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OPERATING LOADS OF IMPULSE NATURE ACTING ON THE SPECIAL EQUIPMENT OF THE COMBAT VEHICLES

OBCIĄŻENIA EKSPLOATACYJNE O CHARAKTERZE UDAROWYM DZIAŁAJĄCE NA WYPOSAŻENIE SPECJALNE WOZÓW BOJOWYCH

Providing the combat vehicles with high operation effectiveness, safety and reliability during execution of complex tasks makes a priority. Therefore the armament and the military equipment have to meet very high requirements in that aspect when used in various conditions. This paper presents basic sources of dynamic loads affecting the combat vehicles. Attention is paid to the loads of impact nature as they mostly affect the effectiveness and reliability of a vehicle, electronic equipment and psychophysical condition of the combat vehicle crew. These loads result from off-road drives, firing the gun, the influence of the land mines or IED, hitting by enemy's missile. As a result, some fragments of the experimental and model tests on combat vehicles are presented. Results of these tests can be helpful when designing internal vehicle equipment including special equipment. Particularly in the aspect of normative requirements for that class of vehicles and their special equipment.

Keywords: *special equipment, combat vehicle, main battle tank, impact loads, research.*

Zapewnienie wozom bojowym wysokiej skuteczności działania, bezpieczeństwa oraz niezawodności podczas realizacji złożonych zadań jest traktowane priorytetowo. A zatem uzbrojenie i sprzęt wojskowy musi spełniać bardzo wysokie wymagania w tym aspekcie podczas eksploatacji w różnych warunkach. W pracy przedstawiono podstawowe źródła obciążeń dynamicznych działające na wozy bojowe. Uwagę skupiono na obciążeniach mających charakter udarowy, gdyż one głównie wpływają na sprawność i niezawodność pojazdu, urządzeń wewnętrznych i stan psychofizyczny załogi. Obciążenia te wynikają z jazd terenowych, strzelania z armaty, oddziaływania miny lub IED, trafienia pociskiem przeciwnika. W rezultacie przedstawiono niektóre fragmenty z badań eksperymentalnych i modelowych wozów bojowych. Wyniki tych badań mogą być pomocne przy projektowaniu urządzeń wewnętrznych pojazdu w tym urządzeń specjalnych. Szczególnie w aspekcie wymagań normatywnych dla tej klasy pojazdów oraz ich urządzeń specjalnych.

Słowa kluczowe: *wyposażenie specjalne, wóz bojowy, obciążenie udarowe, badania.*

1. Introduction

Combat (caterpillar and wheeled) vehicles, as a basic mean of execution of tasks by the army, are designed to execute special tasks in heavy-duty operation conditions. When riding on the roads and in the wilderness they are subject to the influence of dynamic reactions in a constant manner [5, 6, 11]. These loads have very complex structure and differ from each other with many factors, including values, nature, duration, intensity as well as the direction of action. The level of dynamic loads is determined by mutual interactions of a complex system, which consists of the following elements, namely: combat vehicle – internal equipment – ambient environment (the ground) – crew members [1, 12, 15]. A diagram of mutual interactions of components of the aforementioned system are presented on fig. 1.

The main factors causing dynamic loads while driving, affecting motor vehicles, including internal equipment and people located inside, are as follows:

- high driving resistance of significant variation frequency – type of the ground and resulting force reactions,
- dynamic loads resulting from driving at high speeds on various roads (including when crossing natural and artificial obstacles) – fig. 2a,
- influence of inertia (sudden acceleration and delay of motion, driving along a road curve, skidding etc.) – fig. 2b,
- engine, driving system and chassis.

In the caterpillar vehicles, due to the complexity of chassis, generated loads result from:

- cooperation of caterpillar bands with driving wheels,
- waving of upper sections of caterpillars,
- execution of serpentine motion, short jumps – as an element of active defence.

