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APPLICATION OF THE EMBEDDED MECHANICAL SYSTEMS FOR ENSURING THE PRESERVATION OF MILITARY EQUIPMENT PRODUCTS UNDER DYNAMIC IMPACTS

In the process of providing combat operations, the designs of military equipment products are subject to significant effects of both regular and non-regular dynamic loads, which can lead to their mechanical destruction. Among the dynamic loads acting on military hardware products, it is possible to identify short-term, caused by explosive and shock effects, and long-term vibrational loads that arise during transportation. As a result, there is the problem of ensuring the conservation of mechanical products of military equipment under dynamic impacts during the preparation and conduct of combat operations. The impact of a shock wave on military hardware products has a complex dynamic nature, depending on the wave parameters and the features of the object under consideration. Various results of this impact are possible, such as product destruction, turnover, change in the nature of motion, and others. The conservability of products with respect to the air shock wave is established experimentally. In addition to explosive loads, shock loads affect military equipment. In accordance with this, consider the local and general action of the thrust. Local action is characterized by the occurrence of local deformations and structural damage. The general action is accompanied by significant general deformations and destruction of the entire construction. The effect of prolonged vibration loads on military hardware products is mainly related to transportation processes. With prolonged cyclic loading, the destruction of the material of the structural elements can occur also at a stress amplitude less than the elastic limit. The article gives a definition of embedded mechanical systems and formulates their basic properties, which allow us to propose a hypothesis that in order to ensure the mechanical storage of products subject to dynamic influences, it is necessary to use embedded mechanical systems. Based on the nesting principle of mechanical systems, a method for increasing the retentivity of military equipment was proposed. The use of nested mechanical systems makes it possible to ensure the mechanical retention of military equipment by reducing the total energy supplied to the allowable value for the product to be stored.

Keywords: a mechanical system, an elasticity, a plasticity, a deformation, a dynamic loading, mechanical storage of products, means of destruction, products of military equipment, a shock wave impact, embedded mechanical systems, an aggregate state, a physical state, nesting principle of mechanical systems.

Formulation of the problem

Despite the intensive development of modern methods of conducting armed struggle and developing weapons on new physical principles, advanced conventional weapons are in service with modern armies. Therefore, the actual tasks remain to develop modern means of ensuring the retention of military equipment products damaged by dynamic loads.

Among the dynamic loads acting on military hardware products, it is possible to single out short-term, caused by explosive and shock effects, and long-term vibration loads that arise during the transportation of military equipment.

Explosive loads are caused by the action of a shock wave. The study of the interaction of the shock wave with military hardware products was started with the advent of explosives and is aimed at determining the distance from the center of the explosion to the product on which the product is not damaged. As a result of the studies, dependencies were obtained to determine the stress-strain state of military equipment products (MEP) [1, 2]. The impact of the shock wave on MEP is of a complex dynamic nature, depending on the wave parameters and the features of the object. Various results of this impact are possible: product destruction, turnover, change in the nature of motion, etc. The retention of products with respect to the air shock wave is established experimentally. According to the data of work [2], the resistance of land vehicles is 0.025 - 0.035 mPa.

In addition to explosive loads, on the MEP is operated shock loads. The main differences between shock impacts and explosive:

- interaction of the impact body with the construction;
- limited load area of application;
- short exposure time;
- peculiar wave processes arising in the construction [3].

In accordance with this, it is consider the local and general impact of the thrust. Local action is characterized by the occurrence of local deformations and structural damage. The general action is accompanied by significant general deformations and destruction of the entire construction. The main difference between the destruction of structural elements under static and dynamic influences is that under static loading the destruction of structural elements is characterized by some average voltage across the section. Under dynamic loading, the destruction of the structural element is determined by the local value of the voltage, which can greatly exceed the average value of the exertions [4]. As noted in [3], in view of the great complexity of taking into account the phenomena accompanying the action of impact loads and associated mainly with the spreading of waves, now, empirical dependencies are used mainly to determine the possibility of conservation of objects under shock effects.

