ASSESSMENT OF VIBROACOUSTIC CLIMATE IN CASE OF LIGHT RAIL VEHICLES – METHODICAL ASSUMPTIONS

Abstract
Advancing urban development of huge urban and agglomeration spaces triggers development of municipal transport services. Along with development of individual and collective transport, higher and higher percentage of population lives in constant noise and vibrations hazards, which are very often harmful for human body. Trams are a specific source of vibrations and noise in cities. Brief and high level of generated acoustic and vibration signal of impact characteristic is typical for those vehicles. However, because of periodicity of their passages, they do not generate serious vibroacoustic hazard for the environment.

This is different in case of passengers, who do not have direct influence on transport process and are endangered by vibroacoustic interactions in closed tram’s space. Common carriers need to deal with more and more current and even critical task of minimizing the influence of means of transportation on both passengers and the driver. Minimizing adverse effect of means of transportation on passengers has a beneficial influence on raising ride comfort and by this, it increases competitiveness of certain means of transportation in the market of transport services.

With a problem described in such way, it is necessary to assess and estimate the vibroacoustic climate in a vehicle based on procedures other than homologation tests carried out in ideal conditions. Differences stem from necessity to take into consideration operation conditions and the way rolling stock is managed. Because of variety of types of used vehicles it seems to be justified to work out universal measure of vibroacoustic activity of vehicle from the perspective of vibration and sound interaction on the driver and passengers in a vehicle.

In this paper the author present methodical assumptions to solve the problem of assessing vibroacoustic climate in rail vehicle on the basis of carried out preliminary operation tests.

INTRODUCTION
Trams constitute a specific source of noise in big cities. A short-lasting and high level of generated acoustic signal of an impulse nature is characteristic of those vehicles. However, due to periodicity of their passage they do not cause large acoustic hazard for the environment (the environment outside transport). It is different in the case of passengers, who do not have a direct influence upon the transport process and are exposed to mechanical and acoustic effects in the enclosed space of the tram car in so-called inside environment of transport.

A carrier more and more often has a current and, frequently, crucial task to minimize the influence exercised by the means of transport upon passengers and drivers. If we present the problem in this way, it will be a specific task to limit the influence of a wheel rolling on a steel rail upon the buggy and reduce vibrations and structural noise. It is connected with the
shaping of the acoustic climate inside of the vehicle as determined by the structure of the gear system and the buggy. Changes in selected types of trams used in Poznan (PL) were verified through spatial measurements of noise and vibration in selected points of tram.

The main source of noise generated by trams is a wheel rolling over a rail. Generated noise is a secondary effect of processes occurring on wheel/rail contact, particularly micro-slippages resulting from changeable location of contact point of both profiles and changes in meshing area of both elements. Figure 1 presents a change in location of wheel/rail contact point resulting from changes in geometry of both profiles because of wearing.

![Fig. 1. Changes in location of wheel/rail contact point in new profiles (left) and worn profiles (right) [1]](image)

Dynamic loads of wheel and the whole tram buggy caused by transverse change of rail’s profile are additional undesirable excitation occurring during ride of a rail vehicle [2]. Corrugated wear called corrugation and mounting failures of rails are typical examples of such excitation. Figure 2 presents examples of both causes.

![Fig. 2. Example of corrugated wear of rail (left) and mounting failures (right)](image)

Rides on parts of rail’s infrastructure such as rail crosswords and junctions are additional sources of excitations during ride. The level of excitation strongly depends on ride conditions (speed, load, curve radius, etc.) and technical state of pointed units.

Transfer of excitations from the tram drive unit to the tram body results in vibroacoustic effects affecting passengers and the tram driver. Taking into consideration structural dynamics of the tram body itself it may turn out that the mechanoacoustic susceptibility as well as global and local resonances of the tram body may significantly affect safety and ride comfort [3]. This hypothesis became the basis of tram investigations in standard exploitation conditions.

