Experimental assessment of acoustic effects of cannon fire on crew

Dragan R. Stojadinović[a], *Snezana B*. Jovanović[b], *Aleksandar* S. Đurić[c], *Aleksandar B*. Bukvić[d], *Sreten* R. Perić[e]

[a] Technical Test Center, Sector for mototechnical and means of river units, Department for vehicles and superstructures, Belgrade, Republic of Serbia, e-mail: dragan.stojadinovic@vs.rs, dragan.stojadinovic90@gmail.com, **corresponding author**, ORCID iD: https://orcid.org/0009-0004-6534-8443

[b] Technical Test Center, Sector for mototechnical and means of river units, Department for vehicles and superstructures, Belgrade, Republic of Serbia, e-mail: sneza.jovanovic.toc@gmail.com, ORCID iD: https://orcid.org/0009-0004-6468-7726

[c] University of Defence in Belgrade, Military Academy, Department of Military Mechanical Engeneering, Belgrade, Republic of Serbia, e-mail: aleksandar_djrc@yahoo.com, ORCID iD: https://orcid.org/0000-0002-2165-528X

[d] University of Defence in Belgrade, Military Academy, Department of Military Mechanical Engeneering, Belgrade, Republic of Serbia, e-mail: aleksandar.bukvic@mod.gov.rs, ORCID iD: https://orcid.org/0000-0002-3025-8446

[e] University of Defence in Belgrade, Military Academy, Department of Military Mechanical Engeneering, Belgrade, Republic of Serbia, e-mail: sretenperic@yahoo.com, ORCID iD: https://orcid.org/0000-0002-7270-5187

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Abstract:

Introduction/purpose: The noise generated by artillery firing can have an extremely harmful effect on the people using it, namely the crew. The subject of this paper is the measurement and analysis of noise levels on artillery weapons used in the Serbian Army.

Methods: The analysis and comparison of the results were carried out during operation of weapons of different calibers. Also, the aspect of impact and risk on the crew exposed to the mentioned physical phenomena was considered.

Results: The results of the examination of the acoustic parameters in relation to the available criteria show that the crew on certain vehicles is exposed to a higher level of noise than allowed.

Conclusion: It is concluded that all measured noise levels exceed the prescribed limit value. Based on the obtained results, further work can be done on reducing negative physical phenomena, as well as providing adequate equipment for the protection of the crew.

Key words: noise, measurement, assessment, risks, crew.

Introduction

Artillery weapons, which are integrated on various combat platforms, produce extremely high noise levels when firing missiles. When adopting and introducing new assets into the military system, the satisfaction of "humane" characteristics is checked: the requirements of ergonomics, human engineering, and the suitability of the asset to the user, so that it can operate and work efficiently, successfully, and effectively (Jovanović et al., 2024).

By measuring and analyzing noise levels generated by artillery fire, information is obtained about the noise intensity. The quality of the measurement depends on several factors: the correct choice of the measurement location (measuring places), the use of adequate tesing and measuring equipment, and experience in processing the obtained data (Jovanović, 2010).

The literature that clearly defines all tolerance thresholds and permissible limits of exposure of the military equipment crew to risks when firing missiles, as well as the criteria for evaluating the risks, is not fully defined in the Republic of Serbia, or many countries worldwide. Only certain aspects of noise have been defined in the literature and can be used for the purpose of assessing the impact on system crews.

In the Republic of Serbia, the Rulebook on preventive measures for safe and healthy work under conditions of noise exposure ("Official Gazette of RS", No. 96/2011, 78/2015, and 93/2019) which defines general provisions in accordance with the requirements of European directives and standards (Directive 2003/10/EC of the European Parliament and the Council on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents - noise) is used. In addition, the Regulation on noise indicators, limit values, methods for evaluating noise indicators, disturbance and harmful effects of noise in the environment ("Official Gazette of RS", No. 75/2010), prescribes limit values for industrial and traffic noise. The Law on Protection from Noise in the Environment ("Official Gazette of the RS, No. 96/2021") defines mandatory noise

measurements in the environment, as well as other legal issues of importance for the protection of the environment and human health.

