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A fast analytical tool to investigate effects of railway superstructure components on track dynamics

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Abstract

We present a new, detailed analytical model that takes all components of the superstructure into account and calculates a narrowband spectrum of rail accelerance and TDR, both vertically and laterally. The railpads are modelled as combinations of connections with frequency-dependent damping and stiffness. These tabular values are based on detailed finite element models of the pads, which reduce the geometry and material properties to 4 different springs. 2 for translational motion and 2 for rotational effects. The total calculation time of several minutes allows for fast evaluation of the influence of geometrical details such as the placement of slits, and the selection of ideal commercially available materials.

The fast analytical models allow us to predict the influence of stiffness and damping on the main dynamic properties of the superstructure. For vertical motion, the railpads' stiffness has the largest effect on the track decay rate, but their damping influences the pin-pin resonances. This is particularly visible in the narrow-band response spectra. The model captures structural details, but is fast enough to predict the dynamics of 200-sleeper sections in less than 5 minutes. It is therefore particularly useful for optimization purposes.
Keywords: Track decay rate, Modelling and optimization, Track dynamics

1 Introduction

The Swiss railway network is one of the densest in the world. In urban areas, dwellings are being constructed increasingly close to busy railway lines, thereby introducing the need for noise reduction. Railpads are the superstructure component with the highest effect on noise radiation, and they can be much easier replaced than rails or sleepers in case corrective measures are required [1]. The standard hard EVA railpads used by SBB offer the lowest possible noise generation, but the stiff connection to the sleepers results in a faster ballast deterioration. An ideal railpad combines low noise radiation with better vibration mitigation, typically achieved by softer railpads.

Several solutions to achieve these opposing goals are under investigation, most of them exploring the effect of viscoelastic, vibration-damping, materials. In-situ testing of new designs is costly, and can only be done for a limited number of prototypes. On the other hand, lab tests only offer limited predictive accuracy of noise generation and, more generally, important dynamic properties such as the track decay rate (TDR) [2]. Detailed numerical (finite element) models are too slow to allow a proper iterative design [3-4]. Existing fast analytical predictive models exist, but they typically calculate third-octave band results which offers little insight in the detailed effect of relatively small changes in the railpad design [5-8].

We present a new, detailed analytical model that takes all components of the superstructure into account and calculates a narrowband spectrum of rail accelerance and TDR, both vertically and laterally. The railpads are modelled as combinations of connections with frequency-dependent damping and stiffness. These tabular values are based on detailed finite element models of the pads, which reduce the geometry and material properties to 4 different springs. 2 for translational motion and 2 for rotational effects. The total calculation time of several minutes allows for fast evaluation of the influence of geometrical details such as the placement of slits, and the selection of ideal commercially available materials. In this paper, we present the key features of the model and their strength for performing parametric studies.

2 Methods

Existing analytical predictive tools for railway dynamics assume vertical and lateral bending wave propagation in beams, representing the rails. In the simplest of models, beams with a rectangular cross section positioned on a continuous elastic layer offer limited insight on the effect of overall stiffness and damping, and the difference between hard and soft railpads can be shown at least qualitatively in third-octave spectra of the TDR. In reality, the noise generated by vibrating rails depends not only on TDR but also on the rails' vibrational velocity, and thus its accelerance. It is well known that the noise radiation is a fairly modal phenomenon: the contribution of narrowband resonance effects such as pin-pin modes is responsible for the major spectral content of the noise. These discrete features are hard to assess in third octave band spectra, hence narrowband spectra are preferred for a detailed superstructure analysis.

Our calculation tool combines state-of-the-art modelling tools for the highest level of detail available in literature. The modelled components are

- Ballast: a continuous layer with frequency-dependent stiffness and damping
- Sleepers: not point masses but finite thick beams with a dynamic response.
- Railpads: modelled as 4 springs for vertical and lateral translation and rotation along 2 directions
- Rails: Timoshenko beam for vertical bending and 2 coupled Timoshenko beams for lateral bending

The input force location and its spectrum can be freely chosen, as well as the length of the modelled track. For the TDR calculations to converge, we use at least 200 sleeper sections. The rail acceleration spectrum can be exported at all desired positions, thus allowing for the TDR calculation. The Python implementation makes the tool freely available on all operating systems.

To focus on the effect of the railpads on the track dynamics, the model requires detailed quantitative information of the rail pads. The frequency-dependent complex stiffness of the 4 springs that replace each pads come from separate finite-element simulations of the pads.

3 Results

We investigate the role of the rail pads' material parameters on the main dynamic properties of a rail: TDR and the accelerance at the force location. The goal of this study is to find the range of stiffness and damping – quantified as viscoelastic storage and loss modulus – in which the equilibrium between noise radiation and ballast protection is ideal. In other words, we aim to design railpads that are softer than the used hard EVA pads, but at the same time result in a lower accelerance and high TDR.

In this paper, we show the effect of the rail pad on the vertical properties of the rail. The vertical spring stiffness varies from 50 to 5000 kN/mm, which corresponds to realistic values of existing pads. Soft pads (e.g. thick PU rail pads) are at the lower range, whereas hard pads (thin EVA) correspond with the higher values. The damping, expressed as the ratio between the imaginary and real part of the spring constant, is varied between 0.1 and 0.5. For the sake of simplicity in this parametric study, the spring properties are kept constant over the entire frequency range.

