Track Noise Reduction – A single value descriptor of noise radiated by a railway track based on Track Decay Rate

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Introduction

During the STARDAMP project, a laboratory-based test method of estimating the efficiency of rail dampers under real conditions in track was developed [1]. This was based on combining the damping effectiveness obtained from laboratory measurements with the existing damping of the track expressed in terms of its Track Decay Rate (TDR). By combining both data sets, the reduction of the noise radiated by the track can be determined using a calculation method.

To summarise the effect of a rail damper in a particular situation, a reduced calculation procedure has been developed, presenting the acoustic differences of track sections as a single value. This value gives the Track Noise level Reduction (TNR) due to the changes in TDR. This calculation method is used here as the starting point for an extended method to compare differences of radiated noise due to the local TDR at different railway track sites.

A comparison of radiated noise levels related to the local TDR at different track sections without use of special calculation software such as TWINS [2] can only be achieved via several approximations. By use of a given number of pre-calculated theoretical TDRs for railway tracks with predefined stiffness of rail pads, type of sleepers, rails and ballast stiffness, the changes in noise radiation of the track are calculated. The simplified method of determining the influence of TDR on the noise radiation at different track sections is based on an estimation method in which a measured TDR is classified using the set of pre-calculated TDR. This will lead to an estimate of the rail pad stiffness in that track section from which the TDR was taken. The stiffness of the rail pads determined in this way will include temporal effects influencing the noise radiation, such as wear of the rail pads, contact forces due to the clamps at the rail foot and so on. The final step of comparing track-related noise radiation uses a diagram which presents the calculated changes in radiated track noise due to rail pad stiffness for fixed parameters of rail type, sleeper and ballast stiffness.

In recent years several governments and railway companies have strengthened their efforts to reduce the noise radiation of railways by improving the quality of the rolling stock. Because of the high number of wagons and locomotives all over Europe it is a very efficient way to control the achieved improvements by installing continuous measuring devices beside the tracks. The results obtained are only significant for this track section as long as the local track properties such as TDR and local rail roughness can be excluded.

To permit a comparison of radiated noise levels of one train at different railway sections, this paper introduces a method and strategy for estimating noise levels at different track sections.

Historical overview

Within the European research project STAIRRS a method was presented called Vibro-acoustic Track Noise method (VTN) [3]. The intention was to derive the track noise from the overall noise of a passing train. VTN is based on measurements of rail and sleeper vibrations during a train pass-by, separating the track noise from the overall noise. It includes the combined roughness of rail and wheel and the influence of the TDR on noise radiation, but does not separate wheel and track noise. The next step of incorporating the TDR in a track description method was done in [4], as a way of dealing with tracks that do not fully meet the requirements of ISO 3095 [5].

At DAGA 2016 two papers were presented [6, 7] concerning the use of TDR values as descriptors of track noise radiation performance. These studies are based on data measured by the Noise Measurement Coach (Schallmesswagen) of DB Systemtechnik GmbH, which is used for surveying the rail roughness at Specially Maintained Track sections. Due to the conditions of measuring noise under a running coach, the frequency range is limited from 500 Hz up to 2.5 kHz. Hence the results in [6, 7] are only helpful for determining the rail roughness in a more precise manner by taking the TDR-induced changes of the noise radiation of the track into account.

Basic considerations for the design of TNR

In [8] a comprehensive description about the role of TDR in noise generation by railway tracks is given. The noise components from the vertical and lateral rail vibration are inversely proportional to the corresponding TDR. As the TDR is determined by a combination and interaction of different elements in the railway structure, the dependence on the rail pad stiffness is complex.

This dependency will be utilized to estimate the stiffness of rail pads from measured TDR to define a track-related offset in radiated track noise. It will be shown later, that train type, braking system and train speed will also have a contribution, but the main influencing parameters on this method are given by the track substructure as follows

- type of rail – here UIC60 E2

- type of sleeper – here concrete monobloc B70, equally spaced at 0.6 m
- stiffness of ballast –stiffness ≈ 200 kN/mm

To create a basis for estimating pad stiffness from measured TDR a set of TDR data is calculated for a choice of four stiffness values

- 50 kN/mm; 100 kN/mm; 250 kN/mm; 800 kN/mm

This range of pad stiffness covers most rail pads used in European ballasted railway tracks and it will be shown later that these are nearly equally spaced for the purpose of this method (figure 1).

