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Concept for an innovative screw coupling system production process

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The article presents the concept of an innovative approach to the production of a screw coupling system, a key element in rail vehicles. The use of ready-made components from various subsuppliers, combined with new quality control methods, offers an opportunity for a significant reduction in cost and production time while increasing the efficiency and flexibility of the process. Key stages of the production process are highlighted, from the selection of semifinished products, through quality control, to the final assembly and validation. The applied strategies can minimise waste, increase material efficiency, and have a positive impact on the environment. This study constitutes a significant contribution to the development of sustainable production in the railway industry, with an emphasis on organisational, process, and product innovations.

Introduction

In the dynamically developing industrial world, where the competitiveness and efficiency of companies are key, supply chain management plays an extremely important role. This is particularly significant in the context of producing critical safety and efficiency components for rail vehicles, such as screw coupling. This seemingly unassuming but extremely important component is widely used in rail vehicles, being a key element in ensuring their safe and efficient operation.

Screw coupling, despite its simplicity, is an essential element in vehicle design, serving as a necessary bond that connects individual parts. Its history, dating back to the invention by Henry Booth, is a testament to the continuous endeavour of engineers to improve safety and efficiency in transport. Over the course of the nineteenth and twentieth centuries, engineers explored various approaches to the automation of couplings, to increase the safety and efficiency of rail operations. The term safety means freedom from unacceptable risk of harm [2]. In the context of screw and automatic couplings, it is clear that, although screw couplings are historically deeply rooted in European rail transport, they have disadvantages that can negatively affect the safety. Manual coupling of wagons is associated with a higher risk of staff accidents and potential breakages and failures, which can lead to unwanted incidents on the route.

This included the introduction of the Janney coupler and the Scharfenberg coupler, which gained popularity in passenger trains. However, despite these innovations, traditional screw coupling remained the standard in Europe, particularly in freight transport, which continues to influence rail operations on this continent to this day.

Figure 1 shows a map of the use of different railway coupling systems worldwide, highlighting the contrast between the dominance of automatic type couplings in some regions and the predominance of the traditional screw coupling. Particularly noticeable is the division in Europe, where the screw coupling remains the standard, in contrast to North America, where automatic systems have long been favoured. The map shows the complexity and diversity of global

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railway systems, as well as the history of coupling evolution, indicating that every continent has been using automatic couplings for a long time. The map also highlights key moments of system migration, such as the adoption of the SA3 coupler in the Soviet Union and the changes associated with the expansion and adaptation of automatic type couplers. This map is extremely important for understanding the context in which screw couplings operate and the challenges Europe faces in replacing them with more technologically advanced systems, such as automatic couplings with the addition of digital technology. It also reveals the reasons why Europe remains committed to the traditional screw coupling solution, despite the alternatives. Further discussion should take these aspects into account, as well as recent attempts to introduce Digital Automatic Coupling (DAC), which, although late at the mechanical level, has the potential to give Europe a technological edge by integrating digitalisation into freight transport.

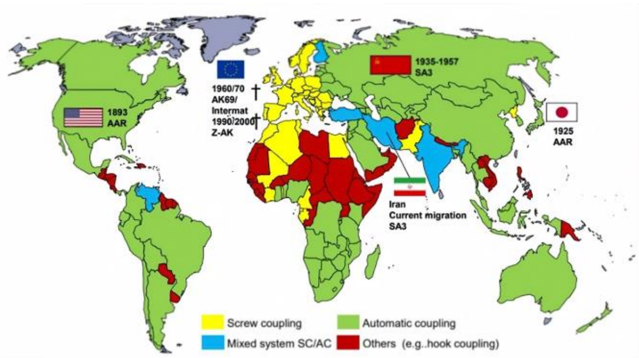

Fig. 1. The current global landscape for railway coupling [4]

There is still a demand for the supply of screw coupling systems and the construction of new freight wagons equipped with this system. The contemporary approach to supply chain management must consider not only the production and distribution of couplings, but also their servicing, replacement, and recycling. In the context of global markets and growing ecological awareness, efficient management of these processes is becoming increasingly complex and requires innovative solutions. Additionally, faced with growing safety and ecological requirements, screw coupling manufacturers are challenged to adapt their products and production processes to changing standards and expectations. This requires not only continuous technological development, but also flexibility and the ability to quickly respond to changes in regulations and market preferences.

