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A STUDY ON EXPOSING THE DRIVER OF A COMMERCIAL VEHICLE TO MECHANICAL VIBRATION

Summary. This article presents the results of research whose objective was to assess the risks of vibration in the workplace to a driver of a commercial vehicle. Under current EU law on working time, daily vibration exposure for drivers of commercial vehicles should be determined for every nine hours of work. Research on nuisance vibrations on a driver was carried out on a commercial vehicle operated under normal conditions in urban traffic and outside urban areas. Vibration exposure assessment was separately made for each direction of vibration influence. The obtained results enable us to conclude that drivers of commercial vehicles are exposed to harmful vibrations, which largely exceed the limits of exposure to mechanical vibrations in general.

Keywords: exposure to vibration, commercial vehicle, work safety

1. INTRODUCTION

An important factor that impacts on traffic safety is the psychomotor performance of the driver. Any decrease may result from the harmful effects of vibration, to which the driver is exposed during transport tasks. The degree of the impact of vibration is dependent on many factors. The most important of which include the extortion and propagation of vibration in the mechanical structure of the vehicle [6]. The basic elements of the mechanical structure of the car responsible for minimizing vibrations are cushioning units, such the suspension system for

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the wheels, pneumatic tyres, suspension systems of the engine, the transmission system, and the suspension of the driver's cab with a seat suspension system. The greatest energy resulting from mechanical vibrations takes over the suspension of the vehicle, along with the chassis. The system consists of elements connecting the wheels to the frame of a commercial vehicle [1], which adapt to all the loads acting on the wheels. A typical solution for the chassis and suspension consists of:

- axis of the wheels (rigid beam axle wheel or driving axle housing)
- bearing units of the wheels
- road wheels (rigid metal rims with pneumatic tyres)
- elastic elements (steel or pneumatic spring)
- vibration dampers (viscous dampers and vibration-isolating elements based on elastomers)
- guide elements in the suspension system (control arms, radius rods)

The purpose of the suspension system and pneumatic wheels is the amortization of the body, or the mitigation of vibrations that are caused, for example, by driving on bumpy roads. On the other hand, the elastic fastening of the wheels to the body results in the potential for resonant vibrations, which adversely affect the ability to transfer forces from the dynamic system of the vehicle to the road surface. Excessive vibrations of the wheels also cause considerable dynamic loads of the tyres and the road surface. This is why the suspension system involves the efficient use of vibration dampers in the form of hydraulic shock absorbers [7, 8].

By damping and mitigating the dynamic interactions between the uneven road surface and the wheels of the car, the suspension system ensures a comfortable ride at an appropriate level, together with the protection for passengers and cargo, while maintaining security due to the adhesion of wheels to the surface [5, 11]. The issues are particularly important when driving at the high speeds that modern commercial vehicles can reach.

2. RESEARCH PROBLEM

The cabin, which is a separate part of the body of the truck, is the workplace of the driver. In modern commercial vehicles, it is elastically mounted to the frame by elastic means (steel or pneumatic springs) and damping elements (hyperviscous dampers). In addition, the cabin is protected against high-frequency vibrations using metal-rubber connectors. Flexible cab suspension meets the need of isolation from the vibration of the vehicle frame, due to the transfer of vibration from the wheels and the powertrain. Inside the cabin are seats for the driver and passengers, as well as devices used to control the vehicle and parameters of the vehicle systems.

The driver's seat is usually placed on seat tracks attached to the cab floor, so that it can be set relative to the cockpit in order to adapt to the anthropometric measurements of the driver. Suspension of the modern driver's seat is based on regulated elastic and damping elements. Armchairs in modern trucks are equipped with pneumatic suspension. By changing the air pressure in air cushions, it is also possible to adjust the vertical position of the seat [1, 2]. Air cushions, placed in the headrest, allow for a proper fit of its shape to the silhouette of the driver.

Accordingly, the assumed distribution of vibration is as follows:

- locally, it is propagated into the body through the hands

- generally, it penetrates the body through the pelvis, legs and back

Drivers of commercial vehicles are mainly exposed to whole-body vibration due to the work done in a sitting position. The vibration energy of seats is transmitted to the human body by the back, pelvis and sides. The negative effects of vibration of a general nature mainly concern the human skeleton and internal organs. The skeletal lesions occur primarily in the lumbar spine. Adverse changes in the internal organs, as a consequence of the impact of overall vibration, are mainly the result of the stimulation of individual organs by the resonant vibration [7, 9]. This can lead to the appearance of disturbances in the activities of these organs and, in extreme cases, mechanical damage to these organs. Even when low energies of vibration intrude the human body after long exposure times, there are negative effects of their influence in the form of psychosomatic reactions (fatigue, elongation of reaction time etc.).

