



PROJECT NONIS - DEVELOPMENT OF OPTIMIZED AND SUSTAINABLE INSULATED RAIL JOINT SYSTEMS

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Abstract

Insulated rail joints are critical elements of the traffic control system that are submitted to heavy dynamic loads. Apart from turnouts, these joints contribute to about 40% of railway disruptions in Austria, significantly causing train delays. The objective of this project is to develop a more sustainable insulated rail joint system by investigating new design strategies and materials. This paper deals in the first instance with the analysis of data gathered from insulated rail joints by the measurement car of the Austrian Federal Railways. The data analysis is primarily based on the rail surface signal and longitudinal level signal. As the signals from the measurement runs are shifted in relation to each other, it is necessary to carry out a stationing process. After creating time series for 150 insulated rail joints, the 14 with a deterioration rate above 0.1 mm/year were defined as “Hot-Spots”. The comparison between these “Hot-Spots” and the entire data set indicates that insulated rail joints in tracks with concrete sleepers perform better than on those with wooden sleepers. The rail profile 49E1 is rarely represented in the tracks of the entire data set, but counts for almost the half of the “Hot-Spots”, while the rail profile 60E1 seems to have a positive impact. The steel grade appears to have a rather small impact on the occurrence of “Hot-Spots”. However, the steel grades for the turnout areas were not available, which may affect this result. Further steps in the project are in situ measurements and the analysis of the newly obtained data, the design of a validated simulation model, the development, installation, and monitoring of a prototype. As a result, an intervention will be proposed in order to protect the ballast from high deterioration due to defect insulated rail joints.

Keywords: railway, insulated rail joint, data analysis

1 Introduction

With their 2025+ target network the Austrian Federal Railways (ÖBB) make a clear commitment against the climate crisis, which requires efficient and at the same time low-maintenance infrastructure. This means that all components must be able to withstand increasing loads more effectively. Insulated rail joints (IRJ) are an indispensable component for safe train operation in the current signalling system [1]. At the same time, they are also responsible for 40% of railway disruptions in Austria (turnouts excluded).

The aim of project NONIS is, building on the findings of [2], the development of optimized and sustainable IRJ-systems. To reach this aim a consortium of the ÖBB, Martin Schienentechnik KG (a manufacturer for IRJ) and two institutes from the University of Technology Graz (Institute for Railway Infrastructure Design & Institute for Railway Engineering and Transport Economy) was established. It is funded by the Austrian Research Promotion Agency.

The project comprises nine work-packages which are partially dependent on each other. However, work-package 2 will be described in detail in chapter 2 as it was the author's task in the project and is the only one finished yet. As the first work- package includes the project management and therefore has no direct technical relevance, it is not described. Chapter 3 provides an overview of the entire project except work-package 1 and 2.

2 Methods for the analysis of existing data

The track measurement car of the Austrian Federal Railways (ÖBB) has been used for measurement runs for over 20 years, the rail surface [3] is measured since 2005. This provides a large amount of measurement data for analysing IRJ and ensures a significant assessment. The used measurement runs were operated between 2005 and 2022.

2.1 Definition of the track sections

The selected track sections for the data analysis are lines with high train frequency and speed and therefore high loading. Five stations on a busy line where IRJs frequently caused problems were selected. After the selection, the measurement data of the sections were provided together with a list of all IRJs in those sections.

2.2 Identification of the insulated rail joints in the signal

The next step was to check if the IRJ in this list are detectable in the rail surface signal. This was done by checking the signal for the typical characteristics of an IRJ (Fig. 1), which has a peak in the middle, as well as the associated peaks from welding joints before and after. The unit of the x-axis is Databreaks (1 Databreak \triangleq 25 cm).

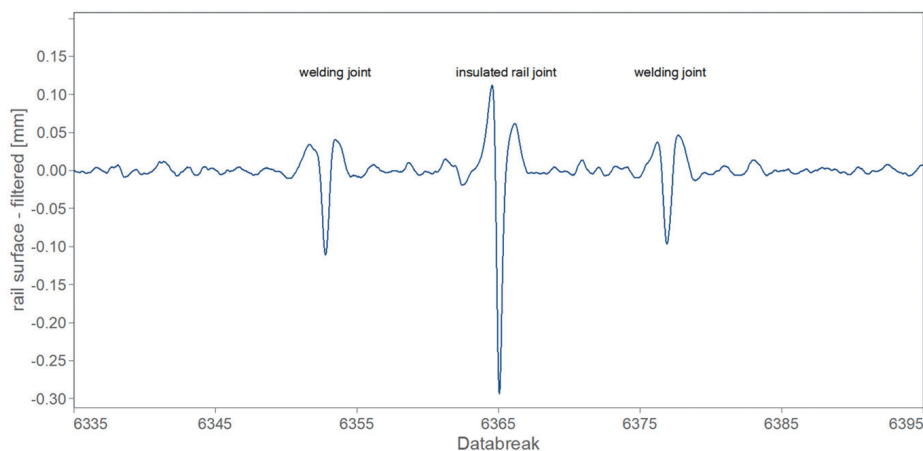


Figure 1 Typical characteristics of an IRJ in the rail surface signal

After this step, 150 IRJ remained in the list. For each IRJ, the location of the peaks in the signal of the most recent measurement run as well as the parameters for the superstructure, including sleeper type, rail profile, steel grade, and installation year, and the parameters for the track, such as allowed speed and load, were added to the list.

