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Journal of Sound and Vibration 267 (2003) 701–707

JOURNAL OF SOUND AND VIBRATION

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Application of MetaRail railway noise measurement methodology: comparison of three track systems

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Accepted 9 May 2003

Abstract

Within the fourth RTD Framework Programme, the European Union has supported a research project dealing with the improvement of railway noise (emission) measurement methodologies. This project was called MetaRail and proposed a number of procedures and methods to decrease systematic measurement errors and to increase reproducibility. In 1999 the Austrian Federal Railways installed 1000 m of test track to explore the long-term behaviour of three different ballast track systems. This test included track stability, rail forces and ballast forces, as well as vibration transmission and noise emission. The noise study was carried out using the experience and methods developed within MetaRail. This includes rail roughness measurements as well as measurements of vertical railhead, sleeper and ballast vibration in parallel with the noise emission measurement with a single microphone at a distance of 7.5 m from the track. Using a test train with block- and disc-braked vehicles helped to control operational conditions and indicated the influence of different wheel roughness.

It has been shown that the parallel recording of several vibration signals together with the noise signal makes it possible to evaluate the contributions of car body, sleeper, track and wheel sources to the overall noise emission. It must be stressed that this method is not focused as is a microphone-array. However, this methodology is far easier to apply and thus cheaper. Within this study, noise emission was allocated to the different elements to answer questions such as whether the sleeper eigenfrequency is transmitted into the rail.

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1. Introduction

In September 1999 the Austrian Federal Railways (ÖBB) built a test track on the Tauernbahn line in Carinthia between the Paternion and Rothenturn stations with Frame-sleepers, BI-block

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doi:10.1016/S0022-460X(03)00734-X

sleepers and the standard K1-ÖBB mono-block sleepers. The objective of the test installation was to check the performance and acoustical properties of the different track systems under practical operational conditions. Five different types of tracks were tested:

- Reference track: UIC 60 rail on K1-concrete sleepers with a Vossloh fastener.
- Frame-sleeper track, 3 sub-variants with UIC 60 rail with a Vossloh fastener.
- BI-block-sleeper track with UIC 60 rail, Nabla fastener and acoustically optimized rail pad.

The Frame-sleeper has a double H shape (Fig. 1) and consists of two concrete sleepers connected by a 40 cm wide concrete block under each rail. The rails are fixed to the sleepers every 75 cm; between them the tracks are quasi-continuously supported.

The double-H shaped sleeper tracks RS1, RS2 and RS3 differ in the thickness of the ballast (RS1, RS2: $d = 20\,\text{cm}$; RS3: $d = 30\,\text{cm}$) and they have different sleeper pad stiffness (RS1: $c_B = 0.038\,\text{N/mm}^2$; RS2, RS3: $c_B = 0.076\,\text{N/mm}^2$).

The BI-block sleeper track (referred to in this paper as BI-Bloc) has a sleeper pad and an acoustically optimized rail pad with standard Nabla fasteners.

2. Measurements

In the MetaRail project [1], pass-by noise and vibration signals were recorded in parallel and which were triggered at the train position by an inductive wheel sensor mounted to one rail. Additional vibration channels made it possible to:

- detect local inhomogeneities (for example ballast damping),
- determine the vibration isolation of the rail fastener and ballast,
- determine the spatial decay of the track.

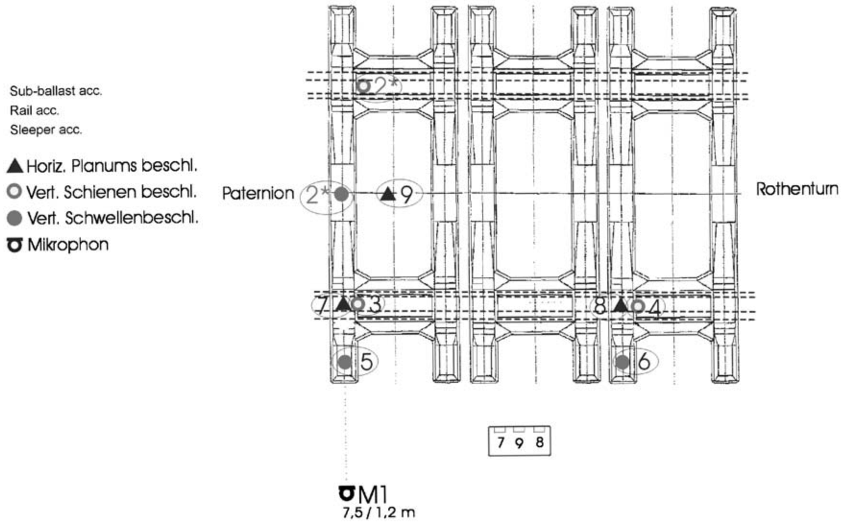

Fig. 1. Double-H shaped sleeper track with measurement positions.