Acceptable exposure to vibration for drivers of commercial vehicles is determined by the legal acts that define the daily exposure to vibration. The determination of daily vibration exposure for professional drivers in the conducted research has been divided into stages:

- identification of the series of separate operations performed by the driver during the working day
- indication of the operations to be assessed
- determination of the values of effective vibration acceleration (RMS) for each operation
- determination of the average daily exposure times for each operation
- calculation of the daily exposure to vibration

According to the current European Parliament and Council Regulation No. 561/2006 of 15 March 2006, the daily driving time, which is understood as the total driving time between the end of one daily rest period and the beginning of the following daily rest period, or between a daily rest period and a weekly rest period, shall not exceed nine hours and can be twice-weekly extended to 10 hours [10]. In planning the driving time, 45 minutes should be allocated for breaks. It must therefore be assumed that the daily vibration exposure for drivers of commercial vehicles, subject to working time registration, should be determined for at least nine hours of work.

3. OBJECT AND RESEARCH METHOD

Research on the vibration nuisance regarding the driving position was carried out on the MAN TGL 12.240, which is a two-axle commercial vehicle with a box-shaped construction with a permissible total weight of 12,000 Mg [2]. The scheme adopted in the research regarding directions of the measurements of vibration acceleration is shown in Figure 1.

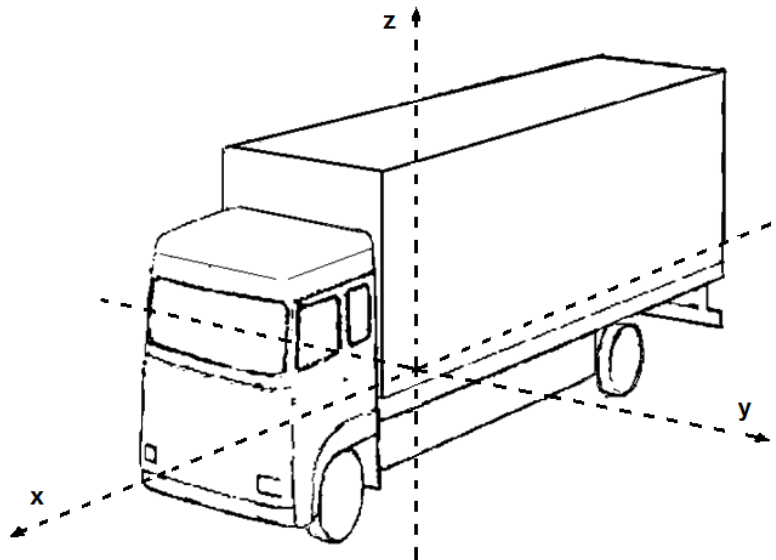


Fig. 1. Directions of vibration measurements in the tested vehicle

The suspension system of the tested vehicle comprised parabolic springs and a stabilizer on the front axle, and air springs and a stabilizer on the rear axle. The car was equipped with a low, elongated cabin, which used four-point suspension. The cabin was amortized from the frame in the front section by means of mechanical springs, with gas ones in the rear. They subsequently entered the hydraulic shock absorbers via all four points of support.

The driver's seat in the test vehicle was equipped with a pneumatic suspension, which facilitated longitudinal adjustment of the seat height and adjustment of the seat tilt. The seat also provided a rest position and the rapid lowering of the seat for easy entry and exit from the car. Views of the driver's seat in the cabin and the method of affixing of measuring pads using acceleration sensors are shown in Figure 2.

During the measurements, the driver was subjected to vibrations, whose main source was uneven surface and changing traffic conditions resulting from changes in the volume of traffic on the whole route. The measurements were carried out while driving without a load. The test vehicle moved along roads located in urban areas and on rural roads. Vibration tests were also conducted on the seat while moving on the highway. The route was chosen in such a way as to best reflect the working conditions of the driver during a typical day of work, that is, in changing traffic, which is associated with the distance from the city centre, and variable surface conditions resulting from the road class.

The measuring set used in the study consisted of a triaxial acceleration converter mounted on a rubber vibration pad (Fig. 2b), which cooperated with the data acquisition and analysis module. The converter was set up in such a way that the x direction coincided with the direction of straight-ahead driving.

