Modeling of the behind armor action of fragments of armor obstacle on elements of combat armored vehicles

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Abstract
According to the experience of military conflicts in recent decades, including the Anti-Terrorist Operation (Joint Forces Operation), it is known that the survivability of armored combat vehicles and crew largely depends on the level of their protection. From the analysis of the received damages during performance of tasks it is known that repeatedly fighting armored cars due to a low level of protection lost a working condition because of receiving damages of knots (aggregates) by fragments of external armoring, which were formed during its penetration. Therefore, the task is to find ways to improve the layout of armored combat vehicles, to reduce the number of deadly fragments generated by external armor.
The article presents an approach for evaluating the results of the impact of fragments of external armor elements on the internal equipment of armored combat vehicles using mathematical modeling of the processes of spreading the action of fragments on the internal units of the vehicle. It was also found that the fragments, which have a high impact capacity, fly behind the obstacle in the form of cone-shaped flows and are evenly separated, and their penetrating ability is a random variable. Therefore, the article shows the probability of damage (penetration) of the aggregate by fragments, as well as the average number of fragments that can affect the aggregate.
For clarity, in accordance with the proposed method determined the probability of damage to the aggregates of some abstract sample of armored combat vehicle, the results allow us to judge the nature of the impact of fragments on various aggregates and combat calculation of armored combat vehicle, as well as identify those vital aggregates that are more subject to influence and damage by fragments.

Key words: armored combat vehicles, armor obstacle, fragments, modeling, fire damage, probability of defeat, elements.

Introduction

The experience of wars and armed conflicts in recent years shows that the success of military formations (units) will largely depend on high-tech (latest) samples of weapons and military equipment (WME).

Analysis of the tasks in the Joint Forces operation repeatedly confirms the practical dilemma, according to which the success of the tasks of mechanized, tank, airborne assault troops will fully depend not only on high-tech samples of weapons and military equipment, but also on the level of their protection to the striking factors of ammunition of kinetic action.

It is impossible to provide full protection of combat armored vehicles (CAV) in modern conditions of intensive development of means of destruction. To solve this problem to achieve the required level of protection of CAV, which would provide the opportunity to be the CAV in working order during the defeat of fire means devoted a large amount of work.

In addition, from the analysis of literature sources it is known that in the troops to protect personnel from fire damage has repeatedly used individual armored protection and other handy tools: boxes, sandbags, protective screens, etc. Such circumstances have led researchers to look for new ways and methods to increase the level of protection of CAV. The simplest way to increase the level of protection of the CAV is to increase the thickness of the armor barrier, but this method leads to an increase in the mass and size of the CAV (Lysyi M., Mysyk A., Dachkovskyi V., Horbachova Y., 2019). Another way is to increase the hardness of the armor barrier, but increasing the hardness of the armor barrier leads to cracks or splits. In this case, most of the studies is aimed at studying the stability of the armor barrier, but they do not address the issue of armor action of fragments of the armor barrier on the elements of the CAV and personnel which is located in the middle when hit by kinetic ammunition.