In this article, the focus is on analysing the challenges associated with an innovative approach to the production and supply chain management of screw coupling systems, emphasising their importance for safety and efficiency in transport.

It also discusses how innovation and technological development can contribute to improving these processes, benefitting the entire transportation sector.

1. Suppliers in the production process

Faced with growing market demands for quality and cost efficiency, particularly in the automotive and rail industries, effective supply chain management becomes crucial. The quality of the final product, in both the automotive and railway industries, is closely related to the quality of raw materials supplied by vendors and the efficiency of production processes. In this context, articles [3, 8] highlight the importance of evaluating supplier performance and applying advanced analytical methods such as Statistical Process Control (SPC), Analytic Hierarchy Process (AHP), fuzzy methods, and neural networks, to optimise the supplier selection process. In both the automotive and railway industries, it is crucial to accurately assess suppliers and monitor production processes to ensure the high quality and cost efficiency of the products. Analytical techniques allow for the evaluation and comparison of potential suppliers based on various criteria, such as price, quality, supply reliability, and innovation capability. In the railway industry, where safety and reliability requirements are especially high, the ability to accurately assess these aspects is extremely important.

Choosing suppliers in the railway industry, similar to the automotive industry, is a key to ensuring the quality of the final product, the efficiency of the production processes, and the overall profitability of the company. Article [3] discusses the application of the DMAIC methodology and Lean Six Sigma in the production of automotive parts, which also has universal application in the railway industry. In the railway industry, as in the automotive industry, continuous improvement of production processes and defect reduction is necessary to ensure the highest quality and safety of products.

Supplier management practices applied in the automotive industry and their adaptation and application in the service industry are discussed in article [1]. The authors of the article focus on the analysis of supplier management methods and strategies that have been successfully implemented in the automotive industry. This also has implications in the railway industry, where customer interactions and delivery speed play a key role. In both industries, the choice and management of suppliers are becoming increasingly important.

Article [6] provides valuable information on the role of suppliers in the railway industry, particularly in the context of module development. The authors analyse what competencies are necessary for the suppliers in the module development process. They found that technical, organisational, and relational aspects are key success factors. Choosing the right suppliers in the railway industry requires considering a range of competencies that go beyond mere technical knowledge. Understanding and properly managing these aspects is crucial to the success of module development and innovation in the railway industry.

Sustainable supply chain management is becoming a key challenge for many sectors, including the heavy vehicle industry. In article [10], specific examples from Sweden and China were analysed. The main goal of the article is to examine and understand the challenges and conflicts that arise in implementing sustainable practices in the supply chain. The research findings indicate the existence of challenges at the regulatory and organisational levels and conflicts between different stakeholder groups, mainly in terms of environmental and economic aspects. Difficulties in implementing solutions that cover the entire vehicle life cycle were also identified, particularly in the Chinese context. In the context of the railway industry, these conclusions have a direct bearing on supplier management in the rail vehicle sector. The challenges related to sustainable supply chain management, such as environmental regulations, cost efficiency, and conflicts of interest, are equally important for rail vehicle manufacturers and their suppliers. The article emphasises the importance of cooperation and understanding between different participants in the supply chain, which is key to achieving sustainable development in the rail industry.

In the face of increasing ecological awareness and pressure for sustainable development, the railway industry has long faced the challenge of integrating ecological principles into its design and production processes. Already in 2004, an article [5] was published focussing on this key issue, proposing a system to support environmental design. It presented the RAVEL project (Rail Vehicle Eco-Efficient Design), which aimed to develop an integrated system to support ecological design of rail vehicles.

The first and most important aspect is that an environmentally orientated design system requires the active involvement and collaboration of all supply chain participants, including sub-suppliers. This means that sub-suppliers must be aware of and prepared to implement ecological practices in their production processes, which may involve changes in materials, technologies, and production methods. In addition, the article emphasises the need to optimise performance and costs throughout the life cycle of rail vehicles, which also affects subsuppliers. This means that sub-suppliers must not only focus on environmental aspects but also on cost efficiency and performance of their products and services. This requires them to be innovative and continuously improve to meet these demands. Finally, the article points to the importance of collaboration among different entities in the rail industry, including manufacturers, suppliers, and operators.

