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EVALUATION AND ANALYSIS OF VIBRATION EFFECTS ON BUS USERS[1]

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Abstract

The paper deals with classification and basic characteristics of vibration that act on users during bus exploitation. Some physiological and psychological effects of vibration acting on bus drivers and passengers are presented. In addition, this paper shows the results of evaluation of vibration effects on the users' comfort (the driver and three passengers) for intercity bus IK-301. Evaluation has been carried out according to the procedure and criteria prescribed by two versions of International standard ISO 2631 (1985, 1997). For the purpose of this analysis, validated bus oscillatory model developed in multibody software package*ADAMS/View*was used. The oscillatory model was excited by road roughness (asphalt-concrete pavement in poor condition) registered on two tracks at speed of 64 km/h. It was found that the passenger seating on the seat in the bus rear overhang has the worst comfort and the shortest allowable vibration exposure time.

Keywords - whole body vibration; comfort; bus users; ISO 2631

INTRODUCTION

The traffic participants, particularly the users of vehicles (both passengers and drivers) of each means of transport (road, railway, air or water transport) are affected by vibrations. The drivers of heavy motor vehicles and busesfall into high risk category[1]. In comparison with car drivers, heavy motor vehicle drivers are affected by higher intensity vibrations during their 8-hour working shifts[2]. As a result, the effects of vibrations have certain side effects (physiological and psychological disorders) which are highly prominent in case if they are affecting someone for a longerperiod of time.

[1] Original scientific paper

Vibrations have anegative effect on vehicle user's comfort and ability to work and if they reach a certain level, they become heath threatening and decrease safety.

The EU passed a directive 2002/44/EC (directive on vibration)in order to alleviate the negative influence of vibrations and protect health at work places. Directive 2002/44/EC defines the indicator of exposure to vibrationsA(8) (*A(8) - daily exposure value to vibrations*) which limit values indicatethat corresponding safety measures should be taken. The bus drivers may be exposed to Whole-Body Vibrations (WBV)intensity that exceeds daily exposure action value A(8)which is 0.5 m/s^2[3]. During one working day, the intensity of Hand-Arm Vibrations (HAV), transmitted from the steering wheel to bus driver's arms and hands, may exceed daily exposure action valueA(8) which is 2.5 m/s^2[3].

The classification and basic characteristics of vibrations that act on bus users are presented in this paper. Certain physiological and psychological effects of vibrations are examined, with accent on bus drivers and passengers. In thepaper, the influence of vibrations on users' comfort (driver and three passengers) for intercity bus IK-301 has been carried outaccording to standard ISO 2631(1997, 1985).The acceleration signals from simulationsanalysiswere processed by programming code written in software package *Matlab*.

CLASSIFICATION AND BASIC CHARACTERISTICS OF VIBRATIONS

The vibrations are divided into two categories according to the body part that is affected: whole-body vibrations and local vibrations (the vibrations of certain parts(segments) of human body).

WBV occur when body comes in contact with the vibrating surface. This category of vibrations affects the body in differentpositions (while sitting, standing or in reclining position). Passengers of motor vehicles are exposed to the effect of these vibrations. The vibrations are transmitted across the whole body through passenger's legs (if the passenger is standing), through the lower back if the passenger is sitting, and across the whole body if the passenger is lying.

WBV are particularly important in frequency range from 1 Hz ÷ 80 Hz. The main resonant points of some organs and human body parts(e.g.head, eyes, stomach and spine) are located in this frequency range[4]. WBV of extremely low frequencies (under 0.5 Hz) cause "seasickness" [4].

Local vibrations have an effect on human body parts (arms, legs, head etc.) in the frequency range from 8Hz ÷ 1000 Hz. HAV in the motor vehicles appear when driver's hands contact the steering wheel and other controls (e.g.gear lever). The intensity of WBVand HAV depend on the bus type, the quality and the type of the pavement surface and the bus speed [5].

The vibrations are transmittedfrom the bus floor to the passenger's legs, through the seat to the passenger's lower back and through the seat back to passenger's back (fig. 1a). The driver's body is affected by the vibrations, which are transmitted from the steering wheel to his arms, too (fig. 1b).The passenger's and the driver's body are alsoaffected by rotational vibrations which are transmitted from their seats.