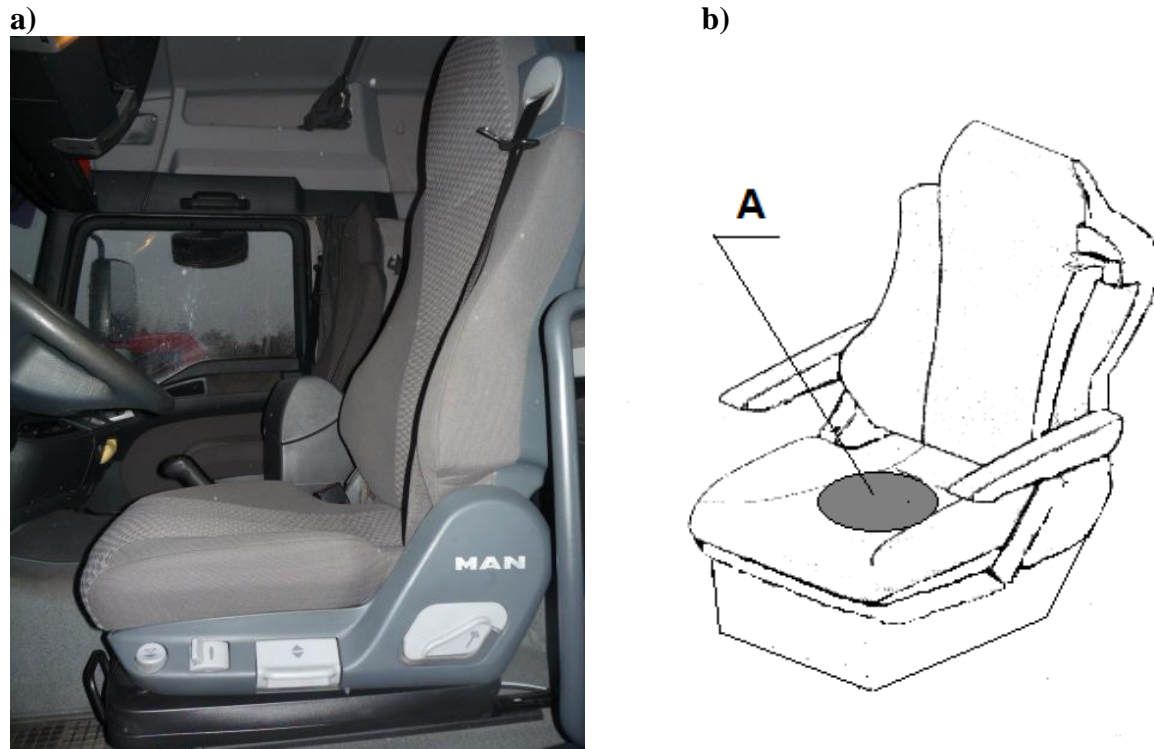


Fig. 2. View of the driver's seat in the MAN TGL: (a) the scheme of placing the vibration acceleration sensor on the seat and (b) the rubber cushion (A) of the vibration acceleration sensor

During the study, effective values of vibration acceleration $a(t)$ were recorded in three directions consistent with Figure 1. Effective values characterizing the energy impact of vibration on the driver were determined according to Formula 1.

$$a_{RMS} = \sqrt{\frac{1}{T} \int_0^T a(t)^2 dt} \quad (1)$$

where T represents the time of measurement and $a(t)$ represents the instantaneous values of vibration acceleration.

The recorded vibration signals indicate a stationary character on the roads with a good surface and a pulsed (non-stationary) character on suburban roads in a poor state with many ruts and flumes. The measured values of vibration acceleration were also influenced by driving style (traffic flow), which changed during the experimental passage.

4. RESULTS AND ANALYSIS

Measurements of RMS vibration acceleration were made in three directions: x , y , z . The measurements were carried out in a cyclic mode, yielding a series of effective value vibration acceleration in a given direction of measurement. The results were divided by the types of road on which the vehicle moved according to the adopted classification for roads: urban, extra-urban and motorway. To assess the harmfulness of vibrations to humans, we used the

vibration energy measure, marked out for an appropriately selected frequency band. The effective value of vibration acceleration a_{wRMS} for each direction of measurement (x, y, z) for a cycle involving an 1 h ride was determined as:

$$a_{wRMS (x,y,z)} = \sqrt{\frac{1}{T} \sum_{j=1}^n a_j^2 t_j} \quad (2)$$

where T represents the reference time of 1 hour and a_j represents the instantaneous values of vibration acceleration recorded at time t_j .