There are additional sources of dynamic loads in the combat vehicles resulting from combat operations. These are loads of impact nature, of various direction and intensity of action. They include:

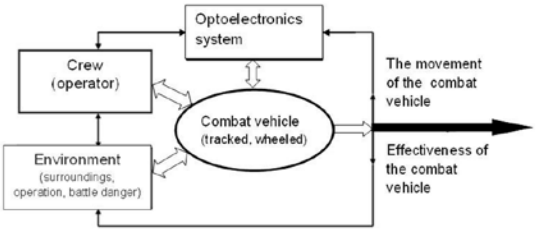


Fig. 1. Diagram of interactions in the system: combat vehicle – human – internal equipment – surroundings a) dynamic overcoming of a slope [3], b) overcoming of a cross ditch

Fig. 2. Combat vehicles during a ride in typical road conditions

- Firing the gun (fig. 3); level of impact depends on the gun calibre and type, missile type, condition of resistance-returners and other factors. The load during firing amounts to a value of several hundreds kN in a reaction of a second and generates the recoil. This force affects the tank tower, therefore it affects the internal equipment, the tank body and the crew. An approximate value of the tank gun recoil can be defined according to the Vallier's hypothesis [19], from the following dependence:

$$R_0 = \frac{0.5 \cdot M_o \cdot w^2_{\max}}{\lambda - L_k + w_{\max} \cdot t_p} \text{ [kN]}, \tag{1}$$

where: M_o – recoil unit weight [kg], λ– assumed recoil length [m], w_{max} – maximum free recoil velocity [m/s], L_k – free recoil path at the end of the post-exhaust period of the gun powder gas effect, t_p – time of completion of the post-exhaust gun powder action [s].

- A hit of a missile or a fragment in the armour without piercing. An effect of such hit is presented on fig. 4. Value of energy of a hitting element can amount to several or over a dozen of MJ. According to [4, 7] the impact energy can be defined on the basis of the following dependence:

Fig. 3. Firing the tank gun

$$E_p = \frac{m_p \cdot V_p^2}{2} \text{ [MJ]} \tag{2}$$

where: m_p – missile weight, V_p – outlet missile velocity.

- Influence of firing factors after the explosion of mines and improvised explosive devices (IED). In case of an impact wave load generated by explosion of a mine, according to a diagram shown on fig. 5, a value of the maximum pressure affecting a vehicle can be estimated according to [Kozłow A. G., Tału K. A., *Tank Structure and Calculation*. Moscow 1958] from the following dependence:

$$p = 60\psi \frac{m_{MW}^{0,87}}{r^{2,6}} (1 + \cos\Theta) \text{ [Pa]}, \tag{3}$$

where: m_{MW} – explosive weight, r – distance from a centre of explosion, Θ – an angle of the impact wave contacting the tank bottom, ψ – coefficient considering a mine depth in the ground and the loss of energy on the influence of the impact wave on the ground and the caterpillar (if explosion takes place under a caterpillar).

Listed loads refer to vehicles operating in the direct threat area and they mostly concern the infantry combat vehicles, wheeled armoured soldier carriers and other construction applications on their chassis.

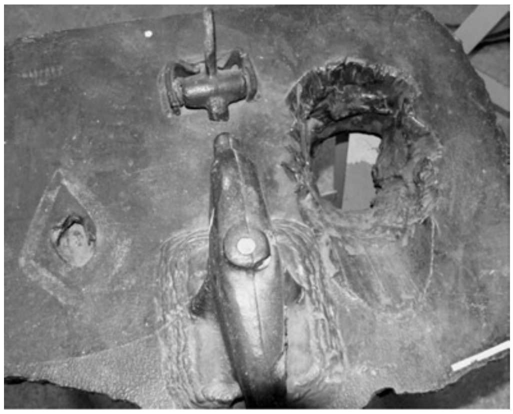


Fig. 4. An armour after missile impact (armour after tests in the Motor Vehicle Institute of the Military Technical University) – a photo from own collections

Fig. 6 presents an arrangement of special equipment in a combat vehicle body against the C centre of mass.

The equipment is located at a significant distance from a vehicle, depending on a vehicle type from 800 mm to even 2500 mm. Such equipment location has a significant influence on a dynamic load level.

