The complex analysis of tram noise in relation to changes in dynamic mobility of tram wheel

Pawel KOMORSKI1; Bartosz CZECHYRA2; Tomasz NOWAKOWSKI3

Poznan University of Technology, Poland

ABSTRACT
Tram wheels are equipped in different kind of mobile inserts which affect to dynamic and construction features of vehicle. The main aim of these elements is to decrease vibroacoustics effects affecting to the urban environment. Changes of dynamic mobility characteristics of tram wheel are influenced to vibroacoustic activity of light rail vehicles in operating condition. In article is presented the complex tram noise analysis in relation to different kind of dynamic mobility of tram wheel. Four series of tram noise measurements were carried out according to pass-by method. Firstly, tram wheels were equipped in the conventional inserts and the bogie covers were mounted on vehicle. Secondly, tram wheels were the same but bogie covers were removed. Then the testing inserts were equipped in tram wheels and two more measurement series were carried out: with and without bogie converts. The impact of bogie covers on emitted tram noise was analyzed. The complex analysis of tram noise includes an acoustic signals recorded in one measurement point, in accordance with ISO 3095 standard. Furthermore the paraseismic vibrations were measured. Tram speed was constant during research. The main aim of analysis was to compare in terms of qualitative and quantitative acoustic signals emitted by vehicle equipped in different inserts inside the tram wheels.

Keywords: Tram wheels, Dynamic mobility, Bogie covers

1. INTRODUCTION
Nowadays urban rail transport is one of the most important elements of public communication system both in Poland and Europe. However there is a noise problem around tram infrastructure which affected on inhabitants living near tramway and during passage. Noise and vibration emitted by tram passage is called vibroacoustic activity of technical object (1, 2). Therefore it is well founded to accurately identify the sources of vibroacoustic signals and try to reduce their impact on the urban environment.

One of the methods of minimizing the impact of the tram-track vibroacoustic interaction in urban environment is elastic wheels usage. Conventional tram wheels are equipped by flexible rubber inserts between the rim and center wheel. This solution affects to reduce the unsprung masses of the light rail vehicle. Thus, the vertical and lateral vibration induced in the vehicle-track system are reduced. By controlling the dynamic mobility of the vehicle’s running system, the negative acoustic impact around the tram line can be minimized. The validity of this solution is confirmed by plenty of scientific research, which takes into account a variety of elastic inserts, in terms of number, shape, type, dimensions and arrangement in wheels of the rail vehicle (4–7). Due to the type of wheel construction and strength transmission by rubber elements, the general division is shown in Fig. 1 (5, 7). In the Fig. 1a, the elastic inserts are subjected to shear during the rail vehicle’s ride. In the second case (Fig. 1b), the compressive forces influence to elastic elements only. While in the last case (Fig. 1c), in which V-shaped inserts are used, both phenomena are at play. Trams of older types, manufactured in Poland (such as Konstal type 105 and its variants and successive upgrades) are equipped with flexible wheels of the type shown in Figure 1a. While the manufacturers of wheels for new type rail vehicles usually use the V-shaped elastic inserts.

The article presents an analysis of the impact of changes in dynamic mobility of tram wheels and the use of bogie covers on the acoustic signals emitted by selected Polish tram. The measurements of

1 pawel.r.komorski@doctorate.put.poznan.pl
2 bartosz.czechyra@put.poznan.pl
3 tomasz.zb.nowakowski@doctorate.put.poznan.pl
the pass-by test were conducted on straight track with constant speed of the vehicle. The main aim of the research was to experimental verification of changes in the quantity and quality values of emitted acoustic signal, as a result of tram wheels modification and removal the side bogie covers from vehicle. Moreover the paraseismic vibration analysis was carried out.

![Figure 1](image)

**Figure 1** – Examples of the tram wheels construction with elastic inserts (5, 7)

### 2. RESEARCH METODOLOGY

#### 2.1 Noise and paraseismic vibration of tram in pass-by test

The complex experimental research presented in this paper can be divided into two parts. Firstly, the normative acoustic measurements in pass-by test were carried out, in accordance with ISO 3095 standard (3). Secondly, the paraseismic vibration measurements on track were performed during tram passage.

