A. Kovtun, V. Tabunenko

National Academy of the National Guard of Ukraine, Kharkiv, Ukraine

DETERMINATION OF RELIABILITY INDICATORS OF COMPLEX ELEMENTS OF ROCKET COMPLEXES IN TRANSPORTATION OF ROCKETS

Under the missile system (MS) it is understood that the totality of the functional and technologically interconnected missiles of a particular type, technical means and facilities intended to maintain their readiness for use, launching missiles, controlling their flight, and performing other tasks (for example, protecting a missile from the impact of the attacking factors enemy weapons). The main properties of LWR are survivability, combat readiness, effectiveness of the action on the target, ability to overcome the enemy's resistance, reliability, manageability, reach. The property of the Republic of Kazakhstan as a whole and its constituent parts separately keep in time the ability to perform functions in accordance with the intended use under the specified modes and conditions of operation (at application, maintenance, storage, transportation). The paper considers the concept of reliability of MS, whose increase is considered one of the important tasks. One of the most important indicators of reliability during operation of the LWR is to ensure the mechanical preservation of their component parts. It is understood that the preservation is understood as the ability to preserve the specified mechanical properties, in particular, during and after transportation. In the process of transporting a rocket, its structure is exposed to various external forces that vary in magnitude and time. During operational loads, there is a process of complex interaction of external force factors. Estimated and experimental studies of the effect of actual operational loads on a launcher with a rocket (LWR) present considerable difficulties, especially considering the dynamics of loads. Apart from this, on the PUs there are striking factors, due to the use of weapons by the enemy. These effects can cause damage and failure as separate elements of the LWR and the product as a whole. The use of LWR constantly requires the solution of specific tasks to ensure the mechanical safety of structures, for the solution of which developed new methods. There are differences between the results obtained to ensure the mechanical safety of the components of the MS and the real results obtained on the basis of existing methods. However, the level of development of the means of defeating the enemy, mechanical safety of the components of the LWR, under the influence of vibration and shock loads, is not ensured. In the considered woMS, it is proposed to evaluate the reliability of the launcher with the rocket during the transportation process with a complex indicator - the coefficient of operational readiness of the launcher with the rocket. The given mathematical model of determining the coefficient of operational readiness of the launcher with the rocket during the transport of the rocket.

Keywords: reliability; rocket complex; launcher; reliability; reparability; safety; indicators; mathematical model.

Introduction

One of the components of combat readiness of missile systems (MS) is their reliability. Increasing the reliability of the components of the LWR is one of the most important challenges faced by developers, manufacturers and specialists using rocket technology. In conditions of conducting military operations, increasing the reliability of the MS, ensures the success of the tasks.

The impact of reliability on the combat capability of the MS is such that the number of launchers (L) and missiles required for the combat task is inversely proportional to their reliability. Increasing the reliability of MS by 1% leads to an increase in the number of combat heads delivered by missiles to targets by 15-17 units, which allows you to hit the same amount of additional enemy objects [1, 2].

One of the most important indicators of reliability during the operation of the MS is to ensure the mechanical safety of their constituent parts (preservation - the ability to maintain the specified mechanical properties, in particular, during and after transportation). In the process of transporting a rocket, its design is subjected to the influence of various external force factors, varying in size and time. In the general case of operating load there is a process of complex interaction of external force factors. Estimated and experimental studies of the impact of real operational loads on missile launcher (LWR) present

considerable difficulties, especially given the dynamics of loads. In addition, on the LWR there are impressive factors used by the enemy of the weapon. These influences can be the cause of damage and failure as separate elements of the LWR and the product as a whole [1].

Formulation of the problem

The practice of the use of MS constantly requires the solution of specific problems of mechanical preservation of structures, for the solution of which developed new methods. However, there has recently been a discrepancy between the required results, which correspond to the current level of development of scientific methods for ensuring the mechanical preservation of the components and real results obtained on the basis of existing methods.

For example, during the transport of missiles, in the course of providing combat operations, the peak values of transverse overloads of missiles can reach values of 4, with the maximum permissible value of overload of the constituent parts of the LWR-2 [2]; the likelihood of a defeat of the LWR with an increase in the time of its occurrence under bombardment increases in (1,5-2 times) [3]. Thus, taking into account modern approaches to the methods of fighting and the level of development of the means of defeating the enemy, the mechanical safety of the components of the LWR, under the influence of vibration and shock loads, is not ensured.