When designing a new vehicle or modernizing and existing one, a number of design works are carried out in order to improve its effec-

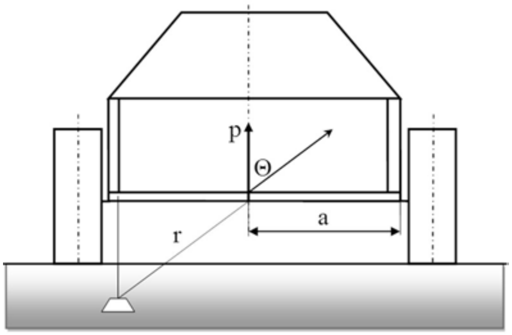


Fig. 5. Diagram of influence of a mine on a vehicle

Fig. 6. Arrangement of special equipment in a combat vehicle

tiveness. Multi-variant and multi-aspect model studies for expected loads are carried out. However, the quality, durability and reliability of introduced solutions and equipment operation can be evaluated only when the experimental tests, meeting the normative requirements, are carried out. [10]. This paper presents selected fragments from the experimental tests on combat vehicles subject to various impact loads. Their results make a good basis and can be helpful when designing the equipment of increased resistance to mechanical impacts.

It should be underlined that works related to the research and evaluation of effects of dynamic load influence on motor vehicles (both short-term and long-term ones) have been carried out for years both in national and foreign centres, presented among others [6, 8, 9, 13]. However, published results refer to a different aspect (load influence on people) and other vehicle category (light vehicles). As far as heavy vehicles are concerned, information about the works in this area is hardly available and not available for public. Therefore this paper tries to present an issue of influence of loads of impulse nature on a combat vehicle (tank) and its internal equipment during various operation conditions. Addressing that issue also results from a fact that the tank crew without properly operating devices of the internal equipment (including special equipment) does not represent a fully valuable mean of combat.

Due to used combat vehicles and scope of performed tests (parameters, conditions), obtained results are characterized by certain sensitivity and therefore they are of a quality nature.

2. Experimental tests on the influence of impulses on a combat vehicle body

2.1. Tests during off-road drives

The load tests were carried out in the premises of the Military Technical University at two stages. The first stage included test drives at pre-set speeds across single triangle prisms of pre-set geometrical parameters. Fig. 7a and b present selected courses of vertical accelerations of a frontal part of a tank body for various initial conditions of a caterpillar chassis. The second stage was carried out during drives on the ground road of average corrugation level.

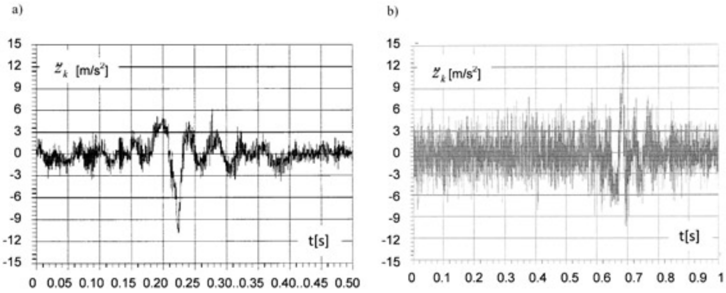


Fig. 7. Courses of vertical body accelerations, crossing a triangle prism of a height of 170mm and length of lo at the speed v=5.56m/s: a) and b) reflect various conditions of a caterpillar chassis

Table 1. Maximum vertical acceleration values of the front part of a vehicle body during off-road drives on the ground road of average corrugation level.

No.	Driving speed V [m/s]	Vertical accelerations of a vehicle body $\ddot{z}_k$ [m/s²]
1.	2,78	9,9
2.	4.17	14,7
3.	5,56	16,6

Table 1 specifies vertical acceleration values registered in the front part of a vehicle body for various driving speeds.

The analysis of obtained test results clearly indicates which factors determine the dynamic load level. Condition of a caterpillar chassis, speed acceleration and road type as well as a level of corrugation have a significant influence on the dynamic load increase. For wilderness of high corrugation level of random location and higher driving speeds (from 8 to 15 m/s), the level of loads, the impulse ones in that case, can exceed the values presented in the table by many times.

If the analysis assumes a drive on a frozen and ploughed field or on the stone or rock (rubble) ground, then a type of a vehicle chassis is important in the aspect of dynamic load level. Results of performed tests indicate the advantage of the caterpillar chassis (characterized by an ability to smooth the bumps of the ground) over the wheeled chassis.

2.2. Tests carried out at the influence of mine explosion on a vehicle

Introduction of non-contact reaction mines and improvised explosive devices (IED) among anti-armour means has increased the issue of resistance of combat vehicles and their equipment. The pressure of the explosion impact wave pressure dispersing at the supersonic velocity is the main firing factor of mines and IED. The wave affects an encountered obstacle. In that case it affects a combat vehicle body. As a result, it causes deformation of vehicle components and usually such vehicle can be eliminated from further actions. That type of firing means is called “humanitarian”, as their main firing factor does not affect directly the combat vehicle crew. It just affects the vehicle structure and internal equipment.

