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Analysis of vibration effects on the comfort of intercity bus users by oscillatory model with ten degrees of freedom

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ABSTRACT

The paper analyzes the effects of vibrations on the comfort of intercity bus IK-301 users. Evaluation of vibration effects was carried out according to the criteria set out in the 1997 ISO 2631-1 standard for comfort in public means of transport. Comfort is determined for the space of a driver, passenger in the middle part of the bus and passenger in the rear overhang. Also, the allowable exposure time to vibrations in drivers for the reduced comfort criterion was determined according to the 1978 ISO 2631-1 standard. The bus spatial oscillatory model with ten degrees of freedom was developed for the needs of the analysis. Bus excitation was generated applying the Power Spectral Density of the asphalt-concrete road roughness, as described by the H. Braun model. The allowable vibration exposure time for the driver's body decreases as the spring stiffness of the driver's seat suspension system increases. Simulation was performed using the MATLAB software.

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1. Introduction

During the ride in a vehicle, drivers and passengers are exposed to vibrations from the road surface. Vibrations cause the feeling of discomfort, reduce working ability, and their lengthy action can affect health [1,2]. Drivers of construction machinery, farm machinery, heavy-duty vehicles and buses fall into a particularly risky group [3]. Investigations [3–5] have shown that bus drivers are exposed to high-intensity vibrations. The most common health problems in drivers due to long-term exposure to high-level vibrations are musculoskeletal disorders (low-back pain, neck, shoulders and kneel pains), mental disorders (tiredness, tension, mental fatigue), sleep disorder etc. [6,7]. In order to reduce adverse effects of vibrations and ensure health at workplaces, European Union adopted on 25 June 2002 the Directive 2002/44. It defines the allowable exposure limit values (thresholds) for whole-body vibrations at work and in accordance with those levels it is clearly emphasized that employers are obliged to ensure appropriate safety measures [8]. Timely action to prevent vibration injury in both drivers and passengers requires continuous monitoring of the vibration level they are exposed to. This means frequent measurements of the intensity of vibration exposure in users under real conditions of bus exploitation. Recently, the measurements of vibration levels in a vehicle in real conditions of its exploitation have been performed not only to analyse its oscillatory comfort, but also to assess the efficiency of the suspension system in the damping of vibrations transmitted from the vehicle wheels to its body. In [9] the signals of vertical accelerations were registered in the suspension system of a delivery car during its passing over a railway cross. The measurements of acceleration allowed for testing the suspension system quality in the damping of shock vibrations transmitted from the railway cross to the vehicle suspended mass. In [10] the analysis of

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registered vertical acceleration signals in the vehicle suspension system, for three different types of excitations (asphalt, sett, and railway cross) has shown that the suspension system is more efficient in damping vibrations at higher frequency levels. Apart from measurements, analysis can be conducted by simulations using vehicle oscillatory model [11,12]. Simulations gain in importance in cases when measurements are seldom done due to various constraints. Quality analysis of the vehicle oscillatory behaviour requires integration of the previously recorded road roughness into the oscillatory model [12]. In this paper, because it was impossible to perform screening in real time of the road roughness, bus excitation was modelled using Power Spectral Density of the asphalt-concrete road roughness in a very good condition. The analysis of user's oscillatory comfort was carried out here by means of the spatial oscillatory model of the intercity bus IK-301 with ten degrees of freedom. The oscillatory comfort in the driver and passengers was assessed according to the procedure and criteria as prescribed by the 1997 ISO 2631-1 standard [13]. Also, it has been determined here the allowable vibration exposure time in drivers for the reduced comfort criterion, in accordance with the 1978 ISO 2631-1 standard [14].

2. Bus oscillatory model

The bus IK-301 (Fig. 1) has the suspension system with stiff axles [15]. Front axle (RABA/A 932.10) is attached to the body by means of two air bags and four telescopic shock absorbers, while rear axle (RABA/A 109.29) by means of four air bags and four telescopic shock absorbers. The bus has two wheels mounted on the front axle and four wheels on the rear axle. Fig. 2 shows the spatial oscillatory model of the bus IK-301 with ten degrees of freedom.

Independent motions of concentrated masses and stiff bodies of the considered mechanical oscillatory system are: vertical motions of the driver, the passenger in the middle part of the bus (passenger 1), the passenger in the bus rear overhang (passenger 2), the center of gravity of the bus mass-elastic system of suspension, and the centers of gravity of the front and rear axles, the angular motion of the bus mass-elastic system of suspension around the longitudinal and transverse axes (x-axis and y-axis) and angular motions of the bus front and rear axles around the axes x_1 and x_2. Fig. 3 gives a schematic representation of the elements of suspension on the rear axle with characteristic geometry which has been used to determine the corresponding stiffness and damping for the oscillatory model depicted in Fig. 2.

Effects of vibrations transmitted from the road to the bodies of the driver and passengers also depend on the properties of the seat suspension system. Driver's seat is equipped with the pneumatic elastic suspension and a shock absorber. Passengers' seats are stiff-suspended, and seats' air bags are of hard polyurethane foam [15]. Elastic-damping properties of these seats are presented in Table 3. Positions of driver's seat, of passengers' in the middle part of the bus and of those in the rear overhang are indicated by numbers 1, 2 and 3, respectively, in Fig. 4. Also, in Fig. 4 the position of the center of gravity of a fully loaded bus is denoted.

The adopted assumptions for the bus oscillatory model are as follows:

- the bus is symmetrical relative to the longitudinal center of gravity axis (x-axis);
- all possible motions of concentrated masses around the position of stationary equilibrium are small;
- the bus body, front and rear axles are rigid bodies;
- the bus engine is included in the bus body, so that engine oscillatory excitation has not been taken into account;
- characteristics of all elastic and damping elements are linear;
- bus wheels are in permanent contact with the road surface;
- the bus is moving along a straight line with constant speed.

The properties of the spring and shock-absorber in the vehicle suspension system as well as those of the tyres and other vehicle elastic elements are nonlinear. Therefore, vehicle nonlinear oscillatory models are used in oscillatory behaviour analyses [16]. In [17] a plane nonlinear oscillatory model with 4DOF is presented, while in [18] a spatial nonlinear oscillatory model with 7DOF to study the vehicle chaotic response.

The notations in Figs. 2–4 are interpreted in Tables 1–3. All values of parameters, originating from literature available [15,19–21], used in the simulation are also given in Tables 1–3.

Fig. 1. Intercity bus IK-301.

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