Acoustic and Biomedical Engineering

Investigation of the Vibroacoustic Climate inside the Buses Solaris Urbino 18 Used in Public Transport Systems — Driver's Cab

Z. Damijan[a,*], S. Skrzyniarz[b] and J. Kwaśniewski[b]

[a]Department of Mechanics and Vibroacoustics, Faculty of Mechanical Engineering and Robotics
AGH University of Science and Technology, al. A. Mickiewicza 30, 30-059 Kraków, Poland

[b]Department of Process Control, Faculty of Mechanical Engineering and Robotics
AGH University of Science and Technology, al. A. Mickiewicza 30, 30-059 Kraków, Poland

Despite new technological solutions and attempts to improve the working conditions during driving of vehicles, city bus drivers are still exposed to negative impacts of noise and vibrations, causing stress, increased fatigue and leads to numerous diseases. Therefore it seems merited to investigate the acoustic climate and the working conditions during the operation of Solaris Urbino 18 vehicles, widely used in public transport systems. The main purpose of this research program was to show the impacts that the conditions at work might have on bus drivers or to demonstrate that these impacts do not exist. No extensive major research was done to investigate the influence of the conditions at work on functional stability of bus drivers. Investigation of vehicle vibroacoustic climate in working (normal) environment are led rarely. Measurements often are done in idle run or during ride at manoeuvring site only for 2–3 min. In this paper results of acceleration and noise in idle run are presented for 3 min measurement and for 3 h until ride. All measurements are done in working environment on streets of Tychy city with passengers on board. In this paper detailed numerical analysis of vibroacoustic parameters are presented. Physical parameters like noise spectral analysis in 1/3 octave frequency bands and histogram of acoustic pressure level in the driver's cabin are presented in results.

PACS: 89.40.−a, 46.40.−f, 07.10.−h, 46.40.Cd

1. Introduction

At the beginning of 21 century of growing urbanisation man is forced to move a great deal. Average growth of urbanization in World in 1990–2006 was about 2.2% [1]. Most growth is in Least Developed countries — 4.4%. Ensuring the efficient transport systems for passengers becomes a major problem faced in large cities and metropolises. Metropolitan transport is a priority of scientific research in years 2007–2013. At the present stage of development of transport system, passengers tend to prefer public means of transport to individual vehicles, this tendency is well apparent in highly urbanised metropolises [2–4].

City buses are most popular vehicles commonly used in public transport systems in Poland. By choosing the public transport, the responsibility for transport safety is shifted onto the bus driver. However, passengers spend decidedly shorter time in a bus than the bus driver in his whole working day. That is why the driver is more exposed to negative impacts produced by the vehicle's motion. It is required, therefore, that the working conditions for drivers should be monitored on a regular basis. In order that they work safely, their working conditions should be as comfortable as possible, in terms of physical and psychical conditions and free from any nuisance [5–10].

Noise involves all types of undesirable, unpleasant, perceived as nuisance or harmful vibrations of an elastic medium, acting via air on the hearing organs and other senses and organs in the human body [11, 12] — noise appears to be a subjective phenomenon, associated with individual perception at the given time and place. It has always existed, though its importance was appreciated only in the previous century, as towns and transport systems (road and air traffic systems) were developing rapidly. Noise affects the whole body, particularly the hearing organ. Depending on the potential hazard level, noise is classified as nuisance (but not producing any lasting damage to the human body) and harmful noise — producing long lasting effects or increasing the risk of their occurrence [11, 12].

All parameters discussed in this section, associated with exposure to noise at work, i.e. the maximal sound level A, peak sound level C, equivalent sound level A,

* corresponding author; e-mail: damijan@agh.edu.pl

sound exposure per a working day (8 h) are derivatives of the acoustic pressure.

Measurements data should be interpreted in the light of the regulations set forth in the Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) [13] (Table I) and EN-12096:2002 which specify the admissible noise levels.

TABLE I

Admissible noise — Directive 2003/10/EC of the European Parliament and of the Council [13].

Groups of workers	$L_{EX,8h}$ [dB]	$L_{c\ peak}$ [dB]
workers — total	80	135

The impacts of vibrations might be analysed in terms of:

- values of parameters describing the vibrations (acceleration, acceleration amplitude, frequency, exposure time),
- the point of transmission (whole-body or local vibrations),
- personal idiosyncrasy (physical and psychical features).

