Automated turnout maintenance for permanent way with high availability

Robot-assisted repair welding of turnouts increases service life, requires less staff, and provides reproducible results

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A fully automated build-up and repair welding system for turnouts offers a sustainable, reliable alternative to the manual work currently performed. The entire work process is robot-assisted: from the inspection and measuring technology to the welding and machining technology as well as complete digital integration, it has all the necessary functions. Embedded in a preventive maintenance approach, it allows infrastructure owners to increase the service life and output of turnouts in an environment characterized by an increasing shortage of skilled workers.

The turnout system is under pressure

Railway systems in Europe and across the globe must meet an enormous challenge: to reach aggressive growth objectives, with the number of maintenance and new-line construction projects increasing while staff numbers decrease [1,2].

The number one priority for infrastructure owners' maintenance management is to keep networks available, reliable, and safe. Unplanned disruptions are a critical cost driver and have a negative impact on customer satisfaction [3]. Planned preventive measures can noticeably lower these costs and significantly increase customer satisfaction.

With specific maintenance services or framework agreements, construction companies are obligated to meet deadlines, budgets, and quality standards. It is always up to them to ensure work is cost-effective. However, these companies face the challenge of gaining and retaining staff. Further, demographic change is speeding up the loss of experience and know-how: staff are retiring, and their knowledge and experience is not being transferred consistently. Another essential factor is occupational safety. Shorter track possessions lead to additional physical and mental strain for staff.

For the turnout system as a critical part of the infrastructure, this increasing utilization means having to handle more traffic with higher loads (more trains with more axles, higher speeds, and higher transport volumes).

	Deutsche Bahn	ÖBB	SBB	ProRail
Number of turnouts	65 550 [4]	13 163 [5]	10 350 [6]	6220 [7]

Tab. 1: Turnout stock of the DACH countries and the Netherlands

The DACH countries and the Netherlands alone are responsible for more than 95,000 turnouts built into their infrastructure. The maintenance requirements of these turnouts can be seen, for example, in an evaluation of the condition of turnouts in the DB network: they received a grade of 3.15 ("comprehensive maintenance required") [8].

Regular measuring and monitoring of the infrastructure provide a sound data base on the current state of the superstructure. This provides a digital image of the current situation and, as a result, a great deal of clarity about the maintenance to be performed. However, the lack of skilled staff makes it more difficult to perform the work required. Nowadays, unplanned repairs are often a priority, and they impede any preventive maintenance required.

Mechanization and automation have paved the path "from the pickaxe to the track maintenance machine", making track work safer and more effective. With robotics and automation technology, the time has come to systematically take turnout maintenance to the next level.

Concept for a complete process: robotizing preventive maintenance and turnout repair welding

In the past few years, there have been various projects and initiatives around the globe dedicated to repair and build-up welding on turnouts. The robot-assisted approaches used were very promising.

Robotized, automated processes are already highly proven in other industries. When applied to maintenance tasks on turnouts, the following advantages are apparent:

- Greater precision of maintenance tasks
- Increased efficiency and effectiveness of maintenance work
- Keeping errors caused by staff with insufficient qualifications to a minimum
- Avoiding human intervention in the danger zone and thus noticeably increasing safety
- Increasing the number of shifts by approximately 25% with a largely reduced number of employees and thus less staff downtime
- Objective assessment of trouble spots through measurements with suggestions for standardized intervention routines (milling, grinding, welding)
- Minimizing training time and expenses: the system operator is qualified to operate the system independently after three months.

Fig. 1: Turnout maintenance is one of the first areas of application for automation on tracks.

Source for all figures: Robel Bahnbaumaschinen GmbH

Fig. 2: The prototype for a maintenance container with fully automated robots was presented at iaf 2022.

In order to generate the maximum benefit for the infrastructure owner or the company performing the work, the [ro'bot] Container (Figures 1, 2) was introduced in 2022: two fully automated robots work together to repair local rail defects. It is the world's first prototype of its kind.

