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ANALYSIS OF THE EFFECTIVENESS OF ARMORED COMBAT VEHICLES PROTECTION SYSTEMS AGAINST DESTRUCTION MEANS WITH A TELEVISION GUIDANCE

The article deals with the peculiarities of the functioning of armored combat vehicle protection systems and their capabilities to counteract weapons with a television guidance system.

Based on the analysis of the structure, characteristics and principles of operation of existing protection systems, tactical and technical characteristics of typical weapons with a television guidance system and features of their use, a classification of armored combat vehicles protection systems by stages of counteracting anti-tank weapons and their capabilities to influence weapons with a television guidance is proposed.

The creation of a system for protecting armored combat vehicles from destruction means with a television guidance system based on laser radiation and directions for conducting research for its implementation are proposed.

Keywords: *armament and military equipment, armored combat vehicle, protection, protection system, means of destruction, unmanned aerial vehicle, television guidance system, laser radiation.*

INTRODUCTION

The experience of local conflicts and wars of the 21st century allows us to confidently state that unmanned aerial vehicles (UAVs) used as means of destruction (MD) for armored combat vehicles (ACVs) are gaining a more and more stable position in the modern combat environment.

The conduct of hostilities during the repulsion of russia's armed aggression against Ukraine emphasizes the growing role of UAVs functioning as bomber drones and kamikaze drones. The most widely used for the destruction of ACVs and other types of weapons and military equipment (WME) are kamikaze drones of the Lancet family and commercial unmanned systems (copters from DJI, Autel, etc., FPV drones), which are specially equipped to function as means to destroy ACVs [1−3].

At the same time, the rapid development of science and technology in the field of microelectronics has brought anti-tank guided missile (ATGM) to a new level of sophistication, which are positioned by manufacturers as 5th generation systems. Their characteristic feature is the presence of a video transmission channel to the operator's console, which, among other things, is used to detect, identify and lock on the target [4, 5].

A common feature of these MD is the use of optical sensors in their structure, the video image from which is used both for spatial orientation and for targeting. This guidance principle can be classified as a «television guidance system» (TGS). It should also be noted that the peculiarities of the functioning of these MD allow attacking the least protected areas of the ACVs − the aft projection and the upper hemisphere [3, 6].

In view of the above, MD with TGS pose a significant threat to the ACVs, and the task of ensuring the protection of WME samples from them is of paramount importance.

The purpose of this article is to analyze the capabilities of existing ACVs defense systems to counteract MD with TGS and to determine directions for further research to improve the security of WME.

RESEARCH RESULTS

1. Capabilities of ACVs defense systems to counteract MD with TGS.

At the present stage of development of WME, increasing the protection of ACVs is achieved by increasing the thickness of armor, integrating differentiated armor, installing on vehicles hinged or mounted dynamic protection complexes (DPC), protective anti-cumulative screens (PACS), anti-drone protective structures (ADPS), equipping active protection system (APS) and optoelectronic countermeasures (OECM), electronic warfare (EW), camouflage systems, etc.

It is known that armor protection is the basis of the ACVs defense system. The armor scheme of modern ACVs was developed based on the analysis of the distribution of projectile load on different projections of combat vehicles, taking into account the experience of combat operations during World War II and other wars. The analysis of the projectile load on various armor projections during World War II shows that about 25 % of hits occurred in the upper and lower frontal parts of the hull, 45 % in the turret, 21 % in the front of the vehicle, 7 % in the rear of the vehicle, and 2 % in the stern. The analysis of the distribution of projectile load became the basis for the formation of layout diagrams of tanks of all postwar generations [7, p. 16]. The developed concept of armor protection remains on modern models of weapons and provides for maximum protection of the front projection of the ACVs, while the rest of the areas, especially the hull roof, turrets, the upper part of the engine compartment and the stern of the vehicle, have a much lower level of armor. The design features of the MD with TGS allow combat vehicles to be attacked in the upper hemisphere and from any heading angle, i.e., in the least protected zones. At the same time, the mass and size characteristics of modern ACVs limit the increase in armor of the least protected zones to increase protection against MD with TGS.

DPC are protective structures (hinged or built-in type) that use explosive energy to reduce the armor penetration of a munition. An analysis of publications [8−13] on this topic shows that they are highly effective in reducing the armor-piercing ability of shaped charges, which are mainly used in MD with TGS, while at the same time, their use has certain drawbacks and limitations:

– the design features of the DPC and the layout of the ACVs make it impossible to cover all projections that are most vulnerable to MD with TGS;
– the principle of operation of the DPC limits their use on ACVs with a low level of armor protection;
– DPC protect a certain projection only once, i.e., the use of several MD in one projection can result in the damaging of the ACV.

