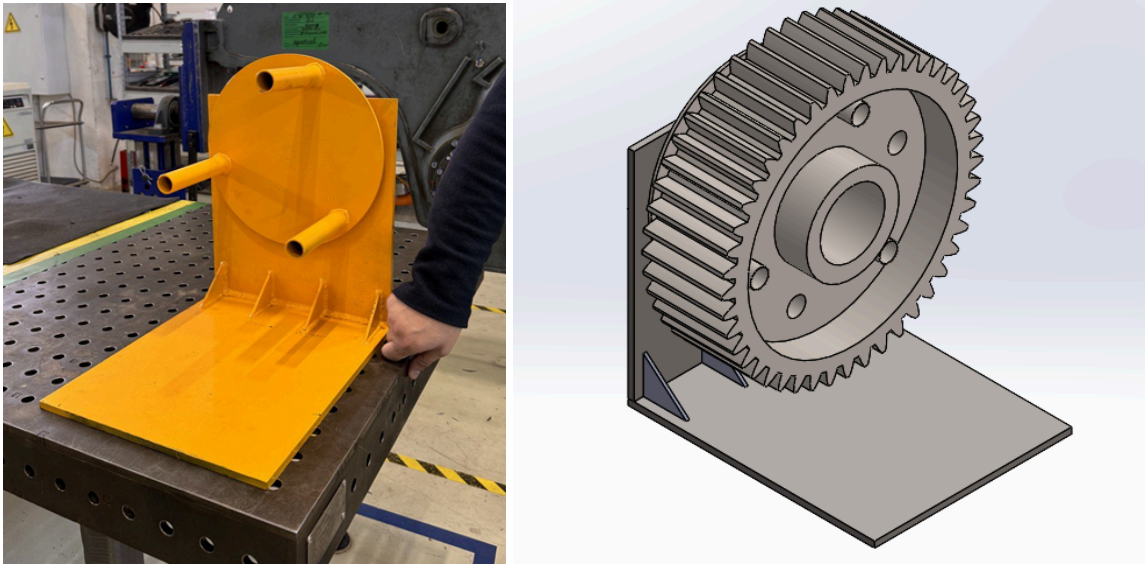


Figure 26. Jig for the wheel inspection: in real life and a 3D model

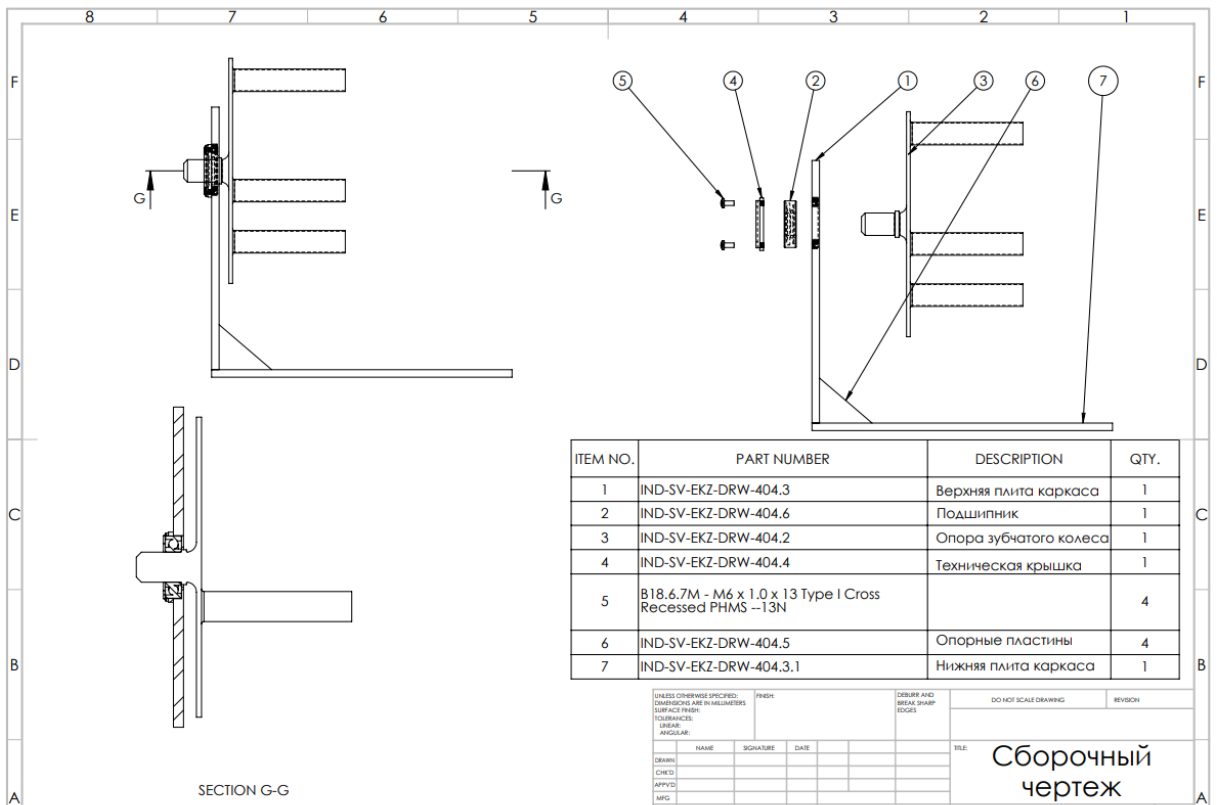


Figure 27. Assembly drawing of the wheel inspection jig

There were several constraints that guided the design: obtaining the lowest cost of production, minimizing total weight, and simplicity of the maintenance work, particularly the removal of bearing. For better accessibility of the bearing, a four-bolted square cover plate was made available. The rotation mechanism is achieved by using a three-pipe hanger assembly that is mounted with a shaft. The shaft is connected to the bearing so that free rotation is possible.

Critical design details include the provision of a clearance fit between the inner ring of bearing and the shaft, while the outer ring is provided with an interference fit with the supporting plates for proper and stable operation. Further, welded triangular plates provided stiffness to the structure for overall strength.

After the initial usage in the workshop for one month, comparison regarding performance was made of the previous process with the new jig. The previous process included manual turning of the wheel, an ergonomically stressful activity causing discomfort in the form of low-back pain. Moreover, the old process required approximately 40 minutes per inspection. In contrast, inspection of the wheel with the new jig is now finished in a mere 15 minutes – a reduction of more than 60% in time. Most importantly, operators have reported finishing the job without experiencing any physical discomfort. This constitutes a significant advance in both plant productivity and workplace ergonomics.

6.2 Brake Pipe Stand

Application: It was designed to hold and store multiple brake pipes together. It avoids pipe deformation as well as damage to the surface, both of which were common issues with improper storage.

