UDC 623.44

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THE INFLUENCE OF THE IMPACTING ELEMENT MATERIAL HARDNESS OF A NON-LETHAL KINETIC WEAPON ON THE DEPTH OF PENETRATION IN THE MUSCLE TISSUES OF THE BODY

The impact of the hardness of the striking element of a non-lethal kinetic weapon on the depth of its penetration into the muscle tissues of the body was studied. The empirical dependence of the depth of penetration into the target of the striking element on its hardness and speed of encounter with the target for non-lethal kinetic weapons was obtained. The specified dependence makes it possible to predict the depth of penetration into the target of the striking element and to assess the safety of non-lethal kinetic weapons for the object of its application.

Keywords: *firearm, impact element, impact element hardness, terminal ballistics, target simulator, non-lethal kinetic weapon.*

Statement of the problem. During the ballistic design of a non-lethal kinetic weapon (NLKW), the correct determination of the characteristics of the striking element (SE) when meeting the target is extremely important. At the same time, on the one hand, it is necessary to ensure sufficient effect of the SE on the target, and on the other hand, not to cause injuries that could cause a fatal consequence of the use of NLKW. Therefore, such a list of the characteristics of striking elements and their values at the time of meeting the target should be determined, which would satisfy the above-mentioned condition. Not a few cases of unsatisfactory results from the use of NLKW (causing fatal injuries or insufficient impact on the target [1, 2, 3]) testify to the imperfection of the scientific and methodological apparatus for the formation of requirements for such weapons, in particular, the completeness of the list of criteria that sufficiently reliably guarantees safety application of NLKW is doubtful. In order to clarify the list of indicators of the criteria for the effect of striking elements on the target, it is necessary to discover the influence of additional factors on the results of the use of weapons, in particular, the hardness of the SE.

Analysis of recent research and publications. Today, the limiting values of the kinetic and specific kinetic energies of the SE are considered to be sufficient criteria for the safety of the effect of the striking element on the target. It is believed that limiting the specific kinetic energy to a value of 0.5 J/mm^2 makes it possible to avoid penetrating wounds and, therefore, to minimize the probability of a fatal effect of SE on the target.

Thus, in the standard [4] it is noted that projectiles with a native kinetic energy equal to or greater than 0.5 J/mm^2 at the minimum permitted distance of use have sufficient striking power. In works [5, 6] it is emphasized that exceeding the specific kinetic energy of the striking element by a value of 0.5 J/mm^2 is the basis for assigning cartridges to the category of ammunition. The maximum allowable value of the specific kinetic energy of SE, equal to 0.5 J/mm^2, is described in the article [7].

Regarding the regulation of the kinetic energy of SE, the situation is less clear-cut. For example, in the article [8], in the algorithm for substantiating the rational values of the technical characteristics of non-lethal kinetic weapons, it is assumed that the kinetic energy of the SE is within 65–80 J.

For example, in works [9, 10], the regularities of the formation of gunshot damage, the morphology of a gunshot wound in the range of kinetic energy 35–100 J were considered, which indirectly indicates the limits of the range of energy values. The article [11] states that 70–100 J of kinetic energy is sufficient for tissue damage.

The issues of developing NLKW are discussed in publications [12, 13, 14], but these sources do not pay attention to the issue of determining the limit values of energy characteristics of SE.

Therefore, it can be argued that there is a lack of consensus regarding the energy characteristics of striking elements, which are sufficient and not excessive for non-lethal kinetic weapons.

Another way of regulating the characteristics of SE NLKW is to limit the depth of its penetration into the muscle tissues of the target body. For example, publications [15, 16] proposed the introduction of an alternative criterion for evaluating the striking properties of traumatic impact bullets based on calculations of the length of the wound channel caused by it. However, this method is acceptable when assessing damage resulting from the actual use of weapons, but it is not suitable for predicting damage at the design stage of the NLKW. In this regard, in order to form requirements for the technical characteristics of NLKW, in particular energy and ballistic characteristics, in article [17] the authors researched the effect of the ballistic characteristics of the striking element of a non-lethal kinetic weapon on the depth of its penetration into the muscle tissues of the body. As a result, the empirical dependence of the depth of SE penetration into the target on its kinetic energy and speed of encounter with the target for non-lethal kinetic weapons was obtained. At the same time, in the course of research, it was noticed that during the use of hyperelastic materials for the manufacture of SE, the depth of penetration of the SE into the muscle tissues of the body is also affected by the hardness of the material.