The rail roughness has been checked and compared with the limit value of the prEN ISO 3095 [2].

2.1. Test train

A test train was prepared specially for the measurements to guarantee known and comparable conditions at all places of measurement. The train consisted of a locomotive class 1042, three disc-braked coaches and three cast iron block-braked coaches. Depending on wheel roughness (block-brake, disc-brake) the rail contribution is variable.

2.2. Analysis

For analysis and evaluation, a time slot was selected for each train pass-by. For each train pass-by one block-braked and one disc-braked coach was selected and analyzed. The exact speed of the test train during pass-by was calculated from the wheel detection signal. Therefore it was possible, for both block- and disc-braked coaches, to determine the acoustical and vibration properties for each track and pass-by speed.

The parameters that were used for evaluation purposes are:

- Time signal of the A-weighted pass-by noise at 7.5 m.
- A-weighted energy equivalent sound pressure level $L_{A,eq,m}$ of a vehicle group at 7.5 m.
- A-weighted 1/3-octave spectrum of $L_{A,eq}$ at 7.5 m.
- Linear equivalent vibration level $L_{V,eq}$ on the rail, sleeper and under the ballast.
- Linear third octave spectrum of vibration $L_{V,eq}$.

3. Results

3.1. Rail roughness

The roughness measurement of the rail has been made on the reference track (K1), on one Frame-sleeper track variant (in this case RS2) and also on the BI-Bloc-sleeper track (BI). For each track, 10 measurements on both rails were undertaken. The measuring instrument checked three tracks over a distance of 1200 mm. The results of the roughness measurements are summarized in the diagram (Fig. 2). The upper line presents the roughness-limited value of prEN ISO 3095 [2]. The existing roughness of the tracks was far below the limit value prEN ISO 3095 [2] in all three profiles. Therefore, the rail was in very good condition. This was expected since the rail had been ground in Autumn 1999.

3.2. Analysis of A-weighted pass-by level $L_{A,eq,m}$

Fig. 3 shows the $L_{A,eq,m}$ at a distance of 7.5 m and a height of 1.2 m of each vehicle group pass by for each track. The average $L_{A,eq,m}$ for each track and each speed, again separated for disc-braked and block-braked coaches, are given in Table 1. The trend is shown for each track, separately for block- and disc-braked coaches.

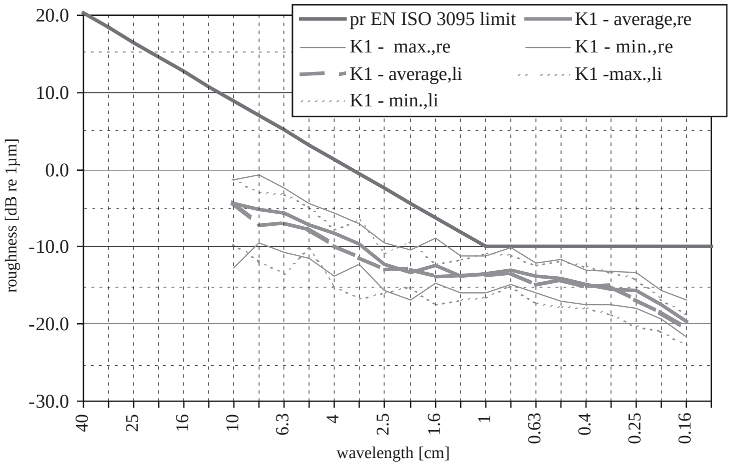

Fig. 2. Rail roughness of K1 track.

