UDC 623.44


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INDICATORS AND CRITERIA FOR ACOUSTIC CONCEALMENT DURING FIRE MISSIONS

The importance of acoustic concealment during certain fire missions and the necessity of indicators and criteria for its evaluation are substantiated. Deterministic and probabilistic indicators of acoustic concealment of fire mission and criteria for them are developed. The advantages and areas of application of the specified indicators and criteria are defined. The obtained results can be used for comparative evaluation of existing samples of low-noise weapons and for forming requirements for the characteristics of prospective samples.

Keywords: *acoustic concealment, gunshot noise, sound pressure, indicator, criterion, small arms, fire mission.*

Statement of the problem. Some fire missions (FMs) require covert execution, particularly in terms of acoustic concealment. For example, when performing tasks by special operations forces, acoustic concealment of fire missions (ACFM) makes it possible to destroy sentries, observers and others, provided that the main enemy forces do not receive immediate information about the attack or penetration of these forces into the prohibited area.

During the active phase of a special operation by security forces, a silent (low-noise) shot can maximize the time during which offenders do not have information about the active use of firearms by law enforcement agencies, as well as the location of individual security forces officers who are launching the special operation. Acoustic concealment also contributes to the success of a hostage situation with limited hostage losses due to increased attempts to hit the person(s) holding the hostages.

Despite the large number of samples of low-noise weapons and shot noise reduction devices, there are currently problems with formulating requirements for the tactical and technical characteristics of such weapons, making decisions on their adoption by the relevant forces, and selecting low-noise weapons from among the available samples that will meet the specific conditions for the implementation of certain FMs [1–4].

One of the steps towards solving these problems is the development of indicators and criteria for the ACFM, the values of which should be the starting points in the processes of formulating requirements for the tactical and technical characteristics of low-noise weapons and the informed selection of such weapons among the options offered by the market.

Analysis of recent research and publications. The issues of acoustic concealment of troops, in particular, weapons and military equipment, have been addressed in a number of works. Most of them are aimed at assessing and ensuring the acoustic stealth of submarines and aircraft. For example [5] discusses the issues of protection and stealth of submarines, the relationship between the concepts of "protection" and "stealth", the role of acoustic stealth for the survivability of an object and ways to ensure it. Publication [6] notes the importance of acoustic stealth for submarine survivability and discusses in detail the ways to reduce their acoustic visibility. The source [7] provides methods for detecting underwater vehicles by acoustic fields. The information resource [8] emphasizes the importance of acoustic stealth of military personnel to ensure their survivability while performing assigned tasks and provides recommendations for covert and silent movement. Means and methods for detecting aircraft by monitoring the sound field are described in [9].

In a significant number of works, authors pay attention to acoustic target reconnaissance. For example, article [10] discusses an acoustic target detection system that provides a soldier with the relative position of the source of a shot. Publication [11] states that one of the types of reconnaissance is sound reconnaissance and discusses the sound complex for reconnaissance of firing positions of artillery guns and mortars. Sources [12] and [13] describe the "Sova" and "OTHELLO-P" shot detection systems designed to determine the firing positions of shooters in real time. Articles [14] and [15] describe acoustic reconnaissance tools that can be used to obtain information about objects that emit sound waves. However, these and other sources do not contain information regarding the indicators and criteria for determining the acoustic concealment of objects or processes.

The purpose of the article is to develop indicators and criteria for acoustic concealment of the fire mission.

Summary of the main material. The very concept of "acoustic concealment during fire mission" is associated with the presence or absence of an event of detection of the fact of using weapons by the enemy, which can lead to adverse consequences (moving the target to cover, return fire, destruction of hostages, etc.) The scientific literature does not provide a clear definition of this (ACFM) or a similar term, so it is advisable to define it. "Concealment" is a state by the meaning of "hidden" [16].

There are several definitions of the term "hidden" [17, 18]: not having prominent features; barely noticeable; not openly or fully revealed; kept secret; acting secretly, without revealing intentions; not yet manifested in something; not showing visible signs.

Acoustics is the study of sound, i.e., elastic vibrations and waves in gases, liquids, and solids that are perceived by the human ear [19, 20].