Other sources of tram noise include running devices connected with vehicle drive and control (ride controller, inverter, converter, etc.) and supporting devices (fans, air-conditioner). Occurrence of those sources of noise depends on the vehicle construction.
1. FIELD TESTS

The purpose of this work was to analyze the level of vibrations in selected types of trams used by various transportation systems in Poland and to define to what extent purchase of new low-floor vehicles improves ride comfort of passengers. In this case comfort means parameters of vibration accelerations in vertical and transverse plane of the vehicle and levels of sound registered in selected parts of the vehicle. Because of innovative character of the works (introduced by Tomasz Roliński† in cooperation with team from Division of Rail Vehicles of Poznan University of Technology, where is still developed), comparative tests were carried out in independent conditions in Poznan and Wroclaw. The tests were carried out on seven various types of vehicles, both high-floor and low-floor. The scope of work comprised recording vibration accelerations in vertical and transverse direction and sound in the following parts:
- wheel set,
- truck frame,
- on tram body over pivot,
- vibrations on driver’s seat,
- vibrations on passenger’s seat near articulation,
- Binaural sounds in the cab,
- Binaural sounds in passenger space near pivot,
- Binaural sounds in passenger space near articulation.

During rides on selected routes vibrations of parts of tram buggy were recorded to characterize its dynamics. For reliable description of ride conditions additional equipment was used. There was inclinometers (mounted on wheelsets) and GPS logger (mounted on a tram roof). All measuring rides were carried out in regular traffic conditions without passengers (technical rides). On a Figure 3 measurement devices set into a tram and example of signals screenshot from measurement unit is presented.

![Fig. 3. Measurement devices set (left) and example of signals screenshot (right)](image-url)

2. EXAMPLE OF RESULTS

The figures 4 and 5 present tertiary spectra a) and time history of analysed acoustic signal b) recorded in tram type A (classic PCC, High-Floor tram) wagon and (for contrast) type B (modern Low-Floor tram) respectively.
As results from figure 4a) the noise in A has a broadband character with definitely marked low-frequency component in the band $f_p = 50$ Hz. There is also a visible increased level of signal in the band $f_p = 250$ Hz. As the analysed rail section is straight, we may assume that the noise in this band is a secondary effect of transfer of vibrations from the driving system onto the buggy and resonance with the bearing structure of the wagon in the band $f_p = 50$ Hz. The determined corresponding level of acoustic signal for A LAeq is 75.6 dB. At the same time it should be noted that there are unfavourable recurrent mechanical and acoustic effects caused by passage on the asphalt road (the market way out of the depot in figure 4b).

To compare, the Figure 5 contains results of the spectrum analysis a) and time history of analysed acoustic signal b) recorded in B.

As results from the figure 5 a) the noise in B tram is of a different nature than the signal recorded for earlier described vehicles. The characteristic component of the analysed signal is within the range of the band with medium frequencies of $f_p = 2500$ Hz and $f_p = 3150$ Hz. The determined corresponding level of acoustic signal for B LAeq is 65.9 dB. The analysis of time and spectrum showed that the characteristic component of the spectrum originated from the door closing signal system, which was presented and indicated with an arrow in figure 6.
The results of preliminary analysis of vibration signal are presented in Figure 7 and 8, where the signal time flow and its spectrum are presented. The analysis was carried out in band 2-200 Hz with resolution of 0.5 Hz and accuracy of amplitude estimation of 0.5 dB [5].

As it can be concluded from the presented diagrams, obtained frequency characteristics of recorded signals in particular types of trams are different. For a tram type A, characteristic frequencies are explicitly exposed in amplitude spectrum (Figure 7) of 54.5 Hz, 74.5 Hz and 95.5 Hz. At the same time attention is drawn to amplitude rising of the signal in band from 110 to 130 Hz. For a tram type B characteristic and dominant spectra are 2.5Hz and 84Hz.

Analyzing the distribution of vibration energy of registered signals, it was observed that for a tram type B vibration energy is comprised in band 2.5 to 110 Hz, whereas for a tram type A, vibro-acoustic activity is shifted to higher frequencies 14-190 Hz. This may stem from
the fact that a tram type B has a more elastic structure and more modern set of the suspension over four times lowering the level of registered vibrations in comparison to type A (respectively for type B and A: 178 mm/s² and 813 mm/s² on the investigated part of the tram track).