The effect of long vibrational loads on MEP are mainly related to the transportation processes. With a prolonged vibration loading of the elements of MEP, formation and accumulation of structural deformations is possible. If under this loading the amplitude of the stresses exceeds the elastic limit of the material of the structure, then this accumulation, according to the data of work [4], becomes intensive. As a result, with a relatively small number of cycles, material can be destroyed at exertions less than the tensile strength. With prolonged cyclic loading, such destruction of the material of the structural elements can occur also at a voltage amplitude less than the elastic limit. In the interval between the limits of elasticity and strength, the level of stress oscillations exerts a great influence on the mechanism of structural destruction. At an exertion level close to the ultimate strength of the material, the destruction of the structure occurs practically either during the first cycle or (due to hardening of the material) after several cycles [4].

According to the data of works [3, 4], when transporting MEP by motor vehicles, the peak values of transverse overloads in such modes can reach relatively large values. Therefore, in the presence of tearing off the wheels from the roadway and the subsequent impact, they can reach values of 3-4, with the maximum allowable amount of overload for many products, for example, missile technology - 2. The destruction of structures encountered in practice is due to a number of reasons. Among these reasons [5]:

- insufficient accuracy of design methods;
- not taking into account the actual regime and the level of loads acting on the structural elements;
- imperfection of materials and technological processes leading to the production of structural elements to the deviation of material properties from calculated and the appearance of defects;
- deviation from the standard operating conditions, expressed in excess of the design loads;
- untimely and poor quality of maintenance and repair;
- the ungroundedness of the criteria of destruction and safety reserves.

Important information to eliminate the causes of structural damage is their analysis. The analysis of destructions allows revealing the causes of destruction of specific products of machinery, to exclude them in the future and to develop appropriate scientific research to study the physical processes that take place, and on this basis, to increase the level of structural stability.

In the literature, many cases are known where the destruction that took place stimulated the development of new scientific directions. For example, the destruction of ship hulls stimulated the development of fracture mechanics, the destruction of structures under conditions of oscillations led to the development of the theory of self-oscillations, fatigue destruction of aircraft - to the development of studies of low cycle fatigue, etc. Studies of the processes of particular relevance are destruction of high-pressure vessels (including the case of nuclear reactors) and pipelines operating at high pressures. Analysis of the causes of possible destruction of high-pressure vessels, which are the accumulator of mechanical energy, was carried out in work [6].

In the general case, structural failure occurs when excessive mechanical energy is applied to it. Therefore, the solution of the problem of ensuring the mechanical stability of structures is associated with solving the problems of developing structures designed for accumulating mechanical energy.

Analysis of the destruction of structures designed to store mechanical energy has made it possible to single out one of the common properties inherent in various mechanical systems designed to store mechanical energy (gas-water-fuel pipes, tanks, gas cylinders, etc.). This property is called the embedding properties of mechanical systems.

Thus, in the process of providing combat operations, the design of MEP are exposed to significant dynamic loads (both normal and not regular) that can lead to their mechanical destruction. In connection with this, the problem of ensuring the mechanical retention of military equipment products with dynamic influences in the process of preparation and conduct of combat operations becomes a number of top priorities. The theory of dynamic interaction of structural elements requires its further development, and the problem of ensuring the retentivity of MEP under dynamic loading is its solution.

The scientific basis for research into the process of ensuring the mechanical retention of military equipment products under dynamic impacts is: the theory of elasticity, plasticity and strength of materials, the theoretical basis for maintaining the retention of military equipment while conducting combat operations, the theory of sample reliability, mathematical modeling, mathematical planning of experiments [6].

The purpose of the article is to investigate the possibility of using nested mechanical systems to ensure the persistence of MEP under the action of dynamic loads.

