Military special vehicle multifunctional seat as an element of vehicle passive safety

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Abstract. Road safety depends on the interaction in the human - vehicle - road system. The proper functioning or condition of each of these three elements is a prerequisite for ensuring the maximum possible level of safety. The most important requirement that is placed on special vehicles is to ensure crew protection during the implementation of operational tasks. Unfortunately, often when putting operational tasks overriding during designing vehicles, aspects related to driving comfort are ignored. The article presents a proposal for the description of light construction of seats for the crews of special vehicles, which, apart from the functions related to the ergonomic use of seats by the crew, in terms of safety ensure a high probability of protection of health and life of the crews during a collision or near detonation of an explosive charge. Proposed modular structure of the seats, in addition to the repeatability of elements, which reduces production costs and easy configuration of seats with various functions, will also contribute to a faster process of restoring their functionality in the event of damage. Modules should be selected and developed in such a way that they can be used in various configurations of seats, the functions of which can be determined due to: location in the vehicle, i.e. driver’s, troops, system operators’ seats, installation method, i.e. to the wall, floor, ceiling, direction assembly, i.e. side mount, rear mount, bottom mount.

Keywords: Explosion-proof seat, safety in transport, equipment of means of transport, explosion energy absorption, modularity, vehicle

1. Introduction

Human safety in transport is one of the elements of safety that is increasingly present in his daily activities. It results, inter alia, from the development of road communication networks, urban development of cities and the logistics supply chain. Generally, it can be argued that this safety depends on mutual interactions in the human (driver, passenger) - vehicle - road conditions and the correct condition of each of these elements. In general, it can also be argued that with respect to the component vehicles, safety is ensured by the proper operation of their functional systems [1].

The safety of vehicle use has not been directly defined, however, active and passive safety of vehicles are defined. Active safety is a set of factors that reduce the likelihood of a collision or a road accident and are provided by those elements that enable the driver to reduce the risk of an occurrence or avoid a hazard [2].

These are devices that allow the driver to take action before the occurrence of a road accident. These include factors such as ensuring good visibility from the vehicle (lighting, windows, mirrors, wipers), ergonomics (thanks to which the driver does not have to take his eyes off the road and his hands off the
steering wheel), stability of the vehicle, installation of the brake system with supporting systems, braking force correctors as well as vehicle traction control systems, steering system, suspension and tires ensuring steerability, proper interaction between the vehicle wheels and the road and adhesion to the road. Safety factors also include a wide range of engine power, which enables the maneuver to be performed, e.g. to accelerate in the event of an emergency. Active safety is also influenced by the driver - his skills, mental and physical condition.

Passive safety is the vehicle's features aimed at reducing the effects of a collision or road accident from the point of view of all its participants, i.e. events occurring at a time when the driver cannot influence the development of events and the nature of the vehicle's movement. The elements influencing passive safety in the structure are side reinforcements, crush zones, a safety cage, the appropriate shape of the body, a broken steering column, seats with a special design, headrests, seat belts, seat belt tensioners, airbags, elements made of non-flammable materials [2].

Compared to vehicles of the “civilian” sphere, there are several fundamental differences in the construction of military vehicles and in the conditions of their use that have an impact on human safety. This applies especially to military special vehicles, which are a special subset of the group of special vehicles. Some elements specific to active and passive safety may not be present, and at the same time, vehicle safety should be viewed much more wider [3].

A special vehicle is defined as a vehicle or trailer intended for special function which causes the body adapting or having special equipment [1]. A vehicle used for special purposes is a vehicle specially adapted for the transport of people or goods used by the Armed Forces. Therefore, a special military vehicle is a vehicle designed to perform special functions and having features that distinguish them from the group of special vehicles or those used for special purposes. Features that distinguish them from the group of special vehicles are: high center of mass, curb weight close to the permissible total weight, high moments of inertia of the body structure, tires with off-road tread, often lack of typical passive and active safety support systems, additional equipment mounted outside body, smaller window area [2,3].

