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ASSESSMENT OF THE COMFORT OF PASSENGER TRANSPORT IN SPECIAL PURPOSE VEHICLES

OCENA WARUNKÓW KOMFORTU TRANSPORTU OSÓB W POJAZDACH SPECJALNEGO PRZEZNACZENIA*

The article discusses the issue of comfort, that should characterize a vehicle which has been designed to work under special conditions. If the criteria of ensuring the proper comfort of the passengers of special purpose vehicles are not met, it might lead to a serious disturbances in perception and in other factors that affect the logical behavior. Performance characteristics generated by the body of the vehicle during tests on the range can be assessed only through research and then related to the characteristics of the human body-vehicle system. The presented results concern the assessment of the ride comfort in the selected vehicles under special conditions and capacity of the crew to effectively perform tasks after long-lasting ride.

Keywords: *special purpose vehicles, passenger transport, vibrations, comfort of a crew.*

W artykule omówiono zagadnienia dotyczące komfortu, jakim powinien charakteryzować się pojazd do pracy w warunkach szczególnych. Nie spełnienie kryteriów właściwego komfortu u przewożonych osób pojazdami specjalnego przeznaczenia prowadzi do powstawania poważnych zaburzeń na tle percepcji i innych czynników niezbędnych w logicznym postępowaniu. Jedynie na drodze badań możemy ocenić charakterystyki generowane przez nadwozie w testach poligonowych i odnieść to do charakterystyk organizm ludzki-pojazd. Prezentowane wyniki dotyczą oceny charakterystyk komfortu poruszania się wybranymi pojazdami w warunkach szczególnych i możliwości wykonania zadań przez przewożony personel po długotrwałej jeździe.

Słowa kluczowe: *pojazdy specjalne, transport osobowy, drgania, komfort załogi.*

1. Introduction

The soldiers who perform their duties while on patrol could be exposed to various stimuli that can cause a fatigue, which can be divided into four categories [2]: muscular, sensory, intellectual and emotional. Unfortunately, it is almost impossible to modify the external treats which are typical for patrol duties – their influence is relatively stable in nature. On the other hand, we can reduce the internal threats, such as muscle fatigue and fatigue on emotional level. It should be mentioned that the need for security, together with some physiological needs, must be satisfied to enable human to undertake further activities [14]. Possibility for changes could be therefore sought in the proper construction of the vehicles that ensure the highest possible level of comfort of the crew. This kind of construction should raise the crew's sense of security by meeting the adequate standards of bulletproofing and shrapnel proofing [1, 25].

One of the areas that have been mentioned above, that significantly affects the quality of work performed by the crew of the patrol vehicle, is ride comfort. Assessment of this variable is usually performed using the ISO 3126 standard [7]. An alternative approach has been codified in british standard [3]. These standards evaluate riding comfort on the basis of the set of physical sensations associated with the dynamics of vehicle's motion, which include: accelerations and its changes in the transverse, longitudinal and vertical direction as well as the angular motion around x, y, z axle – that is the transverse tilt motion, longitudinal slope and tilt movement. Information about the risks associated with the exposure of the human body to the vibrations that could cause a health problems can be found in [5] and limits of a permissible dose of the vibrations are determined in the regulation [21].

The literature concerning this subject is quite extensive and focused mainly on the studies regarding the improvement of performance of the civilian vehicles, with particular emphasis put on the driver's place of work [4, 8, 10, 22, 26, 27]. Especially the work of Griffin [6] extensively presents the requirements and correlations between the standards [3, 7] and the requirements of the European Union's in the scope of health and safety of people exposed to the vibrations generated by the vehicles.

Results of the assessment of ride comfort of military special purpose vehicles are very limited. Partial assessment has been presented in the papers [11, 15, 16, 20]. One of the papers [18] summarizes the results of evaluation of ride comfort of different vehicles, including military vehicles, but provides no details about the type of vehicle. Additionally, the paper [15] summarizes the results in the form of accelerations transmitted to the human body in defined one third octave bands, but only for the selected track-laying vehicles. More detailed information have been presented in the paper [20], where the groups of track-laying vehicles and wheeled vehicles have been compared in the scope of specific doses of maximal permissible concentrations and intensities (NDN). Data on military vehicles concerns most frequently the level of ballistic protection – basing on the asumption that this paramether of the vehicle is the most important and the ride comfort is rather considered to be an issue of secondary importance [12, 13].