The main material

By embedded mechanical systems (EMS), we mean mechanical systems, some of which are located inside others. Although this criterion is absent in the generally accepted classification of mechanical systems, EMS are widely used in the national economy and military equipment. The main feature of the EMS is the possibility of forming a system of substances that are in a different aggregate state (there are EMS type "Solid body-Gas", "Solid-Liquid", and “Solid-solid"). However, solid bodies play a special role in the technique. As is known, they have the ability to maintain (with constant temperature and load) its shape and dimensions. In the vast majority of technical products, the executive organs of machines and mechanisms are solid bodies [5, 6]. Even in cases where the actuating element is liquid or gas, they receive directed motion only because of interaction with a certain system of solids. The combination in a single mechanical system of substances in a different aggregate state, the external of which is in a solid state, leads to the appearance of certain properties in the system. The main properties of EMS can be formulated as follows:

1. Closures (nested mechanical systems can consist of substances in different aggregate states, however, the outer body must be in a solid state).

2. Accumulation (nested mechanical systems can accumulate mechanical energy).

3. Dependence (the amount of stored (accumulated) mechanical energy in embedded mechanical systems is determined by the mechanical properties of the external body).

4. Direction (embedded mechanical systems allow the transfer of stored) mechanical energy in a given direction.

The formulated properties of the EMS allow us to propose a hypothesis that in order to ensure the mechanical retention of products subject to dynamic influences, it is necessary to use the EMS.

On the basis of this hypothesis, it is possible to formulate the principle of nesting of mechanical systems: the required distribution of the total energy brought to the mechanical system to the allowable for individual elements of the system can be achieved by placing some elements of the mechanical system inside others. In a mathematical formulation, the formulated principle can be written in the form:

$$E_{\Sigma} = E_{add.} + \sum_{i=1}^{n} E_i \,, \tag{1}$$

where E_{Σ} – total energy, transferred to the object; $E_{add.}$ – energy, which can be perceived by the stored object; E_i – types of energy conversion in embedded mechanical systems.

The total energy of the system is determined, according to the law of conservation of energy for a system of interacting particles [9]:

$$E_{\Sigma} = T + U_{вз.} + U_{вн.}, \tag{2}$$

where T – kinetic energy of the system; $U_{вз.}$ – particle interaction energy; $U_{вн.}$ – potential energy of external conservative forces.

Allowable energy $E_{доп.}$ characterizes the energy that can be perceived by the object. In this case, the object should not lose its ability to function normally during the entire period of operation. The property of an object to withstand a certain load can be quantified, in general, by a vector function of the bearing capacity adequate to the corresponding vector function of external loading.

The principle of nesting of mechanical systems makes it possible to increase the operability of structures in those cases when the strength of the material limits the further increase in the operability of structures. This principle is more general in relation to known principles [6, 10]:

– the principle of the use of composite rods;
– the principle of fastening of structures;
– the principle of auto-fretting;
– the principle of combining vessels.

At present, the theoretical development of each of the listed principles can be considered complete. From the point of view of the principle of nesting of mechanical systems, all listed types of structures should be considered as constructions subject to a uniform calculation technique and to unified design principles. In this case, the task is not limited to the methodical method of combining individual theories into a single whole. It is possible that when revising these theories from the point of view of a single principle, changes in design and design provisions are possible. In addition, the application of the principle of nesting mechanical systems when considering the structure as a whole will make it possible to simplify the solution of the question of the strength of the structure.

The following provisions can concretize the content of the nesting principle of mechanical systems.

1. Geometric scheme. The principle of nesting of mechanical systems can be depicted as a geometric scheme in which the elements of the EMS can be divided among themselves or in contact (partially or completely).

2. The physical scheme. The materials of the EMS elements, as well as the material of the substance filling the elements, can be of different density and different physical state: solid, liquid, gaseous, with the exception of the outer element, which is in a solid state.