The number of works by authors who have dealt with these problems is low (Ylikoski, 1994; Duvdevany et al., 2006; Biočanin, 2009; Mlynski et al., 2018; Živaljević, 2018, Blevins et al., 2021), so research in this field is certainly a challenge.

This paper aims to present a comparative analysis and evaluation of the acoustic parameters produced by cannons of different calibers on different platforms. The noise measurement data at the appropriate measuring points during firing are presented, and the risks to the crew are analyzed based on the mentioned regulations, standards, and laws.

The measurements were carried out in real field conditions on platforms with integrated 122 mm, 125 mm, 130 mm, and 152 mm cannons. In order to reduce the measurement error, repetitions were carried out at the same measurement point several times.

Methodology and noise measurement procedure

The measurement of the acoustic parameters of military combat systems is of great importance for analyzing the crew's exposure to noise, and it is classified as a priority measurement during all tests of assets under development.

The method for calculating the acoustic energy of the impulse sound above the barrel (muzzle blast) for calibers less than 20 mm or equivalent explosive mass is described in "ISO 17201-1 (First edition 2005, Acoustics, Noise from shooting ranges. Determination of muzzle blast by measurement). This document defines the following quantities:

p [Pa] - current sound pressure, represents the total current pressure at a point when a sound wave is present, minus the atmospheric pressure at that point;

p_0 - reference sound pressure (in air, usually 20 μPa);

Lp [dB] - sound pressure level calculated according to the formula

$$L_p = 10 \cdot \log_{10}\left(\frac{p^2}{{p_0}^2}\right); \quad (1)$$

p_{peak} [Pa] - peak sound pressure, represents the maximum absolute value of the current sound pressure during a certain time interval;

L_{peak} [dB] - the peak sound pressure level is calculated according to the formula

$$L_{peak} = 10 \cdot log_{10}\left(\frac{{p_{peak}}^2}{{p_0}^2}\right); \quad (2)$$

T [s] - the duration of the phenomenon, a time interval that is long enough to include all the significant sounds of the phenomenon;

E [Pa^2s] - exposure to sound, the time integral of the frequency-weighted square of the current sound pressure calculated by the formula

$$E = \int_T p^2(t)dt \quad (3)$$

and it represents the energy (E) of one pulse;

L_E (dB) - the sound exposure level is defined by a formula

$$L_E = 10 \cdot log_{10}\left(\frac{E}{E_0}\right), \quad (4)$$

where E_0 is equal to the square of the reference sound pressure of 20 μPa multiplied by a time interval of 1 s (400 $\mu Pa^2 \cdot 1$ s).

In the Republic of Serbia, the Rulebook on Preventive Measures for Safe and Healthy Work with Exposure to Noise ("Official Gazette of RS", No. 96/2011, 78/2015, and 93/2019) prescribes the following physical parameters that are used in assessing the risk of exposure to noise:

1. peak sound pressure value p_{peak} [Pa];
2. daily noise exposure level $L_{A,EX,8h}$ [dB] in relation to the reference value of 20μPa;
3. level of weekly exposure to noise $L_{A,EX,8h}$ [dB].

The same Rulebook defines the peak value of the sound pressure as the maximum value "C" of the frequency-weighted current sound pressure in the measurement interval and is used primarily in the assessment of impulse noise, while the other two parameters are used in the assessment of continuously variable or intermittent noise. The defined physical quantities are in accordance with the European directive that defines the minimum requirements for safe and healthy work when personnel are exposed to noise (Directive 2003/10/EC of the European Parliament and the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents - noise). Moreover, these quantities coincide with the 2005 document "ISO 17201-1".

In any case, cannon fire is characterized by impulse noise, so the peak value of the sound pressure was considered - the peak noise level, that is, the maximum measured sound pressure value (peak) expressed in decibels [dB].

For the purposes of acoustic measurements, a measuring chain (Figure 1) consisting of a NetdB12 measuring system (manufactured by 01dB Metravib) in a chain with two 1/4" "free-field" microphones (type 46AE, manufactured by G.R.A.S) was formed.