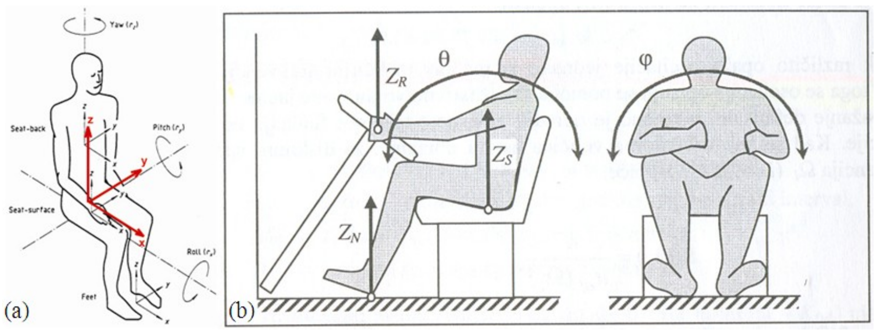

Fig. 1. Receiving positions of vibrationsin a vehicle for
a) Passengerand b) driver

In this paper, the three translational*x*, *y*, *z*-axes vibrations transmitted from users' seats to their bodies were taken into account when examining bus users' comfort. These vibrations have the highestintensities and apparently the most negative influences on users' bodies.

THE EFFECTS OF VIBRATIONS ON THE BUS USERS

The results of the numerous studies show that the vibrations may cause certain disorders of physiological as well as psychological functions of the bus user's body. These disorders are more prominent with bus drivers because of the prolonged exposure to vibrations.

The most important physiological effects of vibrations refer to biochemical changes, neuro-vegetative system impairments and cardiovascular illnesses andmusculoskeletal disorders.

The effect of vibrations causes biochemical changes(hormonal changes, uric acid, enzyme levels, gastric secretions, etc.). Ithas been shown that, even though they are present, these changes were in within regular physiological range.

Neuro-vegetative reactions were noticed under the influence of low frequency vibrations and resulted in vertigo, nausea, etc. Vibrations have an effect on the heart rhythm and blood pressure, too. In Sweden the risk of having particular types of cardiovascular conditions (e.g. hearth attack) is three times higher when being a professional driver in comparison to other workers who are not exposed to vibrations [6]. The death rates caused bycardiovascular diseases depend on the length of the bus drivers working life [6].

Musculoskeletal disorders such as back injuries and back pain (particularly the low back pain), damage of intervertebral disc, vertebra injuries and osteoarthritis are connected to the effect of the vibrations.It is shown that 84% of bus drivers in the USA and 49% of bus drivers in Sweden suffer from low back pain[7]. According to [7] 43% of bus drivers suffer from neck pain, whereas 42% of bus drivers suffer from shoulder pain. Musculoskeletal disorders arethe most prevalent health problems in bus drivers [8].

The effects of vibrations on cognitive processes in drivers and passengers is less researched area. The studies have shown that vibrations have the most significant effect on short memory [9]. Frequency and intensity of vibrations have the biggest influence on passengers' reading and writing ability during transportation [10].

STANDARD ISO 2631

The international standard ISO 2631 *mechanical vibration and shock - Evaluation of human exposure to whole-body vibration* provides the methods of measuring, quantifying and evaluation the effects of random and shock vibrations on human body. Two versions of this standard (ISO 2631 (1997) and ISO 2631 (1985))are being used to analyse the effect of random vibrations [11, 12].

Standard ISO 2631 (1997) defines the method of quantifying the WBV and evaluation oftheir effects on health, comfort, perception and the occurrence of "seasickness". The standard prescribes the total value of the root mean square (*rms*) weighted accelerations as basic quantity for estimating the effect of vibrations on comfort, expression 1.

$$a_v = ((k_x \cdot \ddot{x}_{rms,w})^2 + (k_y \cdot \ddot{y}_{rms,w})^2 + (k_z \cdot \ddot{z}_{rms,w})^2)^{1/2} \qquad (1)$$

where α_v- the total value of *rms* weighted accelerationsfrom users' seats (m/s^2);k_x, k_y, k_z - multiplying factors for *rms* values of weighted accelerations alongdirection of *x*,*y*,*z*-axes (values of the factors k_x, k_y, $k_z$when estimating ride comfort are equal to one); $\ddot{x}_{rms,w}$, $\ddot{y}_{rms,w}$, $\ddot{z}_{rms,w}$ -*rms* of the weighted accelerations for *x*, *y*,*z*-axes (m/s^2) (expressions 2, 3 and 4).

