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Reducing rail noise with acoustically optimised crossings

Field tests were undertaken to measure the noise of trains passing over crossovers at Pfaffstätten on ÖBB's Südbahn in Niederösterreich.

The noise generated by trains passing over turnouts can pose problems for railways, particularly in residential areas. Laboratory trials have shown the potential benefits of high-damping polyurethane composites, and a field test is currently underway on the ÖBB network in Austria.

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Noise in the vicinity of railway tracks has become a major issue in recent years, particularly in Europe where the development of noise maps has been accompanied by investment to limit the impact of passing trains, especially on busy routes with heavy volumes of freight or high speed trains. Measures such as noise abatement walls and soundproof windows are being installed widely to improve the quality of life for nearby residents.

Turnouts can pose a challenge in terms of their acoustic radiation under a passing train, particularly those which have a fixed crossing. The physical impact of each passing wheel on the crossing nose and the adjoining wing rail can often be heard clearly in the vicinity of the turnout. By contrast, much less noise is generated when trains pass over a swing-nose turnout, as there is essentially no flangeway gap. However, swing-nose crossings are significantly more expensive, and as such they are usually only deployed for high speed and heavy haul applications.

As part of our research aimed at reducing railway noise overall, we wondered whether a modification to a fixed crossing might change the acoustic properties enough to achieve an audible or measurable reduction in noise emissions, without affecting the turnout itself.

Initial concept

The crossing geometry of a new turnout is almost perfectly matched to the transition of the rolling wheel between the crossing nose and the wing rail, in order to minimise the impact forces and any resulting noise.

However, after the turnout has spent some time in track, the geometry of the crossing and wing rail begins to deviate from the optimum state, as a result of wear and repetitive loading forces. So the impact between the crossing and the wheel starts to change, and this can be perceived acoustically.

Turnout crossings that are cast from high-manganese steel typically have cavities on the underside facing the ballast. These cavities are necessary for the casting process, but they also offer a worthwhile reduction in material and the overall weight of the component. However, the cavities mean that the oscillation behaviour of the crossing is similar to that of a bell. Under impulse excitation it exhibits wide-band radiation which reverberates for a long time.

High-damping composite

The basic idea for this project was to take a standard cast crossing unit manufactured by Voestalpine Railway Systems and fill the underside cavities with a high-damping composite material developed by Getzner Werkstoffe, in order to reduce the sound pressure level. But this needed to be done in a way which would not affect the overall performance or maintainability of the turnout.

The mechanical properties of polyurethane can be modified almost as desired. This made it possible for us to develop a material which offers both a high level of damping (a high loss factor) and a stable matrix for embedding a high-density filling that could further improve the damping effect.

When selecting an appropriate filling material, the main focus is to ensure a high density composite, but in a way that makes the handling as easy as possible. We used a mineral filling material for the initial prototype, which was successful in our laboratory testing, but this material proved challenging when it came to handling. The mineral filling had to be washed and dried to ensure good adhesion to the polyeurethane.

With an eye to potential series production in the future, we decided to change the filling material for the crossings to be used in the field tests.

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The mineral filling was replaced by a metal filling, which could be introduced without any additional handling (Fig 1).

Measurement concept

To ensure the best possible comparison between the laboratory and field results, we needed a measurement set-up that could be used in approximately the same form in both situations. We therefore adopted an experimental modal analysis process (Fig 2).

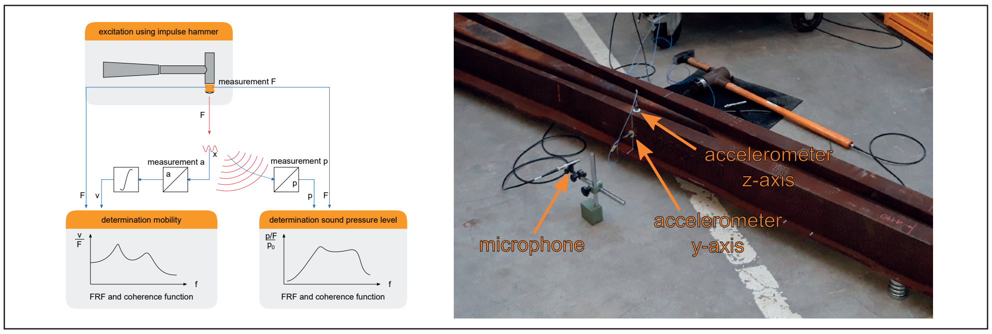
We decided to measure the acoustic radiation from the cast crossing as a result of an excitation using an impulse hammer. To ensure that we could measure a wide range of frequencies, we actually used two different hammers. A large hammer with a soft tip provided excitation of the lower frequency spectrum up to approximately 100 Hz, while a small hammer with a hard tip was used for excitation of the higher frequency spectrum.