First of all, vibrations impacting on people at work are considered harmful, provoking fatigue, drowsiness, discomfort, disturbed equilibrium. Mechanical vibrations cause stress, which affects all organs in the human body. They activate the receptors present in the skin and in other tissues, causing the reflexive response of the whole body. They lead to disturbances in the bone-joint systems, in muscles, the circulatory and nervous systems [11].

In several countries regulations and relevant standards have been developed to assess the noise and vibration hazard.

In literature on the subject, noise and vibration exposures are categorised into passive (whereby passengers are exposed) and active (driver's or machine operator's exposure). The hazard level is obtained by comparing the registered levels with the admissible values. As regards the operators' exposure, regulations relating to vibrations as nuisance should be treated as benchmarks [14]. Admissible vibration exposure levels are specified in the relevant regulations (Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) and ISO 2631-1:1997 [15]) whereas recommendations specifying the vibration nuisance criteria can be found in the literature on the subject and in technical standards. The methods of evaluating the vibration impacts are compiled in the standard EN-14253--A1:2008 [16].

The present study uses the weighted method to evaluate the human exposure to vibrations. In accordance with the standard ISO 5007:2003 [17] the measuring disc is mounted in the driver's seat. After the measurements, the data are further utilised to derive the equivalent weighted acceleration value in accordance with the procedure set forth in the standard. Thus obtained weighted acceleration data are compared to maximal admissible exposure levels specified in the Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002.

The regulation by the European Parliament and of the Council having relevance to work safety in the conditions of noise or vibration exposure gives the threshold levels (specified in the Appendixes), i.e. the values of characteristic parameters of noise and vibrations at work (without any personal protection equipment) [15]. As regards mechanical vibrations:

- local vibrations: daily exposure must not exceed 5 m/s^2 and daily exposure expressed as an energy equivalent of 8 h action of the sum of effective vectors of frequency-weighted acceleration, obtained for the three directional components $(a_{hwx}, a_{hwy}, a_{hwz})$ — the threshold level is 2.5 m/s^2.
- whole-body vibrations: daily exposure must not exceed 1.15 m/s^2 and daily exposure expressed as an energy equivalent of 8 h action of the sum of effective vectors of frequency-weighted predominating acceleration, obtained for the three directional components and appropriate weighing coefficients $(1.4a_{wx}, 1.4a_{wy}, a_{wz})$ — the threshold level is 0.5 m/s^2.

A subject of investigation was Solaris Urbino 18. Solaris Urbino 18 is the longest city bus which Solaris Bus & Coach Company offer. Investigated model has diesel motor. It is 3rd generation model of motor which is environmentally compatible with Euro4 emission standard. Its graphical symbol is green dachshund. It means that this bus is friendly for passengers and environment. Dachshund have red hat in Kraków which is a region sign of city but for buses with hybrid motors it has two red hearts or flower in mouth for motors according with EEV emission standard which is more restrictive than Euro4.

2. Methods and procedure

The measurement procedure was applied in accordance with the relevant standards:

- EN 30326-1 — Mechanical vibrations. Laboratory method of evaluating the seat vibrations in a vehicle. Basic requirements.

- ISO 2631–1:1997 — Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements.
- EN 14253:2003 — Mechanical vibration. Measurement and evaluation of occupational exposure to whole-body vibration with reference to health. Practical guidance.
- ISO 9612 — Acoustics. Guidelines to measurements and assessment of impacts of noise exposure at work.
- EN 60651: 2002 (U) — Sound level measures. General requirements and tests.
- The acoustic climate inside the buses was investigated in accordance with the approved procedure. On the driver's seat a sensor was mounted to measure seat vibrations in three directions, noise levels were measured with a dosimeter placed in the vicinity of the driver's head. Signals from four channels were analysed in a signal analyser SVAN 948.
- Relevant correction characteristics had to be applied during the measurements:
- W_k (for the z-axis) and W_d (for the x and y axes) — during the vibration acceleration measurements,
- A, C and linear — in measurements of audible noise.