$$\ddot{x}_{rms,w} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\ddot{x}_{w_i}^2} \qquad (2)$$

$$\ddot{y}_{rms,w} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\ddot{y}_{w_i}^2} \qquad (3)$$

$$\ddot{z}_{rms,w} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\ddot{z}_{w_i}^2} \qquad (4)$$

where $\ddot{x}_{wi}$, $\ddot{y}_{wi}$, $\ddot{z}_{wi}$ - samples of weighted acceleration for directions of *x, y, z*-axes (m/s^2); *N*- samples number of weighted accelerations signals;

To assess the influence of vibrations on comfort, weighting filters W_k and W_d are being used (fig. 2). Filter W_k is used for weighting of the vertical acceleration(along *z*-axis),whereas filter W_d for weighting of the horizontal accelerations (along *x*, *y*-axes) [11,12].According to analytical formulas for these filters, function subprograms are defined in software package *Matlab* for accelerations weighting.

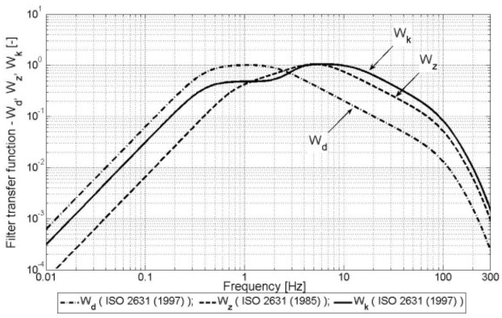

Fig. 2. Weighting filters,ISO 2631 (1985, 1997)

The assessment of comfort was donebycomparing the simulation-established α_v values to comfort criteria in public means of transport defined by ISO 2631 (1997) (fig. 3a).

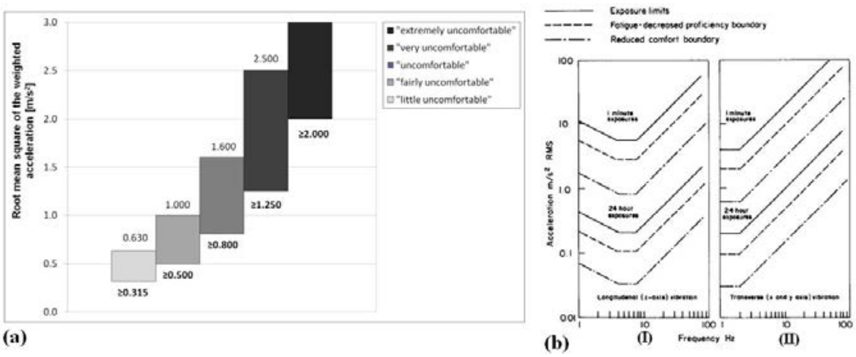

Fig.3. ISO 2631 criteria a) comfort in public transport - ISO 2631 (1997), b) limit curves - ISO 2631 (1985)

Standard ISO 2631 (1985) defines the amount of allowable exposure time to vibrations for three criteria - reduced comfort, workingability and health. When estimating the allowable exposure time, diagrams with ISO limits curves for vertical and horizontal directions are used (fig. 3b).ISO 2631 (1985) standard prescribes filter $W_z$forweighting of the vertical accelerations[12], (fig. 2).

The process of quantifying the accelerations and determining *Root Mean Square*curves (*RMS* curves) was described in detail in [13].

EVALUATION OF USERS’SRIDE COMFORT OF INTERCITY BUS IK-301

Ride comfort of four IK-301 bus users are analysed - driver, passenger in thebus front overhang (passenger3), passenger in the middle part of the bus (passenger18) and passenger in the bus rear overhang (passenger 51). The users’ seats are marked in the fig. 5b andfig.5c.

Fig. 3a shows an recorded signal of the asphalt-concrete pavement roughness in bad condition as a function of travelled distance. It is registered on the road section of 161 m at the speed of the of 64 km/h [14]. Measuring vehicle has recorded roughness on two tracks. The signal was translated in function of time (fig. 4b) and introduced in IK-301bus oscillatory model by *CUBSPL* functions.