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

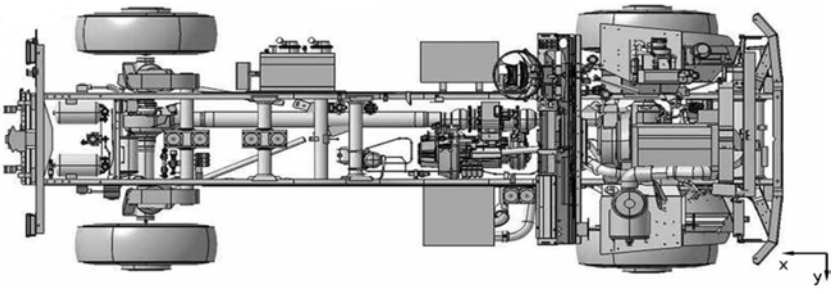

Fig. 1. The chassis of UNIMOG 437.465 with an engine OM924LA Euro3 163kW – view from the top [19]

Fig. 2. The chassis of UNIMOG 437.465 with an engine OM924LA Euro3 163kW – view from the top [19]

Previous publications [22, 23] focused also on the analysis of the selected parts of the vehicles, mainly in terms of quality and safety of their construction. Meanwhile, the analysis of the usage of patrol vehicles shows, that they usually cover very long distances. Because of that, besides of safety guaranteed by proper ballistic protection, minimalization of the negative influence of vibrations on the human body is an important factor that afects the capacity of the crew to undertake specific actions after the long-lasting ride. Lack of information in this area encouraged authors to make an attempt to assesse the riding comfort of the vehicle of the class M-ATV (MRAP All Terrain Vehicle).

2. The object of the research

The research has been conducted on the prototype of the Armored Multi Role Vehicle (AMRV G10) on the chassis of the Mercedes UNIMOG U5000 series, in the military version, model 437.465 (Fig. 1) [8].

Technology demonstrator made in the ballistic development for 10 people (Fig. 2) has been subjected to the road tests with taking into account data compiled in the Table 1.

The measurements have been conducted in one of the european centers for road tests of special and off-road vehicles. Out of the many test sections that are in the disposition of the center, studies have been conducted on the pavements: asphalt, gravel and one made of concrete slabs of symmetrically and asymmetrically arranged vertical faults. Additionally, tests were also carried out on the special road section that simulates the mountain road, driving on railway sleepers and that forces significant torsion of load-carrying structure and thus a large tilts of the vehicle's body. Figure 3 presents the reconnaissance map of the test track. Different driving speeds have been determined for the selected road sections – its combination is shown in Table 2. Time of ride through the whole test track was 1680±120 seconds.

Table 1. Technical parameters of military chassis [19]

Dimensions		Masses	
Axle base	3860 mm	The share of mass – front axle	3,1 t
Length	5994 mm	The share of mass – rear axle	1,9 t
Front overhang	1043 mm	Complete vehicle kerb weight	5,0 t
Rear overhang	1091 mm	Permissible load of front axle	12,5 t decreased by the load of the rear axle, but no more than 6,0 t
Width	2440 mm	Permissible load of rear axle	7,1 t`
Wheel track	1556 mm	Permissible total weight	12,5 t
Clearance	553 mm		
Approach angle	40°		
Departure angle	38°		
Tyres	365/80 R20 with run-flat segment		

Table 2. Recorded speeds of the tested vehicle for different road pavements

Test section	Asphalt road	Gravel road	Driving on railway sleepers	Mountain road	Road made of symmetrically arranged concrete slabs	Road made of asymmetrically arranged concrete slabs
Driving speed [km/h]	50	30	10	10	50	50

3. Formulation of the problem

Description of the quantitative measurements of vibrations that affect the human body has been specified in regulation [21] concerning the maximal permissible concentrations and intensities (NDN) of health hazards in the workplace. This regulation distinguishes short-term vibrations (up to 0.5 hours) and full day vibrations (8 hours) and defines the influence of vibrations on human body while distinguishing between vibrations of general and local influence. This paper presents the values of NDN resulting from the actual time of driving through the entire measured section as well as its convertion to 8 hours of driving. Permissible values of NDN have been shown in Table 3.

