APPLICATION OF DECOMPOSITION METHODS IN TESTS OF COMPLEX MILITARY EQUIPMENT

A methodology for the decomposition of complex technical systems of weapons and military equipment and their properties has been developed to increase the accuracy of the assessment of characteristics during tests. General information about operational characteristics of military technical systems, which are controlled during tests and features of their assessment are provided.

Keywords: weapons and military equipment; testing; operational characteristics; decomposition; diaoptic; modeling.

Introduction

General problem statement. In order to ensure the effective development of all components of the Armed Forces of Ukraine, the concepts and prospects for the development of information technologies, the latest defense technologies and technologies of the defense-industrial complex are defined in the Road Map of Creation project in Ukraine [1–3].

It should be noted that the further development of the Armed Forces of Ukraine is impossible without international cooperation in carrying out systematic studies on the implementation of NATO’s basic principles regarding the search for ways to re-equip the army with the latest types of weapons and military equipment (WME), their testing and certification [4].

The latest samples of WME mostly represent complex technical systems (TS) and complexes that have many constituent parts, subsystems and elements with developed cross-connections. Determining the initial parameters and characteristics of such systems is a rather difficult problem during tests. Modern modeling methods using powerful computing systems, supercomputers, and cluster computing are often used to solve the problems of evaluating the characteristics of test objects. However, the accuracy of calculations significantly decreases with an increase in the number of elements of the studied system. In order to increase the accuracy of the obtained data, it is necessary to develop modern decomposition methods for determining the characteristics of the TS in parts.

The purpose of the work is to develop a methodology for the decomposition of complex technical systems and their properties to assess the quality of weapons and military equipment during tests based on the results of modeling, observation and control.

Main material

The following tasks must be solved to achieve the goal:

– determine the structure of the TS of the WME sample (main components and sets of connections between them), as well as the list of properties (characteristics) subject to control;

– determine the possibility of applying decomposition methods to the analysis of the TS (test object);

– formulate conceptual requirements for the testing system;

– to determine the methodology of decision-making about the quality of the WME sample in parts.

A technical system is a system of service functions and parameters that determine the principles of its functioning and the structure of structural elements for the implementation of these functions. Regardless of the official purpose, TS are conventionally divided into design and technological ones, since any technical system is created to meet the needs of society (for example, the creation of WME) or to implement technological processes.

It is advisable to analyze a complex TS in parts (subsystems) using decomposition methods, as well as mathematical and structural-parametric modeling [5].

The information model of the properties of a complex TS is described in functional and structural terms in the form of a “black box” (fig.1) from a cybernetic point of view which functions in space and time. There is a cross set of different types of connections Z in TS: dimensional connections R; time connections T; connections of materials W; economic relations C and informational relations I, each of which affects each other [6].

Considerable experience has been accumulated in the field of practical decision-making based on the results of simulations and observations of changes in properties during the TS life cycle over the years of research and testing of WME. Each sample of WME is represented by a set of simple or complex properties that distinguish it from others. For example, reliability is
a complex property that contains simpler components: reliability, preservation, durability, maintainability [7].

It should be noted that the statistical processing of empirical data is an urgent task not only in monitoring the process of testing and controlled operation of WME, but also in determining trends and directions of modernization, their maintenance and repair. The degree of manifestation of one or more properties of the product is assessed using quality indicators.

Fig.1. Cybernetic model and TS connections

The structure of a complex TS S (fig.2) is considered as an ordered collection of interconnected subsystems and elements necessary for the performance of specified functions.

Fig.2. Hierarchical structure of the technical system

Fig.3. Diagrams of the division of an arbitrary system S into constituent elements
a) complete (undivided) system;  b) division of the system into elements;
c) independent elements of the system;  d) connection of elements;
e) breakdown with related elements;  f) selection of related elements
It can be described as a set of system elements $E$ and a set of connections $Z$ between elements of a certain structure:

$$ S = \{E, Z\}, $$

(1)

$E$ is a set of $N$ elements selected by a certain feature,

$$ E = \{e_1, e_2, e_3, ..., e_N\}, $$

(2)

$Z$ is a set of connections of a certain kind between these elements,

$$ Z = \{z_1, z_2, z_3, ..., z_I\}, $$

(3)

We will solve the problem of studying a complex system in parts in a general way on the basis of the system theory of sets.

Let the complex system $S$ (fig.3a) have an unknown finite set $D$ of its own properties.

