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Evaluation of Exposure to Impulse Noise at Personnel Occupied Areas During Military Field Exercises

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The tests reported in this paper were carried out to evaluate the exposure of soldiers to noise at operator and control positions during military field exercises. The tests were conducted during firing from a T-72 tank, a BWP-1 Infantry Fighting Vehicle, antitank guided missiles, a ZU-23-2K anti-aircraft gun, and a 2S1 GOZDZIK howitzer. The evaluation of noise exposure showed that the limit values of sound pressure level, referred to by both Polish occupational noise protection standards and the Pfander and Dancer hearing damage risk criteria developed for military applications, were repeatedly exceeded at the tested positions. Despite of the use of tank crew headgear, the exposure limit values of sound pressure level were exceeded for the crew members of the T-72 tank, the BWP-1 infantry fighting vehicle, and the 2S1 GOZDZIK howitzer. The results show that exposure of soldiers to noise during military field exercises is a potentially high hearing risk factor.

Keywords: impulse noise; noise exposure; hearing damage risk criteria; weapon.

1. Introduction

Impulse noise stands out from all other sounds reaching humans in being especially hazardous to hearing. The consequences of human exposure to acoustic impulses may be instantaneously destructive even as a consequence of short exposure (Mrena *et al.*, 2004). Impulsive noise associated with firing weapons is a significant hazard due to high levels of acoustic impulses. Data from the Otolaryngology Clinic at the Military Institute of Medicine in Warsaw where, in 2013, due to acute acoustic trauma emerged after firing weapons, 27 soldiers were hospitalised is an example demonstrating the scale of the danger posed by impulse noise. Each one of the 27 patients suffered a sudden noise induced hearing loss which emerged during firing, with a characteristic hearing impairment seen as a noise notch occurring at 4 kHz. Each patient was subjected to multidirectional treatment which included hyperbaric chamber treatment, steroid treatment (Corhydron, Encorton, or Dexaven), and vascular treatment (Adavin, Nootropil, Cocarboxylaza, Nivalin). The treatment resulted in a hearing improvement for only 17 patients from the group, whereas 11 patients still suffered from tinnitus. These data confirm that impulse noise is a practically high hearing risk factor. Thus, situations in which hearing may be at risk should be recognised. Impulse noise specification and evaluation of exposure to this noise are issues which have been receiving attention for decades (Buck, 2009). The evaluation is strictly related to the necessity of determining impulse noise parameters and their subsequent comparison with the exposure limit values. Parameters related to a signal level may be used to evaluate exposure to impulse noise, as, for example, in a work environment assessment (Directive 2003/10/EC, 2003; National Institute for Occupational Safety and Health [NIOSH], 1998; Occupational Safety and Health Administration [OSHA], 1992). Polish occupational noise protection standards are in force by Minister of Labour and Social Policy Regulation (2014). Soldiers in Poland, in the conditions of military field exercises, are covered by these standards.

The most similar to these regulations is the French hearing damage risk criterion developed for military applications (Dancer, Franke, 1995). Both amplitude parameters related to the signal level and time parameters taking into account impulse duration may also be employed in evaluation of exposure to impulse noise (Buck, 2009). This approach is used in the USA, Dutch, and German hearing damage risk criteria developed for the army (Ward, 1968; Smoorenburg, 1982; Pfander, 1994) on the basis of observations of a temporary threshold shift in soldiers exposed to impulse noise. The amplitude and time characteristics of impulse noise are significant when considering hazards posed by it (Lwow *et al.*, 2011). A special type of approach to the evaluation of effects of exposure to impulses on humans is auditory hazard assessment algorithm for the human (AHAAH) which is the subject of the USA MIL standard (Amrein, 2015). This algorithm is based on an electro-acoustic ear model, where an impulse noise waveform is used as input data characterising impulse noise (Price, 2012). In the event of exposure to impulse noise, possibilities for reducing the influence of the noise on hearing using hearing protectors are also considered (Buck, 2009; Lenzuni, 2012; Młyński, Kozłowski, 2013). There are many works which include measurement results for impulse noise generated by specific sources, e.g. pistols or rifles (Lwow *et al.*, 2011; Lenzuni, 2012). In contrast to these works, the purpose of this study is not to characterise impulse noise sources but to evaluate exposure of soldiers at operator positions during training area exercises and soldiers present during the exercises at control (including observer, paramedic, etc.) positions located at some distance from the operator positions to impulse noise.