The concept of dominant weighted acceleration of vibration has been introduced for the vibrations of general influence. This is the largest value of the weighted acceleration of vibrations, selected from the three directional components of acceleration (in point of fact

Table 3. Permissible values of NDN for the protection of health [21]

Type of vibration	Permissible values (NDN) for daily exposure to mechanical vibrations	Permissible values (NDN) for short-term exposure to mechanical vibrations
Vibrations of general influence	$A(8)_{dop}=0,8\frac{m}{s^2}$	$a_{w0,5dop}=3,2\frac{m}{s^2}$

Table 4. Accelerations acting on the human body in typical situations

Type of motion	a_x [m/s²]	a_y [m/s²]	a_z [m/s²]
walk	0,6	0,6	1,0
march	1,0	0,7	2,5
run	2,0	1,0	4,0

Table 5. The values of effective weighted accelerations of vibrations

	Driver	Passenger no. 1	Passenger no. 2
a_{wx}	0,062	0,102	0,102
a_{wy}	0,102	0,062	0,062
a_{wz}	0,016	0,018	0,024

Table 6. The doses of vibrations absorber during a single ride

	Driver	Passenger no. 1	Passenger no. 2
$A(8)_{2s\min x}$	0,021	0,034	0,034
$A(8)_{2s\min y}$	0,034	0,021	0,021
$A(8)_{2s\min z}$	0,004	0,004	0,006

Table 7. The daily doses of vibrations

	Driver	Passenger no. 1	Passenger no. 2
$A(8)_x$	0,087	0,143	0,143
$A(8)_y$	0,143	0,087	0,087
$A(8)_z$	0,016	0,018	0,024

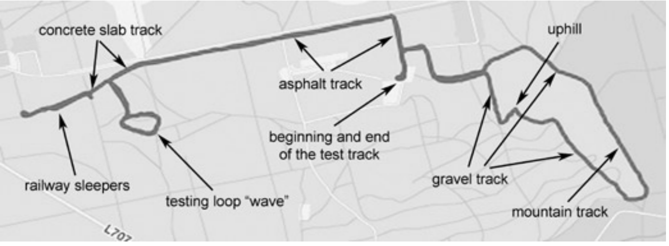

Fig. 3. Map of the test track of the length of 10 km

one directional component). On that basis, depending on the time of influence of the vibrations, calculations are carried out:

a) if the total time of influence of the vibrations during the day is $t \le 1,8e10^3$ seconds, the dominant value $a_{w\max}$ is selected of all the defined effective weighted accelerations of vibration a_{wli} with taking into account relevant coefficients:

$$1,4a_{wx};\quad 1,4a_{wy};\quad a_{wz} \tag{1}$$

The largest value which is equal to the daily exposure to mechanical vibration (NDN) is selected among three defined values.

b) if the total time of influence of the vibrations is $t > 1,8e10^3$ seconds, the eight-hour exposure A (8) is determined for each direction l = x, y or z, according to the formula:

$$A_x(8)=1,4a_{wx}\sqrt{\frac{t}{T}};\quad A_y(8)=1,4a_{wy}\sqrt{\frac{t}{T}};\quad A_z(8)=a_{wz}\sqrt{\frac{t}{T}} \tag{2}$$

where: a_{wx}; a_{wy}; a_{wz} – maximal effective weighted values of acceleration for the directions *x, y* or *z*; *t* – time of the route; $T=2,88e10^4$ s.

Obtained value of the dose of vibrations for the daily exposure is compared with the permissible value presented in the Table 3. This relation helps to reduce the duration of the measurements under the assumption that considered route, where measurements are carried out, is representative of the 8-hour working time of the driver (operator of the machine). Presented relations are the basis for quantitative analysis of vibrations.