A necessary condition for minimizing the loss in vehicles designed conventional and non-conventional battle fields is to carry out the tests leading to define a level of loads and identification of effects of mine and IED impacts. Theoretical and practical tests should be performed on supporting structures and sensible equipment in almost continuous way and as a result they should be performed for complete vehicles. Easy theoretical tests are as more significant as they are verified by the experimental tests. It was one of the reasons why the experimental tests were performed and their results are presented below.

The main purpose of performed experimental tests in the military training ground conditions was to estimate a level of impact conditions affecting the combat vehicle body and equipment during an explosion of a non-contact anti-bottom mine. It generated fragmentary purposes that can be brought in order to obtain:

- information on the distribution of pressure in a highly limited space (between the vehicle bottom and the ground), among others, in the aspect of verification of mathematical model of post-explosion impact wave dispersion between the vehicle bottom and the ground and the caterpillar mechanism components);
- data on a level of loads affecting the caterpillar combat vehicle body and significant components of internal equipment;
- information on a level of pressure in the crew compartment of a combat vehicle;
- information on the effects of explosion of non-contact anti-bottom mines on the internal vehicle equipment.

A scope of tests included a measurement and registration of the following signals:

- pressure on the vehicle body components, in selected points
- vehicle bottom deformation,
- vertical acceleration of a vehicle body and a driver.

The tests were performed on combat vehicles representative for tank class type of vehicles. A profile of one of those vehicles, used in the tests, is presented on fig. 8. A source of loads included the mines with plastic PMW-8 explosive (weight: m_{MWi}) formed in a semi-spherical way. A shape of explosive and the way of arrangement under the vehicle are presented on fig. 9. The mine was places on the ground at a distance of h_i from the bottom, in the longitudinal axis of a standing vehicle, near the first or between the first and the second supporting wheels.

Fig. 8. Test object profile

Fig. 9. An example of explosive position under the vehicle in its longitudinal axis

Test results

Fig. 10 presents selected moments from the tests. While the fig. 11 and 12 present time courses of pressures affecting the vehicle body components, deformations of its bottom and vertical accelerations during explosion of an explosive of weight of m_{MWi}.

Fig. 13 and 14 present time courses of pressures registered on the surface of the combat vehicle bottom, in points distant from the explosion epicentre by R_1 and R_2 respectively, for two tests, both with an explosive of weight of m_{MW3} ($m_{MW3} > m_{MW1}$).

Presented courses of pressures of the impact wave for the next tests in corresponding measurement points are of very similar nature and very similar peak values. It indicates high recurrence of results.

a)

b)

Fig. 10. Selected moments from experimental tests on the influence of explosives on the combat vehicles

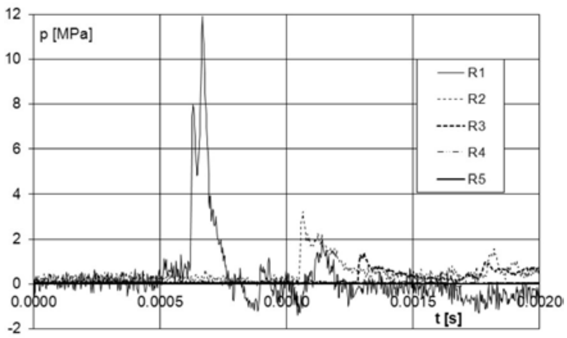


Fig. 11. Pressures in the vehicle body points at a distance of Ri from the source of explosion of an explosive of weight of m_{MW1}, where R1<R2<...<R5