Thus, analyzing the literary sources, it can be concluded that it is not enough to rely only on its energy and speed characteristics in order to predict the results of the impact of striking elements on the target. It is also necessary to take into account the hardness of the material from which the SE is made. At the same time, the permissible values of the energy and speed characteristics of the striking element will be refined, which will be related to its hardness when determining the depth of penetration of the SE into the target.

So, there is a problematic situation, which consists in the contradiction between the need to predict the effect of SE on the target and the lack of models that take into account the impact of the hardness of the striking element of a non-lethal kinetic weapon on the depth of its penetration into the muscle tissues of the body.

The purpose of the article is to obtain the dependence of the depth of penetration of the striking element of a non-lethal kinetic weapon into the muscle tissues of the body on its hardness.

Summary of the main material. Due to the complexity of mathematical modeling of the impact interaction of bodies, as well as due to the wide use of empirical coefficients in relevant mathematical models to study the influence of the hardness of striking elements on the depth of penetration into the muscle tissues of the body, it was decided to give preference to empirical methods. Based on the experience of conducting similar studies at the National Academy of the National Guard of Ukraine [17, 18, 19], the following equipment and materials were used for experimental studies: a pneumatic ballistic gun [19] to provide the SE with the required speed; plasticine target simulators (PTS) made of ballistic plasticine of the "Beschussmasse" brand weighing 6 kg; rubber SE with a caliber of 20 mm, a weight of 0.005 – 0.015 kg and a hardness according to Shore A of 30 units, 50 units, and 80 units; analog hardness tester TSH-A, which makes it possible to measure the hardness of soft polymer materials according to Shore A; digital electronic thermometer Testo 720 for controlling the temperature of the PTS; optoelectronic complexes XR2000 Chronograf for measuring the speed of movement of SE; caliper with a depth gauge to measure the depth of penetration of the SE into the target.

In previous studies, it was established that the depth of penetration of SE in the PTS corresponds to the depth of penetration into the muscle tissues of the body at a temperature of the PTS of 21°C [19]. The results of preliminary studies for SE with a hardness of Sh A = 80 units, which is the most common, are shown in Figure 1. The red markers correspond to the depth of SE penetration into the muscle tissue of the biological target simulator (a fragment of the abdomen of a "Big White" piglet), and the blue ones – into the plasticine target simulator. The red and blue lines are graphs of the approximating functions for the first and second cases, respectively. Taking into account the sufficient convergence of the given dependencies, further studies were carried out using a target simulator made of ballistic plasticine "Beschussmasse", the temperature of which was maintained at 21°C.

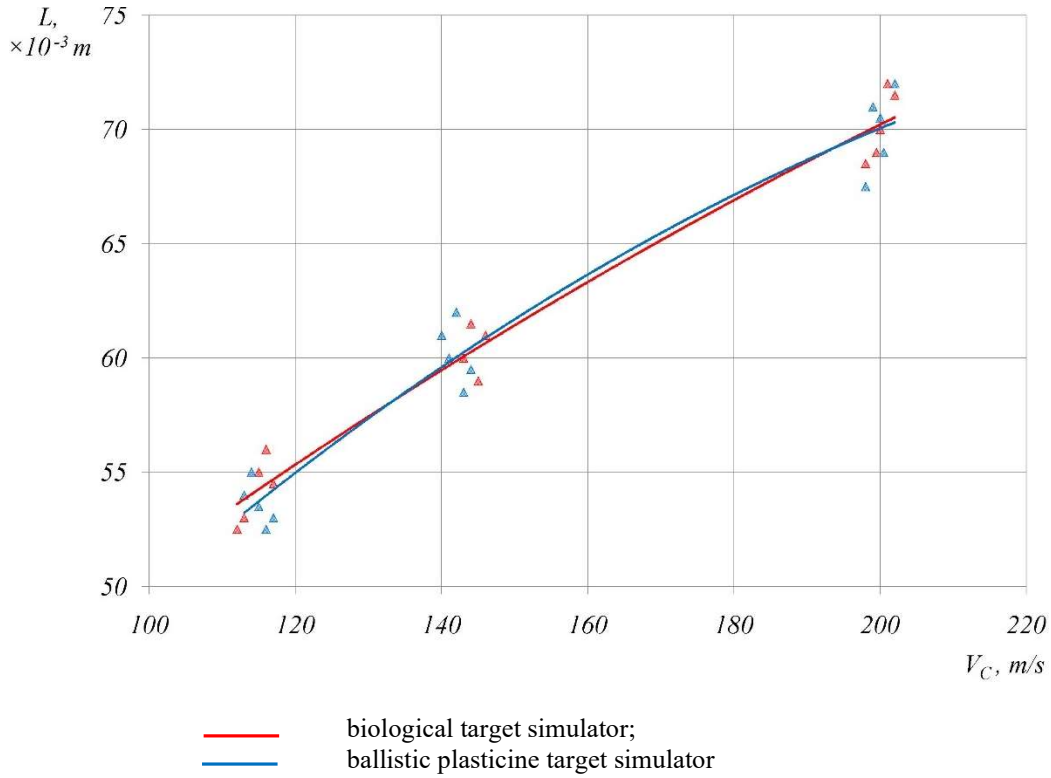

Figure 1 – Dependencies of the penetration depth of the striking element on the speed of impact the target for the striking element with a hardness of Sh A = 80 units