2. Methods

2.1. Subject of testing

The evaluation of exposure of soldiers to noise during field exercises was carried out in four areas. The first of the areas was a tank shooting range where noise was produced during firing from a T-72 tank. The second area was intended for exercises with the participation of infantry. Operations in area 2 consisting of firing from a BWP-1 infantry fighting vehicle (73 mm gun and PPK MALUTKA anti-tank guided missile), a PPK SPIKE anti-tank guided missile, a shoulder-launched anti-tank rocket-propelled grenade launcher and machine guns. The third area was the place of artillery exercises where 23 mm ZU-23-2K anti-aircraft guns were used. The last area was reserved for the howitzer (122 mm 2S1 GOZDZIK self-propelled howitzer) crews. The special feature of the exercises in the first area was that main noise sources moved around the area. In other areas (2, 3, and 4) main noise sources were placed in fixed locations. Measurements in four areas of exercises were carried out in similar weather conditions in the absence of precipitation at positive temperatures.

The evaluation consisted in measurements of the parameters of noise present at selected operator positions and control positions located in the exercise area. The individual positions included in the evaluation of exposure to noise, taking into account the type of weapon producing acoustic impulses at those positions as well as the distance between the positions and noise sources, are presented in Table 1. A distance

Table 1. Specification of operator and control positions included in the noise exposure evaluation.

Area	Position	Type of weapon	Distance from position to noise source [m]
1	Tank shooting-range controller – observation tower	T-72 tank	150–2050
	Shooting controller – observation tower		150–2050
	Axis observers – observation tower		150–2050
	Tank crew (under headgear)		0
2	BWP-1 crew (under headgear)	73 mm BWP-1 gun	0
	BWP-1 crew (under headgear)	PPK MALUTKA	0
	PPK SPIKE operators	PPK SPIKE	0
	Paramedic	73 mm BWP-1 gun and RGP	65
		PPK MALUTKA	70
	Observers – observation tower	73 mm BWP-1 gun and RGP	70
		PPK MALUTKA	100
	Artillery observers	73 mm BWP-1 gun and RGP	45
		PPK MALUTKA	55
3	Gun crew	23 mm ZU-23-2K anti-aircraft gun	0
	Gun crew fire control		7
	Truck driver		3
	Observers – observation tower		300
4	Howitzer crew (under headgear)	122 mm 2S1 GOZDZIK self-propelled howitzer	0
	Howitzer crew fire control		55

PPK – anti-tank guided missile, BWP – infantry fighting vehicle, RGP – shoulder-launched anti-tank rocket-propelled grenade launcher.

from position to noise source of 0 m is synonymous with the consideration of the operator position. Otherwise (distance other than 0 m) the control position is considered. The applied measurement method took into consideration the use of tank crew headgear by measuring the noise parameters using a miniature microphone placed in a soldier's ear. As it was mentioned earlier, during the measurements in area 1, the exercises entailed tanks performing incursions along axes whilst firing at targets. For measurements in areas 2, 3, and 4 individual noise sources were immobile, set at operator positions. Figure 1 shows the site plan of the area 1 during T-72 tank shooting exercises. Measurements in the observation tower were made in the shooting controller, the tank shooting-range controller rooms and at the location where axis observers were present.

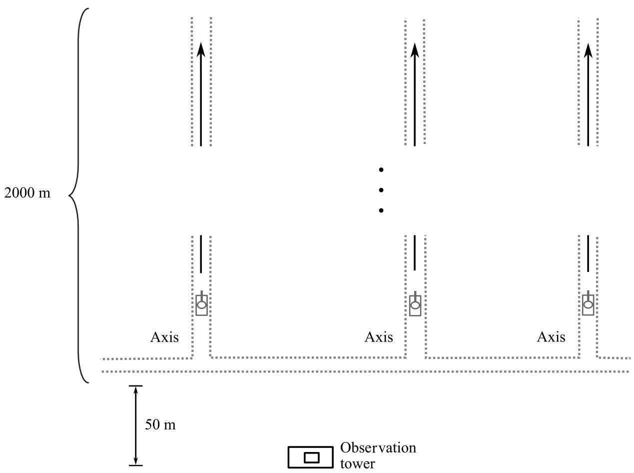

Fig. 1. Site plan of the area 1 during T-72 tank firing.

The arrangement of measurement points in area 2 is shown in Fig. 2. Point "1" indicates the location of BWP-1 when the 73 mm gun firing measurements were taken. The measurement was made using a miniature microphone under the headgear of a soldier inside the vehicle. Point "2" corresponds to the location of the vehicle during PPK MALUTKA firing. This measurement was also taken under the headgear of a soldier. Point "3" corresponds to the location of PPK SPIKE. Measurements at point "4" – taken on the observer tower, those at point "5" registered by the ambulance, and those at point "6" – in the artillery observer position, were repeated twice, i.e. during firing from the gun placed on BWP-1 (where PPK SPIKE, RGP, and machine guns were also fired) and during firing from PPK MALUTKA.

