ANALYSIS OF WHEEL AND TRACK IRREGULARITIES IMPACT ON THE VIBROACOUSTIC SIGNALS EMISSION IN RAIL VEHICLES

Pawel Komorski, Tomasz Nowakowski, Bartosz Firlik and Grzegorz M. Szymanski

Department of Rail Vehicles, Poznan University of Technology, Poznan, Poland
email: pawel.komorski@put.poznan.pl

Decision supporting tools for implementation of cost-efficient railway noise abatement measures (DESTINATE project) is a non-member project funded by the Shift2Rail Joint Undertaking, a Horizon 2020 initiative. The research and innovation project focuses on methodologies, techniques and tools to support cost-effective railway environmental noise reduction and enhance acoustical comfort for passengers. DESTINATE aims to promote modal shift from road to rail transport by facilitating informed decisions on railway noise mitigation alternatives. One of the project tasks was to analyse the impact of the vehicle-track dynamic interactions. The aim of this article is to examine the impact of the track and wheel irregularities (corrugation and roughness) on the vibroacoustic emission. Roughness and vibroacoustic measurements were carried out simultaneously. The correlation between the obtained vibroacoustic results and parametrized irregularities of the wheels and tracks – with special attention given to low frequencies and the internal acoustic climate (due to the aims of the DESTINATE project) – was the main result. Also a statistical analysis of the results to indicate methodically correct correlations of identified phenomena was performed.

Keywords: vibroacoustic emission, roughness measurements, light rail vehicles

1. Introduction

An important aspect in the DESTINATE project is the focus on sources of noise and the attempt to characterise them. Rolling noise is the main source, which mostly depends on the condition of the rail and wheel surface. Examination of the influence of corrugation and waves on the rail head and the wheel tread on the vibroacoustic emission was carried out in this paper. These kinds of experimental research were also made by several researchers in the past, e.g. [1-7]. However not all of them are complex. Many of such works do not include interior and exterior vibroacoustic signals or include only rail roughness measurements. What is more important, none of them concern light rail vehicles and urban transportation. In this article the vehicle-track dynamic interaction is described and examined with respect to the low frequency sounds (50-250Hz) resulting from the wheel and rail irregularities. The main aim of this research is the dynamic interaction that leads to interior and exterior noise emission during tramway passage. Vibroacoustic emission was measured during several series of pass-by tests. Experimental research is well-founded among other DESTINATE project assumptions, like a cost effectiveness analysis of selected railway noise abatement methods.
2. Research objects

2.1 Light rail vehicles

The Four different tramway vehicles were chosen for the examination (Figure 1). The selection was based on the operator’s data (different wheel diameter, wear and mileage) and own observations. All vehicles were in good technical condition which is important due to their vibroacoustic emission. This type of vehicle is a full low-floor articulated tramway, with five carbodies and three bogies. Only the middle one is a trailer bogie. The main technical parameters of the tramway are shown in Figure 1.

![Figure 1: The research object - Tramino Solaris S105p tram.](image1)

2.2 Tracks

All experimental research was conducted on a tram network in Poznań (POLAND). Two different types of tracks with different corrugation wave and wear were selected for examination. Selected sections of tracks are ballasted and separated from the road traffic (as shown in Figure 2). Track A is composed of rail type S49, mounted on prestressed concrete sleepers with fixing system type SB-3. Track B is structurally different and is located at Poznan’s Fast Tram route. The track is composed of rail type R59 with mounting system type K on wooden sleepers. The main difference between track constructions is the ballasting level. On track A up to the level of the rail head, and on track B up to the sleepers’ surface.

![Figure 2: Two different tracks selected for the examination.](image2)
2.3 Research methodology

Experimental study consisted of two different steps. In the first part, the rail head and wheel tread acoustic roughness measurements were carried out in accordance to ISO 15610 standards. The rail roughness device during measurements is presented in Figure 3. Corrugation on the rail surface is also visible.

The wheel roughness device is shown in Figure 4. All wheels of the four selected vehicles were measured. However, in further work only trailer bogie wheel roughness was taken into consideration. The highest wheel roughness values occurred between 5 and 32 cm wavelengths.