In summary, this article makes a significant contribution to the discussion on sustainable development in the railway industry, offering practical solutions and directions for designers, engineers, and managers in the rail transport sector.

In current times, supply chain management in the end-of-life vehicle (ELV) industry is becoming increasingly complex due to various uncertainties that affect the development of this sector. Article [13] focusses on this significant issue, analysing and categorising the sources of uncertainty in the ELV supply chain and identifying management approaches. The authors focused on categorising sources of uncertainty according to their end-of-life (EoL) strategies, identifying logistics and network facility management, production and operations, and environmental aspects as the main areas of uncertainty. The study results indicate that most research focusses on three main areas of uncertainty: logistics and network facilities (31.8%), production and operations (30.7%) and environmental aspects (25.0%).

This article contributes significantly to understanding uncertainty management in the ELV supply chain, emphasising the need for further research in this area. The authors also present research gaps that could be potential directions for future research, especially in the context of ELV supply chain uncertainty management. Although the topic of this article is not strictly relate to the topic of the presented article, there are certain aspects of supply chain management that can be transferred and applied in this context. The article highlights the importance of managing different forms of uncertainty in the supply chain. In the context of the production of components of rail vehicles, companies can apply similar strategies to manage the risk associated with supplier dependency, such as supplier diversification, quality monitoring of supplies, and maintaining flexibility in the supply chain. The article also discusses the need for a holistic approach to supply chain management. In the case of rail vehicles, integration and close cooperation with subsuppliers can be key to ensuring quality, timeliness of deliveries, and innovation. This includes collaboration in design, production, and quality control. In the context of the growing need for sustainable development and innovation in the industry, the conclusions of article [7] are of special significance. This article focusses on the study of sustainable supply chain management in the electric vehicle industry, highlighting financial challenges and funding strategies in this rapidly developing sector.

The authors focus on how electric vehicles, retailers, and other entities in the supply chain can effectively manage financial risk and increase their profits through appropriate funding strategies. The research findings indicate that the application of appropriate supply chain financing strategies can significantly contribute to increasing the profits and competitiveness of companies in the electric vehicle industry. The authors also emphasise the role of government subsidies and the level of retail services in improving the efficiency of the entire supply chain. In the context of the rail industry, the conclusions of this article may be relevant, as similar financial challenges and the need for sustainable development also apply to suppliers in the rail vehicle industry. The financing models and risk management strategies developed for the electric vehicle industry can be adapted and applied in the railway context, especially in terms of technological innovation, sustainable development, and operational and cost efficiency. This shows how solutions developed in one sector can be an inspiration and model for other related industries.

The analysis carried out indicates the key importance of effective supply chain management in the automotive and rail industries, particularly in the face of growing market demands for quality and cost efficiency. Supplier performance assessment is the key to optimising the supplier selection process and ensuring high-quality production. Accurate supplier assessment and monitoring of production processes are essential to maintain the high quality and cost efficiency of end products. Sustainable supply chain management, including environmental, regulatory, and economic aspects, becomes a key to achieving sustainable development, which is particularly important in the context of rail vehicles. Supply chain management reveals the complexity of the problem, highlighting the need for a holistic approach that includes both technical assessment and strategies for risk management, innovation, sustainable development, and operational and cost efficiency. The findings of these studies suggest that solutions and practices developed in one sector can be an inspiration for other related industries.

This chapter identifies the important role of suppliers in the production process in both the automotive and rail industries, with a focus on quality, cost efficiency, and supply chain management. The use of analytical and production process management methods, such as SPC, AHP, fuzzy methods and neural networks can optimise the supplier selection process. In the rail industry, where safety and reliability requirements are extremely high, such techniques are essential to evaluate and monitoring suppliers and production processes. However, the current state of the rail spares market reveals continuing challenges, including the problem of delivery speed, which arises from the high cost of production and the reluctance of intermediaries to build up stock inventories.

The future of the rail industry requires an approach that reconciles the challenges of supply chain management with the need for speed and flexibility in spare parts supply. More cooperation and better coordination is needed between manufacturers, suppliers, and rail operators to counteract long waiting times for complex and costly components such as traction motors or wheelsets. The research presented shows that integration and close collaboration with sub-suppliers can be key to ensuring quality, on-time delivery and innovation. This includes collaboration in design, production, and inspection.