From the point of view of functionality, military special vehicles also have special features indicating their separateness in the group of special vehicles, such as universality - the possibility of using the platform in both local and global conflicts, integrity - the need for connection with other types of equipment, primarily in terms of logistics or communication, modularity - assumes the existence of a base platform and the possibility of changing the purpose of the vehicle, transportability - the possibility of transport by rail, sea and air, mobility - the ability of the vehicle to negotiate the terrain, survivability - the ability to survive, continue tasks despite damage to the vehicle, lethality - ability to destroy the enemy (weapons, firepower) [2].

2. Seats as an element of passive safety

When talking about the safety of military special vehicles, this article will discuss the safety element, which is a seat, the functions of which, and thus also the structure, result from the conditions of “normal” vehicle operation, which include, among others, ergonomics, and on the other hand, the need to counteract threats from the enemy, i.e. such forms of his activity that are aimed at reducing the efficiency of the crew or damaging the vehicle.

The most important threats in this area include [2]:

- low level of anti-mine ballistic protection,
- injuries caused by dynamic loads while driving,
- injuries resulting from the organization of the interior (e.g. sharp edges, no escape routes),
- loss of health as a result of long-term work in a harmful environment (noise, vibrations),
- fatigue, poor mental and physical condition of the crew,
- loss of lateral stability (rollover).

It should be emphasized that seats, regardless of the type of vehicle, whether they are used in the civil or military sphere, are classified as passive safety elements. The appropriate shape and hardness of the seat and backrest with a headrest play a very important role in ensuring safety while driving, and above all in the event of an accident. The seat safety system is complemented by seat belts with tensioners and force limiters, which ensure the correct position in times of high impulse overloads.

In the event of a road collision, approximately 150 milliseconds from the moment of the collision, the acceleration value should automatically decrease. It takes approximately 120-150 milliseconds to stop a vehicle traveling at 50 km / h in a frontal collision. In such a short time, the driver has no chance to
The body does not move forward, and the torso is close to the backrest [1].

In addition, the above-mentioned assumptions overlap with the requirements of the ergonomics of the seat. The tasks of ergonomics are adapting technical objects to the dimensions and shapes of a person, securing the safety and comfort of using a technical object, eliminating the negative impact of the product on the conditions of the human environment, ensuring the functionality of a technical object (e.g. efficiency, reliability, susceptibility to adjustment and repair).

The seat should be able to be adapted to the individual dynamic and anthropometric characteristics of the crew. The term "anthropometric features" includes height, weight and measurable features of the anatomy of the human body, which distinguish in particular the spine, etc. Correct sitting position minimizes the strain on the muscles of the spine, abdomen, pelvis and thighs. The pressure on the backrest is much lower than on the seat surface and from an orthopedic point of view, it is very important to properly support the spine, especially the lumbar vertebrae. The backrest of the seat should be properly adjusted to the natural curvature of the spine.

To prevent lateral displacement of the body when driving on uneven surfaces, it is important to properly adjust the shape of the entire seat. However, in the lower part of the backrest, around the center of gravity of the body, as well as in the rear part of the seat, there should be sufficient clearance. The upper part of the backrest should be constructed in such a way as to ensure freedom of arm movements while e.g. driving a vehicle [4].

Another issue to consider is the universality of the workspace (anthropometry). The percentile of the p order (Cp) is the value for which p% of the population has the feature value lower, and the remainder of the population has the feature value greater than Cp. The ergonomics of the seat should be kept from 5 to 95 Cp. In general, it can be stated that the spatial structure of the seat should ensure safe and comfortable work for 90% of the user population, be adapted to their extreme dimensional characteristics, allow for the adjustment of some spatial parameters of the seat to the individual needs of users, introducing the possibility of adjustment, prevent the emergence of accident and health hazards.

The general requirements of the seat structure are specified, which should ensure the stabilization of the user's torso, limbs and head, the stability and durability of the seat itself, the possibility of its adjustment and easy operation.

Comfort angles have been developed (in the subject standards), i.e. optimal angles determining the sitting position ensuring maximum comfort and minimum fatigue. These angles characterize the bends and tilts of individual body segments, which ensure freedom and relaxation of the muscles and require a minimum of physical effort - Figure 1.