This platform showcases a variety of individual processes such as measuring, inspecting, removing trouble spots, preheating the spot to be treated, build-up welding, and subsequent reprofiling in a mobile, fully automated technological innovation. Testing has already been completed successfully on track, proving that a robot-assisted mobile solution can be implemented.

Due to the high cost and the high maintenance demands of the turnout system, the modules and components used on the technology platform are being developed further so that the complete process of build-up and repair welding can also be fully automated for turnouts.

The focus of the turnout treatment process lies on the following components (Figure 3):

- Common crossing
- Wing rail
- Switch assembly

Damage such as breakage, cracks, or burrs mostly occurs on these components (Figure 4). This damage is caused by high loads, deviations in the target geometry of the turnout, failure to perform preventive maintenance, insufficient and/or faulty repairs, or worn wheels.

The automated process's modular approach makes it possible to flexibly adjust to the circumstances and requirements in connection with the damage at hand and the maintenance strategies to be used. Proven industrial components are used for the implementation of the following steps:

Detect and measure

In order to generate all the data for the next treatment steps, the geometry of the relevant areas in the turnout system is measured.

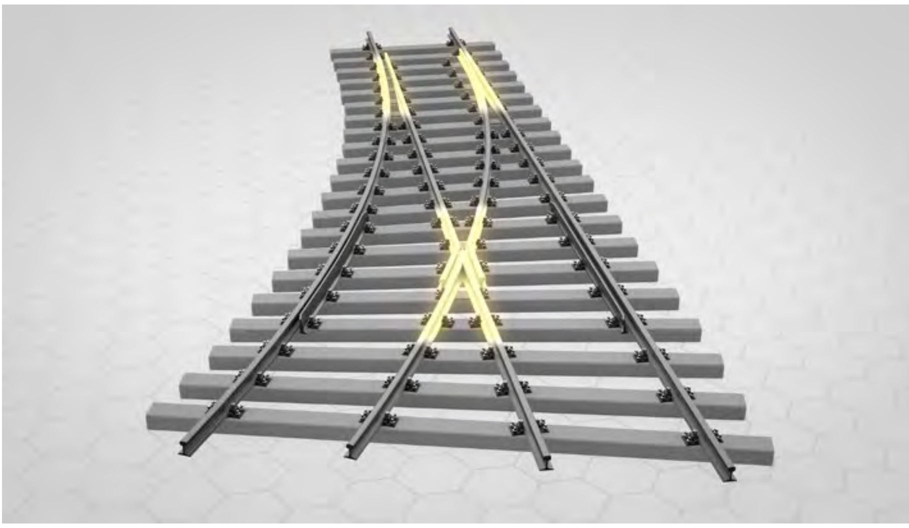

Fig. 3: The focus of fully automated repair welding lies on common crossings, wing rails, and switch rails.

Fig. 4 (collage with 4 pictures): Turnout defects which can be remedied with automation: wear on wing rail and common crossing as well as breakage to the crossing vee on a previously repaired section | breakages to the vee crossing resulting from a wing rail that is too low/one-sided loading | cracks and breakages to wing rail and crossing vee | hydrogen-induced crack caused by incorrect preheating

Careful attention is paid to the transition of the wheel between the wing rail and common crossing as well as to the switch assembly. This data forms the basis of a geometric modelling (Figure 5) of these relevant components.
Besides the measurement of the geometry, it is also necessary to record internal defects, i.e. defects below the surface, and their dimensions. This is achieved with a combination of different measuring methods in a robot-assisted tool. Burrs on the switch blade are also geometrically recorded and assessed.

Calculate the target geometry (wheel/rail transition)

Using special software algorithms, material removal is calculated on the basis of the target geometry for an optimal wheel transition from the common crossing to the wing rail and the dimensions of the defects. There the focus lies on the geometric modelling of the turnout's common crossing and wing rail.