In Figure 2 is shown the scheme of measuring position. The measuring microphone was located at a distance of 7.5 m from axis of the track (3). The vibration transducer was located at a distance of 1 m from the external railhead. Furthermore, two photocells, located at both side of the track, were used to point the beginning and end of the rail vehicle. Also, the speed of tram’s ride was calculated on the basis of the recorded signal.

![Figure 2](image)

**Figure 2** – The scheme of measuring position in the pass-by test; M – the microphone, T – the vibration transducer, F – photocells

INTER-NOISE 2016

6917
Four vibroacoustic measurements in constant conditions were carried out. Each measurement series consisted of six individual measurements. The differences of vehicle modification between series are shown in the table 1. In the first measurement series, the tram was equipped with conventional wheels in SAB system. Also, the bogie covers were mounted on both sides of the vehicle (Fig. 3a). In second measurement series, the bogie covers were removed from the tram (Fig. 3b). In the next two measurement sets, the conventional wheels (in the next part of the article called wheels A) were replaced by testing wheels (next called wheels B). The process of wheel replacement has not influenced into the technical condition of vehicle. Best efforts were taken – by retaining identical wheel diameters and profiles – to ensure that the geometry of the running system does not change its geometrical parameters. In this manner, the dynamic mobility of the wheels of the technical facility was modified without changing the parameters of the vehicle itself. Third and fourth measurement series were different in aspect of bogie covers usage on the vehicle.

**Table 1 – Differences of vehicle modification between four measurements series**

<table>
<thead>
<tr>
<th></th>
<th>With bogie covers</th>
<th>Without bogie covers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheels A</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Wheels B</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

The speed of each ride during sound level measurements was 50 km/h with a tolerance of ± 1 km/h. The background noise level had no impact on the progression of the tests and the results (it was the same and constant during both running tests).

### 2.2 The object and location of the research

The selected Poznan light rail vehicle was the research object. The tram was a high floor vehicle with three bogies. The measurements were done in the first half of December 2015, on the one of Poznan tram depot. During vibroacoustic measurements the weather conditions were as following: wind speed was less than 5 m/s, lack of rainfall (slightly cloudy day), air temperature was around 10 Celsius degrees, humidity was less than 70%.

### 2.3 The measuring equipment

The measuring equipment scheme is shown in Fig. 4.
To vibroacoustic measurements were used following Brüel & Kjær equipment:
- microphone type 4189-L-001,
- vibration transducer type 8344,
- two photocells Autonics type BX15M-TDT,
- the data acquisition system PULSE LAN-XI type 3050-A-060,
- mobile computer,
- router Wi-Fi.

Before the measurements, the calibration process of each measuring equipment was performed.

3. RESULTS

3.1 Vibroacoustic signal processing

To compare and verify the impact of dynamic mobility changes and bogie covers usage on generated sound pressure, the vibroacoustic signal processing had to be done. Acoustic signals were converted to the frequency domain, using the CPB spectral analysis with Constant Percentage Bandwidth. Sound pressure levels in 1/3 octave bands (in the audible frequency range) were results of this operation. Also, the equivalent sound pressure levels to each tram passage were calculated. Frequency A correction was applied to all acoustic signals calculation. While a para seismic vibration signals were transformed by FFT analysis (Fast Fourier Transformation) in the frequency range up to 1000 Hz. Thus, the root mean square values of acceleration signals in the frequency domain were obtained. The results averaged from six measurements in each series.

3.2 Acoustic analysis

3.2.1 Qualitative analysis

The averaged spectrum of sound generated by a moving tram for both wheel types and with mounted bogie covers is shown in Figure 5. The change in dynamic mobility contributed to different sound level distributions in different 1/3 octave bands. Frequency bands of 31.5 Hz, 40 Hz, 250 Hz, 1250–1600 Hz and 6.3–20 kHz show a marked difference in sound level (approx. 1–6 dB depending on the band) to the disadvantage of test wheels A. In contrast, in the frequency bands of 20 Hz, 63–160 Hz, 400 Hz, 800–1000 Hz, 2000 Hz and 3150–5000 Hz, noise generated during the ride of the tram with wheels B is ca. 1–4 dB higher. The remaining 1/3 octave bands are characterized by a lack of major differences in sound level (less than 1 dB).