Substitute values of vibration acceleration $a_{sub,i}$ have been designated as the sum of the vector acceleration operating in three orthogonal directions (Equation 3). This is a measure of the impact of vibrations mainly used in local vibration analysis. In the case of drivers of motor vehicles, the presence of seat vibration is associated with the relative movements of the seat and cabin floor together with the cockpit. The relative movements of the driver on the seat give the effect of local vibrations penetrating the body through the hands, which rest on the steering wheel.

$$a_{sub} = \sqrt{a_{wRMS x}^2 + a_{wRMS y}^2 + a_{wRMS z}^2} \quad (3)$$

The results of effective value measurements (a_{RMS}) of vibration acceleration for various directions of measurement, as well as the resultant acceleration, are shown in Figures 3-5. The numbers of measurements represent the consecutive hours of observation.

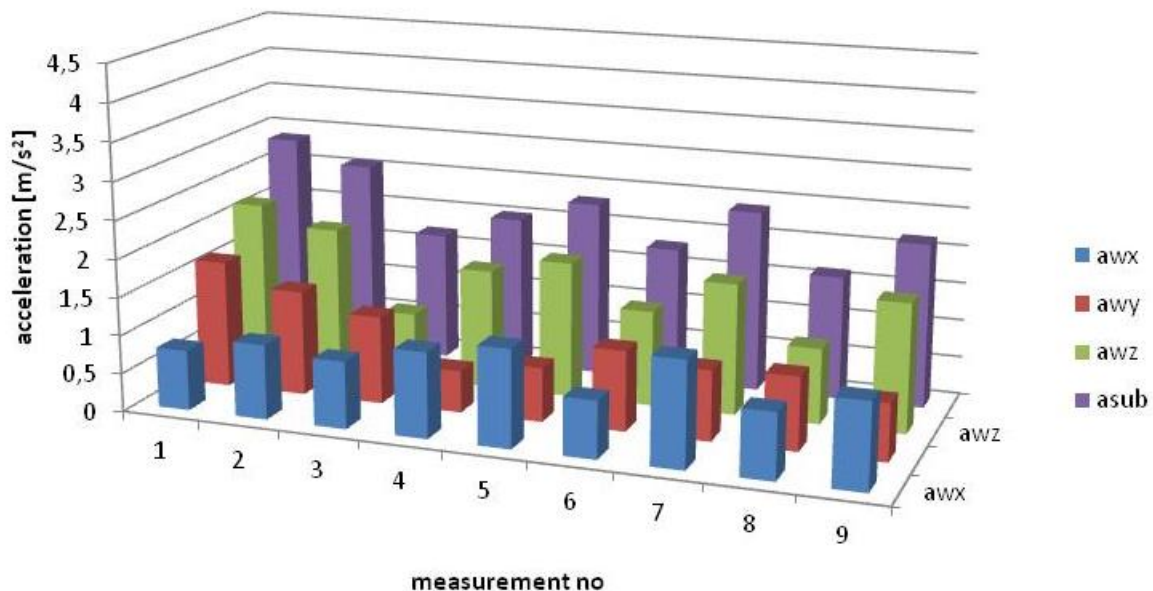


Fig. 3. The results obtained for roads in urban areas