Recorded signal from many tram types and many different tram tracks section is (as the results from real rides) a base to numerical simulations. The signals are used for update of tram model created in MBS software system. Example of application the experimental results in modeling of tram dynamics is presented on Figure 9.

![Figure 9. Example of dynamic model verification based on experimental data](image)

In case, when behaviour of numerical model is adequate to relevant real tram construction answer it is possible to create many variants of suspension system for the vehicle. It is necessary and useful tool for optimization of dynamic characteristics suspension elements on account of track technical state and ride safety criterion [2, 4].

**CONCLUSIONS**

This paper presents assumptions of method of complex assessment of vibroacoustic climate of light rail vehicle. In this paper, motivation to concentrate on this issue was presented and basic sources of vibrations and noise affecting the driver and passengers inside tram were defined. Methodical assumptions of defining the frequency of analysis of vibration signal were described. Kinematics and dynamics of vehicle’s movement in track, and physiological conditions of vibrations’ influence on a human being are the factors taking into account in selection of frequency band. This paper also presents measuring equipment used for tests as well as points of signal acquisition. In the further part of this paper, exemplary results of preliminary analysis of recorded signals were shortly described.

Presented results have a comparative character and analyses are in early stage of realization. That is why the author focused on presenting possibilities of reflecting in vibroacoustic signal, certain effects occurring in regular operation and whose dynamic effects create vehicle’s vibroacoustic climate.
Tomasz ROLIŃSKI – pioneer in domain of acoustic operation tests of rail vehicles with usage of binaural technique. Engineer acoustician, (application engineer of Brüel & Kjær Poland), who each moment devoted to issues connected with fight with communication noise. Actively engaged in social issues, critical observer of reality, friend, died suddenly on 26 December 2009 at the age of 40. Rest In Peace Tomasz.

OCENA KLIMATU AKUSTYCZNEGO W PRZYPADKU LEKKIEGO POJAZDU SZYNOWEGO – ZAŁOŻENIA METODYCZNE

Streszczenie

Rozwój przestrzeni zurbanizowanych oraz aglomeracji miejskich wymusza równolegle rozwój usług transportowych. Wraz z rozwojem indywidualnego i zbiorowego transportu, coraz wyższy odse-tek populacji żyje w ciągłym zagrożeniu drganiami i halasem, które są często szkodliwe dla ludzkiego organizmu. Tramwaje stanowią specyficzne źródło drgań i hałasu w obszarach miejskich. Jednakże pomimo generowania wysokiego poziomu sygnałów wibroakustycznych w szerokim zakresie częstotliwości nie stanowią one znacznego wpływu w ogólne hałas komunikacyjny miast. Inaczej jest w przypadku pasażerów, którzy nie mają bezpośredniego wpływu na proces transportu i są narażeni na oddziaływanie drgań i hałasu w zamkniętej przestrzeni tramwaju.

W związku z koniecznością podwyższania jakości usług w zakresie transportu miejskiego prze-woźnicy muszą radzić sobie z coraz bardziej aktualnym problemem minimalizowania wpływu środków transportu na pasażerów i operatora. Minimalizacja negatywnego wpływu środków transportu na pasażerów ma korzystny wpływ na podnoszenie komfortu jazdy i przez to zwiększa konkurencyjność niektórych środków transportu na rynku usług transportowych. W związku z tym konieczne jest dokonanie oceny i oszacowania wibroakustycznego klimatu w pojeździe na podstawie procedur innych niż badania homologacyjne prowadzone w normatywnych (idealnych) warunkach. Rozbieżności wynikają z konieczności uwzględniania warunków pracy i sposobu zarządzania taborem. Ze względu na różne rodzaje używanych pojazdów wydaje się uzasadnione, aby wypracować uniwersalną metodę oceny aktywności wibroakustycznej pojazdu.

W niniejszym artykule autor prezentuje założenia metodyczne do rozwiązania problemu oceny klimatu wibroakustycznego w pojeździe szynowym na podstawie przeprowadzonych badań wstępnych operacji.
REFERENCES


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