Thus, "acoustic concealment during a fire mission" will be understood as a characteristic of a fire mission that determines the possibility of performing it secretly, without being detected by sound signs.

It should be noted that this possibility should be characterized by certain indicators, which can be both deterministic and probabilistic. Deterministic indicators are simpler, so let's consider this possibility.

Studies show that the acoustic concealment of a fire mission depends on a number of parameters of the fire mission process, the main ones being the following: characteristics of the sound field formed as a result of a weapon shot, characteristics of the sound fields of masking noise (sound maskers), and the distance from the shooter to the target. These sound fields can be described quite fully using sound pressures (sound pressure levels) and frequency characteristics of the corresponding noise [1]. The frequency characteristics of a shot for the same type of weapon and shot noise reduction device are relatively constant, so they will not be considered further.

The dependence of acoustic concealment on several parameters necessitates the use of a certain function as an indicator of the ACFM R_{AC}:

$$R_{AC} = f(\tilde{p}_X, \tilde{p}_0), \quad (1)$$

where $\tilde{p}_X$ – effective sound pressure value of the shot noise at the target location, Pa;

$\tilde{p}_0$ – threshold of humanhearing, Pa.

The combination of values $\tilde{p}_X$, $\tilde{p}_0$ will determine whether the possibility of performing fire missions covertly is realized. If the effective value of the sound pressure level of the noise of the shot $\tilde{p}_X$ does not exceed the maximum human hearing level $\tilde{p}_0$, then according to formula (2) [21], the sound pressure level of the noise of the shot does not gain a positive value and the noise itself will not be heard by the enemy, even in complete silence:

$$L_X = 20\,lg\frac{\tilde{p}_X}{\tilde{p}_0}, \quad (2)$$

where L_X – sound pressure level of the shot noise at the target location (at a distance of X from the weapon), dB.

In practice, in any environment, there are extraneous noises that act as sound maskers. In this case, noises that have effective sound pressure values $\tilde{p}$ that are lower than the effective sound pressure value of the masker noise $\tilde{p}_M$ (at the same point in space) will also not be audible. In fact, formula (2) will take the form (3), which is explained by the effect of sound masking:

$$L_{XN} = 20\,lg\frac{\tilde{p}_X}{\tilde{p}_{MX}}, \quad (3)$$

where L_{XN} – notional sound pressure level of the shot no is eat a distance of X from the weapon, dB.

In practice, as a rule, the parameters of shot and masker noise are known not at the target location, but at the locations of noise sources (or at a certain distance from them). The effective sound pressure level and therefore the sound pressure level of gunshot noise is a function of the distance from the noise source to the target, so the distance X (which is important for the performance of the FM and can take on different values) should also be taken into account when assessing the ACFM.Likewise, the distance from the masker noise source to the target X_M should also be considered, especially in cases of artificial sound masking.

For example, the dependence of the sound pressure level on the distance X can be determined by formula (4) [21], and the dependence of the effective sound pressure values of shot and masker noise on the corresponding distances can be determined by formulas (5) and (6) [21]:

$$L_X = L_1 - 20\,lg\frac{X}{X_1}, \tag{4}$$

$$\tilde{p}_X = \frac{\tilde{p}_1 \cdot X_1}{X}, \tag{5}$$

$$\tilde{p}_{MX} = \frac{\tilde{p}_{M1} \cdot X_{M1}}{X_M}, \tag{6}$$

where L_1 – sound pressure level of the shot noise at some initial distance from the noise source (shooter) X_1, dB;

X – distance from the noise source of the shot to the target, m;

X_M – distance from the source of the masker noise to the target, m;

X_1 – initial distance at which the sound pressure of the gunshot noise was measured (or the sound pressure value is known), m;

X_{M1} – initial distance at which the sound pressure of the masker noise was measured (or the sound pressure value is known), m;

$\tilde{p}_1$ – effective value of the sound pressure of the gunshot noise at distance X_1, Pa;

$\tilde{p}_{M1}$ – effective value of the sound pressure of the masquerade noise at a distance X_{M1}, Pa.