Analysis of recent research and publications

The scientific basis of studies of the level of reliability of components of the MS to the tasks is: the theory of the effectiveness of military equipment, the technical operation of machines, the theory of reliability of products, the theory of probabilities and mathematical statistics. The main dependencies used in determining the level of reliability of the components of the MS are given in [1, 2]. Proposals for assessing the reliability and readiness of modern equipment products are given in [4 -12]. In [6] analytical dependencies of the factors of serviceability and combat readiness of armaments and military equipment were developed.

Since the methods of reliability theory and methods of reliability are applied in various fields of science and practice, then the literature on reliability is quite diverse.

There is enough educational, monographic and reference literature on reliability.

The most complete reliability issue is presented in the ten-volume manual [4].

This guide presents methodological aspects of the reliability of technical products, calculation and organizational methods for ensuring the reliability of products at different stages of their life cycle, starting with the designers design before the aging and decommissioning techniques. The main document, which lists the systems of reliability standards, is DSTU 2860 - 94 "Reliability of technology. Terms and definitions."

However, in certain dependencies and data are not given on the generalized assessment of the existing level of reliability of the components of the MS and the determination of the required level of reliability of perspective complexes.

The purpose of the article is to obtain an addiction to assess the level of reliability of the elements of the MS in the performance of tasks for the purpose and determine the effect on it of individual properties.

Presenting main material

Maintaining a given level of reliability of the constituent elements of the MS remains the most important task that is solved during their exploitation. The solution to this problem is complicated by the fact that MS is a complex technical system consisting of tens of thousands of elements that function during significant time periods in tense modes.

The need to maintain a high level of reliability of the MS also follows from the fact that these complexes are weapons that are in constant high combat readiness. Frequent carrying out on restoration of reliability of complexes, which are on combat duty, leads to a significant reduction of combat readiness of the grouping.

The level of reliability of the complex significantly affects other indicators of its operation. Increasing the level of reliability of the components of the complex reduces the labor costs and the number of personnel of units supporting the combat readiness of the complex, reduces the required amount of spare parts.

Reliability indicators are known to be probabilistic. This is due to reasons that can be divided into two groups.

The first group includes the reasons caused by the instability of the properties of elements and systems of components of rocket complexes due to the heterogeneity of the source materials, the instability of the technological processes of their production, and others.

The second group includes reasons caused by the accidental nature of the conditions of exploitation and military use of the MS.

In terms of the reliability of the functioning of the MS, the complex, in general, should consistently perform the following functions, with the necessary level of reliability, [1]:

- maintenance of the missile complex in the specified degree of readiness for combat use during the specified term of its operation t_e. The probability of finding a MS, at the moment of giving the command to the launch, in the state of readiness for combat application, is estimated by the coefficient of readiness of the K_G;

- preparation for start-up after receiving the command and launching the missile at the set time t_p. Probability of the preparation and launch of the rocket $P_{(t_p)}$ characterizes the reliability of systems and elements of the *MS* during the period t_p - from the moment the command is presented to the launch of the launch rocket from the launching station;

- a rocket flight. The probability of a successful flight of a rocket $R(t_{pr})$ characterizes the reliability of systems and elements of the LWR during the time t_{pr} - from the moment the missile launches from the launch vehicle to the delivery of the warhead to the target.

To assess the degree of performance of the MS of the above functions, a generalized reliability indicator is used, which implies the probability of a successful delivery with the given accuracy of the warhead to the target when the command is received for launch at any time of operation of the complex.

At the stage of operation of the complex its reliability is reduced due to the degradation of the properties of systems under the influence of operational factors. Reliability of the MS can be maintained through constant monitoring, control periodic inspections and regulatory works.

Thus, the reliability of the MS depends on the circuit design features of its systems, the quality of the components and characteristics of the operation process.

It is proposed to assess the reliability of the launcher with the missile in the process of transportation by a complex indicator - the readiness factor of the launcher with the K_{OGLWR} rocket, which is defined as follows:

$$K_{OGLWR} = K_{OGPU} \cdot K_{OGR}, \qquad (1)$$

where K_{OGPU} - coefficient of operational readiness of the launcher; K_{OGR} - coefficient of operational readiness of the rocket.