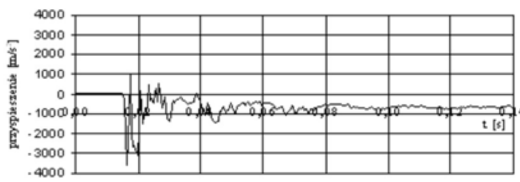
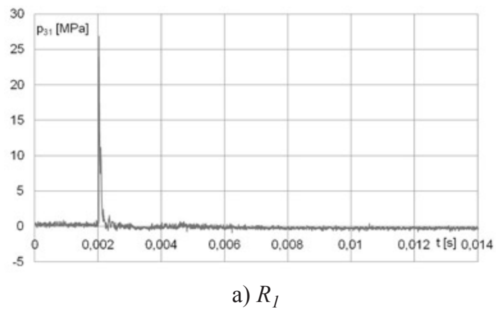
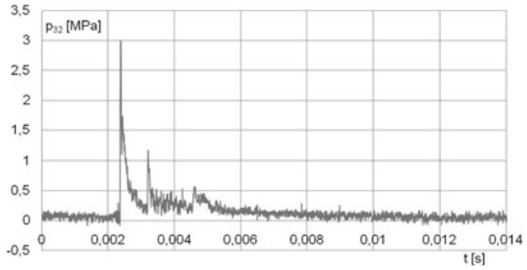


Fig. 12. A course of vertical accelerations of the vehicle body sections during explosion of an explosive of weight of m_{MW1}



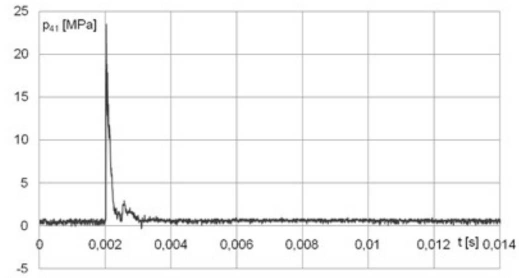
a) R_1

Fig. 13. Courses of pressures in selected points of the bottom for an explosive of m_{MW3}, clearance h, test 3

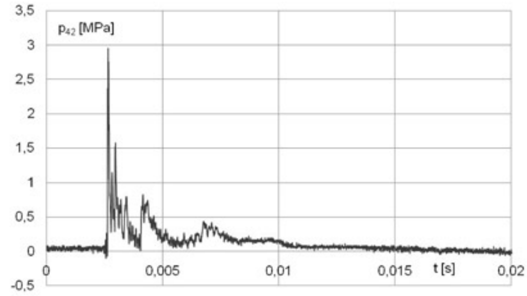


b) R_2

Fig. 13. Courses of pressures in selected points of the bottom for an explosive of m_{MW3}, clearance h, test 3 (continued)



a) R_1



b) R_2

Fig. 14. Courses of pressures in selected points of the bottom for an explosive of m_{MW3}, clearance h, test 4

The influence of such high pressures results in a single or multiple mechanical impacts. Its amplitude can exceed normative values acceptable for values for special equipment or other equipment. The effect of influence of explosives on supporting structures of the combat vehicles and the equipment and the internal equipment depend on many factors and each of them can have a dominating influence as well as an inconsiderable one. However the most important include: the explosive weight and its distance to the vehicle body. Other factors as explosive type, vehicle clearance, location towards the supporting structure, chassis structure can be of secondary significance.

2.3. Tests carried out when firing the main armament

When firing the gun (fig. 15), the load level depends on, among others, the following factors: the gun calibre, missile type.

The gun recoil force affects through the resistance-returners on the vehicle tower and internal equipment installed in it (such as viewfinder, rangefinder, ballistic converter, day observation and night vision instruments, communication equipment and other equipment). Results obtained from the experimental tests [16, 17, 18] – examples of courses of accelerations affecting the gun, vehicle tower components and centre of mass of the vehicle are presented on fig. 16 and 17. Courses presented on fig. 16 refer to firing an explosive projectile, while the courses on fig. 17 refer to firing a kinetic energy penetrator.

Fig. 15. Firing the gun in perpendicular direction towards the longitudinal axis

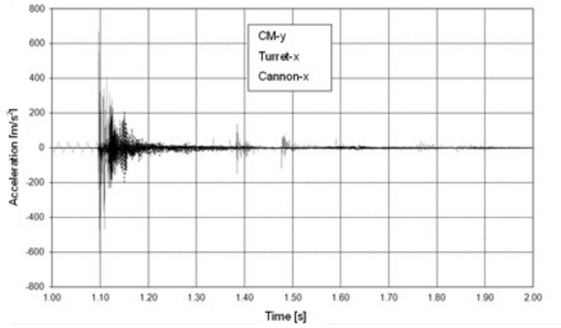


Fig. 16. Courses of accelerations affecting the vehicle tower when firing the gun with explosive projectile