The previous brake pipe stand (Fig. 28) lacked structural integrity, bent under the weight of the pipes, and posed safety risks during transportation. To address these shortcomings, the new design got thicker square tubing (Fig. 29) to enhance load-bearing capacity and secure safer mobility. This modification significantly improves the durability and operational safety of the stand compared to the previous version. A stepped structure provides for the division of pipework according to size and type. The design includes the wheels under the stand for superior mobility: operators will be able to move it from one location to another.



Figure 28. The current Brake Pipe Stand

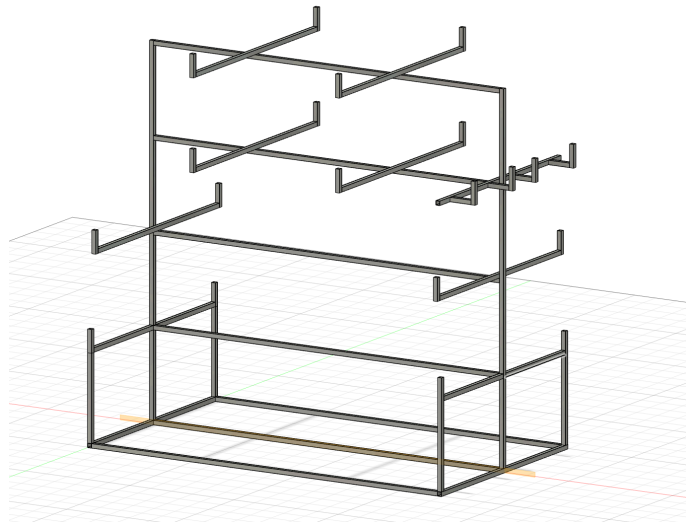


Figure 29. New design for the Brake Pipe Stand

6.3 Shaft Removal Handle

Application: The shaft removal handle serves as the assistance tool for the operators to put and extract shaft from the -140°C fridge and smoothly paste it on the bearing (Fig. 30). It helps with safely putting or removing the shaft, as anyone who is close enough to the fridge will get unwell.

Main Features: L-shaped ergonomic design for optimal operator use with the threaded head for ensuring strong shaft to handle connection. The material of the handle is the same as of the

Key Features: It can accommodate cylindrical shafts of all sizes. It is constructed of high-strength steel because of its extended lifespan. Sloped design helps easy insertion and retrieval of the shaft.

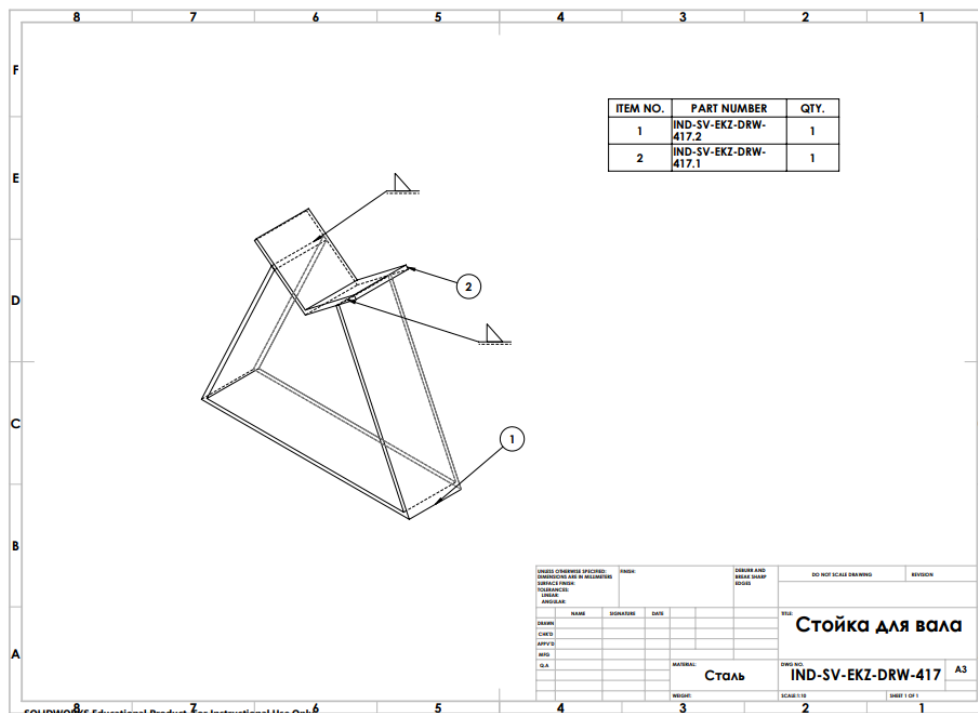


Figure 32. Shaft stand drawing.

Overall, the jig consists of two bended metal sheets that are welded together (Fig. 33). The top part features a "V" shaped cradle made from steel sheets bent at about a 90° angle. This "V" holds the shaft securely and prevents it from rolling off. The support structure consists of two angled legs and a flat base that form a triangular frame for even weight distribution.



Figure 33. Manufactured shaft stand.

6.5 Adhered Spring Pusher

Application: The structure is designed for pressing out the spring from the bushing using a screw lifter during operations on the wheelset. The stand should provide high strength, resistance to loads and vibrations, as well as reliable support for the bucking (Fig. 34, 35).

Key Features: Threaded connection that ensures a secure grip between the lifter and the frame to prevent displacement during lifting (Fig. 36).

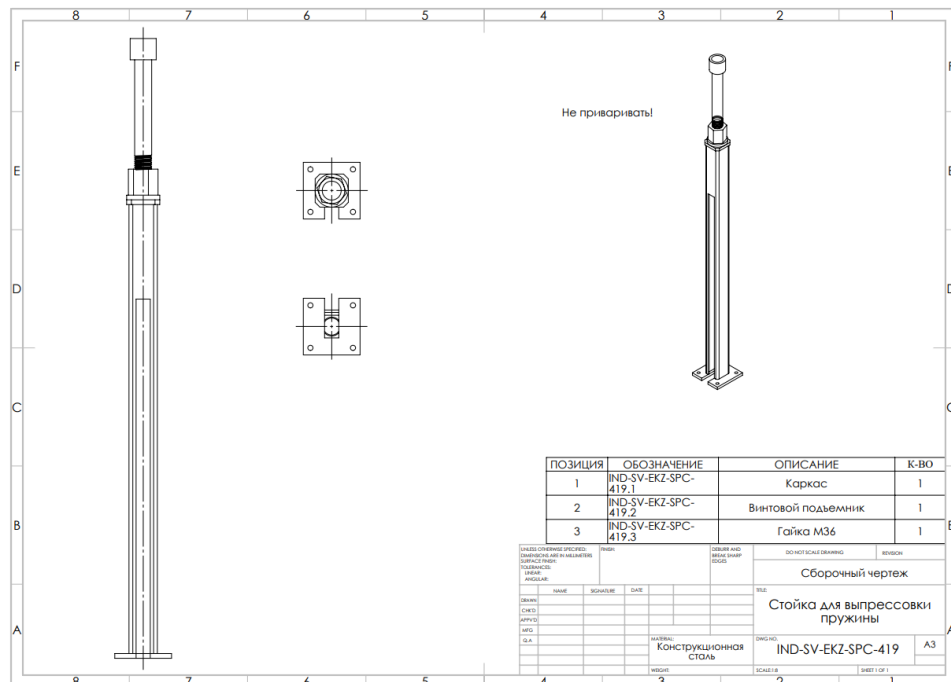


Figure 34. Assembly pusher drawing.