![Figure 1. The angles required in a sitting position for optimal comfort](image_url)

This can be achieved by using profiling and tilting the seat plate (for the working condition, the tilt angle should be between 3° - 15 degrees), shaping the side parts and backrests (support radius > 101.5 cm), supports for the feet, elbows, head (depending on the function).
The standards also provide the so-called curves of the sensitivity of the human body to vertical accelerations, which is related to the pressure distribution of a sitting person. These curves limit the exposure time that is comfortable. They are also a guide to choosing the shape of the seat, proper covering of the seat surface due to their hardness (deflection during dynamic movements), heat dissipation rate, friction coefficient, electrifying properties. A soft seat strains the spine, which causes pain. Lack of support for the thighs also causes fatigue.

Correct sitting position in the car affects the functioning of the musculoskeletal and circulatory systems, but also significantly increases the level of safety of the driver and people who are currently in the vehicle.

It is generally accepted that, depending on the type of car, various elements are movable and allow them to be adjusted depending on the height and dimensions of the driver. The more such elements, the better. Practically in every car, we can set the height of the seat, the angle of the backrest, and the height of the headrest. It is important to sit on the seat in such a way that the back rests completely against the back of the seat, and the body are inserted as far as possible to the entire depth of the seat, at the same time the edge of the seat should not press against the knee pits, the headrest should support the head, it is important that it is neither too low - on the neck, nor too high - above the head.

The acceptable criteria for periodic vibrations for humans are the time of operation, frequency of vibrations and the direction of vibrations - vertical ones cause the greatest injuries in the skeletal system - Figure 2.

![Figure 2. The acceptable criteria for periodic vibrations for humans](image)

However, in the case of special military vehicles, the seat's functions, apart from those listed above, which are typical for driving on the road, are much wider and result from the probability of negative enemy influences.

This challenge comes down to the simultaneous protection of crew members, in addition to ergonomic factors, against force impulses of different amplitude and duration, acting on the vehicle in the horizontal and vertical directions, resulting from a collision and the action of an explosive charge under and on the side of the vehicle (table 1).

|                  | Acceleration (g) | Impulse duration (ms) |
|------------------|------------------|-----------------------|
| Frontal car collision | 25 g to 50 g     | 70 ms to 120 ms       |
| Explosion under the vehicle | 100 g to 400 g  | 3 ms to 30 ms         |
In modeling, due to the multifunctionality of the seat for the driver, commander and the troops, in connection with the above-described requirements, conditions and functions, the assumption was made of the modular structure of the seat. The seat modules are its components, where apart from its main elements (seat, backrest, headrest, footrest), there are also fixing modules, or modules of movable joints, adjustment and shock absorption elements. The modules can be used in other construction configurations of seats, the functions of which can be determined due to: location in the vehicle, i.e. the seats of the driver, troops, system operators, mounting method, i.e. to the wall, floor, ceiling, mounting direction, i.e. side mounting, mounting from the back, from the bottom. The particular location of the seats imposes additional, individual functionalities on them, e.g. a reclining backrest (in the driver's seat due to the possibility of evacuation), seat rotation (for system operators), folding seat and backrest (for a troop), a platform for standing in the hatch, integrated fragments protection (in the backrest, seat and additional side covers). Modularity, in addition to the repeatability of elements, which reduces production costs and facilitates the configuration of seats with different functions, also contributes, in the event of damage to the seats, to a faster process of restoring its functionality during operation (module replacement). The challenge from the point of view of technology is the selection of materials for the production of modules, where the common feature is the strength of the materials with their low weight, selection of the strength, dimensions and mass characteristics of the main components of the seats, and the characteristics of the damping elements and their materials, i.e. such shaping of the characteristics of the damping element with influence the overall movement of the seat to reduce the forces affecting the human body, including those caused by an explosion, to a tolerable one. In addition, on the one hand, it should be avoided that the deformed floor of the vehicle will hit the legs of the crew member and, on the other hand, that it will hit the roof with its head, while reducing the acceleration of the seat. The seat materials should meet other requirements specific to the materials used in means of transport (non-flammability, corrosion resistance).