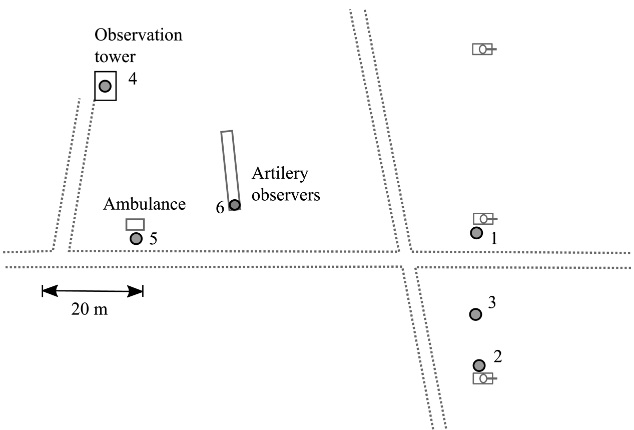

Fig. 2. Site plan of the area 2 during BWP-1 and PPK SPIKE firing.

Figure 3 shows the plan of area 3 which was the site for ZU-23-2K anti-aircraft guns firing. The noise parameters measurements were taken at the gun operating position (point "1"), at the gun crew fire control position (point "2"), inside the cabin of the truck on which one of the guns was located (point "3"), and on the observation tower (point "4"). Figure 4 shows the site plan of area 4 during 2S1 GOZDZIK howitzer firing taking into consideration howitzer arrangement and measurement points: "1" – a measurement inside the howitzer (under headgear), "2" – a firing station.

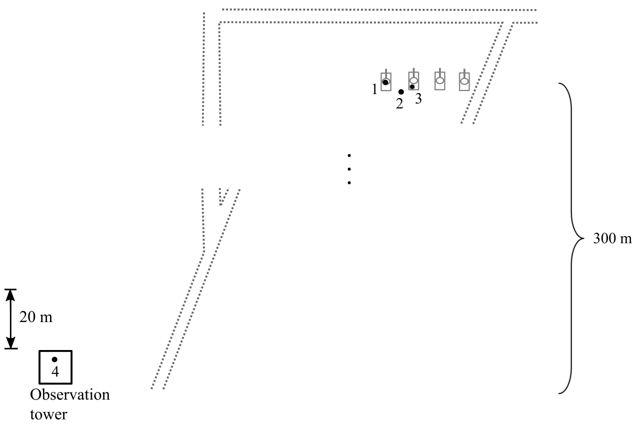

Fig. 3. Site plan of the area 3 during ZU-23-2K anti-aircraft gun firing.

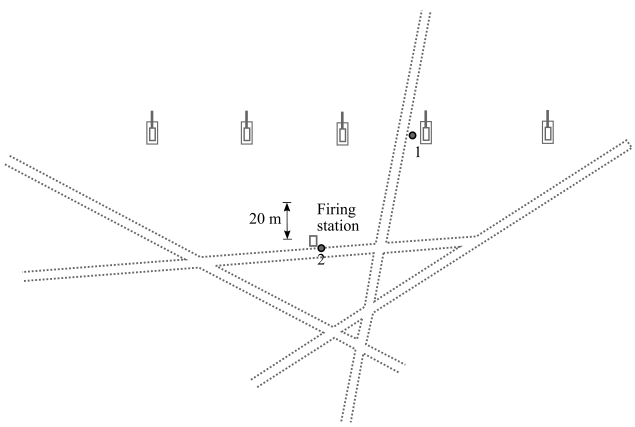

Fig. 4. Site plan of the area 4 during 2S1 GOZDZIK howitzer firing.

2.2. Evaluation of exposure to noise method

The evaluation of exposure to noise was made in accordance with Polish occupational noise protection standards (Minister of Labor and Social Policy Regulation, 2014) and two hearing damage risk criteria developed for the army: Pfander criterion (Pfander, 1994) and Dancer criterion (Dancer, Franke, 1995). When the parameters of noise exceed a limit specified by three above mentioned criteria, it is tantamount to exposure to noise and is a potentially high hearing risk factor.