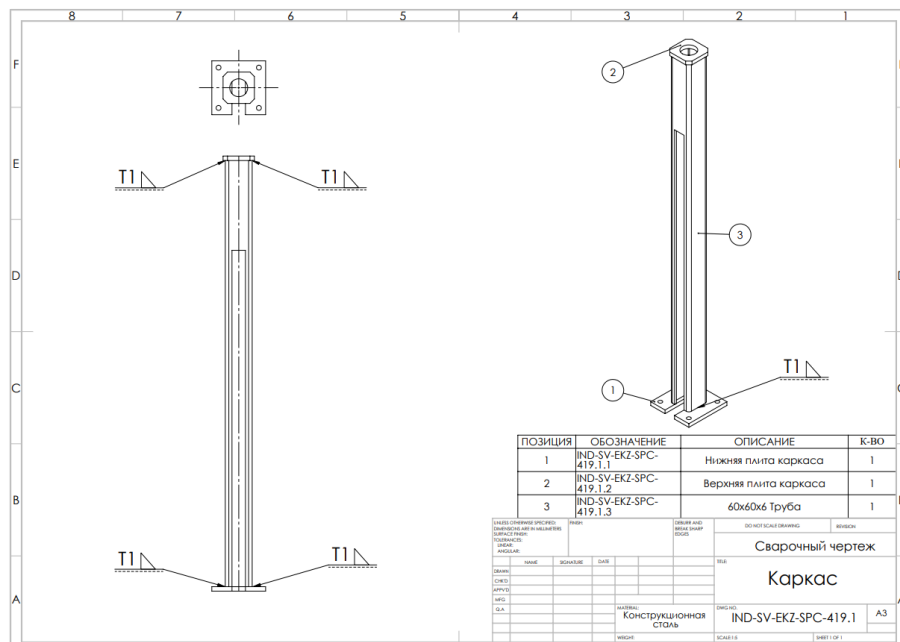


Figure 35. Welding pusher drawing.

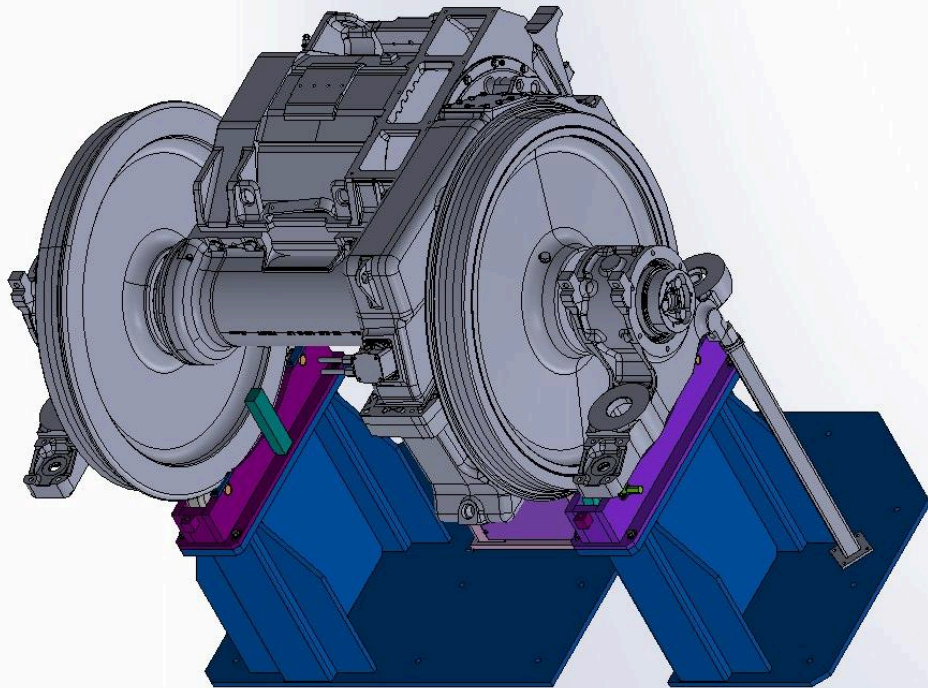


Figure 36. Assembly of the pusher with Wheel Motor Block

6.6 Table for Pressuring System

Application: A fixture table was employed to retain parts in place for pressurization operations of the system. The table also provides support, prevents shifting and misalignment (Fig. 37).

Main Features: Slanting the top allows for easy alignment of components upon pressurization. Structural reinforcement gives strength to the table to support heavy operating loads. Future adjustment for tilt or height is provided through modular legs. The part is still being manufactured.

The tabletop is a large, flat, rectangular steel plate that acts as the main mounting surface. A vertical steel plate is welded to one side of the tabletop. Two smaller flat brackets are placed underneath the tabletop. Lastly, four rectangular tube legs were added, one at each corner. They are expected to withstand static and dynamic loads during maintenance.