Material and methods

A number of works of both domestic and foreign scientists are devoted to the study of the protection of the WME samples from the means of kinetic action during the operation (combat), in particular in the work (Hrebenyk O. M., 2013) identified many options for technical solutions to increase the level of ballistic protection of multi-purpose vehicles for groups of decomposition of their construction, and in the publication (Brel M. P., 2018) the analysis of application of protective devices during conducting military operations which are made in armies, by forces of crews of samples of the WME. Based on this analysis, a variant of classification of such devices is proposed and attention is focused on the need to study the experience of their use. In the literature sources (Hrebenyk O. M., 2013) proposed an approach to the choice of rational design of a multi-purpose car with a high level of ballistic protection, and in the work (Slyvinsky O. A. Bisyk S. P. Chepkov I. B. Vaskivsky M. I. Chernozubenko O. V., 2017) provided the results of analysis and systematization of the main causes of defects in welded hulls of the CAV and identified the main areas of prevention. Some aspects of this issue are presented in the work (Maistrenko A. L. Kushch V. I. Kulich V. G. Нешпор O. B. Bisyk S. P., 2017), which presents the results of numerical modeling of the process of penetration of protective ceramic elements of different designs. The design of two types is offered: the block with ceramic cylindrical elements and the mosaic block consisting of flat ceramic elements, and in the work (Kostyuk V. V. Rusilo P. O. Kalinin O. M. Budyan R. G. Varvanets Y. V., 2014) the analysis of combat use of multipurpose vehicles in local conflicts according to which results, low protection of vehicles is carried out from small arms defeat, as well as fragments of fougasses and mines. The treatment of this problem is also reflected in the publication (Budyan R. G., 2015), which is devoted to the assessment of the level of technical excellence of “light” armored vehicles by assessing the level of technical excellence. The directions of improvement of tactical and technical characteristics, for the purpose of modernization and development of perspective samples are offered, and in work (Vaida T. S., 2013) modern methods of the technical decision of a problem of protection and maintenance of safety of transportation of freights are considered. In the literature (Agishev A. G., Bondarenko V. V., 2009) a comparative analysis of the WME samples, which allows to identify possible critical areas of development of the WME samples, and the work (Dachkovskyi V. O., 2020) is devoted to determining the stability and reproducibility of samples of the WME. In the work (Lester W.) the main focus is on determination of the weaknesses of armored combat vehicles, namely on the basis of the analysis of damage received in local wars and armed conflicts, an album of places of damage of armored combat vehicles was compiled, and in the work (Kolsky H.) the method of determining the ratio of stress and strain of materials is described. In the work (Janusz Sliwinski, 2011) the structural analysis of constructive decisions for increase of level of protection of the CAV from means of defeat is carried out, and in the work (Shanel V., Spaniel M., 2013) discussed some experimental results of the impact of the bullet on the composite armor barrier, to reduce the number of experimental studies were tested various approaches to numerical simulation. In the work (William T.) the analysis of technical characteristics of the CAV M113 is carried out, based on the results of which it is concluded that for its application in current and future operations this CAV lacks survivability, mobility and the ability to use digital networks. To eliminate this discrepancy, it is proposed to focus on the development of a new armored multi-purpose vehicle, and in the work (Astanin V. V., Olefir G. O., 2009) an analysis of the mathematical model of the impact process to study the impact strength of materials.

The purpose of the article is to model the impact of external armor fragments on various aggregates and personnel of the CAV, which are inside and on the basis of these data to find ways to improve the layout of armor protection and other measures to reduce the number of deadly fragments.

Results and discussion

According to the data obtained during the study of combat damage to the CAV in the Joint Forces operation, as well as damage received by the CAV in local wars and armed conflicts, it is established that in most cases the equipment and crew are struck not by the core of kinetic ammunition but are formed during the penetration of the armor obstacle.

Experiments on the shelling of armor obstacles also show the generation of a significant number of fragments that have a high impact capacity and fly behind the obstacle in the form of cone-shaped flows (Dachkovskyi V., Datsenko I., Kotsiuruba V., Yalnytskyi O., Holda O., Nedilko O., Syrotenko A., 2020; Kurtseitov T., Dachkovskyi V., Kizyak Y., Uhrynovych O., 2018). The shelling by ammunition of the kinetic action of armor, showed that the generated fragments fly away in the form of two cones, the vertices of which lie at the point of their sortie. The axis of one of the cones almost coincides with the direction of the velocity vector of ammunition at the time of its encounter with the armor (axial flow). The axis of the second cone coincides with the normal to the rear surface of the armor (normalized flow). Fragmentary flows are characterized by geometric and energy parameters. These include the angles at the vertices of the flying away cones (θ_0 i θ_n), the number of fragments in the flows (n_0 i n_n), as well as their penetrating ability (B_0 i B_n).

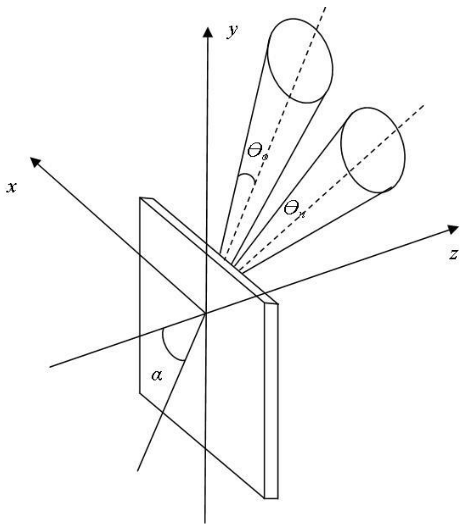

Fig.1. Position in the space of axial and normalized fragments flows

External armor of an armored combat vehicle consists of armor elements that differ from each other in material, thickness and angles. Therefore, fragments flows will be generated, when they break through, which differ in both geometric and energy parameters.