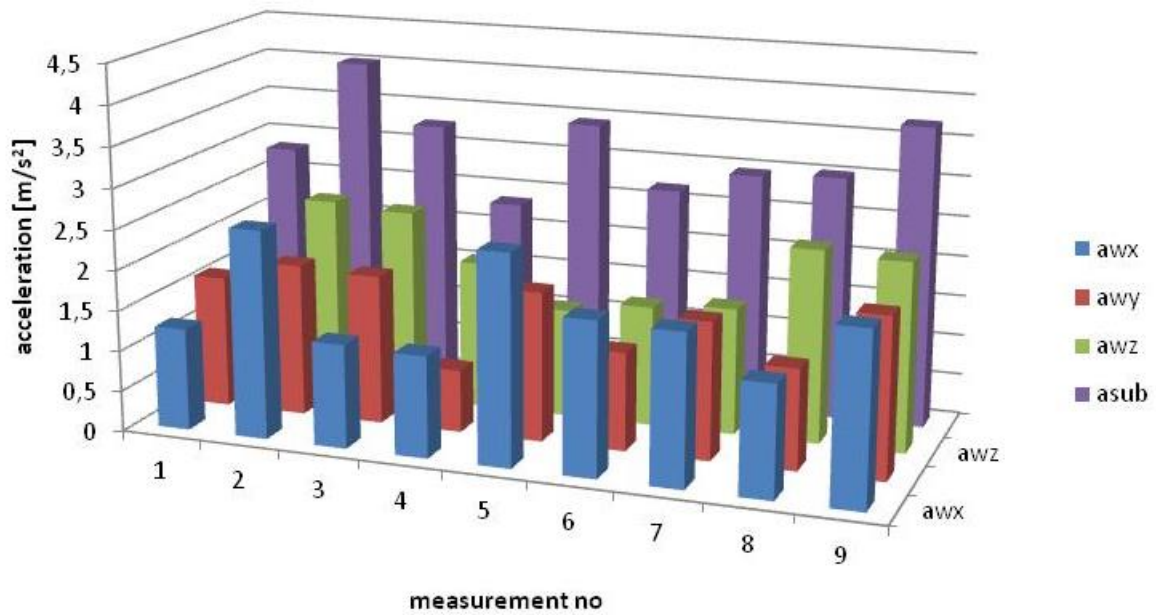


Fig. 4. The results for roads in extra-urban areas

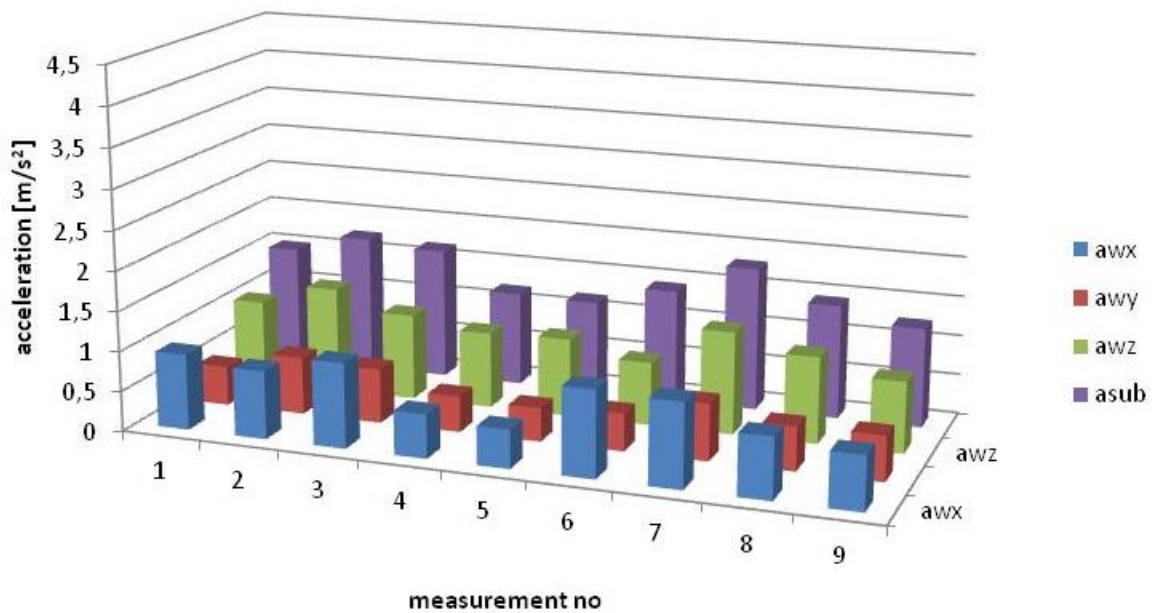


Fig. 5. The results for highways

The daily vibration exposure in each direction of the measurement of vibration acceleration for different types of road was calculated according to Formula 4, which incorporates a nine-hour working time limit for drivers:

$$A_{(x,y,z)}(9) = k_{(x,y,z)} \sqrt{\frac{1}{T_0} \sum_{i=1}^n a_{wRMS(x,y,z),i}^2 t_i} \tag{4}$$

where $a_{wRMS(x,y,z)}$ represents the effective value of vibration acceleration for a specific operation in the direction x , y or z (m/s^2); n represents the number of occasions involving 1 h measurements ($n = 9$); i represents the numbers of successive 1 hr vibration observations; t_i represents the duration of the operation equal to 3,600 (s); T_0 represents the reference time equal to 32,400 (s); and $k_{(x,y,z)}$ represents the value of the weighting factor. For the directions x , y , $k = 1.4$; for the direction z , $k = 1$.