Combining formulas (3) with (5) and (6), we obtain

$$L_{XN} = 20\,lg\frac{\tilde{p}_1 \cdot X_1 \cdot X_M}{\tilde{p}_{M1} \cdot X \cdot X_{M1}}. \tag{7}$$

As can be seen from formula (7), an increase in the sound pressure level of the shot noise and the distance to the masker will negatively affect the ACFM, and an increase in the sound pressure level of the masker noise and the distance to the target will, on the contrary, positively affect the AER.

Expression (7) can be considered as an indicator of the ACFM:

$$R_{AC} = 20lg\frac{\tilde{p}_1 \cdot X_1 \cdot X_M}{\tilde{p}_{M1} \cdot X \cdot X_{M1}}. \tag{8}$$

This indicator can have negative and positive values or be equal to zero. A positive value of R_{AC} corresponds to the fact that the fact of using weapons can be detected by the enemy, and its zero or negative value corresponds to the acoustically hidden execution of the weapon. The negative value of the R_{AC} can be reached when the numerator of the logarithm is less than the denominator, i.e. when $\tilde{p}_X < \tilde{p}_{MX}$, but this situation is hypothetical and rarely happens in practice. It is advisable to use the reserve, which is the difference between $\tilde{p}_X$ and $\tilde{p}_{MX}$, by reducing the difference to zero, for example, by reducing the distance to the target. Even with a positive value of R_{AC}, the detection of the use of a weapon depends on the extent to which the audible sound is associated with a gunshot. However, a value of $R_{AC} \le 0$ guarantees the ACFM.

From the above, it is obvious that a smaller value of the proposed indicator corresponds to a greater acoustic concealment of the performance of the FM. Therefore, a simple threshold criterion can be proposed as a criterion for the ACFM:

$$R_{AC} \le R_{AC\,max}, \tag{9}$$

where R_{ACmax} is the maximum permissible value of the ACFM indicator, dB.

The value $R_{ACmax} = 0$ is the one that guarantees acoustic concealment and can be considered the most rational.

In the case when the effective sound pressure levels of shot and masker noise at the target location are known or can be calculated, it is advisable to use the simpler inequality (9), which follows from expression (3), as the criterion for the ACFM:

$$\tilde{p}_X \le \tilde{p}_{MX}. \tag{10}$$

It should be taken into account that the presence of the earth's surface, various roughnessesand obstacles causes the phenomena of interference and diffraction of the sound wave [22, 23], which affect the parameters of the sound field of gunshot noise. This leads to significant differences between its real characteristics and the calculated ones.

In addition, it has been experimentally established that even under the same conditions, when firing from the same weapon and from the same distance, the perception of gunshot noise by different persons may differ slightly [24, 25]. This is due both to differences in hearing acuity of individual respondents involved in empirical studies and to the complex psychophysical nature of human sound perception. This also explains the differences in the respondent's interpretation of the audible noise, when some identified it as the noise of a gunshot, while others identified it as the noise of another source that was not related to the shooting.

For example, article [24], which investigates the probability of detecting the use of weapons by the enemy as a function of the characteristics of the noise of the weapon shot and the distance to the target, provides four gradations of subjective perceptions of the noise of the shot by individuals: the noise of the shot is clearly audible, but muffled (group A); impulse noise is audible, but there is no clear association with the weapon shot (group B); impulse noise is barely audible and not associated with the weapon shot at all (group C); the sound of the shot is inaudible (group D). At the same time, as the respondents moved away from the noise source, they moved from one group to another not simultaneously, but gradually. Therefore, the authors of [24] took the relative number of respondents who had certain sensations as a measure of the audible noticeability of low-noise weapons.

It can be concluded that the ACFM has a probabilistic nature, and it is advisable to characterize it by probabilistic indicators. As such an indicator, we propose the probability of non-detection by the enemy of the fact of use of weapon P_{ND}:

$$P_{ND} = (1 - P_D)^n , \tag{11}$$

where P_D – probability of the enemy's detecting the use of weapons;

n – number of shots fired from the weapon, times.

A simple threshold criterion can be used as a criterion for assessing the ACFM:

$$P_{ND} \geq P_{NDmin}, \tag{12}$$

where P_{NDmin} – minimum acceptable probability of the enemy's failure to detect the use of weapons.