The results show that the pad's stiffness has the largest influence on accelerance and TDR (Figure 1). A stiff pad leads to higher accelerance resonances, but lower values at frequences below the pin-pin modes starting at 1100 Hz. The TDR is highest for the highest pad stiffness, and furthermore seems to reach a maximum limit curve which cannot be surpassed for stiff pads. This is in line with common knowledge. Highly damping pads are a recent development in railway technology, and the influence of damping materials was so far less investigated. Keeping the static stiffness constant shows that the damping affects most resonant phenomena (Figure 2). Higher damping lowers the pin-pin mode accelerance slightly, but the effect on the TDR is quite large. Every modal dip can be weakened by a factor 5, thereby improving the noise generation.

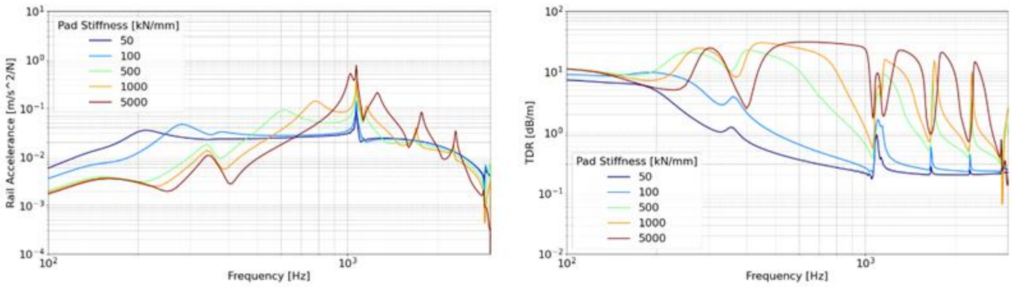

Figure 1: Influence of the rail pad's stiffness on local accelerance and TDR. Higher stiffness leads to a much higher TDR.

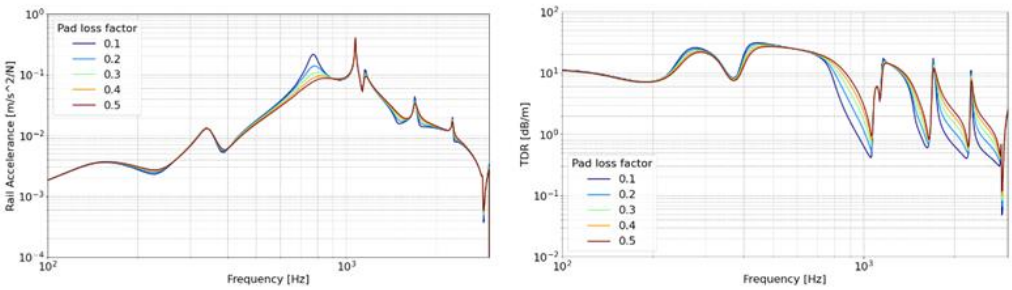

Figure 2: Influence of the rail pad's damping on local accelerance and TDR. Higher damping reduces the pin-pin mode effects.

4 Conclusions and Contributions

Our detailed model is sufficiently accurate to quantitatively predict TDR and accelerance of railway superstructures. The narrowband results show the presence of modal effects, particularly pin-pin modes, which are responsible for most of the radiated noise power by vibrating rails. The speed of the models, a few minutes for the response of a 200-sleeper track, allows parametric studies of each detail of the superstructure. We can show the complex interplay of stiffness and damping, e.g. the higher accelerance and increased TDR when stiffer pads are used, or the reduction of modal effects when the pads have higher damping. This allows to select ideal values

Although only frequency-independent spring constants were used for the results in this paper, tabular values can be inserted to map more realistic representations of a rail pad. In this case, the equivalent stiffness of the detailed geometry and visco-elastic properties can be extracted from a finite element model.

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References

[1] Schwanen, W., Peeters, B., Lutzeberger, S.: Railway noise in Europe, State of the Art Report, UIC, 2021.

[2] Thompson, D.J.: Railway Noise and Vibration: Mechanisms, Modelling and Means of Control, Elsevier, Amsterdam, 2009.

[3] A. Kalliainen, P. Kolisoja, and A. Nurmikolu, 3d finite element model as a tool for analyzing the structural behavior of a railway track," Procedia Engineering, vol. 143, pp. 820 { 827, 2016. Advances in Transportation Geotechnics III.

[4] Wunderli, J.M., Zemp, A.: Projekt OST, Abschlussbericht, 2015. URL: https://www.aramis.admin.ch/Dokument.aspx?DocumentID=46002.

[5] J. Ryue, D. Thompson, P. White, and D. Thompson, Decay rates of propagating waves in railway tracks at high frequencies," Journal of Sound and Vibration, vol. 320, no. 4, pp. 955 - 976, 2009.

[6] T. X. Wu and D. J. Thompson, Analysis of lateral vibration behavior of railway track at high frequencies using a continuously supported multiple beam model, The Journal of the Acoustical Society of America, vol. 106, no. 3, pp. 1369-1376, 1999.

[7] K. Popp, H. Kruse, and I. Kaiser, Vehicle-track dynamics in the mid-frequency range, Vehicle System Dynamics, vol. 31, no. 5-6, pp. 423-464, 1999.

[8] K. Knothe and S. Grassie, Modelling of railway track and vehicle/track interaction at high frequencies, Vehicle System Dynamics, vol. 22, no. 3-4, pp. 209-262, 1993.