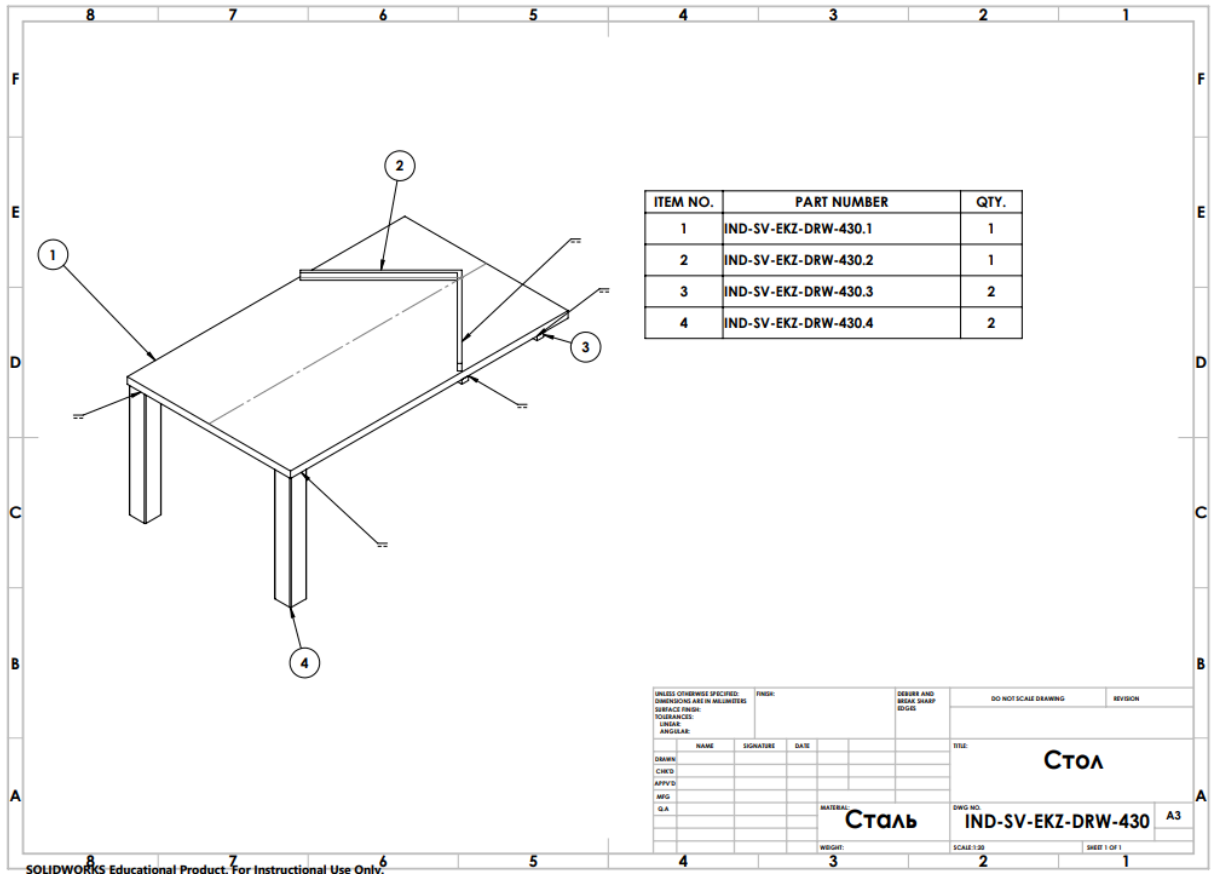


Figure 37. Pressurization table drawing.

6.7 Table for Furnace

The furnace operations table was tailor-made to fit perfectly under the furnace framework to provide the optimal utilization of space within the area. It was even designed such that it could be easily constructed as well as reconstructed with ease, which can provide room for flexibility and adaptability towards varying requirements of operations in the future. The table was accurately specified from the ergonomics point of view, factoring for operator comfort as well as minimized physical exertions while loading and unloading. The modular design of the table allows for easy modifications or changes if the operational requirements change in the future (Fig. 38).

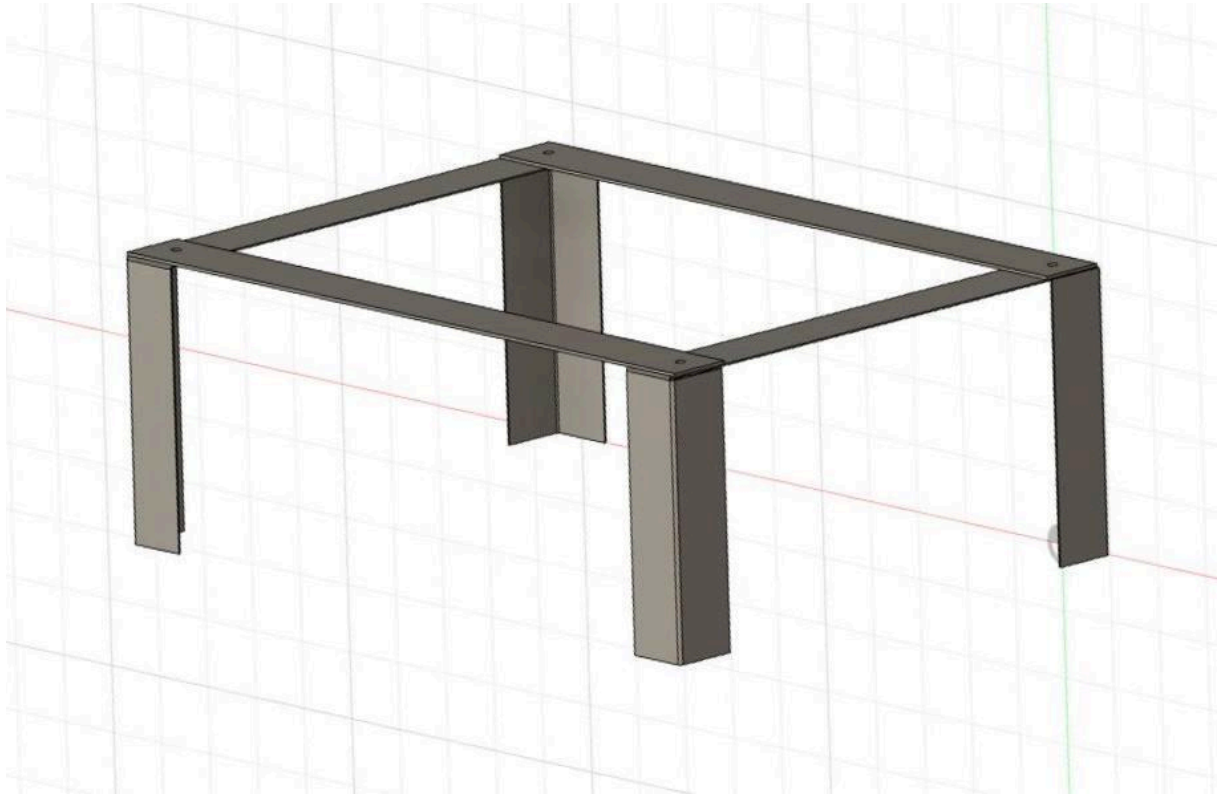


Figure 38. 3D Model of the Table for Furnace

7 Conclusion

This project addressed some challenges in locomotive assembling: the inefficiencies, safety risks, time-consuming crane dependency during the assembly and disassembly processes. The initial problem was the excessive usage of cranes for gearbox alignment and positioning that results in operational bottlenecks, low precision, and safety risks for employees.

The methodology of the project addressed these issues through iterative design and development of custom jigs and fixtures that optimize the processes involved in locomotive assembly. The designed first prototype provided a functional baseline, enabling the alignment and assembly of the gearbox with the motor, reducing crane dependency. However, its limitations in stability and cost-efficiency required some modifications. The second prototype resulted in some enhancements, for example, improved stability, lower cost, and eased required disassembly. These improvements are argued to result in reduced crane dependency, improved safety and optimized operations.