Excitation took place approximately 350 mm behind the theoretical crossing point, at approximately the height of the wheel transition point. The impact on the crossing was made at an angle of 45°, in order to introduce vertical and horizontal force components simultaneously.

To evaluate the impact, we recorded the mobility represented by the vibration velocity normalised to the excitation force, as well as the sound pressure normalised to the excitation force. The vibration velocity was determined by integrating the signals of the accelerometer attached in both the horizontal (y-axis) and vertical (z-axis) directions. The acoustic radiation was measured by using a microphone at a distance of 400 mm from the crossing, level with the top of the rail.

Because our research was mainly focused on acoustic radiation, the rest of this discussion concentrates on the normalised sound pressures determined from our experimental results.

We took a step-by-step approach to analysing the modified turnout crossings. An initial prototype, consisting of just the cast crossing bloc, was tested in the laboratory, sitting on elastic bearings, with and without damping.



Top: Fig 1. Composite material for the damped turnout crossings used in the field test at Pfaffstätten.

Above: Fig 2. Measurement concept and measurement set-up for the experimental modal analysis on the turnout crossing.

This was followed by an approximately identical measurement of the complete pre-mounted crossing assembly before installation, using the turnouts that were subsequently used for the field trials.

The third step consisted of measuring the turnout crossings as finally installed in the ballasted track, including a determination of the pass-by sound levels generated by moving trains.

Our expectation was that the difference in the acoustic radiation between damped and standard turnout crossings would gradually decrease with each stage of this step-by-step process. This assumption was based on the gradual increase in the damping of the overall system as additional elements of the track superstructure such as sleepers and then ballast were introduced into the experimental setup. These additional components would have the effect of preventing the almost free oscillation behaviour that the crossing alone could exhibit in the laboratory.

Laboratory results

The first tests were carried out under laboratory conditions in the development lab at Getzner Werkstoffe. A standard cast crossing manufactured by Voestalpine was supported on soft springs to minimise any coupling to the ‘subsoil’. This bearing used four steel springs with a stiffness of around 200 N/mm each. The component was thus almost unrestricted in its degrees of freedom, allowing it to oscillate practically freely upon excitation with the impulse hammer. Five hammer strikes were carried out per measurement, which were averaged to a transfer spectrum.

After the reaction of the standard crossing had been measured, the casting cavities in the prototype were filled with the polyeurethane composite material using the mineral filling, and the measurements were repeated. Fig 3 shows the measured sound pressures, normalised to the excitation force, in the third-octave spectrum.

The additional damping starts to take effect from approximately 100 Hz, while the biggest differences can be observed from a frequency of approximately 700 Hz. By forming the sum level across the measured spectrum, this results in a reduction in the excitation-normalised sound pressure of 85% due to the additional damping, under laboratory conditions.

Field testing

Following the positive results in the laboratory, we began planning with

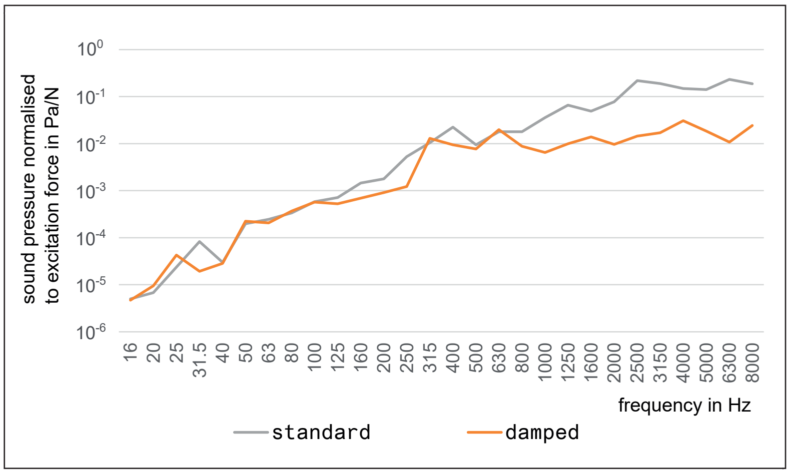


Fig 3. Excitation-normalised sound pressure of the prototype crossing when tested under laboratory conditions.