One of the ways to increase the protection of ACVs from grenades of hand-held anti-tank grenade launchers and rocket-propelled grenades is to equip them with a PACS. The principle of operation of the PACS is to destroy the shaped charge, as a result of which the jet is not formed or suboptimal conditions are created for its formation. The absence of the formation of a jet is achieved by locking the conductive circuit of the fuze of a grenade as a result of its deformation during interaction with the PACS. The creation of suboptimal conditions for the formation of a jet occurs as a result of deformation or destruction of the conical liner of the ammunition. The working elements of lattice PACS are the cells formed by metal plates of steel of the appropriate grade. The design parameters of the PACS cells (geometric dimensions, material characteristics, etc.) are determined by calculation, depending on the specific type of ammunition to be neutralized (to reduce its armor penetration). The calculations carried out by experts show that the expected probability of increasing the protection of an ACVs equipped with lattice PACS is 0.5...0.6 [14, 15].

The ADPSs were widely used during the russian-Ukrainian war to protect WME from attacking UAVs. As a rule, the basis of the ADPS is mesh structures that are installed on the ACVs in the form of visors and screens. The functional purpose of the ADPS is to prevent direct contact of the kamikadze drone with the hull and turret of the ACVs and to cover the plan surface of the sample of WME to protect it from munitions dropped from bomber drones. On tanks, the ADPS is mainly used to increase the protection of the most vulnerable area to MD with TGS − the upper hemisphere. Other types of ACVs can be equipped with ADPS depending on their design and functioning principles.

The analysis of the design and operational features of PACS and ADPS installed on the ACVs shows that they have a number of disadvantages, namely:
– significantly increase the size of the vehicles, which negatively affects their maneuverability;
– easily damaged by attacking ammunition and during operation in difficult terrain (forested areas, urban zones, etc.);
– partial overlap of the projections of the ACVs restricts the functioning of the components of the weapon system (installed screens limit the angles of vertical and horizontal aim of the gun, limit the viewing angles of aiming and observation devices, installation of a screen opposite the receiving and transmitting channel of the laser rangefinder makes its functioning impossible);
– the complete overlap of the ACVs projections of the PACS and the ADPS makes it impossible to operate both the weapon system and the APS, EW, and OECM equipment installed on the vehicle;
– access to the vehicle's components and blocks is restricted, which significantly complicates the maintenance and repair of the ACVs;
– installation of screens on the roof of the turret of the ACVs negatively affects the functioning of crew members in terms of boarding and disembarking the vehicle, loading and unloading the ammunition;
– destruction or deformation of protective structures may restrict access to the hatches of the ACVs, making it impossible to evacuate crew members from the damaged vehicle quickly and in a timely manner.

OECM are means of increasing the security of ACVs, which are functionally designed to interfere with the targeting and guidance systems of precision weapons and other destruction means in order to disrupt their guidance. The OECM of the ACVs consist of means for detecting the fact of an attack on a sample of weapons and means for interfering with the targeting systems of destruction means. The spectral ranges of these means are selected in accordance with the range of electromagnetic radiation in which the targeting and/or guidance systems of the destruction means from which protection must be provided, are functioning.

Papers [16−19] provide a detailed analysis of existing and prospective developments of domestic and foreign-made OECM. The study of the principles of functioning of existing OECM shows that the main factor in countering modern anti-tank weapons (ATW) is the installation of a multispectral aerosol curtain, which provides disruption of the targeting of ATW and the covert maneuver of the ACVs from the point of detection and irradiation. Setting up an aerosol curtain involves firing smoke grenades at a distance of 50−320 meters (depending on the complex) from the protected object and creating an impenetrable multispectral smoke curtain 10−120 meters wide and 3−10 meters high. The calculations show that a smoke screen up to 10 m high at a distance of 50 m or more from the ACVs provides an overlap of visibility in the angular value relative to the vehicle up to 10°. Paper [6] analyzed the distribution of angles of attack of ammunition attacking the ACVs from the upper hemisphere. It has been established that the angle of attack (angle of munition incidence) of an anti-tank guided missile equipped with a two-channel homing head (TV + infrared) and a command TGS via fiber optic cable (Spike-ER, Spike NLOS), when attacking an ACVs from the upper hemisphere along a hinged trajectory, is $\Theta \approx 60^{\circ}$. The peculiarity of the guidance systems of these ATGMs is the absence of active radiation towards the target, which makes it difficult to register the fact of the attack and, as a result, to initiate the aerosol curtain. To detect an ATGM attack without active radiation, the OECM can use ultraviolet radiation sensors that record the trace of the missile engine. At the same time, the angles of attack of these MDs significantly exceed the angular value of the aerosol curtain overlap front in the vertical plane, so there is no effect on the guidance system in this case.