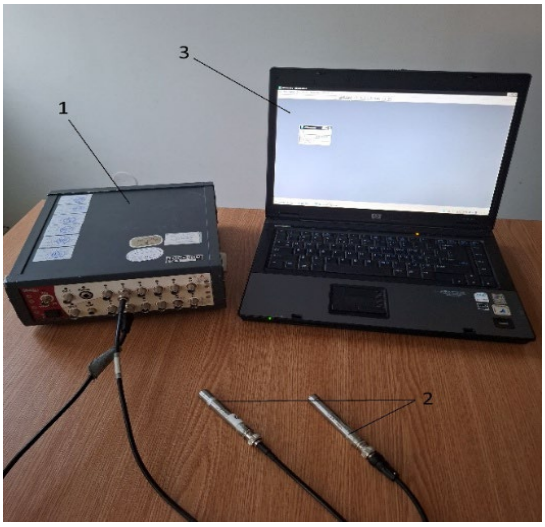

Figure 1 - Elements of the measuring chain: 1 - NetdB12, 2 – microphones, 3 – computer with appropriate software

In the closed dome of the tested vehicle with a 125 mm cannon, the microphone measuring point was at the position of the commander (c) and the gunner (g), at ear level, as well as outside (on the dome, above the gunner's place), which was directed towards the noise source. 125 mm ammunition, instantaneous high-explosive projectile (IHEP) was used for firing. The noise level curve resulting from the firing of the 125 mm cannon is given in Diagrams 1 and 2, where the noise level is presented on the y-axis [dB] depending on the duration of the event itself on the x-axis [s].

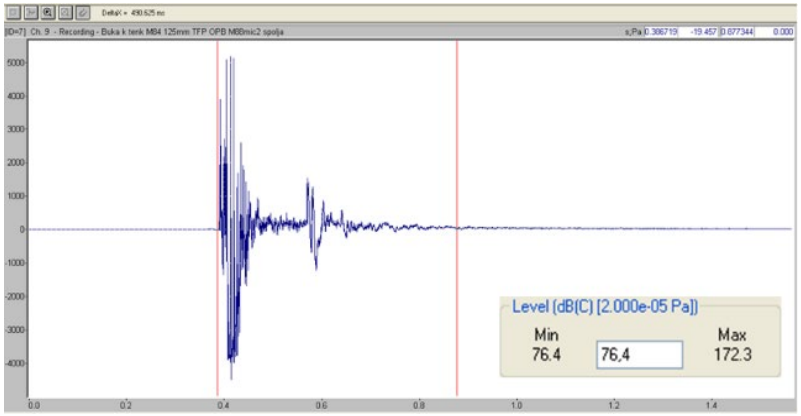

Diagram 1 - Noise curve produced by the 125 mm cannon on a turret

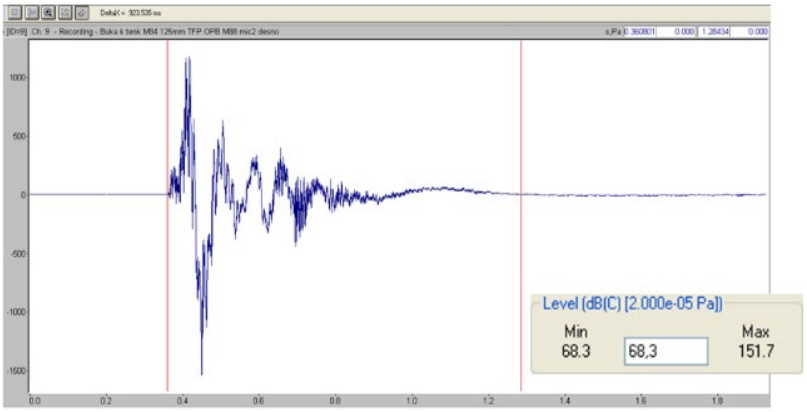

Diagram 2 - Noise curve produced by the 125 mm cannon at the commander's place

In the closed turret of the 122 mm howitzer gun, the measuring point of the microphone was at the position of the commander (c) and the gunner (g), at ear level. Two types of ammunition were used for firing, the 122 mm instantaneous high-explosive projectile (IHEP) and the 122 mm reduced powder charge projectile (RPCP).