In accordance with the Minister of Labor and Social Policy Regulation (2014), the following three parameters are taken into account in the evaluation of exposure to noise: the C-weighted peak sound pressure level (L_{Cpeak}), the A-weighted maximum sound pressure level ($L_{\mathrm{A\,max}}$), and the daily noise exposure level ($L_{\mathrm{EX,\,8h}}$). The daily noise exposure level $L_{\mathrm{EX,\,8h}}$ is calculated from the A-weighted equivalent sound pressure level (L_{Aeq}) and the exposure duration. The daily noise exposure level $L_{\mathrm{EX,\,8h}}$ should not exceed 85 dB, the C-weighted peak sound pressure level (L_{Cpeak}) – 135 dB, and the A-weighted maximum sound pressure level ($L_{\mathrm{A\,max}}$) – 115 dB.

As it was mentioned in the Introduction, Dancer hearing damage risk criterion (Dancer, Franke, 1995) developed for military applications is similar to Polish occupational noise protection standards. In the evaluation of exposure to noise made in accordance with Dancer criterion two parameters are taken into account. The daily noise exposure level $L_{\mathrm{EX,\,8h}}$ should not exceed the same value that is specified in the case of Polish occupational noise protection standards, e.g. 85 dB. At the same time, unprotected exposure to impulses above 140 dB peak sound pressure level is not allowed, and the use of hearing protectors is then required (Dancer *et al.*, 1999).

The evaluation of exposure to noise methods presented above only cover an analysis of parameters related to the signal level, whereas the Pfander hearing damage risk criterion (Pfander, 1994) uses amplitude parameter (the peak sound pressure level, L_{peak}) and a time parameter (the impulse duration expressed as the C-duration). The C-duration is a sum of all time intervals in which the impulse noise waveform exceeds −10 dB relative to the maximum absolute value. The evaluation of exposure to impulse noise carried out in accordance with the Pfander criterion requires checking (with the use of graphical method) whether an impulse of a specific sound pressure level and C-duration is below or above a threshold specified by this criterion (line plotted in the graph as a function of the peak sound pressure level and C-duration). When the data point on the graph representing the impulse is below the criterion line then it can be considered as not potentially dangerous for hearing. Otherwise it means that the impulse poses a hearing damage risk.

The A-weighted equivalent sound pressure level was measured for the duration of the firing exercises for each type of weapon. The number of firings for measuring L_{Cpeak}, $L_{\mathrm{A\,max}}$, L_{peak}, and C-duration depended on the conditions present during the military field exercises and was between one and seven.

2.3. Measurement equipment

The measurements of the parameters of noise present at the operator positions were taken using a Brüel & Kjær PULSE measurement system and a Svantek SVAN 948 sound level meter. The Brüel & Kjær PULSE measurement system consisted of a microphone with a measuring range of up to 184 dB (Brüel & Kjær 4941), a Brüel & Kjær 2669 microphone preamplifier, and a Brüel & Kjær PULSE 3560 C measurement unit operated by Brüel & Kjær LabShop software installed on a portable computer. This measurement unit was used to acquire the measurement data. The acoustic impulse waveforms were recorded using a Brüel & Kjær 7701 Pulse Data Recorder software. The SVAN 948 sound level meter was equipped with a Svantek SV22 measurement microphone and a Svantek SV 12L microphone preamplifier or a Knowles BL1785 miniature microphone used for measurements under crew headgear. For measurements using the Svantek sound level meter, evaluation was carried out in compliance with Polish occupational noise protection standards, based on L_{Cpeak}, $L_{\mathrm{A\,max}}$, and L_{Aeq} parameter value measurements. The measurements taken using a measurement system based on a Brüel & Kjær PULSE system allowed the same evaluation as for sound level meter and in accordance with the Pfander and Dancer hearing damage risk criteria.

3. Test results

3.1. Evaluation of noise exposure according to the Polish occupational noise protection standards

Tables 2–6 present the measurement results for the C-weighted peak sound pressure level (L_{Cpeak}), the A-weighted maximum sound pressure level ($L_{\mathrm{A\,max}}$), the equivalent sound pressure level A (L_{Aeq}), and the calculated values of the daily noise exposure level ($L_{\mathrm{EX,\,8h}}$) during military field exercises at the operator and control positions depicted in Table 1. The results presented in Table 2 relate to measurements carried out in area 1, i.e. tank shooting range. The results of the tests obtained during exercises with the participation of infantry in area 2 are shown in Tables 3 (operator positions) and 4 (control positions). Tables 5 and 6 contain the results obtained during the tests in areas 3

Table 2. Noise parameter values measured in area 1 (tank shooting range).