UAVs used to defeat the ACVs as bomber drones and kamikaze drones use TGS for guidance, i.e., they do not emit laser and radar radiation towards the target. These UAVs use electric motors for flight, so they have low thermal contrast, which makes them difficult to detect by thermal imaging sensors, and do not leave a trace on the flight path that can be detected by ultraviolet radiation sensors. Their geometric dimensions and use in the structure of composite materials provide a low radar cross-section, which makes it difficult to detect them using radar.

The analysis shows that the principles of functioning of the existing OECM are not intended for impacting the guidance systems of the MD with TGS. The APS is a means of increasing the security of ACVs, which are functionally designed to destroy, damage, and deviate from the specified trajectory of attacking munitions.

Analysis of sources [16, 20–28] that discuss and highlight the principles of operation and technical characteristics of the APS shows that currently the vast majority of them are products that exist in the form of technology demonstrators or prototypes and have not yet been used in the composition of ACVs during real combat operations. An exception is the APS «Trophy», which is commonly installed on Abrams and Merkava tanks and adapted for installation on Bradley IFV and Namer, LAV III, and Stryker armored personnel carriers.

The analysis of the design and technical parameters of existing models of APS allows us to formulate their weaknesses in countering the MD with TGS:

- Taking into account the specifics of their application, MD with TGS hit the least protected zone – the upper hemisphere, with angles of attack of 0...90º. The overwhelming majority of APSs provide countermeasures against ATWs at angles of attack up to 60º. The installation of additional modules to protect the upper hemisphere, as implemented in the «Zaslon» and «ADS» complexes, is limited by the layout of individual samples of the ACVs and the high probability of colateral damage to the external equipment of the WME sample, which limits their use;
- limited multiplicity of triggering of protective charges of the APS in a given sector allows for an unimpeded attack of the area left without cover by protective devices;
- high accuracy of guidance of the MD with TGS and the possibility of attacking the target in any plane allows to attack the areas of the ACVs that are not protected by the APS;
- the lower limit of the speed of an ATW that can be intercepted by the vast majority of APS is 70 m/s (to exclude triggering from false targets). The maximum flight speed of bomber drones and kamikaze drones is between 20–50 m/s, which excludes their detection and destruction. The altitude from which bomber drones drop munitions is between 50–100 m (depending on weather conditions). The speed of a body falling freely from a height of 100 meters near the ground is about 44 m/s. This figure is also below the speed limit of existing APS.

The analysis shows that the existing APSs are not able to provide an adequate level of protection of ACVs from MD with TGS.

Classification of armored combat vehicle protection systems by stages of counteraction and their capabilities to affect the means of destruction with a television guidance system

Based on the results of the study of the principles of functioning of the components of the system of protection of ACVs from ATW, it can be concluded that the basic principles of its construction are as follows:

- disrupting the guidance of MDs in which laser radiation and/or infrared coordinators (OECM) are used for aiming (guidance, targeting);
- destruction (trajectory deviation) on the approach of attacking MDs by the active impact of countermeasures (fragmentation fields, explosively formed penetrators, etc.) (APS);
- destruction (absorption and dissipation of energy) during contact with the surface of the protective device (penetration of the main armor) of the MD (DPC, PACS, ADPS, armor).

Taking into account the methodology of constructing existing protection systems and their shortcomings, tactical and technical characteristics of typical MD with TGS and features of their application, Table 1 proposes a classification of the ACVs protection systems by stages of countering ATW and their capabilities to influence (counteract) MD with TGS.

The results of the analysis show that at the current stage of development of WME there are no personal protective equipment for ACVs that can provide protection against MD with TGS. The growing role of these weapons on the modern battlefield actualizes the creation of tools to improve protection against them. From the stages of counteracting MD given in Table 1, it can be concluded that disrupting their guidance (targeting) is the most effective way to increase the protection of the ACV, since it does not involve direct contact of the munition with the protective structures of the WME sample.