The averaging time was 1 s for each sample.

3. Investigation of the vibrations and acoustic climate of the Solaris Urbino 18 bus in driver's cab

Vibrations measurements inside the driver's cab were taken with a vibration sensor attached to the driving wheel (Fig. 1) and connected to the signal analyser SVAN 948. A person working as a bus driver is exposed to seat vibrations transmitted via the floor, vibrations of the steering system and noise inside the cab. These vibrations are mostly caused by the driving systems and the suspension system, during the ride. Measuring equipment (type, measuring precision category, manufacturer, manufacturer's symbol): SVAN 948, I, SVANTEK, 6549.

Measurement procedure for idle run: in accordance with the outlined measurement program. Duration of measurements 190 s. Measurement data are compiled in Fig. 2.

Measurement procedure during run: in accordance with the outlined measurement program. Duration of measurements — 11284 s. Measurement data are compiled in Fig. 3.

The characteristics of the tested object: the age in months — 4, the mileage — 26,916 km (as per the day of March 27, 2008), the time of measurement — 11.37–11.54 for idle run and 13.42–17.05 during ride; the length

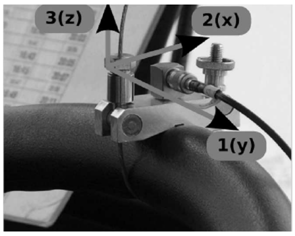

Fig. 1. Vibration sensor attached to the steering wheel.

of the route — 78.8 km, atmospheric conditions — 8.2 ℃, the pressure — 979 hPa, humidity — 44%.

The results of vibration and noise measurements for idle run in driver's cab, noise spectral analysis in 1/3 octave. frequency bands and histograms of acoustic pressure level, measurement data are complied in Table II and Fig. 2.

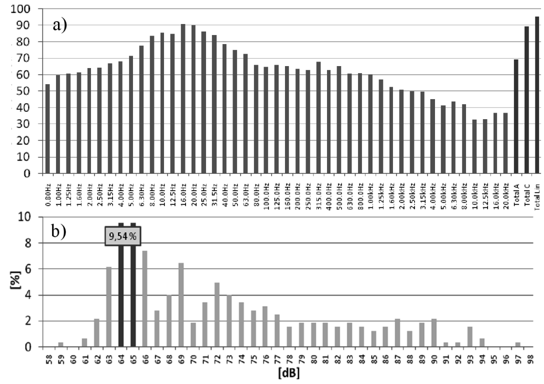

Fig. 2. The results of measurements for idle run in driver's cab: (a) noise spectral analysis in 1/3 octave. frequency bands [dB], (b) histogram of acoustic pressure level in the driver's cabin.

TABLE II

Vibration and noise (where T [s] stands for the length of the sample).

Parameter	Value	Time
$a_{w,eq}$ [m/s^2]	0.449	190 [s]
$L_{\mathrm{Aeq,T}}$ [dB]	69.0	
$L_{\mathrm{A\,max}}$ [dB]	81.6	
$L_{\mathrm{EX,8h}}$ [dB]	47.3	
L_{Cpeak} [dB]	118.2	

The results of vibration and noise measurements during ride in driver's cab, noise spectral analysis in 1/3 octave frequency bands and histograms of acoustic pressure level, measurement data are complied in Table III and Fig. 3.

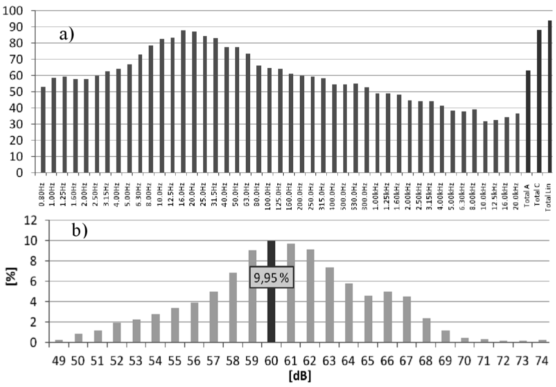

Fig. 3. The results of measurements during ride: (a) noise spectral analysis in 1/3 octave frequency bands [dB], (b) histogram of acoustic pressure level in the driver's cabin.

