Main Directions for the Development of Protection Equipment of Dynamic Type Using Electrical Energy

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Abstract—Dynamic-type protection devices with the use of electrical energy as energy material are a forward-looking direction. Immediate electrifying is highly effective against charges generating a cumulative jet, and the electromagnetic release of protective elements or executive devices at the present is considered particularly promising for protection against projectiles with kinetic action. Unlike the energy of explosives, electricity has a number of benefits in terms of its management.

Index Terms—Dynamic Protection; Armored Vehicles; Cumulative Jet.

I. INTRODUCTION

The modern complex operational environment requires the adaptation of military and other security forces to new internal and international asymmetric threats. Military vehicles intended for traditional land-based conflict are often mildly or insufficiently protected from asymmetric threats such as improvised explosive devices (IEDs) and explosively formed projectiles (EFP’s), common during operations in conflict regions. Modern armies equipped with tanks, armored vehicles and other large defense platforms can still be vulnerable to attacks with relatively cheap cumulative ammunition such as these shot by the system RPG-7, which are a preferred weapon of terrorists and rebels, and are a serious threat to armored combat technique. According to experts, in Iraq, grenade launcher attacks are second in the list of potential risks for tanks and armored vehicles after the anti-tank mines. Grenade launchers are also used to attack helicopters and take-off/landing planes. Hand antitank grenade launchers are usually not effective against the main battle tanks equipped with built-in and external dynamic protection. However, modern models such as the Russian RPG-29 launching grenade PG-29V with tandem-cumulative warhead, damages or destroys modern heavy tanks. Proliferation of advanced weaponry from states to terrorist groups, including shoulder-launched projectiles capable of defeating reactive armor, which dramatically increase the potential of terrorist threats, requires exploring of new materials, systems and strategies to provide maximum protection against anti-tank munitions both in conventional and asymmetric conflicts [1]–[3].

Passive armor is and will continue to be the main way to protect all combat vehicles as it provides protection against kinetic ammunition. The equipment of armored vehicles with passive or active dynamic protection will remain the main mechanism for protection against guided and unguided anti-tank means. This can also be extended to protect against rapidly moving kinetic ammunition, which is currently in various stages of research and development worldwide. Attempts have been made to integrate these armored light armored vehicles [4]. Other new armor concepts such as non-explosive reactive armor, hybrid electric-reactive armor, intelligent dynamic armor and electromagnetic armors are some of the promising protection systems for future armored platforms [5], [6].

A range of new materials, systems and technologies for armor protection against military and terrorist threats are developed or in process of investigation and testing at the Institute of Metal Science, Equipment and Technologies at the Bulgarian Academy of Sciences (IMSETHAC-BAS), including dynamic safety devices using electrical energy. The Institute has been involved in three sub-programs of the NATO Defense against Terrorism Program and has been leading organization in the Protection of helicopters from rocket propelled grenades - protection against anti-tank cumulative grenade PG-7V through electric armor has been developed within the program [7], [8]. Some of the main directions for the protection of armored vehicles which are being explored by the Institute are described below, showing the principal schemes of counteraction against both cumulative and kinetic ammunition.

II. DYNAMIC PROTECTION OF ARMORED VEHICLES

With the increase of the capabilities of the anti-tank means it became clear that the passive method for providing protection for the armored vehicles is practically impossible. Therefore, it is necessary to use an external source of energy for this purpose. Such source may be the explosive substance, electrical energy, energy obtained from the reaction of chemically active substances. There are many different types of devices that implement the principle of dynamic impact of anti-tank means, distinguished by the variant of performance, the use of energy source and the way of realization.

In the literature, a number of terms and terminology have been adopted to designate certain devices such as "reactive armor", "dynamic protection", "explosive reactive armor" and others that may in full capacity characterize a certain type of protective device using an external source of energy.
to counteract the anti-tank means.

Each variant of a protective device has a combination of positive and negative features. As a basic feature characterizing one or other safety device, the range of impact on the anti-tank means, the effectiveness of the different types of protective devices, the mass-size and the performance characteristics, the possibility to be mounted on different types of armored vehicles, etc. To the basic signs of classification characterizing the structural features of the type of protection, the means of initiation and activation, the energy used and the mode of action on the anti-tank means can be added.

The substantial reduction of the armor piercing of the cumulative jets in the barrier requires a significant amount of explosive that causes significant problems due to the impact on the protected object. Studies in this direction continue after more effective means of impacting antitank means with ejecting (moving) plates have been identified at the end of the 1950s. In this variant, the explosive charge plays an ancillary rather than a major role as a source of energy for the plates that directly affect the cumulative jet. This solution allows for increasing the efficiency and reducing the amount of explosive used.

Such a mechanism of action of the protective devices of a dynamic type is realized in series complexes, which can conditionally added to the first generation of type "Contact-1" and "Blazer".