Substantiation of directions for further research to improve the protection of the ACVs from the MD with TGS

In order to substantiate the structure and parameters of the protective device for disrupting the guidance of a MD with TGS, it is necessary to distinguish their characteristic key feature – the presence of an optoelectronic system (television camera) used to generate and transmit video images in real time. Based on the received video image, the operator (or artificial intelligence, target acquisition and self-guiding system) controls the weapon and manages the target attack process.

Thus, it can be argued that the detection of the optoelectronic system and the impact on its sensors will allow to realize the disruption of the targeting of the weapon with the TGS.

Scientists from Ukraine and other countries have conducted studies [29–31] that show that laser radiation directed at the aperture of a television camera can both «blind» it and lead to irreversible changes in its functioning: from the appearance of dark stripes in the image to the complete cessation of its transmission [1]. The above information makes it possible to create a system for protecting the ACVs from MD with TGS based on laser radiation. The functional purpose of such a system is to disrupt the guidance of a MD with TGS by remotely damaging its optoelectronic system with laser radiation, that is, to provide optoelectronic countermeasures. The advantages of the system of protection of the ACVs against destruction means with a laser-based television guidance system include its high selectivity and

Table 1. Classification of ACV protection systems by stages of counteraction and their capabilities to affect the MD with a TGS

Counteraction stage	Methods of influence	Principles of operation	Capabilities to influence (counteract) MD with TGS
Failure of aiming (targeting)	Optoelectronic countermeasures against means of guidance (targeting) (OECM)	Generating a false signal for IR coordinators	No impact on the guidance systems of MD with TGS
		Registration of laser irradiation and setting up an aerosol curtain	
	Radio electronic countermeasures (EW)	Suppression of video transmission and control channels	No impact on MD with TGS, in which control is carried out via a fiber optic channel
			No impact on MD with TGS, in which the homing function is implemented
Destruction (deviation of trajectory) of the MD on approach to the ACV	Force (active) impact on the attacking munition (APS)	Detection of the attacking munition and its destruction (trajectory deviation) on approach to the ACV	Limited number of triggers in a given sector
			The presence of unprotected areas
			Restrictions on countering low velocity weapons
Destruction (dissipation and absorption of energy) of the MD during contact with the ACV	Use of kinetic energy of the attacking munition for its mechanical damage (PACS)	Destruction of the current-carrying circuit (deformation of the conical liner) of the RPG-7 shot	Presence of unprotected areas
			Limited number of triggering in a specific projection
			Lack of counteraction to remotely detonated munitions
			Effective counteraction to only a certain type of ammunition
	Preventing contact of the munition with the surface of the ACV (ADPS)	Covering the projections of the ACV with protective screens that prevent the penetration of low kinetic energy munitions	The presence of unprotected areas
			Limited number of triggering in a specific projection
			Lack of counteraction to remotely detonated munitions
	Absorption (dissipation) of energy of ATW (DPC)	Use of explosive energy to reduce the armor penetration of ATW	The presence of unprotected areas
			Limited number of triggering in a specific projection

an unlimited number of triggering, to repel an attack by a MD with TGS does not require the use of material resources, in comparison with electronic warfare means it does not require measures to ensure electromagnetic compatibility with the onboard equipment of the ACVs.

Paper [32] proposes a methodology for assessing the effectiveness of equipping tanks with OECM. In this methodology, the probability of its miss is used as an indicator of the protective properties of the optoelectronic countermeasures complex against a single impact of a destruction means, which is determined by the formula

$$P_{ki} = P_{detect.i} P_{p.o.i} P_{d.g.i} + \left(1 - P_{detect.i} P_{p.o.i}\right) P_{m.a.o.i}, \quad (1)$$

where i – is the index of the type of attacking MD; $P_{detect.i}$ – the probability of detecting an attack by the means of reconnaissance of the countermeasures complex; $P_{p.o.i}$ – the probability of placing an obstacle in the direction of the i-MD before it approaches the combat vehicle at the minimum range at which the installed obstacle will remain effective; $P_{d.g.i}$ – the probability of disruption of guidance (miss) of the i-MD when placing obstacles; $P_{m.a.o.i}$ – the probability of a miss of the i-MD in the absence of obstacles.