2. Outsourcing in the production process

The dilemma of choosing outsourcing and internal production is significant for many diverse sectors in the manufacturing industry. The contemporary railway industry faces challenges related to optimising production processes, reducing costs, and increasing innovation.

Article [12] provides key information on this choice in the high-tech industry. According to the study, outsourcing can be more advantageous than inhouse production. This conclusion is particularly relevant in the railway industry, where supply chain decisions have a direct impact on the quality, efficiency, and reliability of operations.

In article [15], it is indicated that outsourcing allows manufacturers to focus on their core competencies, such as design, engineering, and final assembly, instead of producing every component. In addition, outsourcing can lead to cost reduction, as subsuppliers often have more specialized skills and more efficient production processes. Moreover, collaboration with various suppliers can stimulate innovation through access to new technologies and solutions. Similar conclusions are presented by the authors of article [14], which analysed the impact of outsourcing on product innovation and internationalisation of companies. It also emphasised the focus on core competencies while simultaneously reducing the resources needed for the production of existing products.

However, as the authors of article [15] point out, outsourcing also comes with certain challenges and risks, such as loss of control over key processes or potential quality and delivery issues. Therefore, it is important for railway companies to carefully analyse their outsourcing decisions, considering both potential benefits and risks.

Article [16] indicates how outsourcing can impact innovation and the process of creating new products in a collaborative development environment. Through cooperation with various sub-suppliers, companies can adapt more quickly to new technologies and solutions, which is crucial in industries where safety and reliability are paramount.

However, as the authors of the article stress, managing outsourcing in a collaborative development environment requires effective coordination and communication between all parties. In the railway industry, where projects are often complex and multidimensional, maintaining clear lines of communication and shared goals between the company and its sub-suppliers is crucial.

Production scheduling and outsourcing decisions are discussed in article [9], which focusses on these aspects, offering new perspectives on production management in the context of outsourcing. The article presents the problem of production scheduling, considering outsourcing manufacturing operations through subcontracting.

They suggest that outsourcing can contribute to increased flexibility and responsiveness to changing market demands and new technological trends. Second, it can lead to lower production costs, as sub-suppliers often have more efficient production processes and can offer better pricing conditions due to specialisation and scale of operation.

However, as the authors emphasise, effective management of production scheduling in outsourcing requires complex planning and coordination. In the railway industry, where projects are often multistage and require close cooperation between various entities, maintaining a precise schedule that takes into account both internal production processes and subcontractor activities is key.

Therefore, outsourcing in the railway industry can be stated to play a key role in increasing innovation and efficiency, offering access to the latest technologies and specialised knowledge. Using external sub-suppliers can allow rail vehicle manufacturers to focus on key competencies, such as design and system integration, while leaving the production of specialised components to external firms. This strategy contributes to enhancing competitiveness and operational efficiency in the railway sector.

In the context of globalisation and increasing competition in international markets, outsourcing provides the flexibility necessary to quickly adapt to changing market and technological requirements. In the railway industry, where safety and precision are priorities, outsourcing provides access to advanced technologies and specialised knowledge, which is crucial for the quality of components. Adopting this strategy allows for focussing on innovations and continuous improvement of products and services. Collaboration with various sub-suppliers stimulates innovation, facilitating adaptation to new technologies and solutions. This is particularly important in an industry where high standards of safety and reliability are paramount. Through outsourcing, rail vehicle manufacturers can better use their resources for development and system integration, delegating the production of individual components to specialists.

In summary, outsourcing in the railway industry is a strategic choice that offers operational and financial benefits. It allows railway companies to manage resources more effectively, focus on key competencies, and introduce innovations faster, while benefiting from the advanced technologies and knowledge offered by sub-suppliers.