In this paper the main emphasis is put on the vertical TDR as the frequency shape is more distinctive than the lateral one. When considering the resulting changes in radiated noise, both vibrational directions are taken into account.

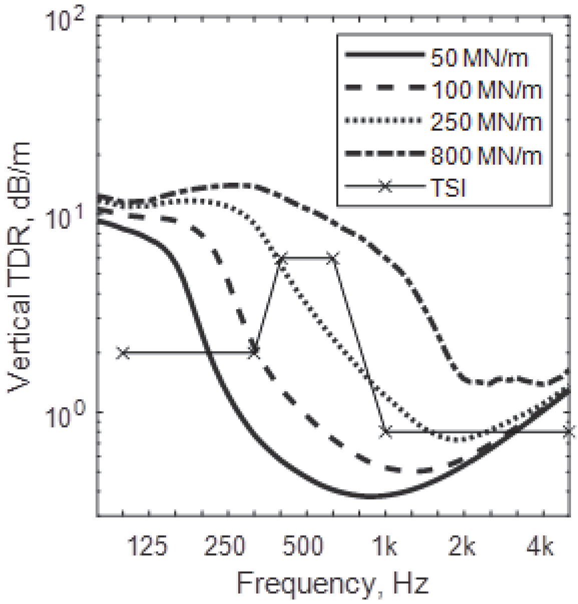

Figure 1: Examples of analytical calculations of TDR related to increasing pad stiffness

Calculation strategy

In figure 2, the four examples of calculated TDR spectra are drawn as one-third octave data averaged from the narrow band spectra presented in figure 1.

In red, a measured TDR spectrum is presented. Concentrating on a frequency range from 160 Hz up to 1 kHz it is obvious that the measured TDR spectrum fits very well between the TDR spectra of a track with a rail pad stiffness of 100 kN/mm and 250 kN/mm. Outside of this frequency range, especially for higher frequencies, the calculated TDR no longer matches with the measured one as higher-order vibrational effects of the rails occur which cannot be considered in this simple calculation model.

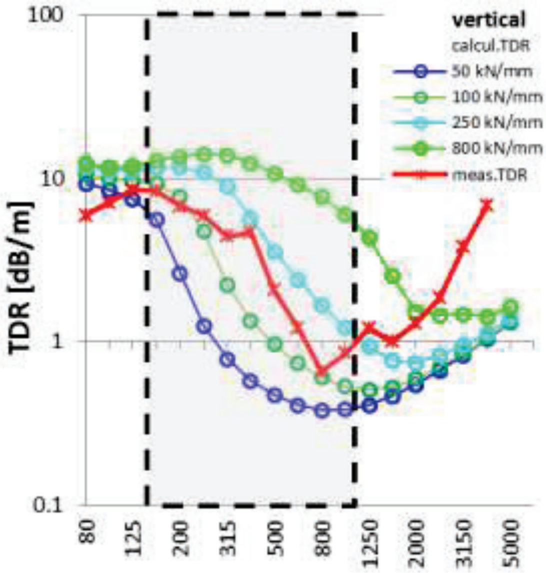

Figure 2: Calculated and measured TDR for vertical direction

Within this analysis window from 160 Hz to 1 kHz the changes in the TDR spectra due to pad stiffness are noticeable as a scalable shift to higher frequencies and to higher TDR values.

It is easy to understand that this effect can be taken advantage of by a stepwise linearization of the shift of TDR due to pad stiffness.