The measuring points on the 130 mm and 152 mm cannons were also in a closed turret, but at the position of the gunner (g) and his assistant (a), at a height of 1.2 m, directed towards the muzzle and the direction of firing. Instantaneous high-explosive projectiles (IHEP) were used for both calibers. The presentation of the noise curve resulting form the firing of the 130 mm cannon is given in Diagram 3, where the noise level is presented on the y-axis [dB] depending on the duration of the event itself on the x-axis [s].

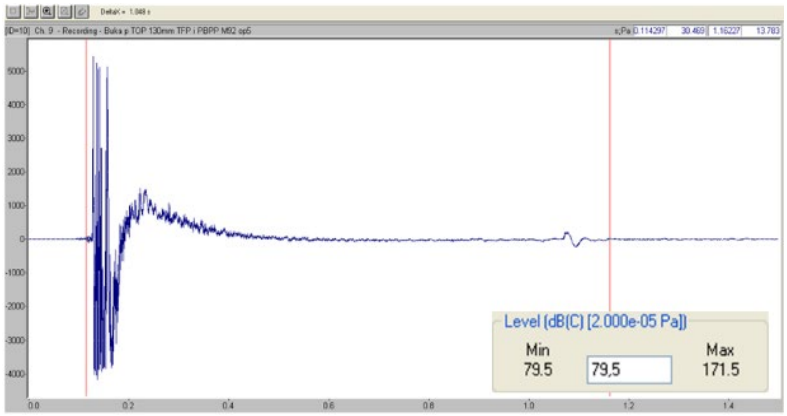

Diagram 3 - Presentation of the noise produced by the 130 mm cannon at the position of the gunner's assistant

Diagram 4 presents an overview of the noise signal (L_{peak}) of all cannons as a function of time (t), in order to compare the amplitude and duration of signals each signal at the marksman's position.

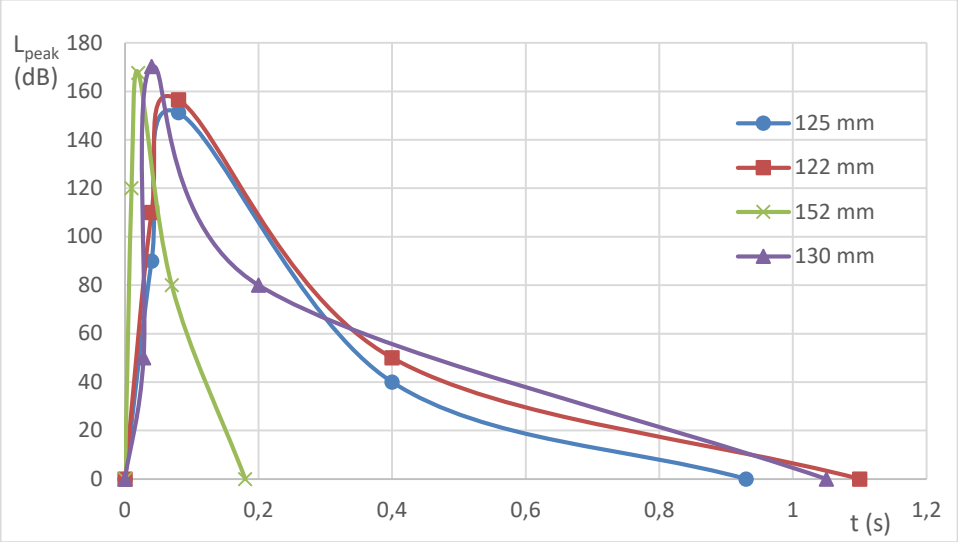

Diagram 4 - Overview of the noise signals produced by all cannons as a function of time at the marksman's position

The results of measuring the noise level on the equipment on which cannons of different calibers are integrated are shown in Table 1.