3. Innovative manufacturing process of the screw coupling system

3.1. Background

In today's global business environment, there is a wide choice of steel and elastomer material suppliers worldwide. What makes this situation even more advantageous is the fact that many of these suppliers are capable of flexibly adapting their production lines to manufacture components of the screw coupling system. Steel and elastomers, used in the production of the screw coupling system, are commonly available materials that form the structural basis of its components. This allows manufacturers to collaborate with various suppliers in different markets, which can bring benefits in terms of costs and availability. Traditionally, the production of screw coupling systems was associated with the necessity of creating everything from scratch. This included the manufacture of each component, the specialisation of production, and significant investments in raw materials, machinery, and human resources. However, many companies now recognise that it is not always cost-effective to produce everything from scratch in their own enterprise. The final manufacturer does not always need to purchase fully ready semi-finished products. Especially when they have an idea for an innovative completion of components into a form that can be directly incorporated into assembly. This comes from the fact that, although there are many suppliers, not all of them can boast advanced manufacturing technologies.

Figure 2 shows the concept of global intermediate product supply as the main axis of the production process. It demonstrates the vastness and complexity of modern supply chains. This multidimensional network is made up of lines connecting different regions of the world, allowing the efficient use of global resources and technologies.

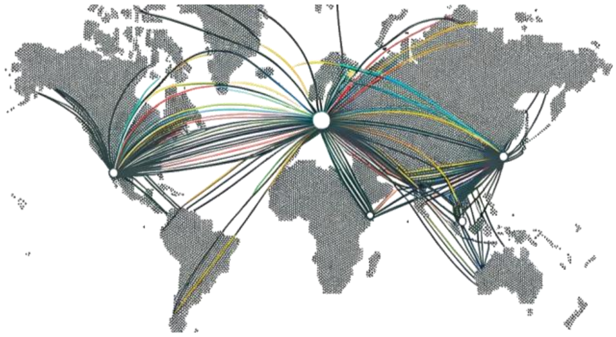

Fig. 2. The concept of global supply of intermediate products as the main axis of the production process

This allows manufacturers of screw couplings to choose from a wide range of suppliers, which in turn can reduce costs and increase the availability of required materials. Fig. 2 also visualises how end manufacturers can benefit from the advantages of a division of labour in the supply chain by selecting semi-finished products, which they then innovatively assemble and partially create themselves into finished components for direct assembly into a screw coupling system. Therefore, in the context described earlier, the use of global sources of supply is not only economically advantageous, but also a key strategy for rapid adaptation to changing market and technological conditions.

The basis of the new approach is to provide low-cost semi-finished products that meet the basic requirements of the technological and material process according to [11]. Flexibility is key, as the manufacturer can choose from various suppliers, adjusting their orders to changing market conditions and the availability of raw materials.

3.2. Description of the innovative production process

The proposed production process involves a carefully defined quality control path for each batch of semi-finished products. From the receipt of the semi-finished products from sub-suppliers to their final use in the end product, each element is thoroughly examined and monitored. The semi-finished products include main screw coupling system components (Fig. 3): Screw (1), Trunion Nut (2), Bent link (3), Shackle Link (4), Pin (5), Lever (6), Towing hook (7), Draw gear (8).

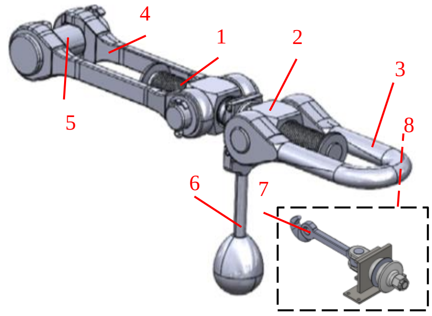

Fig. 3. Main screw coupling system components

The flow of semi-products is based on the functioning of four semi-product warehouses (Fig. 4). At the time of delivery, basic order documentation is checked, after which the semi-products are directed to the semi-finished product warehouse during delivery. The screw coupling system shall be tested in accordance with PN-EN 15566:2016 [11]. This standard specifies the requirements for the draw gear and screw coupling for the end of rolling stock that has to couple with other rolling stock (freight wagons, locomotives, passenger vehicles). This standard covers the functionality, construction, interfaces and testing including pass/fail criteria for draw gear and screw coupling.