Position	Measurement No.	L_{Cpeak}	$L_{\mathrm{A\,max}}$	L_{Aeq}	$L_{\mathrm{EX,\,8h}}$
		[dB]			
Tank shooting-range controller – observation tower	1	120.4	89.1		
	2	123.2	91.2		
	3	122.9	92.3		
	4	120.7	86.9		
	1–4			78.6	75.6
Shooting controller – observation tower	1	117.9	84.5		
	2	117.1	84.0		
	3	119.0	84.2		
	4	116.8	82.4		
	1–4			77.0	74.0
Axis observers – observation tower	1	140.7	109.3		
	2	142.5	114.0		
	3	124.1	88.8		
	4	103.8	78.1		
	1–4			97.5	94.4
Tank crew (under headgear)	1	≥ 143.4	118.3		
	2	≥ 141.7	115.3		
	3	≥ 142.1	112.8		
	4	≥ 143.2	114.4		
	1–4			99.5	91.5

The symbol "≥" indicates that the upper measuring range limit of the sound level meter microphone has been reached.

Table 3. Noise parameter values measured in area 2 at operator positions (exercises with the participation of infantry).

Position	Measurement No.	L_{Cpeak}	$L_{\mathrm{A\,max}}$	L_{Aeq}	$L_{\mathrm{EX,\,8h}}$
		[dB]			
BWP-1 crew (under headgear) 73 mm gun on BWP-1	1	≥ 143.9	114.3		
	2	≥ 144.2	113.9		
	3	≥ 144.8	113.5		
	4	≥ 144.4	112.9		
	5	≥ 144.1	113.2		
	6	≥ 144.6	114.2		
	7	≥ 144.4	113.3		
	1–7			95.5	86.5
BWP-1 crew (under headgear) PPK MALUTKA	1	133.6	117.3		
	2	134.4	117.4		
	3	132.9	117.4		
	1–3			101.4	94.1
PPK SPIKE operators	1	160.7	128.7	94.5	85.5

The symbol "≥" indicates that the upper measuring range limit of the sound level meter microphone has been reached; PPK – anti-tank guided missile; BWP – infantry fighting vehicle.

and 4, that is, during artillery exercises and firing from the howitzer, respectively.

As it was mentioned in Subsec. 2.2, calculating the daily noise exposure level $L_{\mathrm{EX,\,8h}}$ requires information about the exposure duration. In the case of field exercises in area 1 for the T-72 tank, exposure level was determined under an assumption that the exposure duration at all positions located outside the tank was

Table 4. Noise parameter values measured in area 2 at control positions other than operator positions (exercises with the participation of infantry).

Measurement location	Noise source	L_{Cpeak}	$L_{\text{A max}}$	L_{Aeq}	$L_{\text{EX, 8h}}$
		[dB]			
Paramedic	BWP-1 gun and RGP	139.2	99.5	84.0	
	PPK MALUTKA	111.1	87.0	67.5	
	BWP-1 gun and RGP + PPK MALUTKA				78.0
Observers – observation tower	BWP-1 gun and RGP	138.4	97.9	83.4	
	PPK MALUTKA	110.8	85.2	67.1	
	BWP-1 gun and RGP + PPK MALUTKA				77.4
Artillery observers	BWP-1 gun and RGP	141.2	104.4	88.5	
	PPK MALUTKA	113.4	93.8	73.2	
	BWP-1 gun and RGP + PPK MALUTKA				82.5

PPK – anti-tank guided missile, BWP – infantry fighting vehicle, RGP – shoulder-launched anti-tank rocket-propelled grenade launcher.

Table 5. Noise parameter values measured in area 3 (artillery exercises during ZU-23-2K gun firing).

Position	Measurement No.	L_{Cpeak}	$L_{\text{A max}}$	L_{Aeq}	$L_{\text{EX, 8h}}$
		[dB]			
Gun crew	1	156.3	128.8		
	2	158.3	128.3		
	3	153.0	121.3		
	1–3			110.7	104.7
Gun crew fire control	1	160.1	129.8		
	2	162.8	130.7		
	3	154.9	123.3		
	1–3			113.0	107.0
Truck driver	1	151.1	119.7		
	2	148.0	117.5		
	3	149.3	113.6		
	1–3			100.9	94.9
Observers – observation tower	1	125.1	91.4	80.7	74.7

Table 6. Noise parameter values measured in area 4 (howitzer firing exercises).

Measurement location	Measurement No.	L_{Cpeak}	$L_{\text{A max}}$	L_{Aeq}	$L_{\text{EX, 8h}}$
		[dB]			
Howitzer crew (under headgear)	1	$\geq$ 141.2	110.5		
	2	$\geq$ 143.8	112.5		
	1–2			86.5	80.5
Howitzer crew fire control	1	140.5	105.4	84.5	78.5

The symbol "$\geq$" indicates that the upper measuring range limit of the sound level meter microphone has been reached.