To calculate the probability of a miss of a MD with TGS as a result of the impact of optoelectronic countermeasures based on laser radiation according to formula (1), the values of probabilities $P_{detect.i}$, $P_{p.o.i}$, $P_{d.g.i}$ will be determined by the probability of the following events:

$P_{detect.i}$ – probability of detection of the optical system of the MD by reconnaissance means;

$P_{p.o.i}$ – the probability of a laser beam hitting the aperture of the television camera of the MD with its subsequent blinding / functional damage at a distance from the ACV, which will ensure the impossibility of targeting the MD with a TGS due to the loss of the ability to form a video image;

$P_{d.g.i}$ – probability of disrupting the targeting of a MD with a TGS due to damage to its optoelectronic system.

From the logic of expression (1) and the applied probability indicators, it can be concluded that the effectiveness of the functioning of the system of protection of an ACV against a MD with a TGS is directly dependent on the effectiveness of the functioning of its mandatory components, namely, means for detecting the fact of an attack by a MD with a TGS and means for defeating its optoelectronic system (TV camera).

Taking into account the peculiarities of the functioning of MD with a TGS and the peculiarities of the operation of combat vehicles, the task of further scientific research in order to substantiate the rational values of the parameters of the system of protection of ACVs from MD with a TGS is to conduct research on:

– requirements for means of detecting and accurately determining the coordinates of the optical system of the attacking MD;
– requirements for the laser beam guidance system of the ACV protection system against MD with a TGS;
– dependence of spatial-energy parameters of laser radiation and its influence on the functioning of the television targeting system MD;
– the influence of external factors on the effectiveness of the functioning of the ACV protection system against MD with a TGS.

CONCLUSIONS

Based on the results of the analysis carried out in the article, it was found that the existing personal protection systems for ACVs, in terms of their functional purpose and technical characteristics, are not able to effectively counteract MDs with a TGS. It has been established that disrupting the targeting of a munition is the most effective way to increase the protection of combat vehicles, since it does not involve direct contact of the munition with the protective structures of the WME.

To increase the protection of ACVs against MDs with a TGS, it is proposed to create a defense system based on laser radiation. The functional purpose of such a system will be to disrupt the targeting of a MD with a TGS by remotely destroying its optoelectronic system. Taking into account the peculiarities of the functioning of MDs with a TGS and the peculiarities of the operation of armored combat vehicles, the directions of further scientific research are proposed in order to substantiate the rational values of the parameters of the laser-based defense system for ACVs.

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АНАЛІЗ ЕФЕКТИВНОСТІ СИСТЕМ ЗАХИСТУ БОЙОВИХ БРОНЬОВАНИХ МАШИН ВІД ЗАСОБІВ УРАЖЕННЯ З ТЕЛЕВІЗІЙНОЮ СИСТЕМОЮ НАВЕДЕННЯ

У статті розглянуто особливості функціонування систем захисту бойових броньованих машин та їх можливості щодо протидії засобам ураження з телевізійною системою наведення (до них автор відносить протитанкові ракетні комплекси 4 і 5 покоління та безпілотні літальні апарати, які функціонують в якості засобів ураження бойових броньованих машин).

На основі аналізу будови, характеристик та принципів дії існуючих систем захисту, тактико-технічних характеристик типових засобів ураження з телевізійною системою наведення та особливостей їх застосування, запропоновано класифікацію систем захисту бойових броньованих машин за етапами протидії протитанковим засобам та їх можливостями щодо впливу на засоби ураження з телевізійною системою наведення.

На основі проведеного дослідження встановлено, що на сучасному етапі розвитку озброєння та військової техніки відсутні засоби індивідуального захисту бойових броньованих машин, які здатні забезпечити їх всеосяжний захист від засобів ураження з телевізійною системою наведення. За результатами аналізу етапів протидії протитанковим засобам зроблено висновок, що зрив їх наведення (прицілювання) є найбільш ефективним способом підвищення захищеності бойових броньованих машин, так як він не передбачає безпосереднього контакту боєприпасу з захисними конструкціями бойової машини.

Для підвищення захищеності бойових броньованих машин від засобів ураження з телевізійною системою наведення запропоновано створення системи захисту на основі лазерного випромінювання. Функціональним *призначенням такої системи буде зрив наведення засобу ураження з телевізійною системою наведення шляхом дистанційного ураження його оптико-електронної системи.*

Враховуючи особливості функціонування засобів ураження з телевізійною системою наведення та особливості експлуатації бойових броньованих машин, запропоновано напрями подальших наукових досліджень з метою обґрунтування раціональних значень параметрів системи захисту бойових машин на основі лазерного випромінювання.

Ключові слова: *озброєння і військова техніка, бойова броньована машина, захищеність, система захисту, засоби ураження, безпілотний літальний апарат, телевізійна система наведення, лазерне випромінювання.*

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