2.3 Preparation of measurement data

The data pre-processing consisted of a two-step manipulation: Firstly, they had to be repositioned because the signals of the different measurement runs were shifted in relation to each other. Secondly, we created time series for every IRJ to determine the behaviour over time.

2.3.1 Stationing process

For the stationing process, the algorithm CoMPaCT developed by Fellingner [4] was used. This algorithm uses the Euclidian distance function to compare the signals of the longitudinal level and the rail surface. A reference measurement run is selected and the previous one is shifted to minimise the Euclidian distance. The repositioned measurement run then becomes the new reference and again the previous one gets shifted. This process is repeated until all measurement runs have been shifted. Occasionally, a measurement run may not be shifted correctly and requires manual repositioning. Finally, all signals are shifted again so that the peak of the IRJ is at data-break 0. Fig. 2 illustrates the longitudinal level before and after the process, as the signals are synchronized and at data-break 0. To connect the longitudinal level and the rail surface the signal interruption from the half gauge signal and the rail surface signal at the crossing nose gap is used.

2.3.2 Time series creation

After synchronizing the signals, time series were created for both the longitudinal level and the rail surface. For the longitudinal level, the standard deviation was calculated using an influence length of 25 m (± 12.5 m) and 50 m (± 25 m), respectively. The time series of the rail surface was calculated with the minimum of the signal for both the IRJ and the welding joints. The values were saved with the date of the associated measurement run. Fig. 3 displays the time series for the longitudinal level and rail surface.



Figure 2 Longitudinal level before (top) and after (bottom) the repositioning process

The drops in the time series were assumed to indicate maintenance work or track renewal. Linear regressions were calculated between these drops and the gradients were saved as the deterioration rate (mm/year). The deterioration rate per load could not be calculated due to the unavailability of information on the year of installation of the joints. Neuhold [5] discovered that linear regression is the most precise function for deterioration. But since the data used are not exactly the same as in this work, we conducted an own investigation. A linear and an exponential function were compared. The median of the R^2 -values of all deterioration branches of the rail surface signal was for both function types almost the same. To obtain a more definitive result, the standard error of the regressions has also been calculated. The data clearly shows that the median of the exponential regressions is eight times higher than that of the linear regressions. Therefore, a linear regression is a better fit. For the longitudinal level the median of the R^2 -values of the linear regression is slightly better than the exponential one. However, for the standard error, the opposite is true. Before proceeding with the evaluation of the longitudinal level, it is necessary to determine which regression function will be used. Next, the dates with recorded disruptions in the linear relationships were compared with available maintenance records from the infrastructure provider. All IRJ with a deterioration rate above 0.1 mm/year in the most recent deterioration branch were defined as Hot-Spots. In the end 14 such Hot-Spots were defined. These were used on the one hand to find the right IRJ for further investigations such as in situ measurements, and on the other hand for further data analysis.



Figure 3 Time series longitudinal level (top) and rail surface (bottom)

2.4 Analysis of the rail surface signal

Since the superstructure and track parameters are known, it is possible to cluster the IRJ and compare the entire data set with the Hot-Spots. The size of the Hot-Spot is, as already mentioned, 14 IRJ and of the entire data set 150 IRJ. Fig. 4 shows the results of the clustering per sleeper types and rail profiles. It can be seen that wooden sleepers make up nearly the half of the Hot-Spots, while they only account for 11% of the entire data set. The reason for this could be that most of the wooden sleepers are located in turnouts. Concrete sleepers with under sleeper pads (USP) are overrepresented in the Hot-Spots set compared to the entire data set. Further investigations would be necessary to find out why this behaviour occurs. In the investigated tracks the rail profile 49E1 is only installed on wooden sleepers. The high proportion of this type of rail in the Hot-Spots is therefore likely to be linked to the sleeper material. The analysis of data for the rail profile 60E1 shows a lower deterioration rate than for other rail types.