ÖBB for a practical trial on the Austrian rail network. Several locations with pairs of crossovers were shortlisted as potential sites for an in-track demonstration, but the Pfaffstätten crossovers on the Südbahn main line in Niederösterreich offered the most favourable conditions (Fig 4).

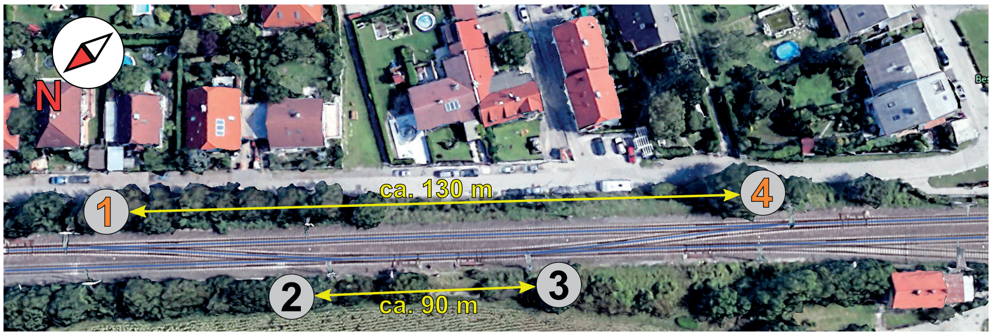
This pair of crossovers is equipped with type 60E1 – R500 – 1:12 turnouts manufactured by Voestalpine Railway Systems. Conventional crossings were used on the westbound track (turnouts W2 and W3), while those for turnouts W1 and W4 on the eastbound track were fitted with damping. As explained earlier, we changed from the mineral filling material used in the laboratory tests to a metal filling material in order to improve handling and recycling.

In line with our staged testing programme, pre-installation testing of the completely pre-mounted crossing areas for the new turnouts was carried out at the Voestalpine plant in Zeltweg at the end of June 2021, and the new turnouts were installed at Pfaffstätten the following month.

Unlike the standalone tests in the laboratory, the pre-installation tests were done with crossings fitted to the bearers and supported on the turnout assembly station at the plant. In this configuration, the cast crossings were no longer able to oscillate freely upon excitation, but were restricted in their degrees of freedom (Fig 5). For comparison purposes, measurements were performed on one standard turnout (W2) and one damped crossing (W1).

As anticipated, Fig 6 shows that the differences in the normalised sound pressures were lower than for the freely oscillating crossing tested in the laboratory, because additional damping had been introduced into the system through the coupling of the crossing to the turnout bearers. The sound measurements were somewhat hindered by background noise from the plant operations, but a 60% improvement in the excitation-normalised sound level was determined in the sum level, subject to the uncertainty introduced by the ambient conditions.

Subjectively, the excitation of the damped turnout crossing using the hammer with a hard tip generated a distinctly different sound (dull sound, no reverberation) compared to the reference crossing (metallic bright sound, reverberating).



Top: Fig 4. Aerial view of the Pfaffstätten crossovers, as seen on Google Earth. Turnouts W2 and W3 are standard, while W1 and W4 are damped.

Above: Fig 5. Measurement setup for the pre-installation tests at the Voestalpine plant in Zeltweg.

Field measurement

Turnouts W1 and W4 with the damped crossings were installed when the Pfaffstätten crossovers were renewed in July 2021. The field measurements were taken a couple of months later, in September of that year. The actual turnout geometries were recorded by Voestalpine before the trial (Fig 7) to confirm that all four crossings still had their optimum geometry at the time the measurements were taken.

The Südbahn main line carries a mix of passenger and freight trains, including ÖBB's premium Railjet trainsets which operate long-distance inter-city services. Local and regional passenger trains are formed of Cityjet EMUs and the so-called Wiesel push-pull sets of double-deck coaches also run over the route. In normal operation, the Railjets pass over the straight side of the turnouts at a speed of approximately 160 km/h, while the Cityjet and Wiesel service run at approximately 140 km/h.