3. Modeling of seat properties in the case of a mine blast under the vehicle
   It was assumed that the resistance to mechanical vibrations and impacts of the entire structure of the seat is to meet the assumptions of the document Defense Standard NO-06-A103 "Weapons and military equipment", the requirements of UNECE Regulation No. 14, in relation to seat belt anchorages, UNECE Regulation No. 17, checking the strength of the backrest and headrest. Particular attention was paid to his energy consumption, i.e. the ability to dissipate the energy of an impact, the requirements of the NATO STANAG 4569 standardization agreement "Levels of protection of persons in logistic and light armored vehicles“ and the accompanying AEP-55 Volume 2 procedure. The seat model was prepared for numerical calculations - Figure 3.

![Figure 3. Model of the modular seat](image-url)
Vertical impacts on the vehicle seat from explosions are short-term forces. The models described in [7] are used to determine the Dynamic Response Index (DRIz) introduced by Stech and Payne [8]. In this model, the assessment of the organism response of a vehicle crew member is determined using the simple single-mass model shown in Figure 4.

The upper body is lumped together and is represented by the analogy of a single mass m resting on the top of the lumbar vertebrae. The stiffness of the vertebral column is represented by the massless spring with spring constant k. The damping behavior of the body is captured by the damping coefficient c.

Figure 4. Model diagram for determining the DRIz coefficient [9]

The equation of motion for this model is:

\[ \ddot{z}(t) = \ddot{\delta} + 2 \cdot \zeta \cdot \omega_n \cdot \dot{\delta} + \omega_n^2 \delta \]  

where

\[ z(t) \] – is the acceleration in the vertical direction measured at the position of initiation;
\[ \delta \] – is the relative displacement of the system with, \[ \delta = \xi_1 - \xi_2 \], and \[ \delta > 0 \Rightarrow \text{compression} \];
\[ \zeta \] – is the damping coefficient with, \[ \zeta = \frac{c}{2 \cdot m \cdot \omega_n} \];
\[ \omega_n \] – is the natural frequency with, \[ \omega_n = \sqrt{\frac{k}{m}} \].

The DRIz is calculated by the maximum relative displacement \( \delta_{\text{max}} \), \( \omega_n \) and the gravity acceleration \( g \):

\[ \text{DRIz} = \frac{\omega_n \delta_{\text{max}}}{g} \]  

Designing a seat with impact protection systems is usually supported by simulations in the LSDYNA program. Simulation models of explosions developed in programs such as MES Explicite, enabling the observation of deformation of the seat structure. There are special mechanisms and protective structures in the explosion-proof seat structures. Designing mechanical systems requires mapping their geometry and parametrization of deformable structures during the simulation process. Optimization of the parameters and characteristics of the elements in an explosion-proof chair should be optimized using the model shown in Figure 5.
Separating the mass of the passenger from the mass of the seat enables a simulation examination of the influence of the stiffness of the seat and seat belts on the DRIz coefficient. Using Multibody System (MBS) software, it is possible to select the design parameters of the springs and dampers used in the seat in order to minimize the acceleration values acting on the passengers. The dynamic model of the seat with seat belts and the mass representing the passenger was developed in the MSC.ADAMS program - Figure 6.

The model developed in the MSC.ADAMS program has play and vulnerability in the passenger seat system. This model is used to optimize the parameters of the dampers of the explosion protection mechanism. A particularly important non-linear element controlled and verified during the simulation is the free movement of the passenger in relation to the seat. Passenger displacements significantly change DRIz values in relation to the model favored by NATO [7].
4. Summary
None of the manufacturers currently offering mine-blast proofing seats offers such a solution that allows the optimal adjustment of the seat to the requirements of the end user, who must compromise between the level of protection and ergonomics.

Due to the current market demand and the modernization plan of the armed forces, there is a need to develop a multifunctional seats to protect the crew members of a special military vehicles against the effects of short-term dynamic loads of significant values. A product should be created that currently does not have a serial counterpart on the domestic market.

The development of the seat structure, in particular the selection of the parameters of the damping elements, was carried out with the use of analytical models with one degree of freedom (Figure 4). The implementation of subsequent iterations of the seat project required the detailed specification of parameters related to energy dissipation during the explosion. The authors proposed the use of simulation models with a greater number of degrees of freedom (Figure 5), and developed a simulation model in the Multibody System ADAMS software (Figure 6).

In the coming years, in the construction of military combat vehicles, activities aimed at ensuring the safety of the crew will be further developed, e.g. by modernizing or adding new systems.

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