The impact on the cumulative jet by means of metal plates that cross the path of the cumulative jet leads to the "spreading" and destabilization of the jet at the expense of the permanent effect of the plates. The main process of destroying the cumulative jet is the "spraying", which is accompanied by the dispersion of parts of the material into a "powdery" state. To ensure that the plates are ejected, a flat charge of a plastic explosive is used which is initiated by the action of the cumulative jet itself.

III. ELECTRICALLY-OPERATED PROTECTIVE DEVICES

The electrodynamic armor has two plates placed at a sufficiently large distance, one of which is connected to a high voltage condenser battery and the other is grounded. When, at stroke, the cumulative jet breaks the plates, it acts between the plates as a conductor that closes the circuit and initiates a discharge of electrical energy that causes a large pulse of current in it. This causes magnetic-mechanical instability of the jet, which leads to its destruction and a sharp decrease in its piercing capacity.

Electromagnetic armors are classified by the principle of self-activation (direct electrification, electro-thermal protection and non-self-activating) that acts on the attacking munitions, preliminary identified with the aid of a radar, a matrix or other external sensors ("smart armor"). There are ways of protection that combine several principles.

A. Direct electrification

Electrodynamic protection of this type removes the disadvantages of the dynamic type protective device with the use of an explosive and the ejection of plates through explosive detonation products as well as such disadvantages as the decreased efficiency at reducing the angle of approach of the anti-tank munition to the normal and the presence of a significant amount of explosive located on the surface of the object.

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The protective devices with electrodynamic action generally provide a high level of anti-cumulative action, regardless of the angle of the cumulative jet approach. The effect of such protection leads to the destruction of the cumulative jet at the expense of a large electrical impulse. In addition, it is possible to combine methods of action, including both the impact of a current impulse and the ejection of plates, with the help of this impulse, towards the jet in order to neutralize the remains of the jet. Such variants of protection appear to be one of the most promising directions for equipping light-weight armored machines (Fig.1) [9].

![Fig.1. Electro-dynamic protection scheme (implementation variant)](image)

Fig.1. Electro-dynamic protection scheme (implementation variant)
1 - Condenser battery; 2, 4 - Metal plates; 3 - Dielectric; 5 - Protected object; 6 – Inductor; 7 - Additional plate.

One variant of the protection design (with several layers of combat elements ("tandem type electrodynamic protection device") proposed by the Research Institute on Special Mechanical Engineering and Research Institute “Stali” [10] contains a pulse source of electrical energy coupled, by the formation of an electric chain, with the combat elements located in front of the protected object.

In the electrical circuit, by means of low-resistance wires, one or more analogous additional combat elements are consecutively connected, located between the main combat elements and the protected object. The battle elements are executed as two electrodes divided by a dielectric. (Fig.1). Electrodes of the main and the additional combat element, facing each other, can be coupled together to form a single combat element by dielectric array of the conducting dividers.

Another variant of the electrodynamic protection device (using combat elements and ejection plates) comprises a condenser battery coupled to the elements of the electrodynamic protection made in the form of metal plates which are separated by a dielectric, with a flat inductor mounted on the main armor connected between the capacitor battery and one of the plates. On the inductor side, facing the electrodynamic protection element, an additional
plate is inserted, which, when the inductor is turned on, is thrown against the striking element.

The device for electrodynamic protection of objects operates as follows: The cumulative jet penetrating through the plate and the electrodynamic protection element closes the circuit and, through the capacitor battery discharge, the increasing current "rejects" part of the cumulative jet. The proposed protection variant has been implemented in a volume less than a cubic meter, with the mass of the whole system, including electrodes and safety mechanisms, within the range of 2-3 tons. Even with such a low power consumption system, a maximum current approaching a million amps can be supplied. The effect of passing such a current through the jet of a modern cumulative anti-tank munition (RGG type) is capable of destabilizing it and causing radial disturbances in a diffusion circuit. At the contemporary level of the pulse energy power supply sources, for example 1 MJ/m² will occupy a volume of 5 m³, which equals one third of the internal volume of the tank.

B. Electro-thermal protection

The electro-thermal armor represents a set of metal plates, one of which is connected to a condenser battery, and the other is grounded. The plates are smaller in size and are separated by a relatively thick layer of insulating material instead of a significant airspace between them. When a pair of plates is penetrated by a cumulative jet or a kinetic projectile, electric current flows from one plate to another. This causes an explosive expansion of the insulating layer of the ejector plate. The electro-thermal armor is therefore self-activating and acts against the jet and the core, as a process resembling the action of an explosive reactive armor. In this concept, two metal plates are ejected not by an explosion but by a rapid expansion of the working fluid, the temperature of which increases at the expense of discharge of a large pulse of electrical energy.

In the test compound, the chosen working fluid has been polyethylene, hard at normal temperature but easily pyrolysed into plasma under the influence of arc discharge from a high voltage capacitor battery. At discharge, the conductor evaporates and transmits its energy to polyethylene, which quickly heats up, and increases its volume by ejecting the plate, similarly to ejection by explosive substance.