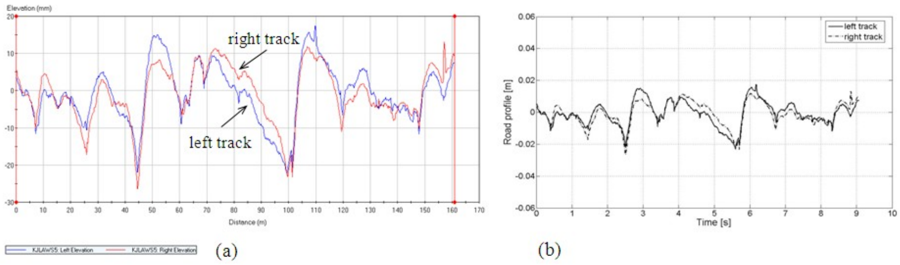

Fig.4. Roughness of asphalt-concrete pavement in function of
a) distance and b) time

The IK-301 bus is intended for intercitypassengers transport (fig. 5a). Technical data of the busis presented in [15]. Seat layoutis shown infig. 5b. The bus has 53 passenger's seats,a seat for the driver and a seat for co-driver.

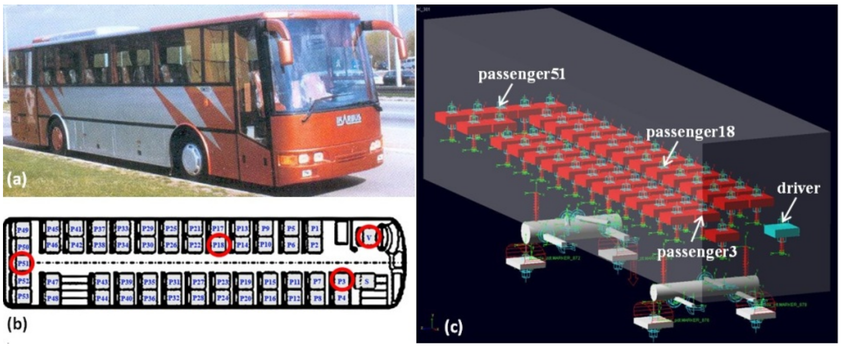

Fig.5. Bus a) IK-301, b) seat layout and c) oscillatory model

Driver's seat is equipped with pneumatic suspension system, whereas passengers' seats and co-driver's seat are rigidly attached to the bus platform. Oscillatory parameters of the users' seats are described in [13].

Bus IK-301 oscillatory model has been built in multibody software package ADAMS/View (fig. 5c). ADAMS/View has an graphic user-friendly interface that enable the users to model mechanical systems, to simulate and to visualize the motions of mechanical system parts in space, to analyse and process the simulation data, etc. These powerful functions are enabled by integrating ADAMS/Solver module and ADAMS/Postprocessormodule into ADAMS/View.

According to*Gruebler's*equation,oscillatory model has 65 degrees of freedom. The process of model validation is described in detail in [13].

ADAMS/Solver uses Euler-Lagrange method when automatically forming differential equations of motion. The Gear Stiff (GSTIFF) integrator is chosen for numerical integration. The acceleration signals have been sampledon every 0.001 s during the simulation time of 9 s.

Fig. 6 shows the results of the simulation - bus users' vertical and horizontal translational accelerations. It can be noticed that vertical acceleration is dominant one for every user, while passenger51 is exposed to the highestvertical accelerations intensity.

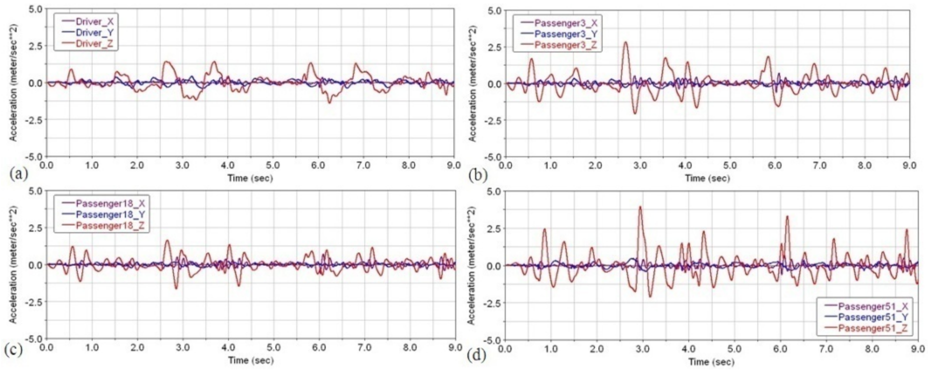

Fig.6. Accelerations in the seat of a) the driver, b) passenger3, c) passenger18 and d) passenger51