4 hours. The exposure duration for tank crew was determined in a different way because crews changed during the exercises. Hence, the $L_{\text{EX, 8h}}$ under tank crew headgear (at the entrance to the ear canal) was calculated under an assumption that one soldier took part in 3 incursions during which a total of 15 shots were fired. For the BWP-1 crew (field exercises in area 2), the $L_{\text{EX, 8h}}$ was determined with an assumed exposure duration of 1 hour (73 mm gun firing) or 1.5 hours (PPK MALUTKA firing). However, for the control positions situated in locations marked with "4", "5", and "6" in Fig. 2 located at some distance from the BWP-1 and PPK SPIKE operator positions, the $L_{\text{EX, 8h}}$ was determined with an assumed exposure duration of 3.5 hours in total. It was assumed that the exposure duration for the PPK SPIKE operating crew was 1 hour. In

the case of field exercises in area 3 the $L_{\mathrm{EX,8h}}$ related to the ZU-23-2K gun crew was determined with an assumed exposure duration of 2 hours. The same exposure duration (2 hours) was assumed for the GOZDZIK self-propelled howitzer field exercises (area 4).

The results presented in Tables 2–6 show high levels of L_{Cpeak}, $L_{\mathrm{A\,max}}$, and L_{Aeq} occurring during the military field exercises at both the operator positions and control positions located at some distance from the operator positions. For crews of the fighting vehicles (T-72 tank, BWP-1 and GOZDZIK howitzer), despite wearing tank crew headgear, the value of L_{Cpeak} exceeded 143 dB. However, the fact that the L_{Cpeak} values measured under headgear using a miniature microphone, presented in Tables 2, 3, and 6 are underestimated because the upper measuring range limit of the sound level meter microphone has been reached should not be overlooked. For the fighting vehicle crews, high values were also recorded for $L_{\mathrm{A\,max}}$ and L_{Aeq} parameters, which, respectively, remained within the 110.5–118.3 dB and 86.5–101.4 dB ranges. Even higher values of the noise parameters were recorded at PPK SPIKE and ZU-23-2K guns operator positions, for which L_{Cpeak} and $L_{\mathrm{A\,max}}$ values reached or exceeded 160 and 130 dB, respectively. Despite being at a certain distance from the operator positions and at control positions, L_{Cpeak} and $L_{\mathrm{A\,max}}$ values exceeding 140 and 95 dB were recorded (axis observers for tank firing and paramedic and observers during BWP-1 gun and RGP firing). However, lower values of the noise parameters ($L_{\mathrm{Cpeak}} < 125$ dB, $L_{\mathrm{A\,max}} < 93$ and $L_{\mathrm{Aeq}} < 76$ dB) were recorded at the tank shooting-range controller and the shooting controller (T-72 tank) positions as well as the observers on the tower (ZU-23-2K).

The presented test results show that the limit values of the C-weighted peak sound pressure level (L_{Cpeak}), the A-weighted maximum sound pressure level ($L_{\mathrm{A\,max}}$), and the daily noise exposure level ($L_{\mathrm{EX,8h}}$) were exceeded for the following positions: T-72 crew, PPK SPIKE operators, ZU-23-2K gun crew, ZU-23-2K gun crew fire control, and the truck driver. For the BWP-1 crew, the $L_{\mathrm{EX,8h}}$ limit value is exceeded during both gun fire and PPK MALUTKA firing. In addition, for the crew, the L_{Cpeak} allowable value is exceeded during gun fire, whereas $L_{\mathrm{A\,max}}$ limit value is exceeded during PPK MALUTKA firing. Also for the GOZDZIK howitzer crew, the exposure to noise results in the L_{Cpeak} limit value is exceeded.

The soldiers located at a certain distance from the operator positions may also be exposed to high C-weighted peak sound pressure levels exceeding the limit value. This pertains to the axis observers during T-72 tank firing, the observers and the paramedics within the range of the noise generated during BWP-1 gun and RGP firing, as well as the howitzer GOZDZIK crew fire control. The people inside the observation tower (tank shooting range), i.e., the shooting range controller and the shooting controller, were not exposed to noise exceeding the limit values because, unlike the other personnel members, they were inside the building and their exposure to the noise was limited.