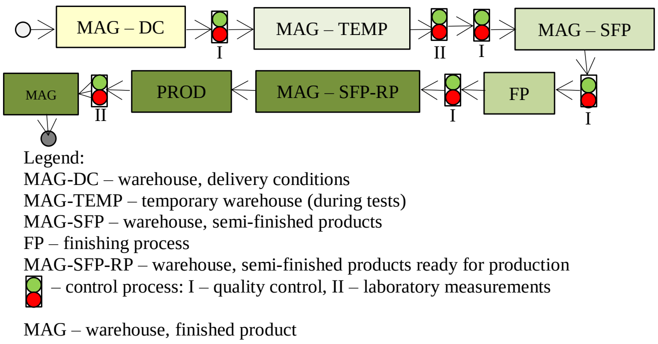

Fig. 4. Warehouses for semi-products – components of the screw coupling system

During the first stage of quality control, semi-finished products in the state of delivery (MAG-DC) undergo detailed examinations. These include visual inspection to detect damage or imperfections, geometric measurement to assess the precision of dimensions, and hardness measurement to ensure the adequate strength of the components. After these initial tests, the semi-finished products are appropriately marked, and a control card is assigned to each of them. This card serves as documentation of all tests and examinations. Subsequently, semifinished products with positive results are transferred to the temporary warehouse (MAG-TEMP), where they await further laboratory testing. In the laboratory, detailed tests are carried out for each batch of individual semi-finished products to verify all key parameters of the semi-product. The process is designed so that each designated batch of semifinished products undergoes a re-examination of quality, and then, after obtaining positive results, they are transferred to the warehouse for ready semi-finished products (MAG-SFP). After quality control with a positive result, selected semi-finished products are included in the finishing process (FP). This applies to those semi-finished products that require further processing or preliminary assembly at the manufacturer. The following finishing operations at dedicated stations have been assumed in the described process:

– heating, bending, thermal improvement, and cooling of the shackle link
– drilling and setting the cap on the screw
– assembling the link
– setting the lever
– assembling the screw and its assembly (welding)
– assembling the draw gear and its installation in the support.

Each of these processes and stations is key to the overall production process, and the workers involved in each must be adequately trained and have specialised knowledge in their field.

Sets of semi-finished products and tools necessary to perform operations must be assigned to each station. For each station, workplace instructions must be assigned to allow the correct execution of operations.

The screw coupling system also includes workstation controls and quality tests to verify the accuracy of the production operations. The following controls should be distinguished:

– quality control of the shackle link after bending
– testing the shackle link after thermal improvement
– complete screw coupling.

The second production process is related to the production of the draw gear, for which the following stations are used.

– station for assembling the draw gear
– station for mounting the draw gear on the support.

After re-examination, batches of semi-finished products that achieve a positive result are placed in the warehouse of semi-finished products approved for production and assembly, where their realisation (PROD) takes place, creating the entire screw coupling system.

Each of these processes is strictly controlled and monitored, allowing for the maintenance of the highest quality standards of the products according to the recommendations and required norms. For each of the production stations, sets of semi-finished products and necessary tools have been assigned. After the production is complete, a quality control of completeness is performed. Each time, after performing laboratory tests and analysing the results by trained personnel, a decision is made about the conformity or non-conformity of the semi-finished products with the normative requirements [11].

Validation of the production of the screw coupling system, consisting of the screw coupling and the draw gear, is a key element of the production process. It is performed after the production process (PROD). This is necessary to confirm that each unit produced meets the highest quality and strength standards. The strength test, also known as the tensile test, is performed on one sample from each batch of production. This process is carried out in a dedicated test station. After confirming that all elements of the screw coupling system have been correctly made and meet the required strength standards, the entire batch is transferred to the finished product warehouse. There, the products are properly stored until they are sent to customers or directed for further distribution.

3.3. Research laboratory

The laboratory used for testing semi-finished products and production stage tests must be located between the semi-finished product warehouse in the delivery state (MAG-DC) and the production area (PROD). The laboratory room must be isolated in terms of vibroacoustic and dust conditions and have an independent ventilation and air conditioning system to ensure appropriate climatic conditions (temperature, air humidity) controlled by a thermometer and hygrometer along with monitoring and documentation.

The research stations must be independent, allowing for the standalone operation of the tests. The laboratory must be equipped with all necessary measuring devices and auxiliary tools so that tests and examinations necessary in the production of the screw coupling system can be conducted independently. Research and measurement devices are presented in Table 1.

It should be noted that due to its measurement sensitivity, the spectrometer must be placed in a separate laboratory room, where, independently of the rest of the laboratory, the required climatic conditions are maintained. This ensures measurement certainty. Samples for strength tests on the tensile testing machine and Charpy's hammer must be prepared in the internal locksmith workshop. This allows independence from external entities and continuity in the testing of production batches.