Table 1 - Noise measurement results

Firing number	Object of examination	Measuring point	Peak noise level **dB(peak)**	
			peak	medium
1.	Cannon 125 mm	marksman	151,2	
2.		commander	151,7	
3.		on the dome	172,3	170
4.			169	
5.			168,8	
1.	Howitzer 122 mm	m (IHEP)	156,5	marksman / commander 155,9 / 156,3
2.		c (IHEP)	157,1	

Firing number	Object of examination	Measuring point	Peak noise level **dB(peak)**	
			peak	medium
3.		m (RPCP)	156,4	
4.		c (RPCP)	156,4	
1.	Gun - howitzer 152 mm	m	167,6	marksman / assistant 166,9 / 168,3
2.		a	169,1	
3.		m	165,9	
4.		a	169,8	
1.	Cannon 130 mm	m	168,7	marksman / assistant 169,9 / 171,2
2.		a	171,5	
3.		m	170,2	
4.		a	170,1	

Criteria for noise assessment and analysis of measurement results

The criterion of exposure of a person to the effects of noise, according to the Rulebook on preventive measures for safe and healthy work when exposed to noise (Official Gazette of RS, No. 96/2011, 78/2015, 93/2019), defines the following classes:

- class A (up to 140 dB) - the permitted daily number of exposures is unlimited,
- class B (from 140 dB to 162 dB) - the permitted number of exposures is:
  - 0, no protection,
  - up to 2000 firings per day, with earplugs or ear defenders,
- class C (from 162 dB to 167 dB) - the permitted number of exposures is:
  - 0, no protection,
  - up to 100 firings per day, with earplugs or ear defenders,
- class D (from 167 dB to 173 dB) - the permitted number of exposures is:

- 0, no protection,
- up to 5 burns per day, with earplugs or ear defenders,
- from 5 to 100 firings per day, earwith plugs and ear defenders.

By analyzing the results of the measured values of the peak noise level for the mentioned devices, which are shown in Table 1, it is stated that the devices fall into:

- class B, for gunners and commanders at the 125 mm cannon, which means that the use of earplugs or ear defenders is mandatory for exposure up to 2000 shots per day;
- class C, for the gunner's position of the 152 mm howitzer gun, which means that the use of earplugs or ear defenders is mandatory for exposure up to 100 shots per day;
- class D, on the turret above the gunner for the 125 mm cannon, for the position of assistant gunner of the 152 mm howitzer, and for the position of the gunner and gunner's assistant for the 130 mm cannon, which means that for persons who are in those zones during firing, it is mandatory to use earplugs or ear defenders for exposure to up to 5 shots per day, i.e. earplugs and ear defenders for exposure from 5 to 100 shots per day.

Graphical representation of the peak noise levels for the examined objects and the relation to the limit value is given in Diagram 5.

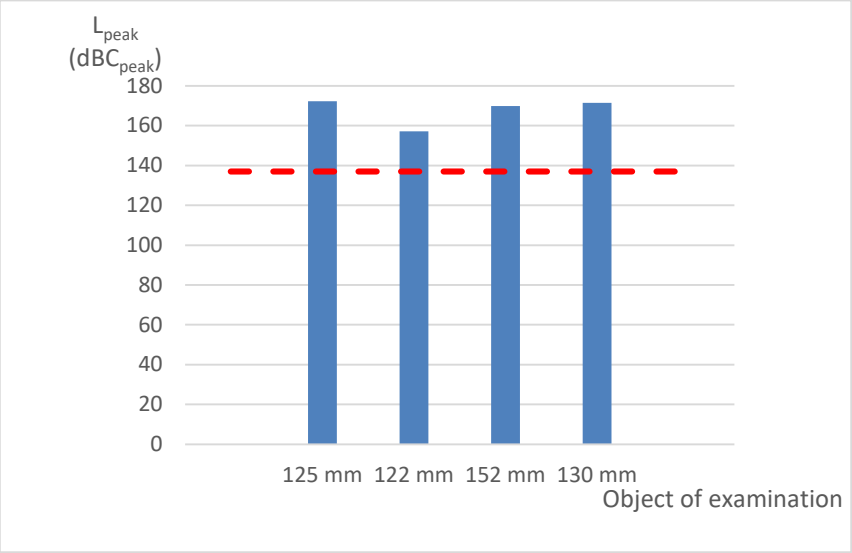

Diagram 5 - Summary of the peak noise level for all cannons in relation to the limit value

According to the Rulebook on preventive measures for safe and healthy work when exposed to noise ("Official Gazette of the RS No. 96/2011, 78/2015, and 93/2019"), the limit value of exposure to impulse noise is 137 dB(peak), which means that all noise measurement results from Table 1 exceed the limit value.