In the second part, several vibroacoustic measurement series have been made during pass-by tests. The vehicle’s speed was about 50 km/h. Interior and exterior vibroacoustic measurements were carried out simultaneously. Due to the aim of this task and lack of additional motor/gear noise emission, the vibroacoustic signals emission only from trailer bogies was taken into further examination. The weather condition during research was optimal for noise measurements (no rain, approx. 50% of humidity, temp. 4°C, wind speed less than 3 m/s). The pass-by measurements were
carried out during night time conditions, when background noises did not influence experiment results. Five vibroacoustic measurements were made for each vehicle and on each track. A significant amount of different measurement data can provide well-founded analysis.

The location of noise and vibration measuring devices inside and outside the vehicle is shown in Figure 5. Complex interior measurements included three microphones (MI-1,2,3) type B&K 4958 located above each tram bogie (according to ISO 3381 standard). On the floor, above the trailer bogie, one-axis vibration transducer (T-1) type B&K 4519-002 was mounted (according to the ISO 12299 standard). Also one three-axis vibration transducer (T-2) type B&K 4504-A was placed on the axlebox of the trailer bogie. On-board GPS system was used to point out the measuring cross section. Thus, interior measurements could be harmonized with exterior measurements.

![Figure 5: Measurement points location: MI-x - inside microphones, MO-x – outside microphones, T-x – vibration transducers.](image)

Exterior vibroacoustic measurements consisted of three microphones (MO-1,2,3) type B&K 4958 located at different points of the track: 1 m (on the height of 0.5 m above the ground), 3 m and 7.5 m (on the height of 1.2 m above the ground – according to the ISO 3095 standard). Also two vibration transducers were mounted on the rail web (T-3) and on one of the track sleepers (T-4). Thus, rail vibrations on the z-axis were measured during the vehicle-track dynamic interaction. Two photocells were located on both sides of the track. Signals emitted between them were used to pinpoint the start and the end of a tram passage Furthermore, the time selection of signal measurements was determined. Therefore, all acoustic measurements were synchronized in the speed domain.

### 3. Results of examination

#### 3.1 Selected combined roughness analysis

The wheel and rail effective acoustic roughness levels are expressed as one-third octave spectra with respect to wavelengths. Combined acoustic roughness levels were calculated according to equation (1):

\[
L_{r,\text{tot}}(\lambda) = L_{r,w}(\lambda) \oplus L_{r,r}(\lambda).
\]

The frequency filter (high pass) of the contact patch can be ignored in this assessment, because the comparison is focused only on the low frequency bands. Two different combined roughness wavelength spectra are shown in Figure 6. Combined roughness amplitude levels are high in context of limited values in wavelength bands. Typical corrugation wavelengths in both examples are between 5 and 50 cm. This wavelength range corresponds to low frequency sound between 30–270 Hz. Shapes of combined roughness were influenced by irregularities of both rails and
wheels. Moreover, wheel roughness had a major influence on the shape of the graphs in the presented results. In comparison to railway noise, the rail roughness has more significant impact than the wheel roughness. It is probably caused by more strict railway procedures for rail and wheel grinding, especially in passenger trains.

The comparison of sound pressure level (SPL) and combined roughness spectra are shown in Figure 7 and Figure 8. Both interior SPL are processed signals from microphones located in the middle of the trailer bogie (previously marked as MI-2). Acoustic signals recorded by microphones at a distance of 7.5 m from the track axis are marked as exterior SPL. The A-weighted characteristic is not applied in this specific analysis, however it was intended by the authors to see how roughness in low frequencies influences the raw acoustic wave (without filtering). Results are expressed as one-third octave spectra in a low frequency range. This range is relevant in context of impact of combined roughness on sound emission. The significant correlation between the combined roughness and sound emission can be observed. In the first example there is an increase of combined roughness in lower frequency bands, between 40-100 Hz. It can be observed in a similar case of sound emission. In the second example the combined roughness is higher, between 100-500 Hz frequency bands which translates into higher SPL in this range. Differences in dB amplitudes (even 5 dB when interior SPL is considered and even 10 or more dB when exterior SPL is considered) are visible especially between the 63-500 Hz bands in both examples.
Moreover the correlation coefficients (Table 1) were calculated to show the relations between wheel and rail irregularities and vibroacoustic emissions in several research examples. These values are taken from signals processed in the full rolling noise frequency range, also including low frequency bands (30-5000Hz).