Qualitative analysis has been also conducted to show the distribution of amplitudes of accelerations for the selected directions and frequencies. The most adverse vibrations are considered to be those

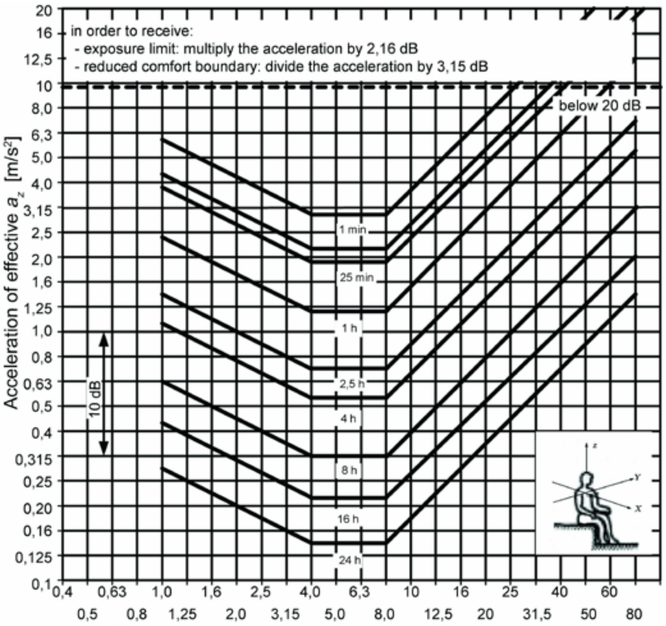

Fig. 4. The course of changes in sensitivity of the human body to the vertical vibrations [7]

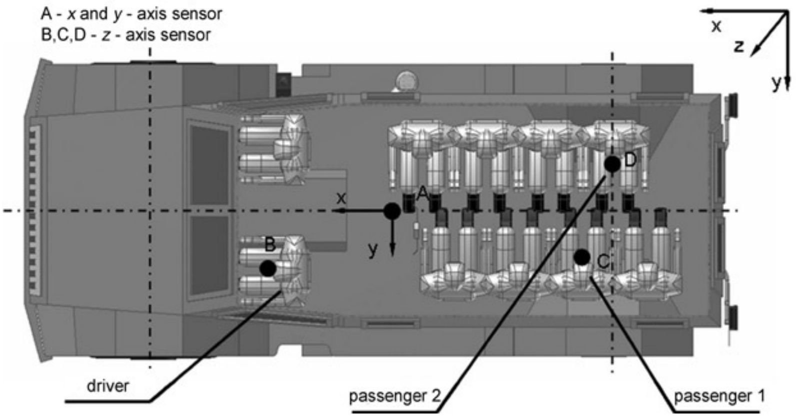

Fig. 5. Schematic location of PCB acceleration sensors of T352 series

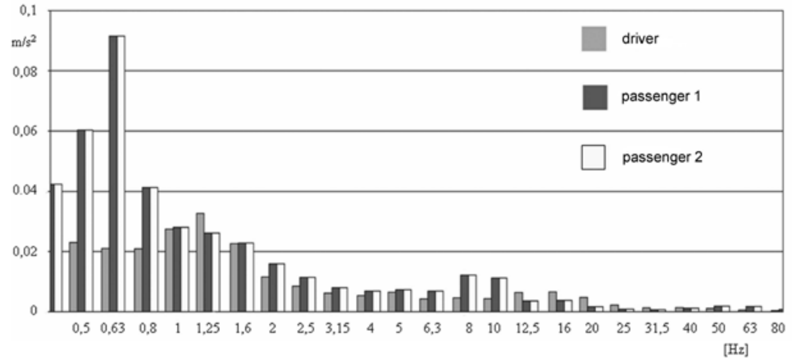

Fig. 6. The chart of the frequency of accelerations in one third octave bands in the x axis