Conclusion

Assessments of the crew's exposure to noise due to cannon fire were carried out according to the criteria of the Rulebook of the Republic of Serbia on preventive measures for safe and healthy work when exposed to noise (which relies on the requirements of Directive 2003/10/EC of the European Parliament and the Council on minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents - noise).

Based on the noise measurement results, it can be concluded that all measured levels exceed the prescribed limit value. This requires additional crew protection measures. This means that the use of protective ear defenders with a high noise reduction rating above 30 dB is mandatory, which would reduce the noise level below the prescribed warning value of 137 dB (peak) according to the Rulebook on preventive measures for safe and healthy work when exposed to noise ("Official Gazette of the RS, No. 96/2011, 78/2015, and 93/2019").

By using adequate measuring equipment to examine the acoustic effects on the crew and by comparing the results with current standards, European directives and existing research, concrete indicators in the domain of safety and protection of human health from the effects of physical phenomena are obtained, which was the goal of this work.

The described measurement methodology can also be applied to other types of military equipment, the ultimate goal of which is to meet European standards in terms of occupational safety, health protection, and comfort. Considering that this work does not include all factors that can influence the measurement results, there is room for improvement, especially regarding the different conditions under which the tests are conducted. In future research, it is recommended to extend the analysis to the effects of different types of ammunition and variations in loading. Such measurements enable a more precise analysis, which would lead to the creation of a document which could lead to the creation of the criteria for assessing acoustic effects on the crew, for the specific equipment and calibers used in the army.

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Uredba o indikatorima buke, graničnim vrednostima, metodama za ocenjivanje indikatora buke, uznemiravanja i štetnih efekata buke u životnoj sredini ("Sl. glasnik RS", br. 75/2010).

Zakon o zaštiti od buke u životnoj sredini („Sl. Glasnik RS broj 96/2021“).

Eksperimentalna procena akustičnih uticaja topovske paljbe na posadu

Dragan R. Stojadinović[a], **autor za prepisku**, *Snezana B*. Jovanović[a], *Aleksandar* S. Đurić[b], *Aleksandar B*. Bukvić[b], *Sreten* R. Perić[b]
[a] Tehnički opitni centar, Sektor za mototehnička i sredstva rečnih jedinica, Odeljenje za vozila i nadgradnje, Beograd, Republika Srbija
[b] Univerzitet Odbrane u Beogradu, Vojna Akademija, Odsek za vojnomašinsko inženjerstvo, Beograd, Republika Srbija

OBLAST: mašinsko inženjerstvo
KATEGORIJA (TIP) ČLANKA: naučna kritika

Sažetak:

Uvod/cilj: Buka koja nastaje kao posledica opaljenja iz artiljerijskog naoružanja može imati izuzetno štetno dejstvo na korisnike - posadu. Predmet ovog rada je merenje i analiza izmerenih nivoa buke na pojedinom naoružanju koje se koristi u Vojsci Srbije.

Metode: Analiza i poređenje rezultata su izvršeni prilikom dejstva iz sredstava sa različitim kalibrima naoružanja. Takodje, razmatran je i aspekt uticaja i rizika na posadu koja je izložena navedenim fizičkim pojavama.

Rezultati: Rezultati ispitivanja akustičnih parametara u odnosu na dostupne kriterijume pokazuju da je posada na pojedinim vozilima izložena većem nivou buke od dozvoljenog.

Zaključak: Svi izmereni nivoi buke prelaze propisanu graničnu vrednost. Na osnovu dobijenih rezultata može se dalje raditi na smanjenju negativnih fizičkih pojava kao i na obezbeđenju adekvatne opreme za zaštitu posade.

Ključne reči: buka, merenja, procena, rizici, posada.

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