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 szczególne. 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.
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 affects 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 assess 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.

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 conversion 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
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 \( t \leq 1.8 \times 10^3 \) seconds, the dominant value \( a_{\text{max}} \) is selected of all the defined effective weighted accelerations of vibration \( a_{\text{ord}} \) with taking into account relevant coefficients:

\[
1.4a_{wx}; \quad 1.4a_{wy}; \quad a_{wz}
\]

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 \( t > 1.8 \times 10^3 \) seconds, the eight-hour exposure \( A(8) \) is determined for each direction \( l = x, y \) or \( z \), according to the formula:

\[
A(8) = 1.4a_{wx}\sqrt{t \over T}, \quad A(8) = 1.4a_{wy}\sqrt{t \over T}, \quad A(8) = a_{wz}\sqrt{t \over T}
\]

where: \( a_{wx}; \quad a_{wy}; \quad a_{wz} \) – maximal effective weighted values of acceleration for the directions \( x, y \) or \( z \); \( t \) – time of the route; \( T=2.88 \times 10^4 \) 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

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

<table>
<thead>
<tr>
<th>Type of vibration</th>
<th>Permissible values (NDN) for daily exposure to mechanical vibrations</th>
<th>Permissible values (NDN) for short-term exposure to mechanical vibrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibrations of general influence</td>
<td>( A(8)_{\text{dop}} = 0.8 \frac{m}{s^2} )</td>
<td>( a_{\text{wdop}} = 3.2 \frac{m}{s^2} )</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type of motion</th>
<th>( a_x [m/s^2] )</th>
<th>( a_y [m/s^2] )</th>
<th>( a_z [m/s^2] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>walk</td>
<td>0.6</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>march</td>
<td>1.0</td>
<td>0.7</td>
<td>2.5</td>
</tr>
<tr>
<td>run</td>
<td>2.0</td>
<td>1.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

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**Table 5. The values of effective weighted accelerations of vibrations**

<table>
<thead>
<tr>
<th></th>
<th>Driver</th>
<th>Passenger no. 1</th>
<th>Passenger no. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_{wx} )</td>
<td>0.062</td>
<td>0.102</td>
<td>0.102</td>
</tr>
<tr>
<td>( a_{wy} )</td>
<td>0.102</td>
<td>0.062</td>
<td>0.062</td>
</tr>
<tr>
<td>( a_{wz} )</td>
<td>0.016</td>
<td>0.018</td>
<td>0.024</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Driver</th>
<th>Passenger no. 1</th>
<th>Passenger no. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A(8)_{2x\text{min}x} )</td>
<td>0.021</td>
<td>0.034</td>
<td>0.034</td>
</tr>
<tr>
<td>( A(8)_{2x\text{min}y} )</td>
<td>0.034</td>
<td>0.021</td>
<td>0.021</td>
</tr>
<tr>
<td>( A(8)_{2x\text{min}z} )</td>
<td>0.004</td>
<td>0.004</td>
<td>0.006</td>
</tr>
</tbody>
</table>

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**Table 7. The daily doses of vibrations**

<table>
<thead>
<tr>
<th></th>
<th>Driver</th>
<th>Passenger no. 1</th>
<th>Passenger no. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A(8)_x )</td>
<td>0.087</td>
<td>0.143</td>
<td>0.143</td>
</tr>
<tr>
<td>( A(8)_y )</td>
<td>0.143</td>
<td>0.087</td>
<td>0.087</td>
</tr>
<tr>
<td>( A(8)_z )</td>
<td>0.016</td>
<td>0.018</td>
<td>0.024</td>
</tr>
</tbody>
</table>

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

Fig. 4. The course of changes in sensitivity of the human body to the vertical vibrations [7]
in the range of $4 \div 8$ [Hz] for the vibrations along the axis of the body ($z$) and in the range of $1 \div 2$ [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 $\nu=400$ [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 $0.5 \div 80$ [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 measurements, 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 $1.8e10^3$ 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 parameters for short-term exposure and the daily exposure. Special focus has been given to the most disadvantageous case, that is the verti-
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 0.5−8 [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.

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

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