3. The physical scheme. The materials of the EMS elements, as well as the material of the substance filling the elements, can be of different density and different physical state: solid, liquid, gaseous, with the exception of the outer element, which is in a solid state.

4. Material state diagram. The material of the elements of the EMS can combine any state that preserves or changes the external form in accordance with the specified conditions.

5. Loading scheme. Elements of the EMS can be presented to those subject to various force impacts and various deformations.

To improve the efficiency of structures under the action of dynamic loads, it is possible, using the nesting principle of mechanical systems and, based on it, the method of constructive solution of the issues of ensuring the mechanical retention of the MEP in cases where the strength of the construction material limits the increase in external loads. In this case, two important tasks are solved:

1) with a material of the highest strength, to take even greater efforts than can be tolerated for the usual type of structures;

2) when perceiving known (limited) efforts, use less durable material.

These problems will be considered a single cycle of problems, the solution of which is methodologically subject to a single method.

The essence of this method, called the method of directional compliance, and its target orientation can be characterized as an increase in the mechanical retention of MEP under the action of dynamic loads by applying the design of the nesting principle of mechanical systems. Let us consider a general method for solving problems of ensuring the mechanical retention of military equipment products under the action of special dynamic loads. Figure 1 shows a diagram of the MEP designed to perceive a concentrated or distributed dynamic load.

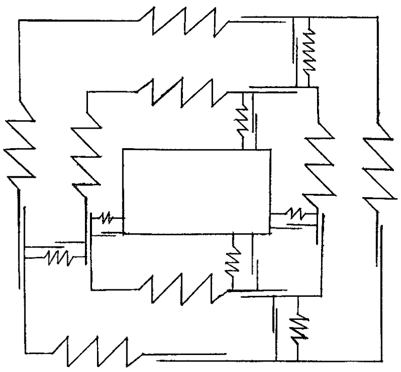

Fig. 1. Scheme of the embedded mechanical system

The total energy transferred to the embedded mechanical system under dynamic action is recorded in the form (1). The damping (transformation) of the energy of dynamic impact can occur due to the following components: E_1 – energy of elastic deformation of elements of the EMS; E_2 – the energy of destruction of some elements destined for destruction (without taking into account the energy of elastic deformation); E_3 – energy of elastic deformation of bonds included in the elements of the EMS; E_4 – energy of elastic bonds between elements of the EMS; E_5 – the energy of breaking bonds between elements of the EMS; E_6 – dissipation energy in the relationships between the elements of the EMS; E_7 – the energy of plastic deformations of elements of the EMS; E_8 – the energy of plastic deformation of bonds between elements of the EMS.

If we take:

– number of elements of the EMS - d_1;

– number of elements destined for destruction - d_2;

– the number of elastic bonds included in each element - d_3;

– the number of elastic bonds between two elements - d_4;

– number of links between elements destined for destruction - d_5;

– the number of dissipative bonds between two elements - d_6;

– the number of plastic bonds included in each element - d_7;

– the number of plastic bonds between two elements - d_8,

then the condition of ensuring the retention of the product ($E_{current}< E_{additional.}$), is determined from equation:

$$\sum_{i=1}^{n} E_i = d_1E_1+d_2E_2+d_1d_3E_3+d_4(d_1-1)E_4+ \\ +d_5E_5+d_6(d_1-1)E_6+d_1d_7E_7+d_8(d_1-1)E_8. \qquad (3)$$

Expression (3) has a constructive form, indicating a variety of design options for structures operating under the action of dynamic loads. In this way,

$$E_\Sigma = E_{add.}+ \\ +d_1E_1+d_2E_2+d_1d_3E_3+d_4\left(d_1-1\right)E_4+ \\ +d_5E_5+d_6\left(d_1-1\right)E_6+d_7d_1E_7+d_8\left(d_1-1\right)E_8. \qquad (4)$$