3.2. Evaluation of noise exposure according to the Pfander criterion

In evaluating the exposure to impulse noise in accordance with the Pfander hearing damage risk criterion, the values of L_{peak} and C-duration for individual impulses were used to present the measurement results on a graph (Fig. 5) with the criterion line plotted. Examples of waveforms used to obtain its parameters are shown in Figs. 6–8. As it was mentioned in Subsec. 2.2, if a data point (Fig. 5) is located above the criterion line, it means that the noise characterised by the parameters constituting the coordinates of this point poses a hearing damage risk. An analysis of the measurement results with reference to the Pfander hearing damage risk criterion demonstrated that the noise parameter values at the axis observer position during T-72 tank firing, the PPK SPIKE operation and the gun crew fire control position, and inside the truck during ZU-23-2K gun firing already exceeded those allowed by the Pfander criterion upon exposure to just one firing. Exposure to two shots results in the Pfander criterion for the ZU-23-2K gun crew being exceeded as well. Multiplying the number of firings means an increase of the impulse effective duration, hence a shift to the right on the figure showing the criterion. Keeping in mind that the exposure to only one or two shots

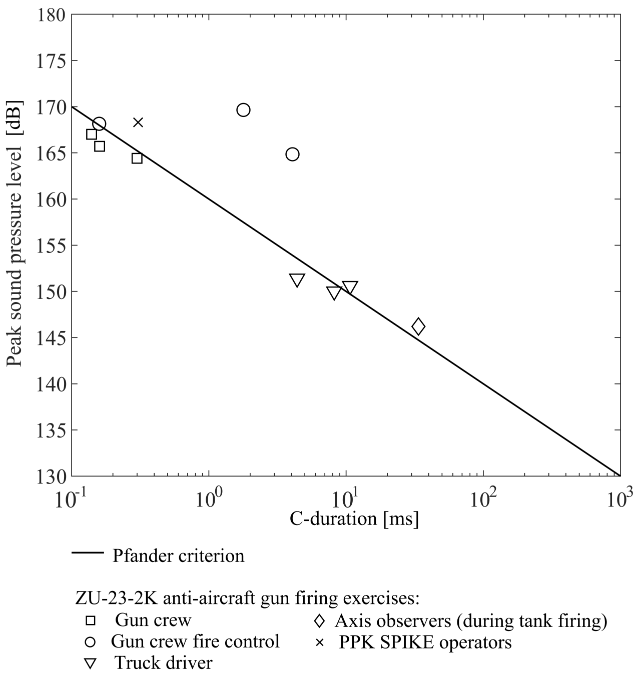

Fig. 5. Parameters of the impulses measured during the exercises. The parameters of impulses were determined assuming exposure to just one firing.

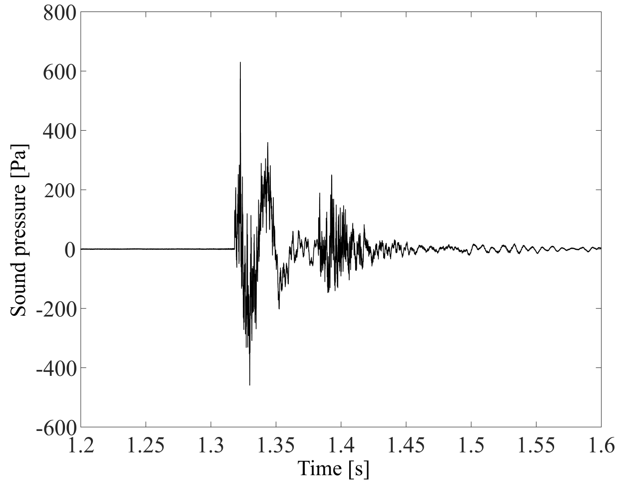

Fig. 6. Waveform of the sound pressure recorded inside the truck during ZU-23-2K gun firing.

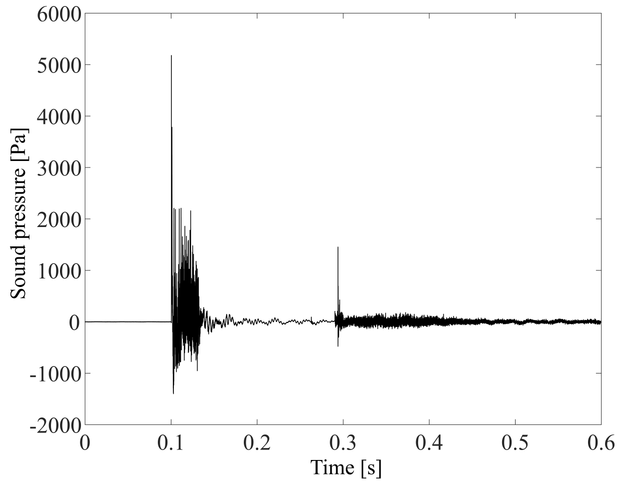

Fig. 7. Waveform of the sound pressure recorded during PPK SPIKE (anti-tank guided missile) firing.