The designed jig is expected to demonstrate following improvements:

- Significantly reduce assembly and disassembly times between gearbox and motor.
- Increase the efficiency by minimizing the crane dependency and reduce the delays
- Improve the safety of work space by integration of ergonomic and controlled mechanisms

The methodology and solutions applied in this project are not restricted to the locomotive assembly and could be beneficial for other heavy manufacturing sectors to optimize the processes.

References

- [1] F. Fiedler *et al.*, "Jigs and fixtures in production: A systematic literature review," *Journal of manufacturing systems*, vol. 72, pp. 373–405, Feb. 2024, doi: <https://doi.org/10.1016/j.jmsy.2023.10.006>
- [2] S. Choi and R. K. Gupta, "Digital Twin: Enabling Technologies, Challenges, and Future Directions," in **Advanced Computational Intelligence for Industrial Internet of Things (IoT)**, Springer, Cham, Switzerland, 2019, pp. 61-78. [Online]. Available: https://link.springer.com/chapter/10.1007/978-3-030-28782-5_6
- [3] M. Rivera *et al.*, "An Economic and Environmental Analysis of Using Recycled Waste Materials in Road Construction," **Automation in Construction**, vol. 98, pp. 120-131, 2018. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0003687018303168>
- [4] C. Chikwendu Okpala, "The Design and Need for Jigs and Fixtures in Manufacturing," *Science Research*, vol. 3, no. 4, p. 213, 2015, doi: <https://doi.org/10.11648/j.sr.20150304.19>.
- [5] Adi Saptari, S. Wong, M. R. Lai, and Salleh, "Jig Design, Assembly Line Design and Work Station Design and their Effect to Productivity," vol. 5, no. 1, Feb. 2011, Available: https://www.researchgate.net/publication/266471974_Jig_Design_Assembly_Line_Design_and_Work_Station_Design_and_their_Effect_to_Productivity
- [6] P. S. R. Chowdary, "Impact of Lean and Agile Manufacturing on Organizational Performance," **Science Research**, vol. 3, no. 4, pp. 137-142, 2015. [Online]. Available: <https://www.sciencepublishinggroup.com/article/10.11648/j.sr.20150304.19>
- [7] H. Radhwan, M. S. M. Effendi, M. Farizuan Rosli, Z. Shayfull, and K. N. Nadia, "Design and Analysis of Jigs and Fixtures for Manufacturing Process," *IOP Conference Series: Materials Science and Engineering*, vol. 551, no. 1, p. 012028, Aug. 2019, doi: <https://doi.org/10.1088/1757-899x/551/1/012028>
- [8] "441N20A0-2-U+500.000Y=10.000," Thomsonlinear.com, 2021. <https://www.thomsonlinear.com/en/product/441N20A0-2-U%2B500.000Y%3D10.000#> (accessed Nov. 28, 2024).

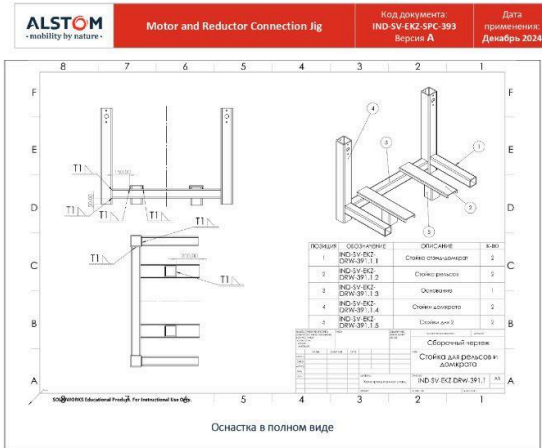
Appendix A: Technical specifications

ALSTOM -mobility by nature-		Motor and Reductor Connection Jig	Код документа: IND-SV-EKZ-SPC-393 Версия А	Дата применения: Декабрь 2024
ТОО «ЭКС СЕРВИС»				
Техническое задание				
«СОГЛАСОВАНО»		«УТВЕРЖДАЮ»		
(директор по направлению)		(директор по направлению)		
(подпись) (Ф.И.О.)		(подпись) (Ф.И.О.)		
" " 20__ г.		" " 20__ г.		
Направляющая шпилька для втулок ТЕХНИЧЕСКОЕ ЗАДАНИЕ (на приобретение оборудования/оснастки)				
ПРОВЕРИЛ:		РАЗРАБОТАЛ:		
(закрепить исполнителем)		Шаймерден Куанганов (исполнитель документа)		
(подпись) (Ф.И.О.)		(подпись) (Ф.И.О.)		
" " 20__ г.		" " 20__ г.		
СОГЛАСОВАНО:				
(должность) (Ф.И.О.)		(подпись)		
(должность) (Ф.И.О.)		(подпись)		
(должность) (Ф.И.О.)		(подпись)		
(должность) (Ф.И.О.)		(подпись)		
(должность) (Ф.И.О.)		(подпись)		
2024 г.				
<small>НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСЧЕТАМИ – Не использовать до проверки актуального номера версии КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА™ – © ALSTOM SA 2022. Все права защищены. Воспроизведение, использование или раскрытие третьими лицами без письменного разрешения строго запрещено.</small>				
Код документа: SCS-AST-FRM-002_версия А				1/20