Introducing the generalized safety factor η, the energy, perceived by the protected object is determined using expression:

$$E_0 = h^{-1}\times \\ \times\left(E_\Sigma-\left(\begin{matrix} d_1E_1+d_2E_2+d_1d_3E_3+d_5E_5+ \\ +d_4\left(d_1-1\right)E_4+d_6\left(d_1-1\right)E_6+ \\ +d_7d_1E_7+d_8\left(d_1-1\right)E_8\end{matrix}\right)\right). \qquad (5)$$

The generalized technique of ensuring the mechanical retention of military equipment products under dynamic influences is based on determining the total energy supplied to the object, comparing it with the allowable energy and developing ways to reduce the energy supplied to the product.

Practical application of the proposed method of directional compliance to ensure the mechanical retention of the MEP under the action of small arms and to ensure a non-parachute discharge of goods in the works is considered [11, 12].

Conclusions

The use of nested mechanical systems makes it possible to ensure the mechanical retention of military equipment by reducing the total energy supplied to the allowable value for the product to be stored.

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Застосування вкладених механічних систем для забезпечення зберігання виробів військової техніки при динамічних впливах

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В процесі забезпечення бойових дій, конструкції виробів військової техніки піддаються значним діям як штатних так і не штатних динамічних навантажень, які можуть привести до їх механічного руйнування. Серед динамічних навантажень, що діють на вироби військової техніки, можна виділити короткочасні, такі, що викликаються вибуховими і ударними діями, і тривалі вібраційні навантаження, що виникають в процесі транспортування. У зв'язку з цим існує проблема забезпечення механічної збереженості виробів військової техніки при динамічних діях. У роботі дано визначення вкладеним механічним системам і сформульовані їх основні властивості, які дозволяють висунути гіпотезу про те, що для забезпечення механічної збереженості виробів, схильних до динамічних дій, необхідно застосовувати вкладені механічні системи. На підставі принципу вкладеності механічних систем запропонований метод підвищення збереженості виробів військової техніки. Вживання вкладених механічних систем дозволяє забезпечити механічну збереженість виробів військової техніки, шляхом зниження підведеної повної енергії до допустимої для зберігання виробу.

Ключові слова: механічна система, пружність, пластичність, деформація, динамічне вантаження, механічна збереженість виробів, засоби уразки, вироби військової техніки, дія ударної хвилі, вкладені механічні системи, агрегатний стан, фізичний стан, принцип вкладеності механічних систем.

Применение вложенных механических систем для обеспечения сохраняемости изделий военной техники при динамических воздействиях

А. В. Ковтун, В. А. Табуненко, С. М. Мельников

В процессе обеспечения боевых действий, конструкции изделий военной техники подвергаются значительным воздействиям как штатных так и не штатных динамических нагрузок, которые могут привести к их механическому разрушению. Среди динамических нагрузок, действующих на изделия военной техники, можно выделить кратковременные, вызываемые взрывными и ударными воздействиями, и длительные вибрационные нагрузки, возникающие в процессе транспортировки. В связи с этим существует проблема обеспечения механической сохраняемости изделий военной техники при динамических воздействиях. В работе дано определение вложенным механическим системам и сформулированы их основные свойства, которые позволяют выдвинуть гипотезу о том, что для обеспечения механической сохраняемости изделий, подверженных динамическим воздействиям, необходимо применять вложенные механические системы. На основании принципа вложенности механических систем предложен метод повышения сохраняемости изделий военной техники. Применение вложенных механических систем позволяет обеспечить механическую сохраняемость изделий военной техники, путем снижения подведенной полной энергии до допустимой для сохраняемого изделия.

Ключевые слова: механическая система, упругость, пластичность, деформация, динамическое нагружение, механическая сохраняемость изделий, средства поражения, изделия военной техники, воздействие ударной волны, вложенные механические системы, агрегатное состояние, физическое состояние, принцип вложенности механических систем.