This approach allows for specifying all significant technical requirements and testing conditions. Each research station is assigned a test card which details the process of conducting the test on each research sample, considering the necessary devices and measuring instruments, as well as environmental conditions. After each test, a test report must be developed, allowing the assessment of test results against normative requirements.

Table 1. Research and measurement equipment

No.	Device	Description
1	Microscope	Basic optical microscope. A tool used to observe structures invisible to the naked eye.
2	Defectoscope	Defectoscope in conjunction with a cable and probe head for detecting discontinuities in material structure through the emission of ultrasonic waves.
3	Length Measurer	The length measurer allows measurements with an accuracy of up to 0.000001 mm. It is used to control the dimensions of samples for impact testing, tensile strength, and microstructure.
4	Comparator of Standard Plates	This device allows for precise verification of the execution of samples for microstructure analysis – checking the parallelism of surfaces.
5	Research Metallographic Microscope	A microscope used in macrostructure analysis to determine the distribution of sulphide inclusions in steel, and in microstructure analysis to determine the distribution of non-metallic inclusions in steel.
6	Charpy's Hammer	The Charpy's hammer is used to determine the absorbed energy needed to break a notched sample. Samples with precisely defined dimensions are required for the test. They are controlled under a measuring microscope, allowing precise verification of the dimensions, angle, and radius of the notch.
7	Tensile Testing Machine	The tensile testing machine is used for static tensile testing which determines the tensile strength, elongation, and reduction of the tested material. With the additional use of an extensometer, it is possible to determine the yield point of the material.
8	Hardness Tester	The hardness tester measures hardness using the Brinell method, which involves pressing a spherical indenter into the tested object. An adjustable table height allows testing objects and samples of various geometry and dimensions.
9	Spectrometer	This device analyses the chemical composition of steel based on the spectrum analysis of spark-excited elements in the tested material. The surface of the sample must be properly prepared before testing by grinding it on a disc grinder.
10	Hydrogen Content Analyzer	This device allows for the determination of the hydrogen content in steel. This test complements the analysis of chemical composition.
11	Pyrometer	The pyrometer enables the measurement of the material temperature. It is used in penetrant testing where the temperature of the tested material is a crucial issue.

As part of its commitment to ensuring the highest quality and safety standards, a rigorous testing system is in place for semi-finished products supplied by global sub-suppliers. Each batch of semi-finished products undergoes detailed verification in an in-house test lab strategically located between the semi-finished products warehouse and the production area. This process is designed to ensure that all components comply with the standards of EN 15566:2016, regardless of regional differences in the workmanship and precision of the sub-suppliers' measuring equipment. Re-verification not only ensures that semi-finished products comply with the requirements of the standard, but also provides motivation for suppliers to maintain high production quality and puts pressure on them to continuously improve, which translates into an overall improvement in rail transport safety.

4. Summary

Innovation in the production of screw coupling system production lies in a novel approach to production, primarily related to a new approach to quality control and production technology. Traditionally, such systems were built from scratch, requiring specialisation, a large amount of resources, and time. The presented concept departs from this approach, focussing on the use of ready-made subassemblies from various sub-suppliers. Moreover, until now, the production of the screw coupling system was the domain of a single company in Europe.

The presented innovations in the production of screw coupling systems represent a deviation from conventional production methods, characterised by the integration of components supplied by suppliers. An important aspect of this process is not only that sub-suppliers ensure that components comply with applicable standards, but also that additional verification procedures are implemented by the final manufacturer. These measures are designed to increase confidence that each screw coupling component meets the established quality criteria.

Inspection processes have been strengthened through the use of modern testing methods and equipment, enabling precise assessment and guaranteeing a higher standard of products. The optimisation of the supply chain through the selection and thorough testing of components supplied by various sub-suppliers contributes to reducing wastage and improving material efficiency, while also promoting sustainability.

The final production results and the impact of the innovative manufacturing process on the rail industry will be further analysed. The inclusion of stringent quality control standards beyond conventional expectations highlights the drive for continuous improvement in screw coupling manufacturing. Future studies will continue to assess the effectiveness of the changes introduced and their real impact on increasing the quality and efficiency of production in the rail sector.

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