Tackle trouble spots (milling, grinding)

Based on the target geometry, turnout system defects are corrected using a milling process. The milling strategy and its parameters are automatically adapted to the material. Rail and turnout material grades R260, R260Mn, R350HT, R400HT, and Mn13 have already been machined with a very high level of quality and an acceptable tool life of the tools.

Weld wing rail and common crossing

For optimum reconditioning of turnouts, the welding method and upstream processes are of crucial importance. Depending on the trouble spot and base metal, the welding parameters and feed speed are automatically selected. Depending on the geometry to be restored, a suitable welding strategy which enables an optimum bond and temperature control (e.g. changing between wing and the crossing vee layer by layer) is calculated with the aid of software. The entire welding process is temperature-monitored in order to prevent soft annealing. A preheating process with variable parameters is used with all carbon steels (R260 – R400HT). It enables a consistently good bonding of the weld metal; this depends on the base metal. The same is true of the hardness of the metal applied. A different approach is required to achieve the same results with manganese steels. On the one hand, preheating is not used. On the other hand, a welding method with a significantly lower heat input is used. Additionally, the manganese crossing is actively cooled.

Reprofile (milling, grinding)

A combination of milling and grinding processes is used to reprofile the turnout. The paths in which the tools are guided are based on 3D software algorithms. These algorithms account for the properties typical of robots. The overall aim is to achieve the required precision. Once the weld seam's protrusion has been detected, reprofiling begins using milling. The use of roughing milling helps to achieve the desired rail surface down to a few tenths of a millimetre. A faceted rail surface is created during the milling process. It provides the best possible basis for the downstream grinding process. Finally, a grinding machine is used for finish grinding, performed in a few cycles (Figure 6).

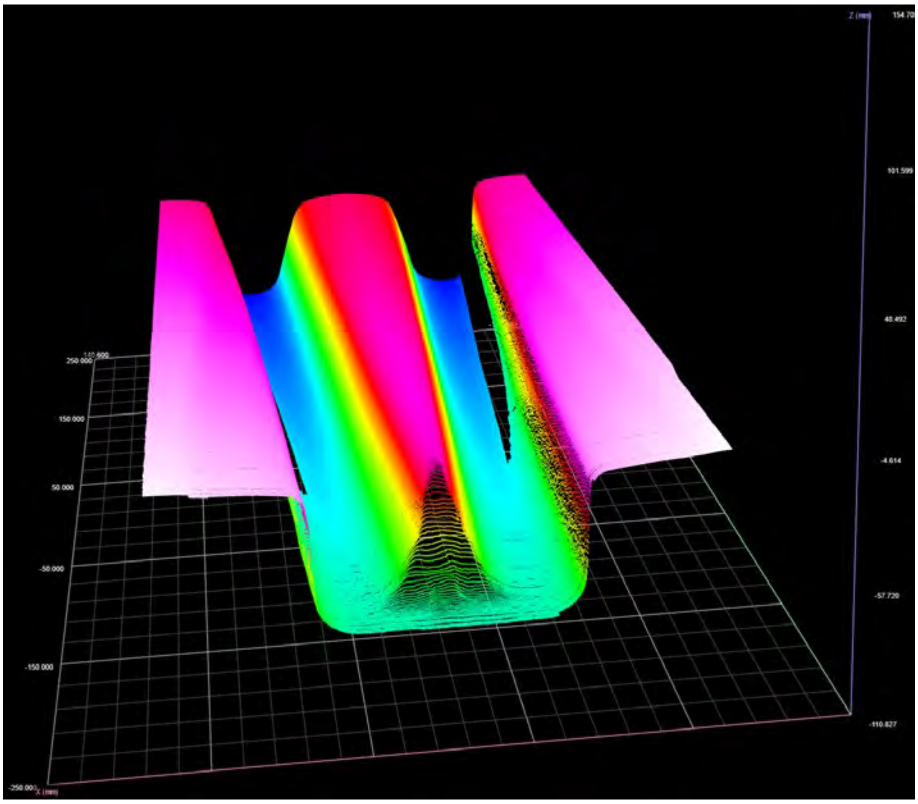

Fig. 5: Visualization of the measuring data of the robotized 3D scan of a turnout crossing vee

Quality check: measure and provide digital results

In addition to the initial situation and machine data of the technologies used, in the end it is also necessary to record the results of the work performed. This is done to provide proof of work and for documentation. The data is recorded locally on the machine and can be transferred to defined systems (e.g. cloud solutions).