According to the plan of the experiment, shots were fired from a pneumatic device on a plasticine target simulator with impacting elements that had a hardness of Sh A = 30 units, Sh A = 50 units, and Sh A = 80 units. The variation in the speed of the striking element impacting the target at constant kinetic energy was ensured as a result of the change in the mass of the SE.

The obtained empirical data were processed by generally accepted methods of mathematical statistics [20], as a result of which, was obtained the dependence of the penetration depth of the impacting element into the target L on the speed of the SE at the moment of impacting the target *Vc* for the above-mentioned material hardnesses.

The penetration depth of the SE into the target is a function of its kinetic energy, therefore, to ensure the comparability of the results, the energy of the SE was fixed at the level of 100 J. The analysis of the available samples of NLKW [11, 21, 22] showed that this value can be considered the maximum from the point of view of the safety of using NLKW regardless of other SE parameters.

In Figure 2, the original empirical data obtained during the experiments are marked with markers, and the results of the approximation of the specified data are marked with lines. The indicated data are well approximated by the logarithmic function (1), (2), (3). The value of the coefficient of determination for the obtained dependencies is not lower than 0.96, which indicates a sufficiently close connection between the initial statistical data and their approximating functions. An exception is the dependence for the hardness of SE Sh A = 30 units, for which the value of the coefficient of determination is 0.67. This is explained by the insignificant influence of the SE speed on the depth of its penetration for too soft materials.

The obtained dependences can be presented differently: as dependences of the depth of penetration into the target of the striking element on the hardness of the material for different speeds of impacting the target (Figure 3) or as the dependence of the depth of penetration into the target of the striking element on its hardness of the material and speed of impacting with the target (Figure 4).

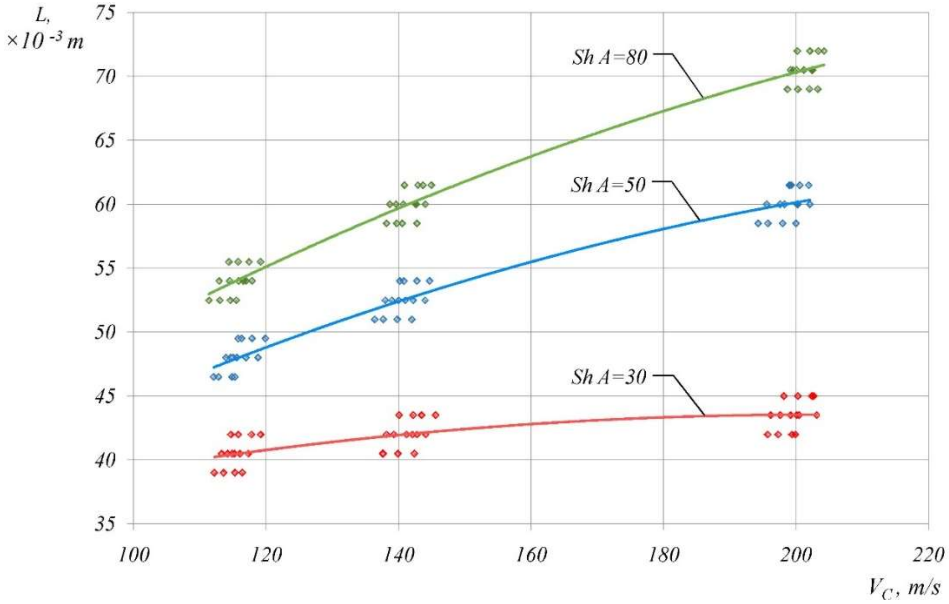

Figure 2 – Dependences of the depth of penetration of the striking element into the target on the speed of impact the target for different hardnesses of the material