TABLE III

Vibration and noise (where T [s] stands for the length of the sample.

Parameter	Value	Time
$a_{w,\,eq}$ [m/s^2]	0.32	11 284 [s]
$L_{\mathrm{Aeq,\,T}}$ [dB]	64.9	
$L_{\mathrm{A\ max}}$ [dB]	89.5	
$L_{\mathrm{EX,\,8h}}$ [dB]	60.9	
L_{Cpeak} [dB]	119.3	

4. Conclusions

Investigations of vehicle vibroacoustic climate in working (normal) environment are led rarely. Measurements often are done in idle run or during ride at manoeuvring site only for 2–3 min. In this paper results of acceleration and noise in idle run are presented for 3 min measurement and for 3 h for during ride. All measurements are done in working environment on streets of Tychy city with passengers on board. In this paper detailed numerical analysis of vibroacoustic parameters are presented. Physical parameters like noise spectral analysis in 1/3 octave frequency bands and histogram of acoustic pressure level in the driver's cabin are presented in results.

Basing on the conducted tests, the following conclusions can be formulated:

1. Admissible acceleration levels for upper limb (5 m/s^2) and whole body (0.5 m/s^2) are not exceeded inside the driver's cab during the idle run (0.449 m/s^2) and during the ride (0.321 m/s^2).

2. Admissible noise levels — equivalent sound pressure level A in 8 h (80 dB) are not exceeded inside the driver's cab during the idle run (47.3 dB) and during the ride (60.9 dB).

3. Admissible noise levels — peak sound pressure level C (135 dB) are not exceeded inside the driver's cab during the idle run (118.2 dB) and during the ride (119.3 dB).

4. Differences between A filter and Total Linear filter in 1/3 noise spectral analysis frequency band for idle run and during ride showed infrasounds are presented in drivers cab. It should be precisely checked.

Acknowledgments

The research has been conducted within the framework of the author's research no. 10.10.130.631 and the statuary ones no. 11.11.130.119 and promoter's grant no. 18.18.130.729.

References

[1] UNICEF — Economic and social statistics on the countries and territories of the world, with particular reference to children's well-being. `http://www.unicef.org` (last seen 2010.04.10) p. 134.

[2] A. Eskandarian, R. Sayed, P. Delaigue, J. Blum, A. Mortazavi, *Advanced Driver Fatigue Research*, U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Ashburn 2007, p. 9.

[3] I. Hostens, H. Ramon, *J. Sound Vibrat.* **266**, 453 (2003).

[4] A. Kaczmarska, D. Augustyńska, A. Wierzejski, *Work Safety* **10**, 6 (2006) (in Polish).

[5] J. Koton, A. Majewski, *Work Safety*, **7-8**, 12 (2004) (in Polish).

[6] M. Kolich, *Appl. Ergonom.* **34**, 177 (2003).

[7] N. Nawayseh, M.J. Griffin, *J. Sound Vibrat.* **298**, 725 (2006).

[8] O.O. Okunribido, S.J. Shimbles, M. Magnusson, M. Pope, *Appl. Ergonom.* **38**, 29 (2007).

[9] P. Eriksson, O. Friberg, *Struct. Multidisc Optim.* **20**, 67 (2000).

[10] A. Markom, N. Hjorth, *Health and safety at work in building small and medium enterprises*, Polska Agencja Rozwoju Przedsiębiorczości, Warszawa 2005, p. 104 (in Polish).

[11] J.H. Czajka, *Measurements of Oscillation and the Noise on Workstations in the Transport*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2000 (in Polish).

[12] S. Skrzyniarz, J. Kwaśniewski, *Drivers work safety: Review of direct researches of environment impact on driver body in car transport*, Poznań 2008, p. 187.

[13] *Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (Seventeenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC).*

[14] *Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) — Joint Statement by the European Parliament and the Council.*

[15] *ISO 2631-1:1997 — Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements.*

[16] *ISO 5007:2003 — Agricultural wheeled tractors — Operator's seat — Laboratory measurement of transmitted vibration.*

[17] *EN-14253:2003 — Mechanical vibration. Measurement and evaluation of occupational exposure to whole-body vibration with reference to health. Practical guidance.*