Table 1 presents the deviation of the measured TDR data to the four spectra of the calculated TDR data.

table 1 difference of measured TDR to pad stiffness TDR

$TDR_{meas}(f_i)$ - $TDR_{calc}(f_i)$

Hz	50 kN/mm	100 kN/mm	250 kN/mm	800 kN/mm
160	2.73	-0.92	-3.31	-4.56
200	4.07	-1.06	-4.92	-6.89
250	4.65	1.21	-4.99	-8.07
315	3.62	2.19	-4.48	-9.34
400	4.07	3.31	-1.02	-7.66
500	1.58	1.09	-1.50	-8.61
630	0.79	0.47	-1.18	-7.92
800	0.27	0.05	-1.02	-7.00
1000	0.47	0.32	-0.36	-5.18
sum	0.86	0.26	-0.88	-2.51

The total sum of the one-third octave deviations for each pad stiffness leads to two numbers with the lowest absolute values, closely spaced below and above the calculated TDR – in this case pad stiffnesses of S_{low} = 100 kN/mm and S_{high} = 250 kN/mm.

The estimation of the pad stiffness S_m can be calculated from the measured TDR by logarithmic interpolation. The related pad stiffness of the measured TDR presented in figure 2 is estimated to S_m ≈ 130 kN/mm.

Calculation of track noise and data normalization

The calculation of noise radiated by track and wheels of rolling stock in general or for particular sources via TWINS [2] - or, as done in this case, by STARDAMP tool - is well known and accepted. In figure 3 the dependence of the track noise due to pad stiffness for K-block braked freight trains running at different speeds is presented. All calculations used in this paper are done for a regional disc braked train and a freight train with K-block brakes. Calculations for freight trains with cast iron brakes are not included here, as they will gradually be eliminated over the next few years.

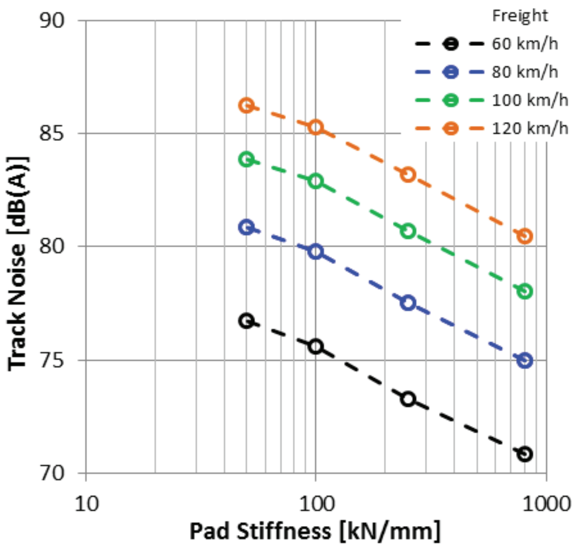

Figure 3: calculated noise levels of K-block braked freight trains at different speeds due to different pad stiffness; SPL at 7.5m beside track 1.2m above rail head

From figure 3 it can be taken that increasing pad stiffness reduces the radiated track noise. The shapes of the speed-dependent curves are very similar. When each of the pad stiffness curves are normalized to the lowest pad stiffness, the noise reduction due to increasing pad stiffness can be seen more clearly.

In figures 4 and 5 these normalised changes of the noise level are presented for K-block braked freight trains and disk braked regional trains.

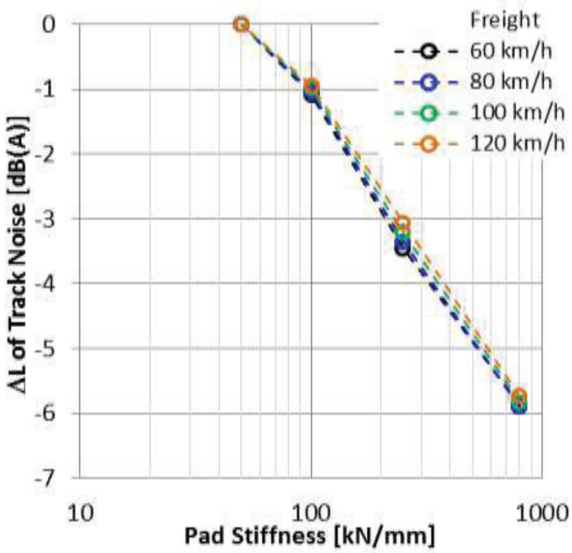

Figure 4: change in the radiated noise of K-block braked freight trains at different speeds normalized to pad stiffness of 50 kN/mm