The readiness factor is the probability that a rocket launcher will be in a state of combat at any one time, except for scheduled periods, when the use of the object is not foreseen, and starting from this moment, will work without fail for a given period t [13].

The operational readiness rate of the K_{OGPU} launcher is determined as follows:

$$K_{OGPU} = K_{OLS} \cdot P_{ffo}(t), \qquad (2)$$

where K_{OLS} - coefficient of readiness of the launching station; $P_{ffo}(t)$ is the probability of failure-free operation, the probability that within the set time t does not occur the failure of the launcher.

$$P_{ffo}(t) = 1 - P_{VPU}(t), \qquad (3)$$

where $P_{VPU}(t)$ - the probability of failure of the launcher.

$$P_{VPU}(t) = P_1 + P_2 - P_1 \cdot P_2, \qquad (4)$$

where P_1 - is the probability of forecasted missile failures; P_2 - probability of non-predicted missile failures (battle damage).

For a period of normal operation, a fair exponential law of reliability [13]:

$$P_B(t) = 1 - e^{-\int_0^t \lambda(t)dt} = 1 - e^{-\lambda t}, \quad \lambda = const, \quad (5)$$

where $\lambda(t)$ is the intensity of the failures.

The readiness factor for the K_{SSU} - launcher is the probability that the launcher will be in an operational state at any time, except for scheduled periods during which the use of the launch vehicle is not foreseen.

From this definition it turns out that the readiness factor characterizes the readiness of the launcher for its intended use only in relation to its combat capability and it means the probability that the launching device

will be able to be in an operational state at any given time, and this time moment can not be selected at intervals where the application of the launcher is excluded.

The value of K_{OGPU} corresponds to a given interval of the time of operation of the launcher, with the increase of which the coefficient of operational readiness monotonously decreases. Therefore, taking into account the coefficient of operational readiness, one can determine the average number of operational launchers before the end of the operation (period t) $M_{SPR_{ko}}(t)$:

$$M_{SPR_{ko}}(t) = K_{OGPU}(t) \cdot M_{SPR_{PO}}, \qquad (6)$$

where $M_{SPR_{PO}}$ - the number of able-bodied launchers at the beginning of the operation.

Taking into account the average speed of the launcher, depending on the category of conditions of its operation, this formula can be written down through the mileage in km:

$$M_{SPR_{ko}}(L) = K_{OGPU}(L) \cdot M_{SPR_{PO}}, \qquad (7)$$

where L – mileage km.

Adoption of a mathematical model:
- for new LWR $P(L)=1$ where $L = 0$;
- during the warranty period $P(L) = 1$.
- $Lim_{L \to \infty} P(L)=0$,
- $dP(L) / dL \le 0$,

Initial conditions:

$$L = 0 \quad P(L) = 1; \; L_B \le L_0. \qquad (8)$$

Charts of the dependence K_{OGPU} for launchers at various operating conditions from run L, are represented on Fig. 1.
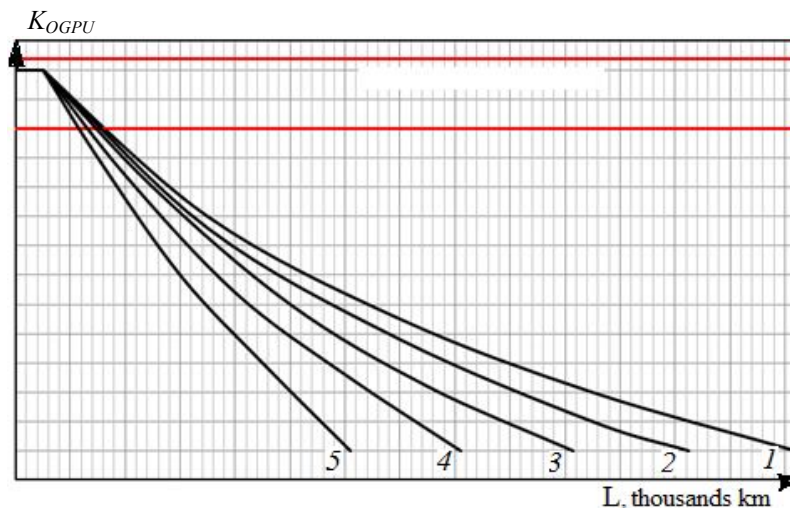

Fig. 1. Chart of the change of the K_{OGPU} from L to launchers in different categories of operating conditions

Probabilities of non-predicted missile failures $- P_2$ related to the use of an enemy weapon.