Table 1 represents the *rms* value of weighted acceleration for the *x, y, z*-axes direction, as well asthe total *rms* value α_v for IK-301 bus users. In the last column, the assessment of users' comfort has been shown.

Table 1. *RMS* values of weighted acceleration and assessment of comfort for IK-301 bus users

Bus users	*RMS* values of the weighted acceleration [m/s^2]			Total *RMS* value [m/s^2]	Comfort evaulation (ISO 2631 (1997))
	$\ddot{x}_{rms,\ w}$	$\ddot{y}_{rms,\ w}$	$\ddot{z}_{rms,\ w}$	a_v	
driver	0.035	0.146	0.301	0.336	little uncomfortable
passenger3	0.053	0.126	0.454	0.474	little uncomfortable
passenger18	0.058	0.066	0.370	0.380	little uncomfortable
passenger51	0.055	0.135	0.640	0.656	fairly uncomfortable

Simulation results from table 1show that*rms*values of weighted accelerations for vertical direction are dominant ones. The lowest total *rms*value at 0.336 m/s^2 has been determined for driver.Driver's comfort were assessed as *"little uncomfortable"*. The same assessment has been determined for passenger3 and passenger18. Passenger51 has been exposed to the highest total*rms*value at 0.656 m/s^2, and his comfort was assessed as *"fairly uncomfortable"*.

Fig.7 represents ISO 2631 (1985) limit lines for ride comfort in *z*-axis direction and RMS curves. Peaks of RMS curves define the allowableexposure time to WBV.

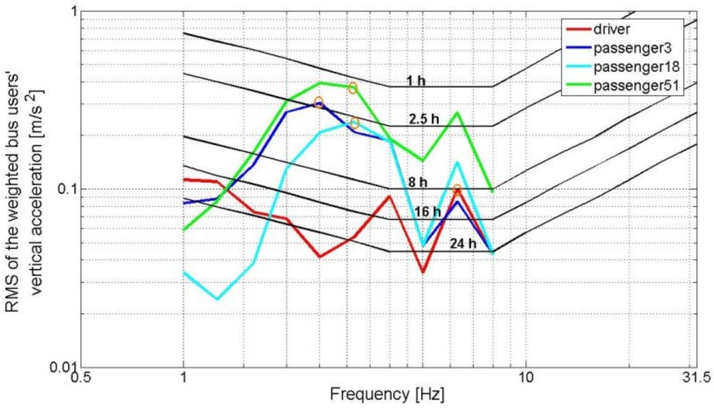

Fig.7. Allowable exposure time to vibration for *z*-axis for the reduced comfort criterion

It can be noticed that the driver has the longest allowable exposure time to WBV (8 hours), whereas the passenger51 has the shortest one (about 1 hour). Passenger18 has longer allowable exposure time (little over 2.5 hours) in comparison to passenger3 (less than 2.5 hours).

CONCLUSION

Passengers and bus drivers are exposed to WBV that are transmitted from roughnesspavement through seat to their bodies. Vibrations affect the comfort, work ability and jeopardize vehicle user's health.

According to simulation results, passenger in the rear overhang of the bus IK-301has the lowest oscillatory comfort according to criteria of standard ISO 2631 (1997). Among all analysedusers, the driver has the most favourableoscillatory comfort because of his elastically suspended seat.According to ISO 2631 (1985), passenger in the back has the shortest allowableexposure time to WBV (approximately 1 hour), and the driver has the longest one (approximately 8 hours).

The knowledge about the vibrations intensity, which the bus users are exposedto,is important for taking proper safety measures by which users' comfort and health could be improved. Results from simulation researches could be usedto optimize oscillatory characteristics of the bus systems in order to increase the bus users' comfort.

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