<table>
<thead>
<tr>
<th></th>
<th>Interior SPL</th>
<th>Exterior SPL 7.5m</th>
<th>Floor Vibration</th>
<th>Wheelset Vibration</th>
<th>Rail Vibration</th>
<th>Sleeper Vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Roughness</td>
<td>0.91 ± 0.93</td>
<td>0.92 ± 0.95</td>
<td>0.55 ± 0.69</td>
<td>0.08 ± 0.09</td>
<td>-0.72 ± -0.57</td>
<td>-0.72 ± -0.57</td>
</tr>
</tbody>
</table>

Figure 7: The roughness and acoustic spectra comparison measured on the B track and tramway No. 525

Figure 8: The roughness and acoustic spectra comparison measured on the A track and tramway No. 547
The correlation coefficients between roughness and sound emission are above 0.9 which points to a significant relation. Thus, it is vital to monitor wheel and rail surface condition by a frequent grinding process. Usually, in the tramway field it is not so common as in the railway. Considering the floor vibration, there is extensive roughness influence in low and medium frequency bands. Vibration amplitude levels in a whole rolling noise frequency range are high while roughness levels are decreasing with increasing frequency. Similarly with respect to wheelset vibration where vibration values are enormous (between 120-140 dB re 10-6 m/s²). There is no correlation between wheelset vibration and combined roughness in presented results. However it is obvious that the tram suspension characteristics determine how well the vibrations are damped before reaching the vehicle body. Opposite phenomena occur with track vibration. Rail and sleeper amplitudes vibration are small in low frequencies and increasing in medium and high frequency bands. Thus, the correlation with roughness signals is negative.

4. Summary

Based on experimental research the influence of rail and wheel irregularities on the vibroacoustic emission in low frequency bands was proven. The acoustic combined roughness spectra for several research examples were calculated and compared to vibroacoustic emissions expressed in one-third octave spectra. Wheel roughness levels measured from motor bogies were not taken into examination due to worse surface technical condition (the negative sand impact) and due to additional noise sources, namely gears and motors, in vibroacoustic signal measurements. Moreover, the correlation coefficients between combined roughness and vibroacoustic signals in a rolling noise frequency bands were calculated. Based on the examination it can be concluded that:

1. There is a significant correlation between sound pressure levels and acoustic combined roughness (the correlation coefficient above 0.9).
2. The floor vibration is not as related to roughness as sound pressure levels. This is highly dependent on vehicle suspension and damping characteristics.
3. The wheelset vibration is not related to roughness in rolling noise frequency range at all. It is most likely due to extensive vibration levels throughout all low and medium frequency range. However it can be observed some correlation between 50-100 Hz frequency range.
4. The negative correlation occurred between combined roughness and track (rail and sleeper) vibration. It means that combined roughness does not influence z-axis track vibration in low frequencies. The main vibration amplitude occurred to 200-500 Hz, 2000 Hz and 4000 Hz frequencies.

Research shows that not only rail roughness (corrugation), but also wheel roughness has strong influence on the overall noise emission. It is a slightly different case than in a railway where rail roughness is the main component in combined roughness and noise emission. Nevertheless, a more frequent grinding process of wheel and rail surfaces is one of the best solutions for decreasing the level of vibroacoustic emissions, especially in the urban rail transport where dynamic wheel-rail interactions are rapidly changing.

Furthermore, based on the measurements, the transfer function between different signals can be calculated. Using the OTPA assumptions (the Operational Transfer Path Analysis which was described in detail in the other DESTINATE task), a basic interior and exterior sound prediction can be carried out and a transfer path between the source (combined roughness) and the receiver (noise emission) can be estimated.

REFERENCES