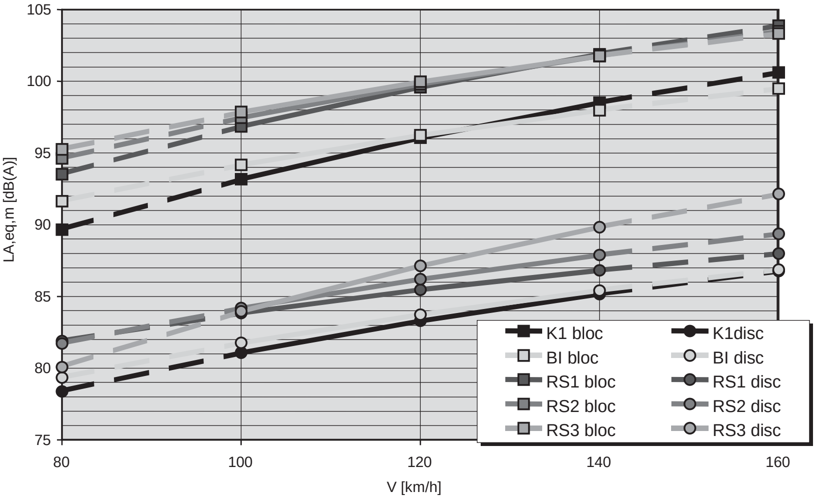

Fig. 3. Regression analysis: trend of $L_{A,eq,m}$ at a distance of 7.5 m and a height of 1.2 m dependent on the speed.

3.3. Analysis of A-weighted 1/3-octave spectrum $L_{A,m}(f)$

Fig. 4 shows the 1/3-Octave Spectra $L_{A,m}(f)$ of the test train for block- and disc-braked coaches at a speed of 140 km/h, separated by track type. The car body, the sleeper, the rail and the wheel have different and significant frequency ranges where they dominate the $L_{A,m}(f)$. Up to a frequency of 63 Hz the car body dominates the noise emission. This can be seen clearly in Fig. 4 since there is no difference between the track types and wheel roughness (disc- vs. block-braked).

At about 63 Hz the curves start to separate. In the frequency range between 63 Hz and about 300 Hz there is only a small difference between wheel roughness (disc- vs. block-braked) but a significant difference between the 5 track types. This spread is an indication that sleeper dominates

Table 1
Average $L_{A,eq,m}$

V (km/h)	K1 disc	BI disc	RS1 disc	RS2 disc	RS3 disc	K1 bloc	BI bloc	RS1 bloc	RS2 bloc	RS3 bloc
80	78.4	79.3	81.9	81.7	80.1	89.7	91.7	93.5	94.6	95.3
100	81.1	81.8	83.9	84.2	84.0	93.2	94.2	96.9	97.5	97.9
120	83.3	83.7	85.5	86.2	87.1	96.1	96.2	99.6	99.8	100.0
140	85.2	85.4	86.8	87.9	89.8	98.5	98.0	101.9	101.8	101.8
160	86.8	86.9	88.0	89.4	92.2	100.6	99.5	103.9	103.5	103.3

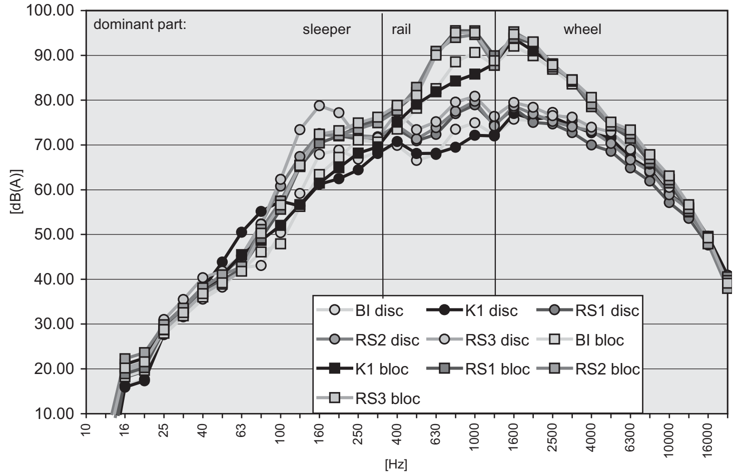

Fig. 4. 1/3-Octave-spectra for bloc- and disc-braked coaches $V = 140\,\text{km/h}$.

the noise emission. K1 and BI-Bloc tend to have the lowest levels here while RS3 has the highest level.

At about 300 Hz the curves start to form 2 peaks for disc- and block-braked wheels. In the frequency range between 300 Hz and 1.2 kHz the rail dominates the sound pressure level. Since the total roughness is the main factor for pass-by noise the rough block-braked wheels have a significantly higher level than the smoother disc-braked wheels. Within the 2 curve peaks there is a spread between the 5 track types with lowest levels again for K1 and BI-Bloc and the highest levels for the RS types.

Finally, above 1.2 kHz the wheel noise becomes dominant. Differences between the track types start to disappear, with separate curves for high (block-braked) and low (disc-braked) wheel noise levels.