Probability of not impressing launchers without taking into account the time spent in the zone of fire, is determined by the dependence [3]:

$$P_2 = 1 - P_G, \qquad (9)$$

$$P_G = e^{-\lambda^* S}, \qquad (10)$$

where e^{λ^*} – the distribution density of the field of fragments, units/m^2; S – the projection area of the target in a fragmentary field, m^2.

The probability of not impressing the P_G launchers, taking into account the time spent in the zone of fire and the moment of its detection, is determined by the expression [3]:

$$P_G(t) = \frac{1}{p \cdot \lambda \cdot t}\left[1 - e^{-p \cdot \lambda \cdot t}\right], \qquad (11)$$

where λ – the number of shots per target in time t = t*- T, hours; t^* – time of the launcher in the area of fire, hours; T – time of detection of launcher, hours; p – is the probability of reaching the target.

Coefficient of operational readiness of the K_{OGR} missile is determined as follows:

$$K_{OGR} = K_{GR} \cdot P_{BR}(t), \qquad (12)$$

where K_{GR} - rocket readiness factor; $P_{BR}(t)$ - the probability of failure-free operation - the probability that within the specified time t will not occur missile failure.

$$P_{BR}(t) = 1 - P_{VR}(t), \qquad (13)$$

where $P_{VR}(t)$ - probability of missile failure;

$$P_{BP}(t) = P_{1R} + P_{2R} - P_{1R} \cdot P_{2R}, \qquad (14)$$

where $P_{1R}(t)$ – the probability of missile failures during the forecasting; $P_{2R}(t)$ is the probability of missile failures that are not predicted.

The probability of missile failures in the predicted transport - $P_{1R}(t)$ is determined as follows:

$$P_{1R}(t) = 1 - P_{B1R}(t), \qquad (15)$$

$$P_{B1R}(t) = 1, \quad \text{where} \quad n_i \le n_{per},$$

$$P_{B1R}(t) = 1 - e^{-n_{per}/n_i}, \quad \text{where} \quad n_i \succ n_{per},$$

$$n = n_i - n_{per},$$

where n_i – the number of bends (fluctuations) of the rocket during transportation; n_{per} – average permissible number of bends (fluctuations) of the rocket during transportation.

The probability of missiles failing during transportation that is not predicted - $P_{2P}(t)$ is determined by the expressions (9 - 11).

A comprehensive indicator K_{OGLWR}, which is determined by the formula (1), estimates comprehensive assessment of the reliability of the launcher with a rocket in the transport process.

Conclusions

1. An approach for quantitative assessment of the reliability of component elements of the MS during the transport of missiles is proposed. The obtained dependencies allow us to estimate the level of reliability of the component elements LWR, as a component of the readiness of the MS to perform tasks.

2. Dependencies for assessing the reliability of the elements MS make it possible to determine the effect on it of individual properties and to identify ways to ensure a high level of reliability of the elements MS during the development of requirements for modern missile technology samples.

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Визначення показників надійності складових елементів ракетних комплексів при транспортуванні ракет