We decided to use only the passenger trains for the measurement campaign, as these had a more standardised formation than the freight trains of variable length and weight. For the purpose of this article, we have focused on the results for the Railjet trains, as these offered the best comparison.

Acoustic measurement with a single microphone could not be carried out strictly in accordance with DIN EN ISO 3095 due to the local conditions, including the surrounding vegetation and the embankment location, which meant that the recording distances had to be reduced considerably. Fig 8 shows

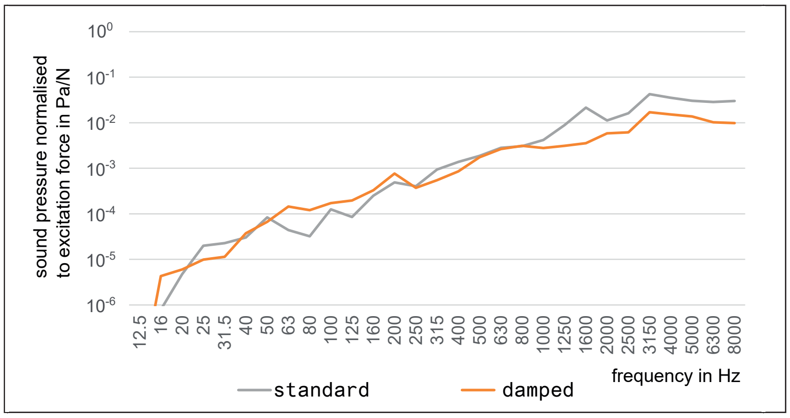


Fig 6. Excitation-normalised sound pressure on turnout crossings W1 (damped) and W2 (standard) as tested in Zeltweg.

Fig 7. Voestalpine staff checking the turnout crossing geometry at Pfaffstätten prior to the in-track noise measurements being recorded.

Fig 8. Setting up the measurement equipment to record the noise of passing trains during the field trials at Pfaffstätten.

how the measurement equipment was set up on site.

In addition to the single microphone for sound measurement, we also used an 'acoustic camera' to record the passage of the train. This used a microphone array positioned behind the single microphone.

For the evaluation, we needed to make a distinction between the facing turnouts W3 (standard) and W4 (damped) and the trailing turnouts W1 (damped) and W2 (standard). Between four and six passages by Railjets were evaluated for each turnout.

Fig 9 shows the results as recorded using the single microphone. The damped crossings showed a slight reduction of 1·9 dB in the average sound pressure level for the two facing turnouts, but only 0·2 dB for the trailing turnouts. Due to the insufficient number of passing trains, wide scatter bands within the same vehicle class and minor differences in the averaged spectra, in our evaluation we considered that both situations were approximately the same.

These measurements taken in September 2021 are essentially an evaluation of the crossings in their new condition. At the time the measurements were taken, the crossings exhibited no signs of wear, and as such the wheel roll-over behaviour for all four crossings was smooth, without any acoustically perceptible impact.

At this stage, the measurements taken with the acoustic camera are only provided to show the potential of the measurement method itself. The process enables sound sources to be localised with the aid of a microphone array, with the results presented as a spectrogram or acoustic image (Fig 10).

In retrospect, the positioning of the microphone array on the outside of the turnout proved not to be ideal. The crossing area on the 'inside' rail was hidden by the passing train, and could not be observed directly. As a result, we intend to change the position of the camera for the next campaign, taking the measurements from the opposite side of the line. Although the crossing will be further from the array, it can be observed directly, and we anticipate that this will provide better localisation of the crossing in the acoustic image.