When the complete system is divided into $n$ parts (Fig. 3b) by breaking the connections $Z$, we get a number of independent subsystems and the corresponding system $S$ of sets of their properties:

$$ S = \{X_1, X_2, ..., X_n\}. $$

(4)

At the same time, the $S$ system must satisfy the following basic conditions:

- an arbitrary set $X_k$ from the system $S$ is a subset of the set $D$:

$$ \forall X_k \in S : X_k \subseteq D, $$

(5)

- any two sets $X_i$ and $X_j$ from the system $S$ are completely independent:

$$ \forall X_i, X_j \in S : X_i \cap X_j = \emptyset; $$

(6)

- any two sets $X_i$ and $X_j$ from the system $S$ are not the same:

$$ \forall X_i, X_j \in S : X_i \neq X_j; $$

(7)

- any two sets $X_i$ and $X_j$ from the system $S$ must have no connections between themselves (their disjunction is zero):

$$ \forall X_i, X_j \in S : X_i \otimes X_j \neq \emptyset; $$

(8)

- an arbitrary set $X_k$ itself can be a system of sets of properties of a lower level (that is, it is possible to build a system according to a hierarchical structure):

$$ X = \{x_1, x_2, ..., x_n\}; \forall x_k, x_1 \in X \Rightarrow \forall x \subseteq S \Rightarrow x \subseteq D. $$

(9)

Thus, the problem arises of finding the properties of each of the elements of the system $S$ separately, as independent (unrelated) subsystems with properties $X_i$.

Then the unknown set of properties $D$ of the complete system can be found by a simple combination of the properties of all sets included in the partition $S$:

$$ U_{X \subseteq S} X \subseteq D \Rightarrow U_{X \subseteq S} (U_{X \subseteq S} x) \subseteq D. $$

(10)

Based on this statement of the problem, decomposition methods can be used to study the properties of the complete system.

Decomposition is the division of the system into separate parts and the independent analysis of the resulting parts under the conditions of accepting simplified assumptions about the mutual influence of the parts. At the same time, the complete system is usually divided into a number of subsystems of a lower order, they are examined independently, and then a solution for the complete system is obtained. This makes it possible to significantly reduce computing resources (machine time – $T_m$ and machine memory – $I_m$) for obtaining the solution of a large system of equations in mathematical modeling on computers. Thus, the $T_m$ indicator is estimated by the expression $T_m = C \cdot n^\alpha$, where $C$ is the proportionality coefficient, $n$ is the order of the system of equations, $\alpha$ is the degree index, and usually $\alpha > 2$. If we divide the model into $m$ equal parts, we get $T_m = C \cdot m(n/m)$, that is, the machine time $T_m$ decreases by $k = m^{-\alpha/2}$ times. The amount of required machine memory $I_m$ is also significantly reduced.

This approach can be used for a simplified solution of many problems during the analysis of complex systems in which the connections between subsystems are not significant (for example, to find volumetric, mass-inertial, thermal and other static indicators and characteristics of machines as component units).

However, in dynamics (in a complex dynamic system), any connections between subsystems are significant and cannot be ignored. When independent subsystems are combined into one system, additional connections are imposed on them, and when disconnected, they are removed. According to Rayleigh’s theorems, when additional connections are imposed on an oscillating system (or when they are removed), all frequencies of the system change.

In complex dynamic systems connections can be very influential and must be taken into account. Therefore, to the analysis of dynamic systems in general, diacoptic methods are more suitable for the study of complex dynamic systems in parts.

Diacoptic is a direction of research of complex systems in parts, taking into account all existing connections between subsystems. It differs from decomposition by the absence of a simplified approach to taking into account the mutual influence of constituent parts. At the same time, the efficiency of the diacoptic method is comparable to the decomposition method and the accuracy is much higher.

When considering system (4), it is necessary to change the conditions for the entry of subsystems $X$ into the complete system $S$ of the finite set of properties $D$, taking into account the above-mentioned features of the connected dynamic systems (fig.3d). Thus, while
keeping the conditions (5)–(7) and (9), it is necessary to add to the properties of the isolated subsystems $X$ also the properties of the links $Z$ that connect them in the complete system, that is, to change the condition (8).