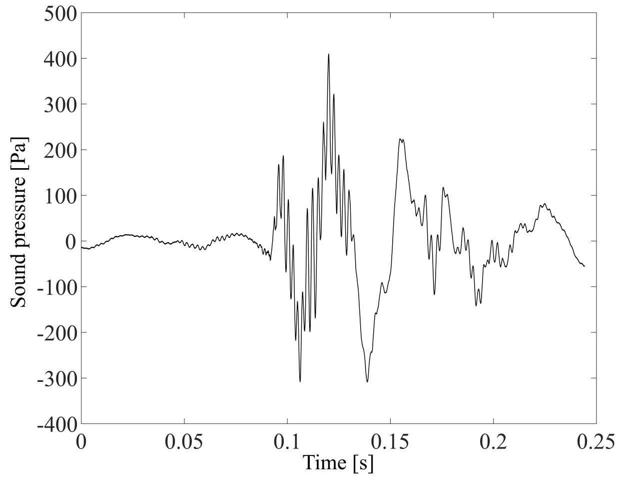

Fig. 8. Waveform of the sound pressure recorded at the axis observer position during T-72 tank firing.

during military field exercises is improbable, the total duration of exposure to impulses generated during the exercises will result in exceeding the criterion line to a much greater extent than that presented in Fig. 5.

When comparing the results of the evaluation of exposure to noise carried out in accordance with Polish occupational noise protection standards and in accordance with the Pfander hearing damage risk criterion, their compatibility should be stated. In five positions for which the occupational and the Pfander criterion could be compared, they indicated that the exposure limit values were exceeded. In the case of the Pfander criterion, the assessment for the comparison was carried out assuming the exposure for at least two shots.

3.3. Evaluation of noise exposure according to the Dancer criterion

As it was mentioned in Subsec. 2.2, the evaluation of exposure to noise made in accordance with Dancer criterion requires to take into account two $L_{\mathrm{EX,8h}}$ and L_{peak} parameters. Due to the availability of measurement data, the same cases that were included in Subsec. 3.2 were analysed in the evaluation carried out in accordance with Dancer criterion. The values of L_{peak} are the same as presented in Fig. 5 (Subsec. 3.2), while the values of $L_{\mathrm{EX,8h}}$ were included in Tables 2, 3, and 5 in Subsec. 3.1. In all analysed cases, the values of $L_{\mathrm{EX,8h}}$ parameter exceeded 85 dB. Thus, impulse noise present in all analysed positions (axis observers – observation tower in area 1; PPK SPIKE operators in area 2; gun crew, gun crew fire control, and truck driver in area 3) should be considered potentially dangerous to hearing. It should be noted that when the limit value of 85 dB is exceeded, the evaluation of exposure to noise made in accordance with Dancer criterion must coincide with the evaluation carried out in accordance with the Polish occupational noise protection standards. In the opposite situation (no limit value exceeded) in the case of the Polish criterion, the values of the L_{Cpeak} and $L_{\mathrm{A\,max}}$ parameters will be decisive.

With the use of the Dancer Criterion the assessment according to the value of the L_{peak} parameter is also related to. It has a significant meaning when the limit value (85 dB) of the $L_{\mathrm{EX,8h}}$ parameter is not exceeded. Then the L_{peak} value exceeding 140 dB means that hearing protectors should be used. The L_{peak} value exceeded 140 dB in 12 out of 14 cases considered in the analysis. Nevertheless, the earlier analysis of the $L_{\mathrm{EX,8h}}$ value showed the risk of hearing damage.

4. Conclusions

The performed tests of impulse noise reaching the operator and control positions during analysed military field exercises, showed numerous situations when the limit values at the tested positions were exceeded, with respect to both the Polish occupational noise protection standards and developed for the army Pfander and Dancer hearing damage risk criteria. Moreover, the tests demonstrated that the crews of the T-72 tank, BWP-1 infantry fighting vehicle, and 2S1 GOZDZIK howitzer, despite wearing hearing protection (crew headgear) when firing from the weapons of these vehicles, were exposed to noise exceeding the exposure limit values. This stems from the fact that the crew headgear does not attenuate the noise generated by the weapons and engines of the vehicles sufficiently. The determined occurrence of very high noise levels makes it necessary for the soldiers to wear hearing protector devices. For positions where verbal communication is required, hearing protectors equipped with electronic systems to improve speech sound transmission may be used.

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