C. Discharge plates (with electromagnetic actuation)

The scheme of impact of the ejector plates on attacking kinetic ammunition is generally similar to the built-in dynamic protection. The difference is that the energy that is fed to the insertion and actuation plate is secured by the electrical system creating an electrical impulse rather than an explosion. (Fig. 2) [11]. Difference is that the energy that is fed to the plate to bring it into action is provided by the electrical system generating an electrical impulse, not by explosion.

This method offers a number of advantages compared to the use of an explosive as a source of energy. The electromagnetic start is associated with a small impact wave effect and fragments formation, the corresponding impact on the protected object proceeds in a predictable direction and location. There is an option to turn off the system when it is not needed, which also appears to be an advantage.

D. Dynamic-type protection devices activated by external sensors

Dynamic-type protective devices activated by external sensors occupy an intermediate niche between the dynamic-type protective devices and cumulative active protection with a short radius of action because the impact of the anti-tank means pre-captured by the sensor can be achieved not only directly upon contact with the armor, but also when approaching the armor, which increases the efficiency of such complexes.

When an anti-tank device is picked up by the multi-sensor interception system, the control unit activates the electronic computing machine and gears the switch, thereby transferring current from the capacitor battery to the disc coil of the induction type plate trigger system (or activates the explosive charge) (Fig. 3). The launching system ejects the plate on the trajectory of the upcoming anti-tank mean. The means of counteraction to the anti-tank means may consist of plates of homogeneous or composite armor or of dynamic protection devices.

 DOI: http://dx.doi.org/10.24018/ejers.2018.3.5.730
E. Smart” armor

The need to optimize the protection of armored machinery without increasing their mass has led to the development of a protection system including a dynamic type protective device and a pickup and control system. This has led to the development of the so-called "smart" armor which has been the subject of interesting research in recent decades.

For the realization of the "smart" armor system it is necessary to: determine the place of strike and logical processing, recognition of the threat and management of the corresponding countermeasures.

As a source of energy, both explosive and electrical energy can serve. The presented invention relates to non-self-activating protective devices of a dynamic type.

A number of sensors have been developed, capable of detecting a full range of type shocks that pose a threat to the object.

Optical analogs of the electrical foil, including a network of optical fibers, have also been used. They function by controlling the attenuation of passing light radiation in the direction of the fibers in the event of their interruption. In the third type of sensor, a piezoelectric polymer is used. Discretization of the sheets of this material generates stress by being exposed to controlled effects that are controlled.

Realizing a "smart armor" system that is able to “read” the projectile's trajectory is performed through the armor scheme using the strike location on the two layers of sensors placed in front of the machine's main armor. A logic block has been created that collects information from a set of sensors and performs the necessary processing to approximately determine the expected location of strike. The necessary calculations can be performed within several microseconds. For comparison, the means of attack go this distance for 50-60 microseconds. It is therefore possible to design a "smart armor" system using the passive detection method with sensors placed at a distance of no more than half a meter from the machine body.

These systems are capable of recognizing a different class of threat, based on their dimensions and speed. The amount of damaged sectors of each layer of sensors shows the area of the cross section. The magnitude of the signal produced is related to the physical dimensions of the projectile, and the time to signal increase is comparable to the projectile velocity. Therefore, the piezoelectric polymer has potential capabilities as a discriminator. The "smart armor" block is designed to control the response to an attacking projectile directed in the area of armor system where the strike is being experienced. The response can occur within the time interval between the impact on the sensor and reaching the main armor by the attacking projectile.

The operation principle of some samples is as follows: the anti-tank charge passes through two layers of sensors that transmit the information to the logic block that “reads” the projectile's trajectory and determines its type, then the attacking munition is actively effected by ejection plates [13].

IV. CONCLUSION

As noted in the publication [14], dynamic type protective devices have a high potential for improvement through optimization of the structure, choice of element parameters, use of new materials and schemes of impact on attacking anti-tank means.

The examined dynamic protective devices reveal the possibility of significantly increasing the safety of armored combat machines.

Important merits of such protection are:

- High efficiency in lowering the cumulative ammunition penetration ability;
- Significant reduction of the armor piercing of under-caliber projectiles and impact elements of "impact core" type;
- Relatively inexpensive and simple to manufacture protective device of a dynamic type, with the corresponding production capacities available, which in particular is justified by the large quantities (one armored machine is needed average about 200 units) of protective devices;
- Lack of the need for complex maintenance and control;
- Insensitiveness to various external influences.

At the same time, dynamic-type protective devices have weaknesses, such as high vulnerability to attacks from fragmentation-fougasse, volume-detonating and other means, capable of disabling the protective devices of a dynamic type or removing them from the surface of armor.

It has also been pointed out that prospective directions are the work on the protective devices of a dynamic type with the use of electric energy as an energetic material. Immediate electrification is highly effective against charges generating a cumulative jet, and the electromagnetic release of protective elements or executive devices at the present time is considered particularly promising for protection against projectiles with kinetic action. Unlike the energy of explosives, electricity has a number of benefits in terms of its management.

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