Then, in the general case, the system of sets of properties of subsystems $S$ will consist of $n$ interconnected subsystems $Y$ (fig.3e)

$$ S = \{Y_1, Y_2, ..., Y_n\}. \quad (11) $$

moreover

$$ Y \neq X : Y \supset X : Y \supseteq Z : Y \supseteq X \cup Z. \quad (12) $$

From here we have

$$ Y = X \cap Z \cap X = Y \setminus Z. \quad (13) $$

At the same time, $Y$ also belongs to the finite set $D$

$$ \forall Y \in S : Y \subseteq D. \quad (14) $$

However, in contrast to condition (8), for any two sets $Y_i$ and $Y_j$ from the system $S$ that have connections between them, their disjunctive combination will no longer be equal to zero

$$ \forall Y_i, Y_j \in S : Y_i \oplus Y_j \neq \emptyset. \quad (15) $$

that is, these subsystems of sets in the complete system intersect

$$ \forall Y_i, Y_j \in S \Rightarrow Y_i \cap Y_j \neq \emptyset. \quad (16) $$

Then the initial set of properties $D$ of the complete original system, taking into account the connections between subsystems, can be found by combining the properties of all sets that are part of the system $S$ (fig.3f)

$$ U_{Y \subseteq S} Y \subseteq D \Rightarrow U_{Y \subseteq S} (X \cup Z) \subseteq D \quad (17) $$

Thus, knowing the properties of the sets of isolated subsystems $X$ and their connections $Z$ of the system $S$, it is possible to find the set of properties $D$, that is, to perform the task of synthesizing the properties of the complete system by the properties of its subsystems.

The proposed diaoptic approach establishes the conceptual foundations for the theoretical justification of the methodology of dividing a complex system into subsystems with the selection of individual subsystems as independent units with their own properties. This opens up new opportunities for researching the dynamics of complex vehicles in parts.

Decomposition methods are quite effectively used in the study of complex WME systems. They are the basis of the block-hierarchical approach during the design and mathematical analysis of complex objects using CALS technologies [8].

The structural elements that are part of the WME system are determined by the tactics of the most complete realization of the combat potential. They, in turn, can be systems. Therefore, the concepts of “system” and “system element” are relative.

For example, we will show the application of decomposition methods during tests of the specialized armored vehicle “NOVATOR” (fig.4). When analyzing its strength by modeling, the following subsystems were separately calculated: armored cabin (capsule), front and rear axles, transmission and others.

![Fig.4. Specialized armored vehicle “NOVATOR” and its elements: a) general appearance (photo); b) 3D model; c) capsule; d) capsule stress graph; e) rear bridge; f) stress diagram of the rear axle]
The general conclusion about the strength of the entire system of the “NOVATOR” specialized armored vehicle was made based on the analysis of the strength of its individual subsystems and elements as components of the entire structure.

If the quality of even one element does not meet the specified criterion (for example, strength), then this object is considered to have failed the quality check.

In many other TS, the distribution by subsystems is carried out according to a similar scheme.

Conclusions

A methodology for the decomposition of complex technical systems and their properties has been developed to assess the quality of weapons and military equipment during tests based on the results of modeling, observations and control. It is advisable to use this methodology to increase the assessment accuracy of the characteristics of the test objects and to make decisions about their quality as a whole. This will ensure an increase in the efficiency of all types of tests (preliminary, interdepartmental, determining departmental, state, etc.).

The comparative characteristics of decomposition and diaoptic methods showed that diaoptic methods are more accurate and it is advisable to use them for systems with influential interconnections.

Based on the results of structural-parametric modeling and observations during the life cycle of the WME, the technique of ranking the properties of test objects subject to control during tests and during controlled operation has been improved.

References

ЗАСТОСУВАННЯ МЕТОДІВ ДЕКОМПОЗИЦІЇ ПРИ ВИПРОБУВАННЯХ СКЛАДНОЇ ВІЙСЬКОВОЇ ТЕХНІКИ

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Наведена структура складної технічної системи, яка розглядається як упорядкована сукупність взаємопов’язаних підсистем та елементів, необхідних для виконання заданих функцій.

Дана порівняльна характеристика методів декомпозиції і діакоптики та умов їх застосування. Показано, що діакоптичні методи більш точні і застосовуються для систем з впливовими взаємозв’язками підсистем.

Наведено загальні відомості про експлуатаційні характеристики складних військових технічних систем, що контролюються під час випробувань, та особливості їх оцінки. На основі результатів структурно-параметричного моделювання та спостережень на протязі життєвого циклу озброєння та військової техніки удосконалено методика рахування властивостей об’єктів випробувань, що піддаються контролю при випробуваннях та під час підконтрольної експлуатації.

Розроблена методологія декомпозиції складних технічних систем і їх властивостей для оцінки якості озброєння і військової техніки під час випробувань на основі результатів моделювання та спостережень і контролю. Розроблену методологію доцільно використовувати для підвищення точності оцінки характеристик об’єктів випробувань при прийнятті рішень про їх якість в цілому. Застосування методології забезпечить підвищення ефективності виконання усіх видів випробувань (попередніх, міжвідомчих, визначальних відомчих, державних тощо).

Ключові слова: озброєння і військова техніка; випробування; експлуатаційні характеристики; декомпозиція; діакоптика; моделювання.