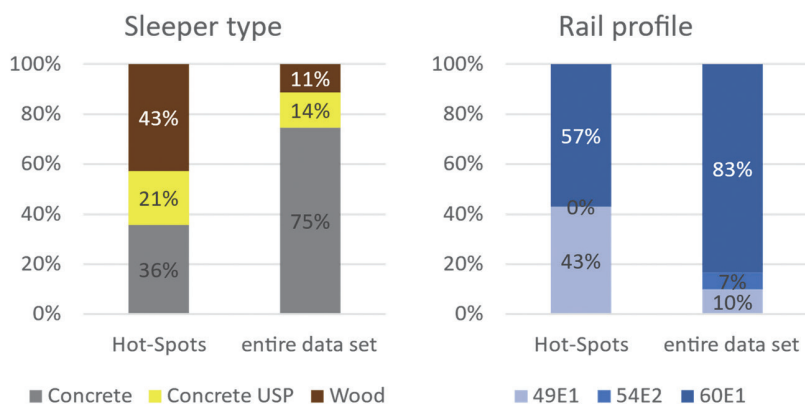


Figure 4 Results of the analysis of sleeper types and rail profiles

A combined analysis of sleeper type and rail profile confirms this statement, as the combination of wooden sleeper and rail profile 49E1 has a share of 43% of the Hot-Spots, but only 10% of the entire data set. A rather small impact of the steel grade is observed: all Hot-Spot IRJ are installed on rails with steel grade R260, while this type accounts for 71% of the entire data set. A higher steel grade might therefore improve the durability of IRJ.

3 Project outlook

The following points deal with the description of the aims and give the reader an overview of current work and expected results in further work packages of the project. As the project is running until 2025, not all results are currently available for presentation.

3.1 In situ measurements and data analysis

A further task is the development of a measurement setup for in situ measurements, the recording of new in situ datapoints and their analysis. To this day (3/2024), the development of the measurement setup is completed and implemented on one IRJ. It comprises 45 sensors, including linear strain gauges, shear strain gauges, laser sensors, acceleration sensors and temperature sensors. These sensors can detect and record the deflection of the surrounding sleepers, the stress and strain at the rail next to the gap as well as at the joint bar, the acceleration at the joint bar and the temperature.

Two different locations are chosen for the in situ measurements. The first one is on a straight open track with concrete sleepers with USP and rail profile 60E1. Two of three planned measurements have already been completed at this location. A measurement of the old track was conducted as to obtain reference values. A measurement after a renewal of the track was also performed. A third round will be conducted after the prototype is installed. The second location is in a curve and a turnout with wooden sleepers and rail profile 54E2. The first measurement is completed and a second one will be also done when the prototype is installed. Results of the measurements are not available yet.

3.2 Derivation of a new optimised system

With the aim to investigate different options for a prototype of an insulated joint, simulation models were designed. In the first step, a straight track without an IRJ was modelled and verified against an analytical formulation of the deflection according to Zimmermann [6]. The results were within a realistic range. Further validation of the simulation models will be conducted using the in situ measurements described in 3.1.

3.3 Design and installation of the prototype

By conducting a screening of the literature and inspecting IRJ in the tracks, we could gain important insights into the weaknesses of the individual components and their materials. A new type of joint bars, treated with a special hardening process, is already under investigation.

The next steps will be to refine the selection of the materials and shape/design of the components, adapt the manufacturing process to function, material and construction changes and make a prototype. An official test centre will test the prototype for failure before installation on the tracks.

The prototypes will be installed according to rules and regulations of the ÖBB. As a result of our preliminary results, different superstructure components will be additionally tested. For example, special sleepers with a broader support base to reduce the support point distance or ballast stabilization in the area of the joint.

3.4 Measurement of the prototype

The prototype will be equipped with a permanent monitoring setup, that will measure accelerations, deflections and noise. One prototype will be installed at a measurement location described in 3.1. We therefore will be able to assess the impact of the prototype compared to a standard IRJ. In another set, a prototype and a new state-of-the-art IRJ are installed in different locations on the same track. The gained measurement data are analysed and then compared to the results of the simulation.

3.5 Derivation of an intervention limit

Another aim of the project is to create a link between deterioration of the rail surface and the longitudinal level to define an intervention limit. This limit should prevent that a bad rail surface negatively affects the ballast bed. Since tamping or ballast bed renewal is time consuming, expensive and impacts the availability of the track it is important to protect the ballast bed from high deterioration. The breadth of the analyses to be able to obtain a meaningful deterioration limit has not been fully defined and will be described in further work from our team.

4 Conclusion

The results and findings of the presented methodologies will be transferred as recommendations for the optimisation of existing IRJ. This could encompass strategic measures for improved maintenance management, leading to fewer interruptions of the operation due to defective IRJ and a positive economic and ecological effect.

To respond to increasing train traffic and at the same time keep infrastructure availability high, the various track components must be as durable as possible. IRJ are good candidates for further development due to their high failure rate. The data analysis showed that wooden sleepers and small rails could pose a problem around IRJ. It also seems that concrete sleepers with under sleeper pads perform worse than concrete sleepers without them, but this needs to be further investigated. Rails with higher steel grade may have a positive impact on IRJ. For the development of a prototype different materials and forms will be investigated. To support this process, simulation models will be developed. Once the prototype is approved and ready to be installed in track a measurement setup will be applied to monitor it for a longer period.

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