$$L_{80} = 29{,}69ln(V_C) - 87{,}05, \quad (1)$$

$$L_{50} = 22{,}21ln(V_C) - 57{,}45, \quad (2)$$

$$L_{30} = 5{,}51ln(V_C) - 14{,}49. \quad (3)$$

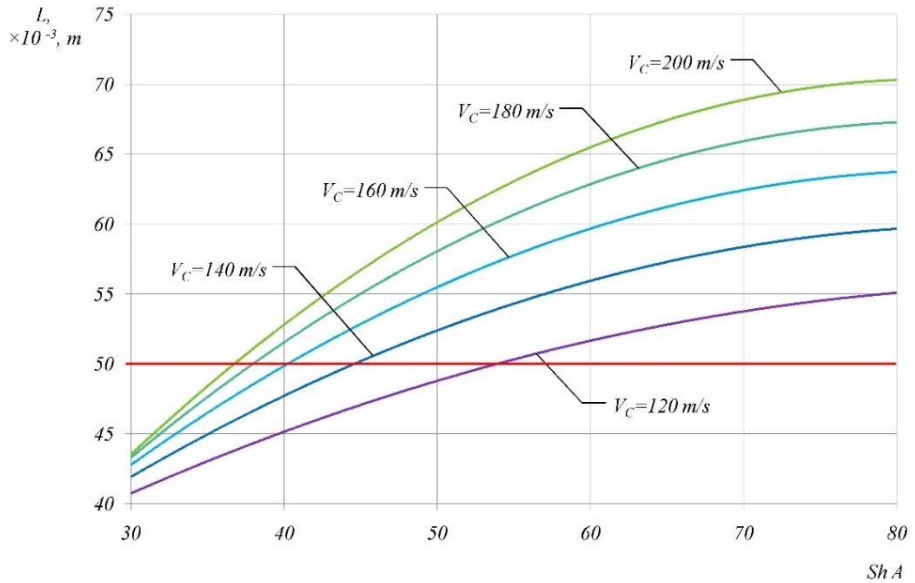

Figure 3 – Dependencies of the depth of penetration of the striking element into the target on the hardness of the material for different speeds of impacting the target

Dependencies shown in Figure 3, are described by equations (4) – (8).

$$L_{120} = 2{,}29\cdot10 + 7{,}11\cdot10^{-1}ShA - 3{,}86\cdot10^{-3}ShA^2, \quad (4)$$

$$L_{140} = 1{,}78\cdot10 + 9{,}73\cdot10^{-1}ShA - 5{,}62\cdot10^{-3}ShA^2, \quad (5)$$

$$L_{160} = 1{,}29\cdot10 + 1{,}21ShA - 7{,}21\cdot10^{-3}ShA^2, \quad (6)$$

$$L_{180} = 8{,}28 + 1{,}43ShA - 8{,}62\cdot10^{-3}ShA^2, \quad (7)$$

$$L_{200} = 3{,}85 + 1{,}62ShA - 9{,}84\cdot10^{-3}ShA^2. \quad (8)$$

From the point of view of the safety of using non-lethal kinetic weapons, it is considered important not to exceed the penetration depth of the SE into the target, which is equal to 50 mm [15, 16]. The combination of E_k and V_C, which are limiting from the point of view of the above mentioned criterion, corresponds to the red line in Figure 3 and Figure 4.