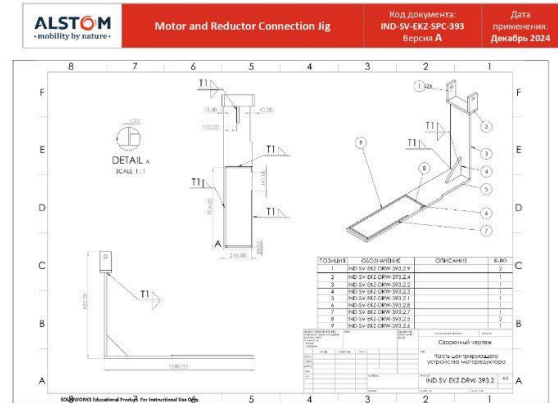
ALSTOM -mobility by nature-		Motor and Reductor Connection Jig	Код документа: IND-SV-EKZ-SPC-393 Версия А	Дата применения: Декабрь 2024
№	Перечень основных данных Состав требований	List of basic data Composition of requirements		
1	Цель Центрирующее устройство предназначено для обеспечения точного позиционирования мотор-редуктора относительно тележки локомотива с целью предотвращения смещений и перекосов при сборке и эксплуатации	Goal: The centering device is designed to ensure precise alignment of the motor-gearbox relative to the locomotive bogie, preventing misalignment and distortion during assembly and operation.		
2	Местоположение поставки оборудования/оснастки поставщиком: Казахстан, г. Астана, ул. А358, 4	Location of equipment/jig delivery by supplier: Kazakhstan, Astana, A358 4 str.		
3	Основные технические характеристики: <ul style="list-style-type: none"> Назначение: Обеспечение точного соосного соединения оси мотор-редуктора и тележки. Способность компенсировать небольшие отклонения геометрии тележки или креплений в пределах ±2 мм. Надежная фиксация мотор-редуктора в рабочем положении. Возможность повторного использования устройства для сборки и разборки узлов. Обеспечение высокой прочности, устойчивости к нагрузкам и вибрациям. Материалы: <ul style="list-style-type: none"> Конструктивная сталь 	Main technical characteristics: <ul style="list-style-type: none"> Purpose: Ensure precise coaxial alignment of the motor-gearbox and bogie axle. Ability to compensate for minor deviations in bogie geometry or mounting points within ±2 mm. Reliable fixation of the motor-gearbox in the operating position. Reusability for multiple assembly and disassembly cycles The guide must provide high strength and resistance to loads and vibrations. Materials: <ul style="list-style-type: none"> Structural steel 		
5	Комплектация оборудования/оснастки: Отсутствуют	Equipment/jig configuration: Not needed		
6	Необходимые запасные части и расходные материалы на оборудование/оснастки: Отсутствуют	Necessary spare parts and consumables for equipment/jig: Not needed		
7	Номер чертежа: IND-SV-EKZ-DRW-393	Drawing number: IND-SV-EKZ-DRW-393		
8	Требуемое количество:	Required quantity:		
<small>НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСЧЕТАМИ – Не использовать до проверки актуального номера версии КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА™ – © ALSTOM SA 2022. Все права защищены. Воспроизведение, использование или раскрытие третьими лицами без письменного разрешения строго запрещено.</small>				
Код документа: SCS-AST-FRM-002_версия А				2/20

ALSTOM -mobility by nature-		Motor and Reductor Connection Jig	Код документа: IND-SV-EKZ-SPC-393 Версия А	Дата применения: Декабрь 2024
1	(один) комплект	1 (one) unit		
8	Требования к разработке КД/ТД/Проекта (при наличии): Отсутствуют	Requirements for the development of design documentation, technical documentation/project (if available): Not needed		
9	Дополнительные требования к оборудованию/оснастке: Оснастка должна быть новой, ранее не использованной, дата производства не ранее 2024 года. При возникновении вопросов по изменению и отклонению от исходного источника, согласовывать с инициатором.	Additional requirements for equipment/jig: The equipment must be new, not previously used, the production date is not earlier than 2024. If you have any questions about the change and deviation from the original source, coordinate with the initiator.		
10	Необходимый срок поставки оборудования/оснастки на территорию заказчика: 19.02.2024	Need delivery time of equipment/jig to the customer's territory: 19.02.2024		
11	Требования к поставщику: Отсутствуют	Supplier requirements: Not needed		
12	Требования к предоставлению сертификатов на оборудование/оснастку поставщиком: Сертификат соответствия материалов	Requirements for the provision of certificates for equipment/accessories by the supplier: Certificate of conformity of materials		
13	Требование по монтажу/установке/наладке оборудования/оснастки: Отсутствует	Requirements for installation/installation/adjustment of equipment/jig: Not needed		
14	Требование по обучению обслуживанию оборудования/оснастки: Отсутствуют	Equipment/jig maintenance training requirement: Not needed		
15	Требование по обучению эксплуатации оборудования/оснастки: Отсутствуют	Training requirements for equipment/jig operation: Not needed		
16	Документы, предоставляемые поставщиком: Сертификат соответствия материалов	Documents provided by the supplier: Certificate of conformity of materials		
17	Гарантия на оборудование/оснастку: <ul style="list-style-type: none"> Поставщик обязан предоставить гарантию, действующую не менее 24 месяцев от даты его принятия Заказчиком в эксплуатацию в отношении всех дефектов изготовления. 	Warranty for equipment/jig: The Supplier shall provide a guarantee valid for at least 24 months from the date of acceptance by the Customer for use against all manufacturing defects.		
<small>НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСЧЕТАМИ – Не использовать до проверки актуального номера версии КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА™ – © ALSTOM SA 2022. Все права защищены. Воспроизведение, использование или раскрытие третьими лицами без письменного разрешения строго запрещено.</small>				
Код документа: SCS-AST-FRM-002_версия А				3/20

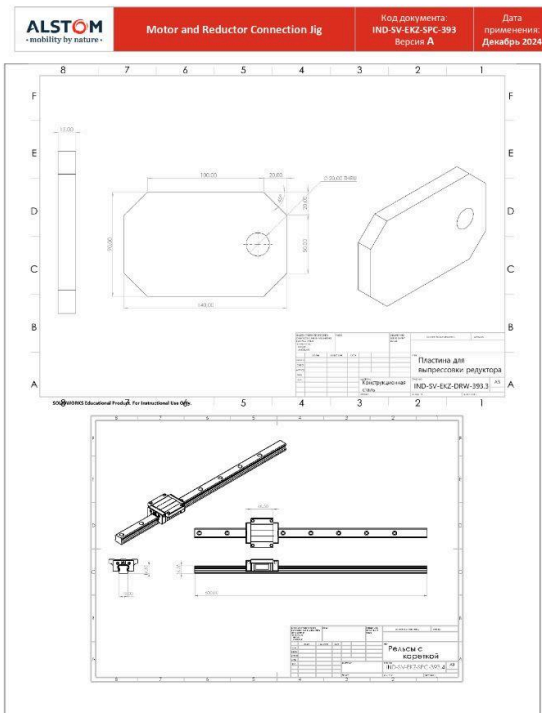
ALSTOM -mobility by nature-		Motor and Reductor Connection Jig	Код документа: IND-SV-EKZ-SPC-393 Версия А	Дата применения: Декабрь 2024
*допускается добавление дополнительных пунктов к перечню основных данных		*it is allowed to add additional items to the list of basic data		
Чертеж оснастки				
<small>НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСЧЕТАМИ – Не использовать до проверки актуального номера версии КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА™ – © ALSTOM SA 2022. Все права защищены. Воспроизведение, использование или раскрытие третьими лицами без письменного разрешения строго запрещено.</small>				
Код документа: SCS-AST-FRM-002_версия А				4/20