3.4. Vibration analysis

The vibration $L_{V,eq}$ on the rail, the sleeper and under the ballast, as well as the vibration isolation between rail and sleeper and the ballast, were obtained for each track and speed. Results for block-braked coaches are shown in Fig. 5.

3.5. Spatial decay

Track spatial decay is an indicator for the longitudinal attenuation of rail vibration (Fig. 6), expressed by dB/m for lateral and vertical rail vibration. It influences the effective radiating length of the rail. The decay rate varies with frequency and is typically high for low frequencies. This is well known from the sound produced by the rails during the approach of a train. The magnitude is dependent on pad damping and stiffness and the behaviour of the fastener systems, which can dissipate vibration energy (Table 2).

4. Conclusions

- Rail roughness measurements indicated excellent good rail conditions at the test site.
- A-weighted pass-by levels were lowest for the reference track K1 in each case.

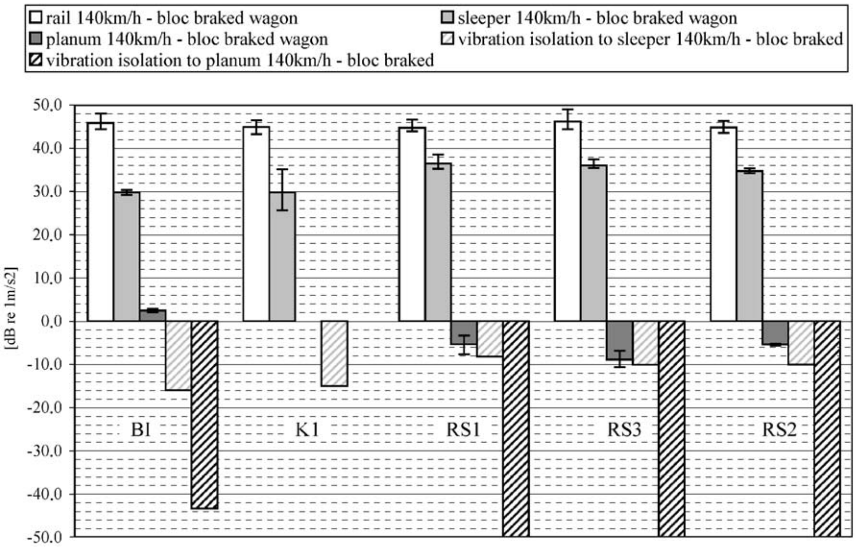

Fig. 5. $L_{V,eq}$ and vibration isolation, bloc braked coach; $V = 140\,\text{km/h}$.

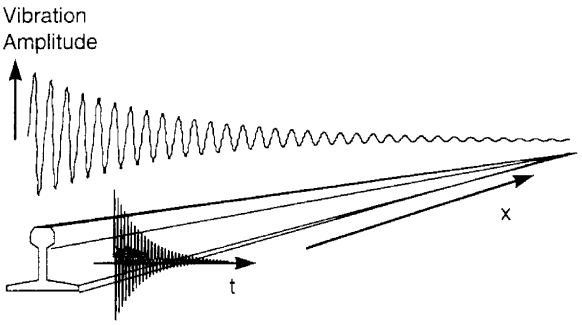

Fig. 6. Spatial decay of rail vibration.

Table 2
Spatial decay of each track

	BI	KI	RS1	RS2	RS3
Average spatial decay (dB/m)	1.1	2.0	1.8	2.1	2.0

- Significant differences in noise emission were measured between the K1- and BI-Bloc tracks and the double-H shaped sleeper tracks for both block-braked and disc-braked systems; for all track types, noise emissions were shown to be significantly different for the two types of braking systems.
- The BI-Bloc track exhibits its expected speed and frequency dependency for noise emission as it is acoustically optimized for high-speed trains (TGV).
- Significant differences between K1-/BI-Bloc-sleepers and double-H shaped sleepers were observed at frequencies of 50–315 Hz.
- Rail vibration is significantly higher for RS-tracks than for K1-/BI-Bloc-tracks.
- The analysis of track vibration shows significantly higher vibration isolation (6–10 dB) between rail and sleeper for BI and K1 track than for the double-H shaped sleepers. The damping is in the range of 4–10 dB.
- The vibration isolation from the rail to below the ballast is significantly (7–12 dB) higher for double-H shaped sleepers than for BI-Bloc-sleepers (K1 not tested).
- The spatial decay was shown to be similar for all track types except for BI which is the most "flexible" track. However, the results show that spatial decay is not the only determining factor for noise emission.

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