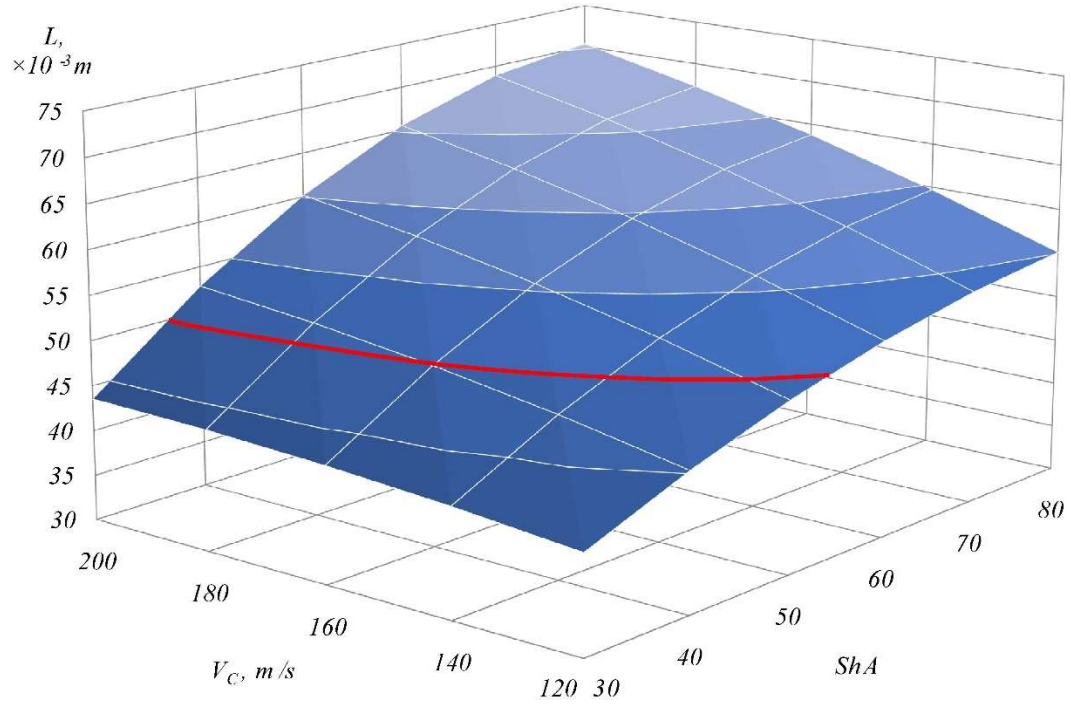

Figure 4 – Dependence of the depth of penetration of the striking element into the target on the hardness of its material and speed of impact with the target

Therefore, the conducted studies confirm the need to take into account the hardness of the striking element when predicting its action on the target. The obtained dependencies make it possible to predict the depth of SE penetration into the target depending on its hardness and speed of impact with the target, for the value of kinetic energy in the moment of impact with the target Ekc = 100 J. For other values of Ekc and hardness of the SE, additional research is required.

Conclusions

1. The empirical dependence of the depth of penetration into the target of the striking element on the hardness of its material and the speed of impacting the target for a non-lethal kinetic weapon was obtained.

2. The resulting dependencies make it possible to predict the depth of penetration of the striking element into the target and to assess the safety of non-lethal kinetic weapons for the object of its application, as well as to set the limit values of the speed or hardness of the striking element, provided that the values of other indicators are fixed.

The direction of further research is to obtain similar dependences for other values of the kinetic energy of the striking element during the impacting with the target and its hardness.

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The article was submitted to the editorial office on 25.09.2024

УДК 623.44

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ВПЛИВ ТВЕРДОСТІ МАТЕРІАЛУ УРАЖАЮЧОГО ЕЛЕМЕНТА КІНЕТИЧНОЇ ЗБРОЇ НЕСМЕРТЕЛЬНОЇ ДІЇ НА ГЛИБИНУ ПРОНИКНЕННЯ У М'ЯЗОВІ ТКАНИНИ ТІЛА

Під час балістичного проєктування кінетичної зброї несмертельної дії правильне визначення характеристик уражаючого елемента у момент зустрічі з ціллю є надзвичайно важливим. При цьому, з одного боку, необхідно забезпечити достатню дію уражаючих елементів по цілі, а з іншого, – не завдати травм, що можуть спричинити летальний кінець застосування кінетичної зброї несмертельної дії. Отже, слід визначити такий перелік характеристик уражаючих елементів та їхніх значень у момент зустрічі з ціллю, які б задовольняли зазначену вище умову. Аналіз літературних джерел свідчить про непоодинокі випадки отримання незадовільних результатів застосування кінетичної зброї несмертельної дії, що вказує на недосконалість науково-методичного апарату формування вимог до такої зброї. Зокрема, викликає сумнів повнота переліку показників та критеріїв, які достатньо надійно гарантують безпечність застосування кінетичної зброї несмертельної дії.

У ході попередніх досліджень установлено, що під час використання гіперпружних матеріалів для виготовлення уражаючих елементів на глибину проникнення у м'язові тканини тіла цілі впливає твердість матеріалу, але в наявних моделях для кінетичної зброї несмертельної дії цей параметр не враховується.

У статті досліджено вплив твердості уражаючого елемента кінетичної зброї несмертельної дії на глибину його проникнення у м'язові тканини тіла цілі. Отримано емпіричну залежність глибини проникнення у ціль уражаючого елемента від його твердості та швидкості зустрічі з ціллю для кінетичної зброї несмертельної дії. Зазначена залежність дає змогу прогнозувати глибину проникнення у ціль уражаючого елемента та оцінювати безпечність цієї зброї для об'єкта її застосування.

Одержані результати можуть використовуватися під час формування вимог до кінетичної зброї несмертельної дії, зокрема характеристик уражаючого елемента під час проєктування такої зброї або відбору наявних зразків кінетичної зброї несмертельної дії для постановки на озброєння.

Ключові слова: *вогнепальна зброя, уражаючий елемент, твердість уражаючого елемента, термінальна балістика, імітатор цілі, кінетична зброя несмертельної дії.*

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