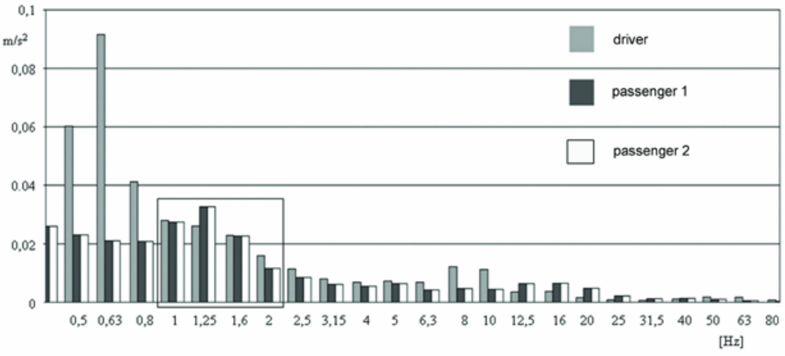

Fig. 7. The chart of the frequency of accelerations in one third octave bands in the y axis

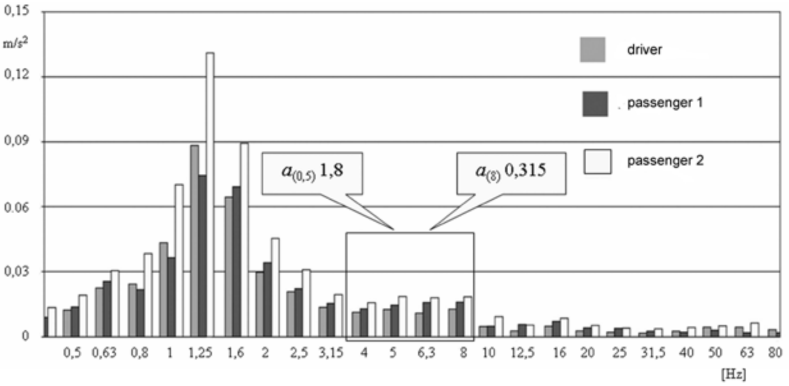

Fig. 8. The chart of the frequency of accelerations in one third octave bands in the z axis

in the range of 4÷8 [Hz] for the vibrations along the axis of the body (*z*) and in the range of 1÷2 [Hz] for the horizontal transverse and longitudinal axle (*x* and *y*) [7]. The course of changes in sensitivity of the human body to the vertical vibrations is presented in the Figure 4 and accelerations acting on the human body in typical situations in Table 4.

4. The course of research

The values of acceleration have been measured with PCB sensors of T352 series and were recorded on a storage device using a 24-channel recorder LMS SCADAS Recorder with sampling rate *v=400 [Hz]* and 24-bit resolution, which together gave a bandwidth of *200 [Hz]*. Sensors have been located in the horizontal, longitudinal and transverse axle of the vehicle and in vertical axis on driver's seat as well as in the transport compartment, which allowed to measure the acceleration of the general influence. Passengers seats were located along the walls of the vehicle in such way that people were sitting side-facing and face to face to each other. Passenger no. 1 have been sitting before the rear axle of the vehicle and passenger no. 2 directly behind it. It was assumed that the horizontal accelerations experienced by the driver and passengers will be measured by the common sensor, which has been located in the middle of the vehicle at the height of the passengers seats (Fig. 5). The frequency range 0,5÷80 [Hz] that was important due to the comfort of riding, have been determined based on the appropriate standards [7]. GPS system coupled with the recorder has been used to record the speed of the vehicle and its route.

5. Results and analysis

On the basis of conducted measurments, the values of effective weighted accelerations of vibrations have been determined: a_{wx}; a_{wy}; a_{wz} . The results are presented in Table 5.

Given that the time of a single ride took an average of *1,8e10³* seconds, it allowed to determine the doses of vibrations that have been absorbed by the driver and passengers bodies during a single ride. The results are shown in Table 6.

Assuming that the time of driving in the vehicle equals 8 hours, the daily doses of vibrations were determined and are presented in the Table 7.