Next steps

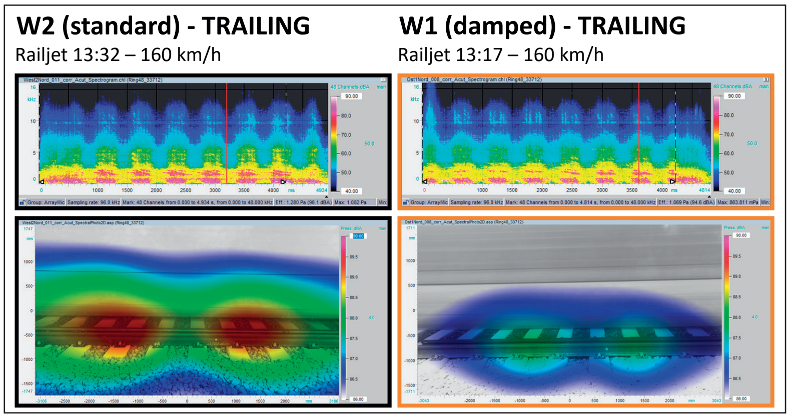
These initial measurements on the newly installed pair of crossovers at Pfaffstätten are regarded as a preliminary evaluation, which will form the basis for comparison with future campaigns as the track begins to deteriorate under regular usage.

As the crossings exhibited no wear at the time of measurement, the minimal differences in the pass-by noise levels for the Railjets were not surprising. Subjectively, only rolling noises (from wheel/rail contact) could be perceived during the measurement campaign, and there were no significant acoustic impacts.

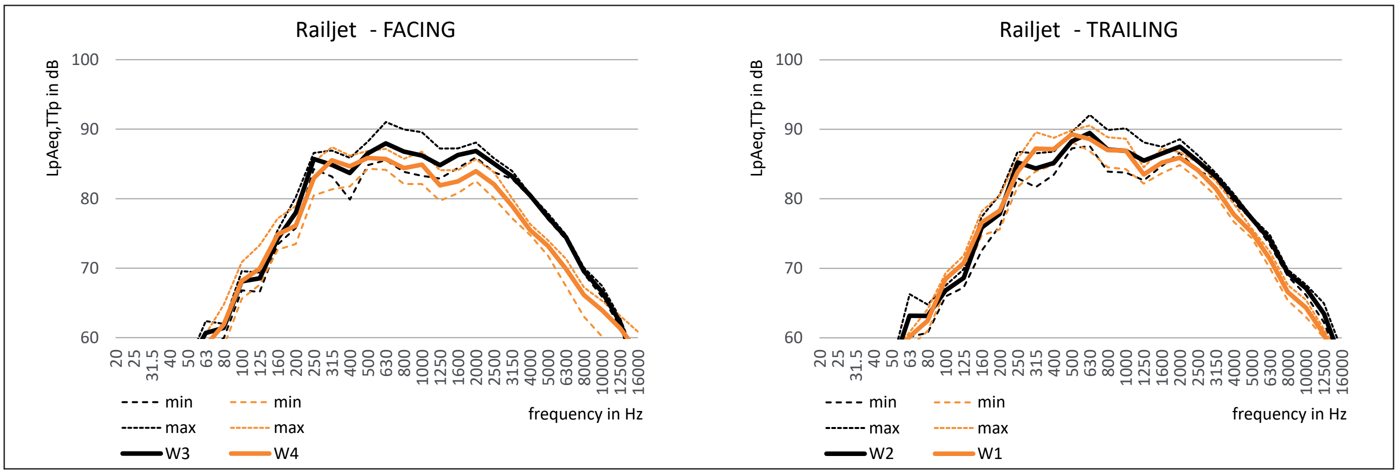
We expect to record an increasingly audible impact sound in future visits due to progressive wear of the crossings. The dominating sound in the vicinity of the turnouts under a passing train will start to change from a pure rolling noise to a clearly audible impact between the wheel and the crossing nose. In line with this assumption, we anticipate that the beneficial damping behaviour of the composite material should become more apparent as time passes. We expect subsequent measurements to find lower noise emissions for the damped crossing than the reference crossing.

The next on-site measurements will be carried out once we have been able to observe a certain level of wear on the crossings — which will be monitored both qualitatively and quantitatively by periodic measurement of the crossing profiles by Voestalpine.

Our experience suggests that, based on the volume of trains using the Südbahn, sufficient wear for the next evaluation will have occurred sometime in 2024.



Right: Fig 10. Evaluation of an acoustic camera measurement for a Railjet trainset passing over crossings W2 (standard) and W1 (damped) at 160 km/h.



Below: Fig 9. Pass-by noise level of a Railjet trainset passing over the facing turnouts W3 (standard) and W4 (damped) and the trailing turnouts W1 (damped) and W2 (standard). (ref $p_0 = 2 \times 10^{-5}$ Pa)