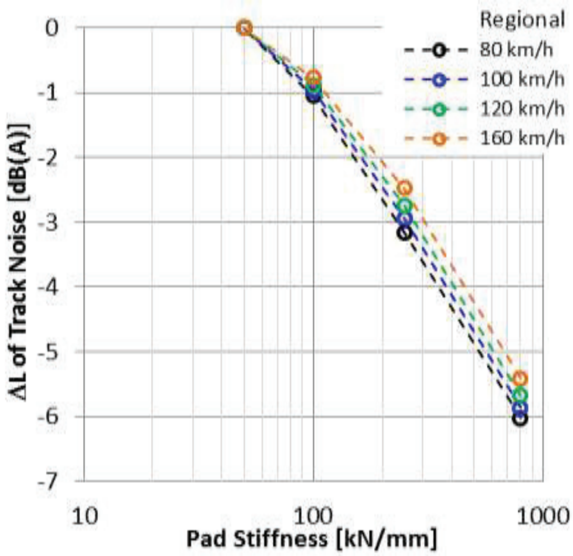

Figure 5: change in the radiated noise of disk braked regional trains at different speeds normalized to pad stiffness of 50 kN/mm

In Figures 4 and 5 the changes in track noise ΔL represent the TNR value. The reference stiffness of 50 kN/mm was chosen to point out the importance of pad stiffness, as stiffer ones are causing less noisy tracks which is the target of more silent railways.

From both figures it can be observed that the TNR is influenced to a small extent by train speed and the deviation is increasing with pad stiffness, less for freight trains than for disk braked regional trains.

Referring to the basic consideration for the estimation procedure to obtain pad stiffness from measured TDR, here a semi-logarithmic interpolation between the adjacent pad stiffness will lead to estimated changes in the TNR, as presented in figure 6.

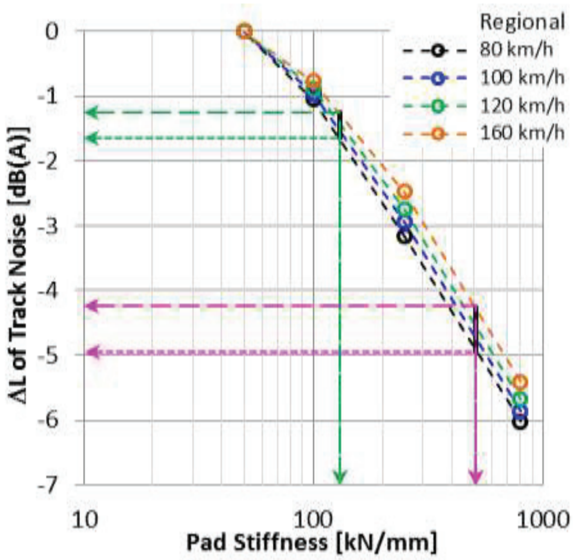

Figure 6: change in the radiated noise of disk braked regional trains at different speeds for soft (green lines s ≈ 130 kN/mm) and hard pad stiffness (purple lines s ≈ 510 kN/mm)

Figure 6 points out that the consideration of train speed within this method becomes more important when the noise of tracks with low pad stiffness is to be compared with the noise of tracks with high stiffness.

It should be mentioned that the precision of determining the results of TNR from these diagrams, which are gained from a stepwise linearization of speed-related data, provides a good estimation for comparing two track sections for the same type of train.

Conclusions

Comparing the radiated noise at different track sections requires more detailed knowledge about the factors affecting the noise generation such as the local TDR.

The method of estimating the Track Noise level Reduction (TNR) includes two steps. The first step involves an interpolation of calculated TDR spectra for representative track forms with varying pad stiffness to find the best fit to the measured TDR.

The second step is to transfer the resulting pad stiffness into a diagram in which the change in track noise level is pre-calculated for varying pad stiffness, train speeds and types of trains, by use of the same interpolation between adjacent calculated data.

The results displayed in the diagrams in this paper are valid for UIC 60 E2 rails, concrete monobloc sleepers B70 and standard ballast stiffness. As these chosen track parameters are met at most of the relevant main railway routes in Europe, the diagrams in figures 2, 3 and 4 may cover the most of the comparisons of different track sections that are of interest.

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