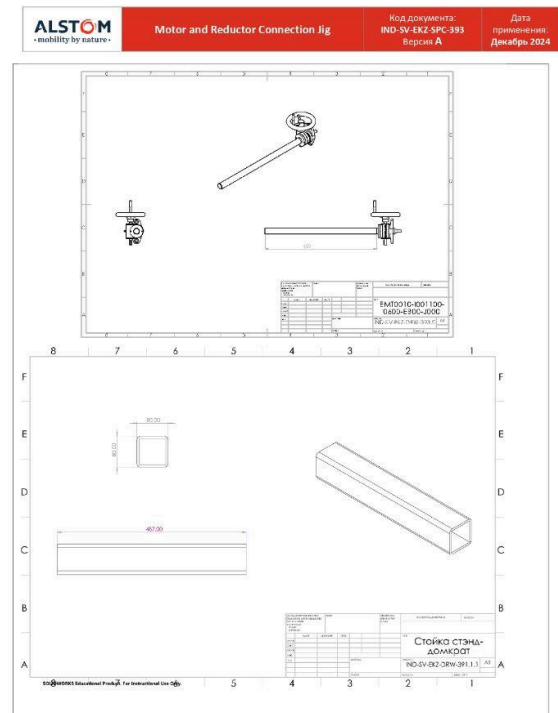
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуальности номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® - © ALSTOM SA 2021. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код документа: SCG-AST-FRM-002_версия А 5/20



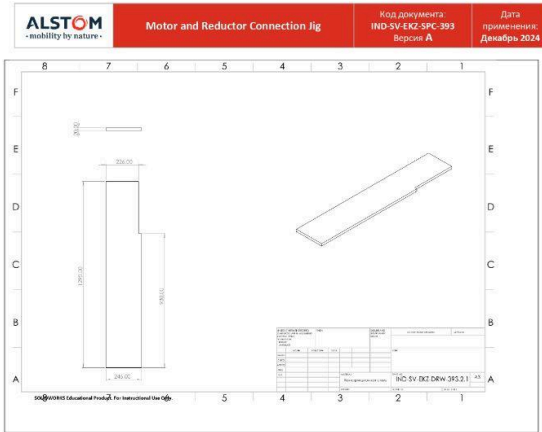
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуальности номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® - © ALSTOM SA 2021. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код документа: SCG-AST-FRM-002_версия А 6/20



НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуальности номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® - © ALSTOM SA 2021. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код документа: SCG-AST-FRM-002_версия А 7/20



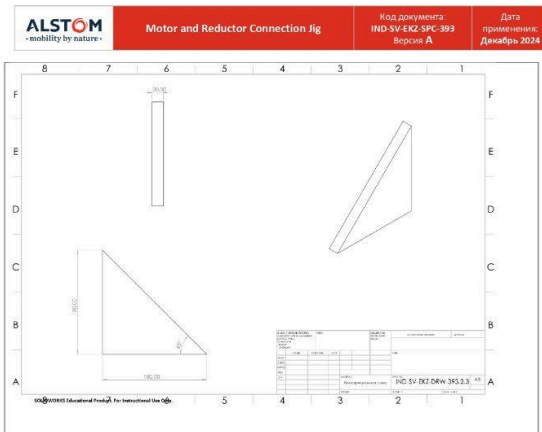
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуальности номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® - © ALSTOM SA 2021. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код документа: SCG-AST-FRM-002_версия А 8/20



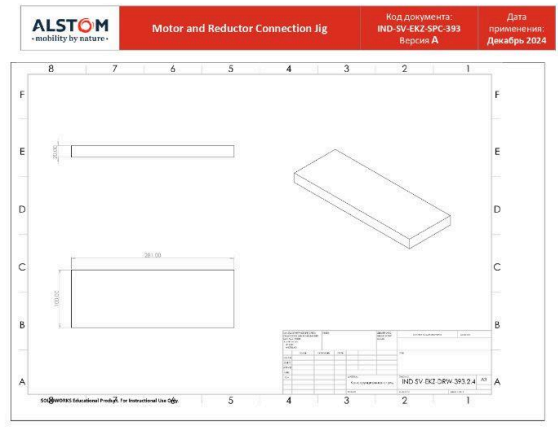
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® - © ALSTOM SA 2021. Все права защищены.
 Вспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код Документа: SCS-A1F-FRM-002_версия А 15/20



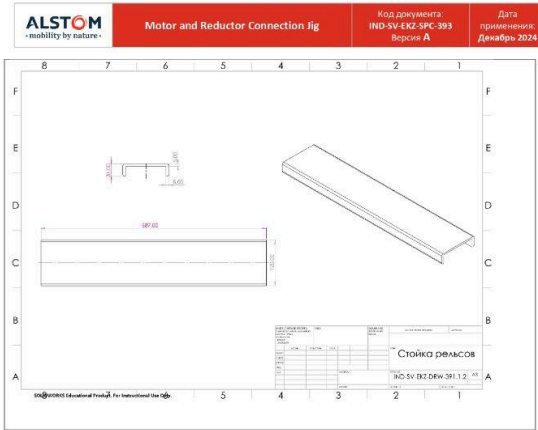
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® - © ALSTOM SA 2021. Все права защищены.
 Вспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код Документа: SCS-A1F-FRM-002_версия А 15/20



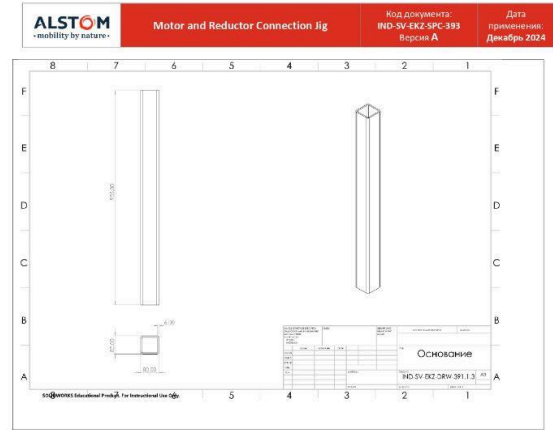
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® - © ALSTOM SA 2021. Все права защищены.
 Вспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код Документа: SCS-A1F-FRM-002_версия А 15/20



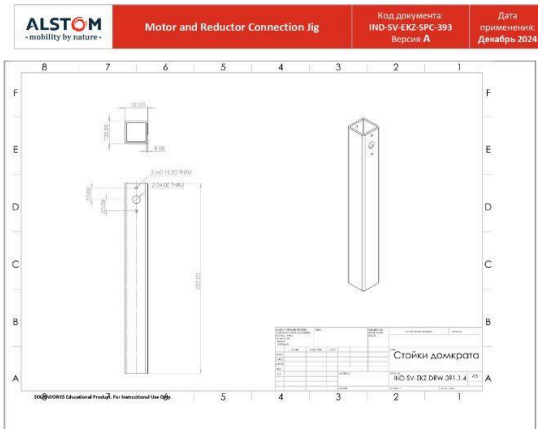
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® - © ALSTOM SA 2021. Все права защищены.
 Вспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код Документа: SCS-A1F-FRM-002_версия А 15/20