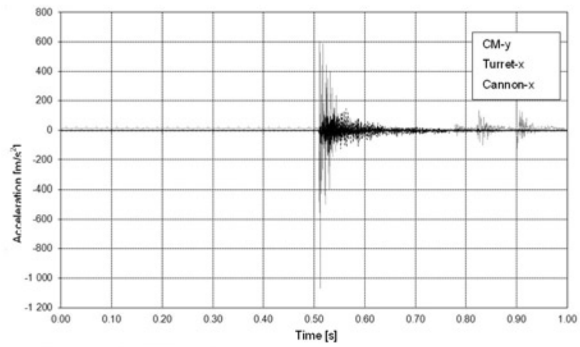


Fig. 17. Courses of accelerations affecting the vehicle tower when firing the gun with kinetic energy penetrator

Significant values of accelerations affecting the aforementioned elements, as a result on the internal equipment, can be noticed. The maximum values of the longitudinal accelerations of the gun amount to a level close to 2500 m/s^2, of the vehicle tower to over 700 m/s^2 the centre of mass to over 800 m/s^2, which is located below the axis of the gun trunnion. It should be underlined that the value of impact affecting the components of the vehicle body and tower depends not only on a type of missile but also on a technical condition and quality of resistance-returners.

3. Model tests

Usually, elimination from further operations and often destruction make the effect of missile acting on a vehicle. Model tests are one of the methods of shaping the resistance of the supporting structures and internal equipment. They are executed on the models that fully reflect the real vehicles. Models can be used many times and analysed in multiple variants until obtaining a supporting structure that fully meets the resistance requirement. The variants that are the most frequent in practice were chosen from various possible ones. Variants of missile impact on the tank tower or a front section of the tank body were analysed. The missile does not cause the piercing of the armour but gets stuck in its material or rebounds. Then the whole or a significant part of the missile energy in a dynamic (impulse) way is transferred directly or indirectly to the vehicle chassis. As a result, the impulse affects the internal equipment. The vehicle load level depends on a gun calibre, barrel length, missile type and initial velocity, impact angle, impact location, position assumed for structure node analysis etc. Courses of longitudinal accelerations, presented on fig. 18, refer to a case of hitting a tower of a tank, weight of 40 000 kg, with a rebounding missile fired from a gun of 120 mm calibre.

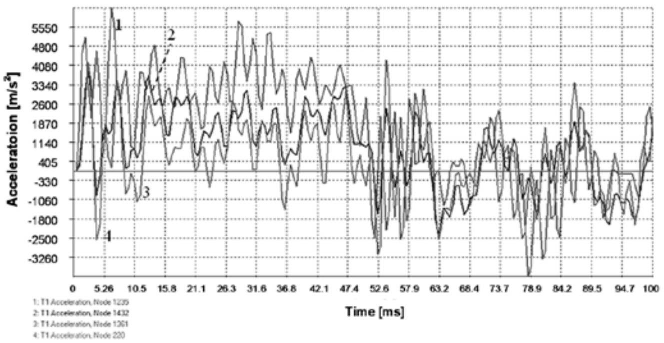


Fig. 18. Longitudinal accelerations in selected points of the tank body after a hit of a non-piercing missile: 1 – tower centre of mass, 2 – tank body centre of mass, 3 – a driver, 4 – floor under a driver's seat

Fig. 19. Caterpillar combat vehicle during rides in complex operating conditions

When using caterpillar combat vehicles, sometimes in unexpected conditions, the load can be more complex, as partially presented on fig. 19 – firing from an own gun when overcoming a counterscarp.

That type of load can consist of forces from the road roughness, firing an own gun, impact of the enemy's missile, explosion of antitank mine or improvised explosive.

4. Final conclusions

Dynamic loads affecting special equipment, as shown, are characterized by a high variability both in relation to a value as well as to direction of impact (vertical, longitudinal and transverse).

Sometimes the maximum values of mechanical impacts affecting special equipment of the combat vehicles significantly exceed the level of normative values and they can be even higher in the future. It is a consequence of permanent competition between a missile and armour.

Installation of special equipment fixed to the supporting structure of combat vehicles forces designers and manufacturers of the aforementioned equipment to imply solutions increasing their impact resistance and low sensitivity to forcing values, direction of action and frequency band.

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