A summary of the research results concerning the driver of a commercial vehicle's exposure to vibrations while driving on various road surfaces is shown in Figure 6.

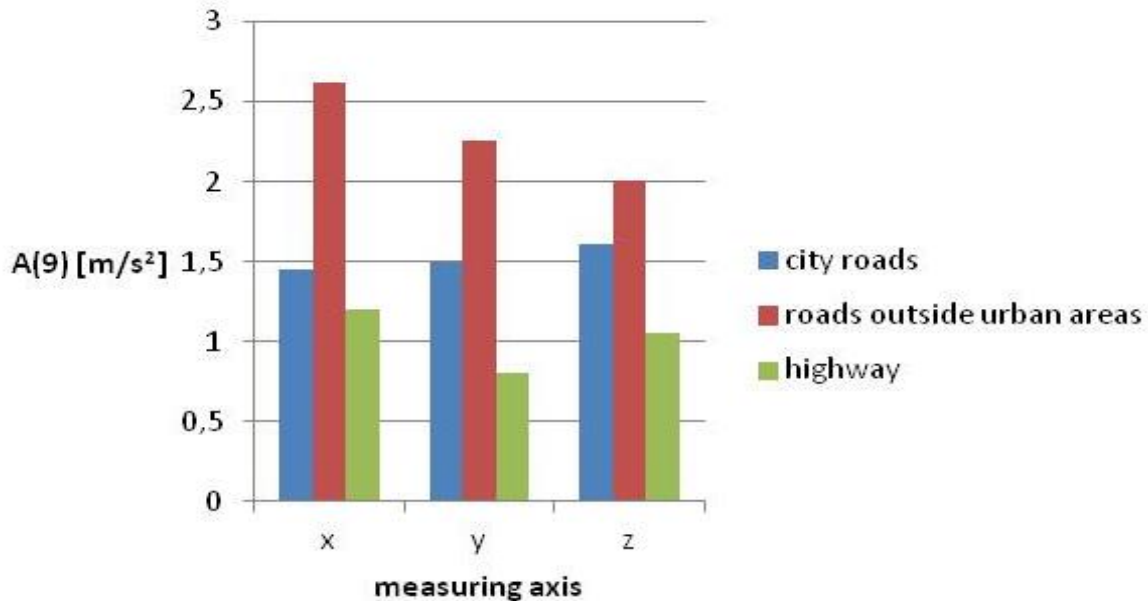


Fig. 6. The value of the driver's exposure to vibrations (for nine hours) when driving on roads of different categories

Vibration exposure assessment was separately conducted for each direction of vibration influence. In the case of movement on roads located in urban areas, the highest values occurred in the vertical direction. In non-urban traffic, the maximum values of exposure occurred in the longitudinal direction. Similarly, in motorway traffic, the highest value of exposure occurred in the direction of the longitudinal axis of the vehicle. For all tested directions, the effects of vibration energy on the vehicle driver while driving on the selected road types were the selected maximum values; this is consistent with the assessment procedure specified in the standard [3].

5. SUMMARY

For a driver of a commercial vehicle, who is used to roads of different categories, the daily exposure level depends largely on the condition of the road surface. The test vehicle was in good condition, which was confirmed before and after the conducted research by service inspections. It transpires that, during transportation tasks, in the shuttle cycle, when using roads outside urban areas, the exposure limits for vibration are likely to be substantially exceeded. This is particularly important when planning driving routes, where route selection may result in a negative impact on the vehicle driver. Limit values for exposure to general

vibrations in an eight-hour working cycle are set out in the Annex to the Regulation of the Minister of Labour and Social Policy of 29 November 2002 [4]. According to this document, vibrations that have a general impact on the body should not exceed the value of daily exposure $A(8)$ for 0.8 m/s^2 .

Summing up the results of this research, it is clear that drivers of commercial vehicles are exposed to harmful vibrations, which significantly exceed the limits of exposure to general mechanical vibrations. There is also an incompatibility between the regulation of drivers' working time and the standards related to daily exposure to vibrations. It is therefore important to continue working on design solutions that can reduce the value of drivers' exposure to mechanical vibrations, as well as synchronize the legal frameworks for the regulation of drivers' working time and daily vibration exposure.

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