А. В. Ковтун, В. О. Табуненко

Під ракетним комплексом (РК) прийнято розуміти сукупність функціонально і технологічно взаємопов'язаних ракет конкретного типу, технічних засобів і споруд, призначених для підтримки їх в готовності до застосування, пуску ракет, управління їх польотом і виконання інших завдань (наприклад, захисту ракети від впливу вражаючих факторів зброї противника). Основними властивостями РК є: живучість, боєготовність, ефективність дії по цілі, здатність долати протидію супротивника, надійність, керованість, досяжність. Властивість РК в цілому і його складових частин окремо зберігати в часі можливість виконувати функції відповідно до призначення при заданих режимах і умовах експлуатації (при застосуванні, технічному обслуговуванні, зберіганні, транспортуванні). У роботі розглянуто поняття надійності РК, підвищення якої вважається однією з важливих задач. Одним з найважливіших показників надійності при експлуатації РК є забезпечення механічної зберігання їх складових частин. Під збереженістю прийнято розуміти здатність зберігати задані механічні властивості, зокрема, в період і після транспортування. У процесі транспортування ракети, її конструкція піддається впливу різних зовнішніх силових факторів, що змінюються за величиною і в часі. При експлуатаційних навантаженнях має місце процес складної взаємодії зовнішніх силових факторів. Розрахункові і експериментальні дослідження впливу реальних експлуатаційних навантажень на пускову установку з ракетою (ПУР) представляють значні труднощі, особливо з урахуванням динамічності навантажень. Крім цього на ПУР діють вражаючі фактори, за рахунок застосування зброї противником. Ці дії можуть бути причиною пошкоджень і виходу з ладу як окремих елементів ПУР, так і вироби в цілому. Застосування РК постійно вимагає вирішення конкретних завдань забезпечення механічної цілісності конструкцій, для вирішення яких розроблялися нові методи. Є відмінності між одержуваними результатами щодо забезпечення механічної збереження складових частин РК і реальними результатами, отриманими на основі існуючих методів. Однак, рівень розвитку засобів ураження противника, механічна збереження складових частин ПУР, при впливі вібраційних і ударних навантажень, не забезпечується. У даній роботі запропоновано оцінювати надійність пускової установки з ракетою в процесі транспортування комплексним показником - коефіцієнтом оперативної готовності пускової установки з ракетою. Наведено математичну модель визначення коефіцієнта оперативної готовності пускової установки з ракетою під час транспортування ракети.

Ключові слова: надійність; ракетний комплекс; пускова установка; безвідмовність; ремонтопридатність; збереженість; показники; математична модель.

Определения показателей надежности составляющих элементов ракетных комплексов при транспортировке ракет

А. В. Ковтун, В. А.Табуненко

Под ракетным комплексом (РК) принято понимать совокупность функционально и технологически взаимосвязанных ракет конкретного типа, технических средств и сооружений, предназначенных для поддержания их в готовности к применению, пуску ракет, управления их полетом и выполнения других задач (например, защиты ракеты от воздействия поражающих факторов оружия противника). Основными свойствами РК являются: живучесть, боеготовность, эффективность действия по цели, способность преодолевать противодействие противника, надежность, управляемость, достигаемость. Свойство РК в целом и его составных частей по отдельности сохранять во времени возможность выполнять функции в согласовании с предназначением при заданных режимах и условиях эксплуатации (при применении, техническом обслуживании, хранении, транспортировании). В работе рассмотрено понятие надёжности РК, повышение которой считается одной из важных задач. Одним из важнейших показателей надёжности при эксплуатации РК есть обеспечение механической сохраняемости их составных частей. Под сохраняемостью принято понимать способность сохранять заданные механические свойства, в частности, в период и после транспортировки. В процессе транспортировки ракеты, ее конструкция подвергается воздействию различных внешних силовых факторов, изменяющихся по величине и во времени. При эксплуатационных нагрузках имеет место процесс сложного взаимодействия внешних силовых факторов. Расчетные и экспериментальные исследования влияния реальных эксплуатационных нагрузок на пусковую установку с ракетой (ПУР) представляют значимые трудности, особенно с учетом динамичности нагрузок. Кроме этого на ПУР действуют поражающие факторы, за счёт применения оружия противником. Эти воздействия могут быть предпосылкой повреждений и выхода из строя как отдельных элементов ПУР, так и изделия в целом. Применение РК постоянно требует решения конкретных задач обеспечения механической сохранности конструкций, для решения которых разрабатывались новые методы. Имеются различия между получаемыми результатами по обеспечению механической сохранности составных частей РК и реальными результатами, полученными на основе существующих методов. Однако, уровень развития средств поражения противника, механическая сохранность составных частей ПУР, при воздействии вибрационных и ударных нагрузок, не обеспечивается. В рассматриваемой работе предложено оценивать надежность пусковой установки с ракетой в процессе транспортировки комплексным показателем - коэффициентом оперативной готовности пусковой установки с ракетой. Приведена математическая модель определения коэффициента оперативной готовности пусковой установки с ракетой во время транспортировки ракеты.

Ключевые слова: надежность; ракетный комплекс; пусковая установка; безотказность; ремонтопригодность; сохранность; показатели; математическая модель.