Thus, we have developed indicators of acoustic concealment of the fire mission [formulas (8) and (11)] and the corresponding criteria [formulas (9), (10), (12)]. In the case of using weapons against targets located near the ground, it is advisable to use indicator (11) and criterion (12). In conditions when the influence of surfaces and objects can be neglected (for example, when firing at targets located in buildings at a sufficient height, or when sound masking from reconnaissance aircraft is required), the ACFM indicator (8) and criterion (9) are more appropriate. In specific cases, it is possible to apply the ACFM criterion (10).

The advantage of the ACFM indicator (8) is the ability to predict the characteristics of the sound field and ACFM by analytical methods based on data on the location of the shooter and target, as well as physical parameters of the atmosphere. To use the indicator (11), it is necessary to have an empirical dependence $P_B(\tilde{p}_1, \tilde{p}_{M1}, X)$ or $P_B(L_1, L_{M1}, X)$, which will be unique for each weapon sample. However, the existence of such dependencies makes it possible to make more reliable predictions of the P_{ND}. This is due to the advantages of empirical dependencies, which take into account the peculiarities of human perception and interpretation of sounds, in particular the noise of a gunshot, as well as other factors that are not taken into account in analytical models.

Conclusion

In this article, deterministic and probabilistic indicators of acoustic concealment of a fire mission and criteria for them are developed. The advantages and areas of application of these indicators and criteria are determined.

The direction of further research is to determine the influence of acoustic concealment indicators on other indicators of the effectiveness of the fire mission.

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The article was submitted to the editorial office on 08.02.2024

УДК 623.44

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ПОКАЗНИКИ І КРИТЕРІЇ АКУСТИЧНОЇ ПРИХОВАНОСТІ ВИКОНАННЯ ВОГНЕВОГО ЗАВДАННЯ

Деякі вогневі завдання вимагають прихованого виконання, включаючи акустичне маскування. Наприклад, під час виконання завдань силами спеціальних операцій акустичне приховування дає можливість знищити чатових, спостерігачів та інших, якщо основні сили противника не отримають негайної інформації про атаку або проникнення цих сил у заборонену зону.

Незважаючи на значну кількість зразків малошумної зброї та пристроїв для зниження рівня шуму пострілу, наразі є проблеми з формуванням вимог до характеристик такої зброї, ухваленням рішень щодо її прийняття на озброєння відповідними військами та вибором малошумної зброї, шумової зброї з числа наявних зразків, яка відповідатиме конкретним умовам виконання певних вогневих завдань.

Одним із кроків на шляху вирішення цих проблем є розроблення таких показників і критеріїв акустичної прихованості вогневих завдань, значення яких мають бути відправними у процесах формування вимог до малошумної зброї та обґрунтованого вибору цієї зброї серед варіантів, які пропонуються ринком.

Розроблено детермінований і ймовірнісний показники акустичного маскування вогневого завдання та критерії до них. У разі застосування зброї по цілях, розташованих поблизу поверхні землі, доцільно використовувати ймовірнісний показник з відповідним критерієм. В умовах, коли впливом поверхонь і об'єктів можна знехтувати, більш доцільним є детермінований показник.

Перевага детермінованого індикатора акустичного маскування вогневих завдань полягає у можливості прогнозування характеристик звукового поля та акустичного маскування вогневих завдань аналітичними методами на основі даних про фізичні параметри атмосфери. Для використання ймовірнісного показника необхідно мати емпіричну залежність імовірності виявлення шуму пострілу від характеристик шуму пострілу, маскуючого шуму та відстані до зброї, яка буде унікальною для кожного зразка зброї. Проте наявність зазначеної залежності дає змогу робити більш достовірні прогнози акустичного приховування, що пояснюється тим, що ця залежність ураховує особливості сприйняття та інтерпретації людиною звуків, зокрема шуму пострілу.

Отримані результати можуть бути використані для порівняльної оцінки наявних зразків малошумної зброї та формування вимог до перспективних її зразків.

Ключові слова: *акустична прихованість, шум пострілу, звуковий тиск, показник, критерій, стрілецька зброя, вогневе завдання.*

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