The qualitative assessment of the vibrations transmitted to the body of driver and passengers has been conducted based on the charts of the frequency of accelerations in one third octave bands in the directions *x*, *y* and *z*. The results are shown in Figures 6 to 8.

6. Summary

Assessments of the comfort of the passengers during transportation in special purpose vehicles (off-road vehicles of high mobility) were narrowed down into two areas. In the area of quantitative studies, the doses of vibrations that affect the human body have been defined on the scale of permissible paramethers for short-term exposure and the daily exposure. Special focus has been given to the most disadvantageous case, that is the verti-

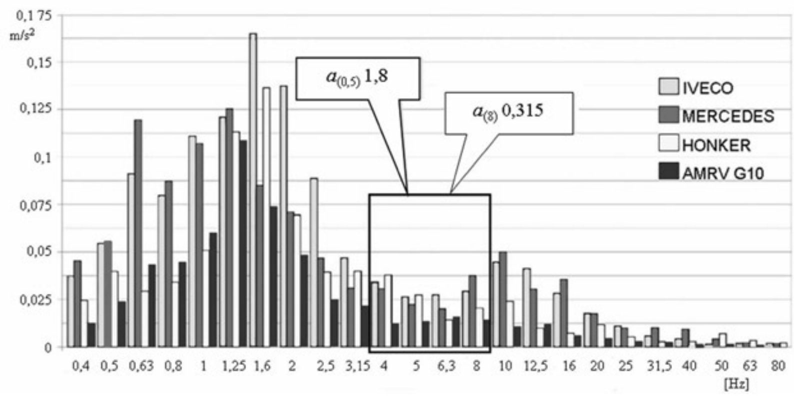

Fig. 9. The partial diagram of accelerations in one third octave band in z axis for the selected special purpose vehicles

cal acceleration (of *z* axis, Fig. 8). In the area of qualitative studies, an analysis concerned illustrating (Fig. 6 to 8) the distribution of the amplitudes of accelerations for the determined directions with taking into account the particular frequencies. Special focus has been given to the values determined by the regulations [7] such as the adverse vibrations in the range of 4÷8 [Hz] for vertical accelerations and in the range of 1÷2 [Hz] for the transverse and longitudinal accelerations.

The presented results of the analysis of spectrum of accelerations in the selected points of the vehicle, lead to the following conclusions:

- available ride comfort for driver and passengers does not exceed the limits for the vibration dose established in the regulations [21]. This leads to the conclusion that this dimention, although affects the overall ride comfort, is not dominant. So, if we want to provide better driving conditions, we should reduce the negative impact of other factors mentioned in the introduction. Furthermore, when comparing the values of the dose of vibrations to the similar results obtained by other special purpose vehicles (Fig. 9), we may conclude that the tested vehicle provides the lowest values of accelerations and the smallest doses of vibration, which means that it is the most comfortable vehicle [12],
- partial decomposition of the accelerations determined on the basis of conducted tests and related to the regulations [7] gives a qualitative picture of vibrations that occur in the analyzed points of measurement. This distribution is advantageous and there is an evidence of significant decline in the value of accelerations in the range of 4÷8 [Hz].

The presented results of assessment of ride comfort for the selected group of vehicles operated by the user (Fig. 9) aimed at showing that the vehicles of Honker 2000 type that have been critically reviewed by its users in terms of durability, provide the similar ride comfort of passengers to the Mercedes 290G and are much better than Iveco 4012 if concerning the values of accelerations in the range of 0,5÷80 [Hz]. The parameters presented in the graphical form (Fig. 9) show that driving Iveco 4012 can be associated with accelerations that may exceed passengers tolerance. Characteristics of the ride comfort of the vehicle is similar to characteristics of the trucks. Comparison of the spectrum of accelerations prepared for three vehicles (Honker, Mercedes, Iveco) was a base while designing new vehicle. In this case, the detailed analysis of the passengers ride comfort have been conducted on the early stage of the project to check if the characteristics of accelerations are in the range that is established in the regulations. The results of comparison of the most adverse accelerations (in the *z*-axis) presented below confirm the right selection of characteristics of the chassis and also the technical parameters or the seats.

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