In order to obtain the necessary data to evaluate the results of the impact on the internal equipment of the fragments generated by the penetration of various elements of the external armor in different conditions of fire impact, it is necessary to conduct a large number of experimental shootings on the object (Dachkovskyi V., Datsenko I., Kotsiuruba V., Yalnytskyi O., Holda O., Nedilko O., Syrotenko A., 2020). Conducting such experiments involves significant time and material costs. The above problem can be solved theoretically on the basis of mathematical modeling of the processes of scattering and interaction of fragments on the internal aggregates of the vehicle, and then test the hypothesis experimentally (Dachkovskyi V., Datsenko I., Kotsiuruba V., Yalnytskyi O., Holda O., Nedilko O., Syrotenko A., 2020; Kurtseitov T., Dachkovskyi V., Kizyak Y., Uhrynovych O., 2018).

It is known from experiments (Dachkovskyi V., Datsenko I., Kotsiuruba V., Yalnytskyi O., Holda O., Nedilko O., Syrotenko A., 2020) that the fragments inside the CAV housings are evenly distributed, and their penetrating ability is a random variable that corresponds to a uniform distribution law in the range from 0 to B_{max}. In addition, the number of fragments in the flows that pierce the armor barrier of a given thickness is known. It is necessary to determine the probability of damage (penetration) of the aggregate in the middle of the CAV fragments, as well as the average number of fragments that pierce appropriate aggregate.

The simulation problem can be solved as follows. Suppose that each of the fragments pierces an obstacle of thickness h with probability p. Then the average number of fragments that break through this obstacle can be determined by the following dependence

$$\overline{n} = \sum_{k=1}^{\infty} kp^k = p\frac{d}{dp}\sum_{k=1}^{\infty} p^k = p\frac{d}{dp}\left(\frac{1}{1-p} - 1\right) = \frac{p}{(1-p)^2} \qquad (1)$$

where k – the number of fragments that pierce the obstacle during one test.

From the experiments the value of $\overline{n}$ is determined, knowing which p can be found by transforming the expression (1)

$$\overline{n}(1-p)^2 = p;$$

$$\overline{n}p^2 - 2\overline{n}p + \overline{n} = p;$$

$$p = \frac{(2n+1) \pm \sqrt{4\overline{n}^2 + 4\overline{n} + 1 - 4\overline{n}^2}}{2\overline{n}} = 1 + \frac{1}{2\overline{n}} \pm \frac{\sqrt{1+4\overline{n}}}{2\overline{n}}.$$

$$p = 1 + \frac{1}{2\overline{n}}\left(1 \pm \sqrt{1+4\overline{n}}\right) \qquad (2)$$

T

he choice of the sign in expression (2) is based on the condition $\lim_{n\to 0} p = 0$, the physical meaning of which is that with a decrease in the number of fragments to zero, the probability of penetration also goes to zero.

Therefore, the probability of piercing a given obstacle will be determined as follows

$$p = 1 + \frac{1}{2\overline{n}}\left(1 - \sqrt{1+4\overline{n}}\right) \qquad (3)$$

Since the fragmentary flow, which is formed by the armored obstacle, is divided into axial and normalized, it is necessary to talk about the probability of breaking through the obstacle by fragments of both axial p_0, and normalized flows p_n

$$p_0 = 1 + \frac{1}{2\overline{n}_0}\left(1 - \sqrt{1+4\overline{n}_0}\right),$$

$$p_n = 1 + \frac{1}{2\overline{n}_n}\left(1 - \sqrt{1+4\overline{n}_n}\right),$$

where n_0, n_n – the average amount of fragments in axial and normalized flows.

As an object of fragmentation, the unit, which is located in the middle of the CAV, can be represented as a set of flat armored elements, which is divided into the outer surface of the aggregate S_α; $\alpha = 1,2 \ldots m$, where m – the number of elements.

Consider the possibility of influencing the element of the aggregate fragments of one of the flows, for example, axial (these considerations will be valid also for a normalized flow).

Draw at some distance the perpendicular section of the cone from the top of the cone – the plane Z and design an element S_α on it in the manner shown in Fig.2. As a result, a figure R_α will be created on the plane Z.