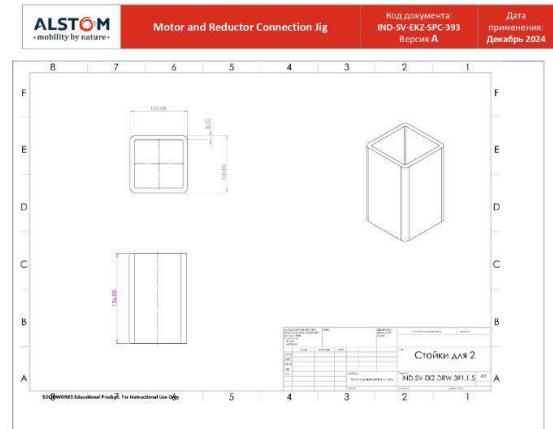
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – не использовать во избежание во проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА™ © ALSTOM SA 2022. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код документа: SCS-A1T-FRM-002_версия А 3/20



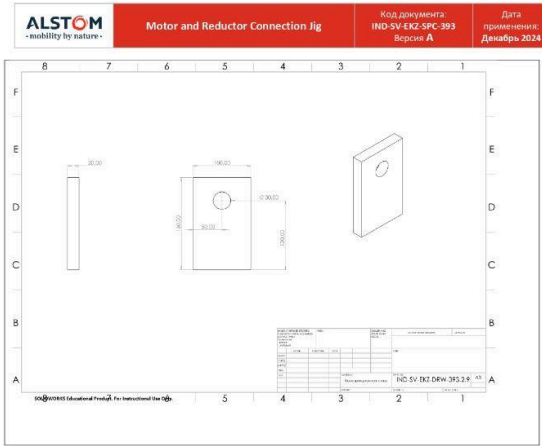
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – не использовать во избежание во проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА™ © ALSTOM SA 2022. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код документа: SCS-A1T-FRM-002_версия А 15/20



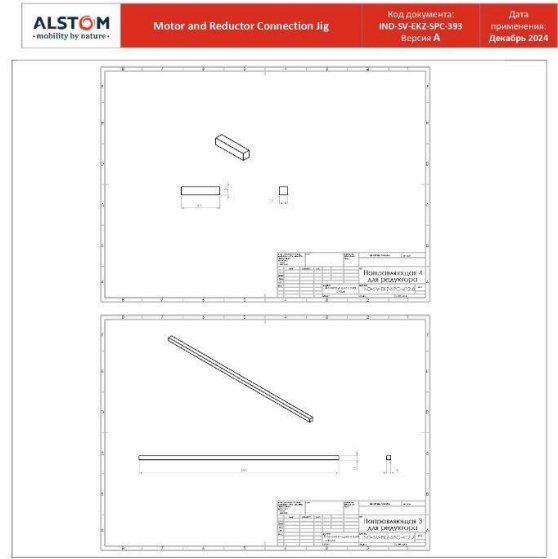
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – не использовать во избежание во проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА™ © ALSTOM SA 2022. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код документа: SCS-A1T-FRM-002_версия А 13/20



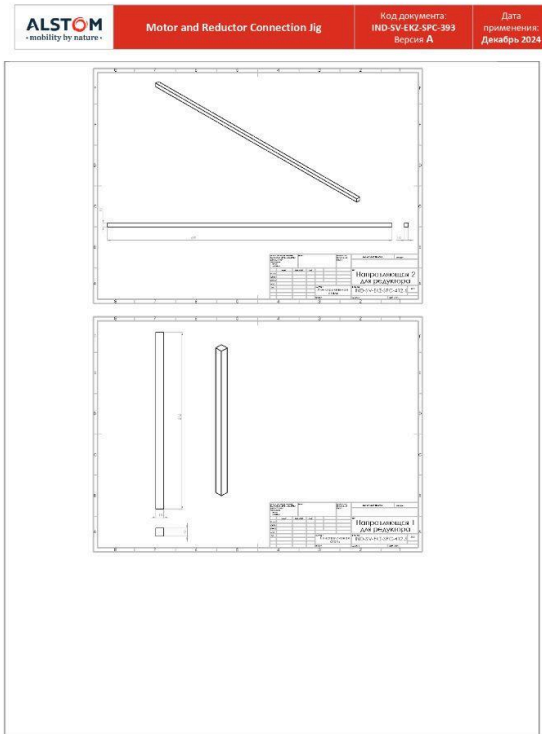
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – не использовать во избежание во проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА™ © ALSTOM SA 2022. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код документа: SCS-A1T-FRM-002_версия А 12/20



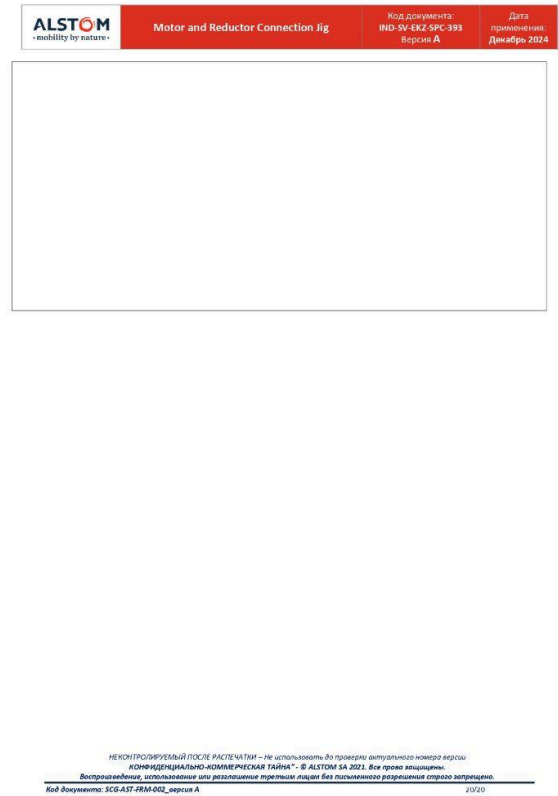
НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® © ALSTOM SA 2021. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код Документа: SCG-AST-FRM-002_версия А 1/1(2)



НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® © ALSTOM SA 2021. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код Документа: SCG-AST-FRM-002_версия А 1/1(2)



НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® © ALSTOM SA 2021. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код Документа: SCG-AST-FRM-002_версия А 1/1(2)



НЕКОНТРОЛИРУЕМЫЙ ПОСЛЕ РАСПЕЧАТКИ – Не использовать до проверки актуального номера версии
 КОНФИДЕНЦИАЛЬНО-КОММЕРЧЕСКАЯ ТАЙНА® © ALSTOM SA 2021. Все права защищены.
 Воспроизведение, использование или разглашение третьими лицами без письменного разрешения строго запрещено.
 Код Документа: SCG-AST-FRM-002_версия А 1/1(2)