Ongoing maintenance processes prevent unplanned deployments

The owners of highly developed, organized railway infrastructures frequently use preventive maintenance strategies to ensure the reliability and safety of said infrastructure. Continuous inspections of ballast, sleeper, rail, and turnout make extensive data and information available. The data provides a basis which can be used to detect potential failures and to introduce measures which can prevent them.

The concept of automation described in the previous section was developed in order to systematically plan preventive turnout maintenance and to be able to perform it with a quality that can be reproduced.

The advantages of preventive maintenance strategies are as follows:

- Work quality increases because the uncertainty for and strain on employees associated with unplanned interventions disappear. As a result, the quality of maintenance is higher and the results last longer.
- The use of resources, such as labour, materials, and machines, improves when repair welding for turnouts and plain-line tracks is planned.
- The costs associated with intervening too late don't arise.
- Total costs are lower overall compared to unplanned repair welding of turnouts and plain-line tracks.
- It can be seamlessly integrated into systems which already work in the continuous measuring and maintenance process, such as mobile maintenance systems, turnout measuring trains, or automatic turnout tamping machines.

Digitalization is a basic prerequisite for preventive maintenance and for everyone involved to work together smoothly. Automated systems generate a variety of data and information during operation. On the one hand, this includes inspection and measuring data, such as the geometric position and dimensions of the turnout. On the other hand, there are important machine and process data, such as the measurement of the interpass temperature during build-up welding or the data for checking that cracks or defects have been completely removed.

It is equally important to include prior information through project-specific data on the planned worksite, such as the exact spot of preventive work positions at the turnout or any known pre-existing damage that needs to be corrected.

Fig. 6: Finish grinding of the facets on the surface of the rail generated during the milling process

In doing so, the infrastructure owner and the user receive valuable supplementary information on the turnout system, its condition, and the history of the work performed.

Collaboration is key to innovation

"From the view of the hitherto, the new is always wrong" [9]. Concepts that dare to be different and an unbureaucratic approach are key to putting new solutions on track quickly, efficiently, safely, and reliably, not least because the renaissance of the rail already began a long time ago. This entails rethinking and trying out collaboration as well as defining financial limits.

With wide-ranging collaboration, it is possible to advance the next steps for development and implementation of fully automated build-up and repair welding for turnouts. To that end, the following measures are necessary to quickly and efficiently realize improvements that are technically possible:

- Testing and validation of the necessary measuring and testing procedures on the turnout to provide proof that it was crack-free from the beginning and has a suitable overrun geometry
- Testing and validation of the welding process for steel and manganese crossings
- The development and implementation of a human machine interface with simple, safe, and reliable operation of the whole system
- Testing and acceptance of individual steps and the entire process for use on track
- The joint development and implementation of digitalization components with users and infrastructure owners
- Preparation of a learning system that continues to develop based on the use of technology

In the past decades, mechanization and automation has been used to a large extent in the various working systems and machines in the world of railways. As a result, staff safety in the track has increased while heavy manual labour has decreased.

In view of the demographic changes which can be felt today and the resulting strain on construction companies and infrastructure owners, further automation of track maintenance work is unavoidable.

The complete process for turnout build-up and repair welding introduced here will aid in utilizing the benefits of automated preventive maintenance solutions and, as a result, will ensure ambitious growth objectives as well as the availability, reliability, and safety of networks are achieved. ■

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