![Figure 5 – Average sound spectra recorded in the pass-by test in case with bogie covers](image)

In Figure 6 is shown the comparison of average sound spectrum emitted by tram passage equipped with two types of tram wheel and with removed side bogie covers from the vehicle.
Compared to the Fig. 5, the sound levels in different frequency bands are increased. Frequency bands of 250 Hz, 1250-1600 Hz and 10000-20000 Hz show a marked difference in sound level (approx. 1–3 dB) to the disadvantage of test wheels A. The highest sound level difference is about 3 dB and occurs in the 1250 Hz frequency band. While in the frequency bands of 20-25 Hz, 63-125 Hz, 400 Hz, 800-1000 Hz and 2000-5000 Hz, differences in sound levels were about 2-5 dB to the disadvantage of case study of wheels B. In other frequency bands sound level differences were less than 1 dB.

In relation to impact of the use of bogie covers on emitted noise, it can be concluded that the most of characteristic frequencies bands in both cases are coincide with each other. However, the average sound levels are higher for cases, where bogie covers were removed from the tram.

### 3.2.2 Quantitative analysis

The comparison of equivalent sound pressure levels is shown in Fig. 7. Four different research cases are analyzed: wheels A in black color, wheels B in grey, with and without bogie covers in lined regions.
The difference of equivalent sound levels between A and B wheels test is about 0.5 dB in comparison of both research cases: with and without bogie covers. Wheels B are noisier in global point of view but the differences are very small and not perceptible by the human sense of hearing. In contrast to differences between equivalent sound levels with and without bogie covers, which are about 2 dB. In acoustic point of view, the use of bogie covers, is worthwhile because it significantly reduces noise around the tram infrastructure.

3.3 Paraseismic vibration analysis

The final parameter defining vibroacoustic activity of the tram fitted with the tested wheel types, which was included in the comparative analysis, were paraseismic vibrations generated by the tram in motion.

The signal of acceleration in paraseismic vibrations was recorded in the same manner for all realizations of the vibroacoustic process. The mean level of paraseismic vibrations recorded for the tram equipped with conventional wheels (A) was 0.22 m/s². For the new wheels (B), the value was 0.35 m/s². The quantitative increase in vibrations is accompanied by a qualitative change in the recorded signal. The averaged spectrum of recorded vibration signals for both wheel types is shown in Figure 6.

![Figure 6](image.png)

As shown in Figure 6, there is a significant difference in signals recorded for both wheel types. The greatest differences in recorded values can be noted in the band from ca. 50 Hz to 160 Hz. At the same time, there is an observed shift in vibration energy towards higher frequency bands. One example is the band from ca. 500 Hz to ca. 700 Hz. Such changes in the spectrum of paraseismic vibration signals point to a change in the type of interaction occurring between the vehicle and the track.

4. CONCLUSIONS

The findings presented above show that the wheels of a new design induce a change in the vibroacoustic activity of the tram. With respect to the acoustic impact, the changes are slight. The recorded signals point to local differences in sound pressure in individual 1/3 octave frequency bands. Characteristic frequency bands for the wheels A, are: 250 Hz, 1250-1600 Hz and above 10 kHz, where the sound level was higher by about 1-6 dB. While in the case wheels B, the characteristic frequency bands are 20 Hz, 63-125 Hz, 400 Hz, 800-1000 Hz, 2000-5000 Hz. The changes, however, do not translate into significant global changes in sound levels recorded in conformity with ISO 3095. The difference is just 0.5 dB, which in practical terms does not exceed the level of detection of a potential listener/passer-by.

The impact of bogie covers usage on generated acoustic signal is significant. The equivalent sound levels are about 2 dB higher to the disadvantage of research cases with bogie covers removed from the tram. Such a difference might have a big impact on the acoustic climate around tram lines in urban
areas.

The situation is different in terms of paraseismic vibrations generated in the test track. The increase in relative values over the entire test band (1 kHz) is nearly 60%, to the disadvantage of wheel B. The differences are even higher, if local changes in signal spectrum are considered. In this case, the local increase in vibration level is more than twofold.

The study thus shows that the proposed wheel B may be a good alternative to wheel A in terms of acoustic characteristics. However, wheel B is a bad alternative with regard to vibrations generated by the vehicle. Markedly modified dynamic mobility characteristics of wheel B – compared to the conventional design – translate into very unfavorable vibration characteristics. Furthermore, they carry a tangible risk, as trams typically operate in dense urban areas. Consequently, an elevated vibroacoustic activity of trams equipped with B-type wheels may be dangerous to buildings located in the vicinity of tram lines.

REFERENCES