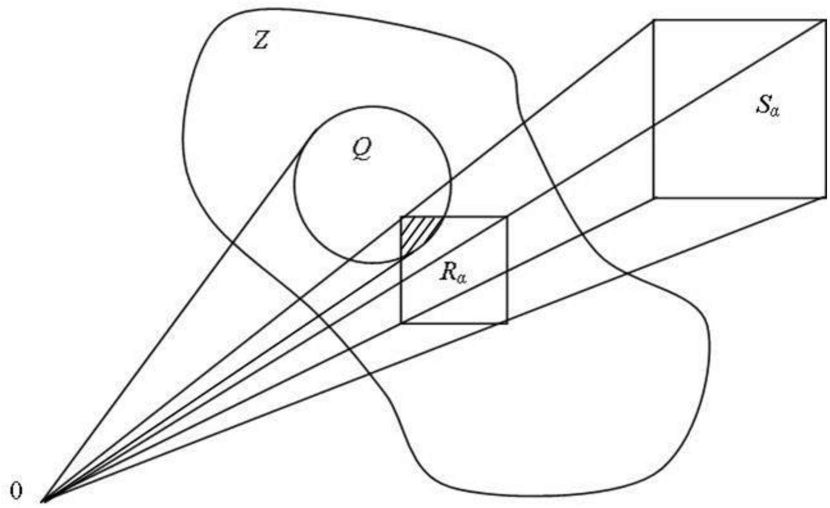

Fig.2. Scheme for determining the effect of fragments flow on a given obstacle

If the intersection of the cone Q and the figure R_α intersect, then the element S_α may be affected by fragments that flew off in this cone.

Denote the geometric probability of the element S_α getting into the zone of scattering of fragments through $p_\alpha{}^{(g)}$, then

$$p_\alpha^{(g)} = \frac{S(Q \cap R_\alpha)}{S(Q)}, \qquad (5)$$

where $S(Q \cap R_\alpha)$ – solid angle of the figure created as a result of crossing of a cone of scattering of fragments with an element of the aggregate;

$S(Q)$ – the solid angle of the cone of the scattering of the fragments.

The probability of defeat of the element S_α by one of the fragments in the axial and normalized flows can be determined as follows

$$p_\alpha^{(o)} = p_\alpha^{(g_o)} p_o; \quad p_\alpha^{(n)} = p_\alpha^{(g_n)} p_n; \qquad (6)$$

The average number of fragments that hit the element S_α in one of the flows is

$$\overline{n}_\alpha^{(o)} = \frac{p_\alpha^{(o)}}{\left(1-p_\alpha^{(o)}\right)^2}; \overline{n}_\alpha^{(n)} = \frac{p_\alpha^{(n)}}{\left(1-p_\alpha^{(n)}\right)^2}. \qquad (7)$$

Since the aggregate can be exposed to both flows at the same time, then the total average number of fragments that can hit it can be determined as follows

$$\overline{n_\Sigma} = \sum_{\alpha=1}^{m} \left\{ \frac{p_\alpha^{(o)}}{\left(1+p_\alpha^{(o)}\right)^2} + \frac{p_\alpha^{(n)}}{\left(1+p_\alpha^{(n)}\right)^2} \right\}. \qquad (8)$$

According to the proposed method, the probability of damage to the units of some abstract sample, which in its compositional and protective characteristics is close to infantry fighting vehicles, was calculated.

Five aggregates were used for the calculations, four of which were installed in the body of the machine and one in the tower. The first unit simulates the engine of the object, the second – the mechanic-driver, the third – ammunition, the fourth – the landing, and the fifth – the sight of the gunner-operator.

Analysis of the results of the impact of fragments flow on the internal aggregates shows that the probability of hitting the aggregate, which is located in the area of the engine-transmission compartment at its front placement, is 0,52, and the intensity of the flow of fragments that affects it – 1,435. (the average number of fragments per shot). However, due to the high protective properties (thickness of the elements), this aggregate does not break through the fragments.

The probability of hitting the aggregate located in the control room of the machine is equal 0,262. The aggregate is affected by the flow of fragments intensity 0,567. Since it has a relatively weak defense, equivalent in the stability of the defense of the combat calculation, and the probability of its penetration is 0,205, the intensity of the flow of fragments of the penetration is 0,425.

The third aggregate, located in the combat unit, despite the shielding of other aggregates, is significantly affected by the fragments flow. The probability of hitting it is 0,308, the intensity of the flow of striking fragments – 0,713.

The fourth aggregate, located in the area of the landing unit, is the least affected by fragments. The intensity of the flow of fragments that affects it is equal to 0,079, and the probability of hitting – 0,068. With the thickness of the elements that make up this aggregate, the intensity of the fragments flow which broke through is 0,039.

The probability of hitting the aggregate located in the tower is 0,088, the intensity of the fragments flow that hit and punched is equal to 0,11 і 0,073.

Conclusions

Thus, the results allow us to judge the nature of the impact of fragments on various aggregates and combat calculation the CAV, identify those vital aggregates that are more affected and damaged by fragments and on the basis of these data to find ways to improve layout, differentiation of armor protection and other measures , which are aimed at reducing the number of deadly fragments generated by external armor and their neutralization.

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