

COMPARISON OF THE EFFECTIVENESS OF METHODS TO OPTIMIZE THE PARAMETERS OF THE MAINTENANCE STRATEGY COMPLEX TECHNICAL OBJECTS

The present article is devoted to comparing the effectiveness of methods for optimizing the parameters of maintenance strategy of complex technical objects. First of all, it concerns the methods for optimizing the parameters of maintenance strategy by state, by resource and adaptive technical maintenance (TM). In addition, a comparative assessment of indicators of target functions of the object without maintenance is made. That is, the article is devoted to one of the important and not fully solved problems: ensuring the reliability of operation of complex objects of machinery of ordinary and high responsibility.

The basic principles and elements of the construction of the methodology are considered, the technology of performing the optimization task of the corresponding strategy developed by the authors earlier is applied. The calculation of parameters under the condition of the optimal methods for solving problems, namely, simulation and statistical modeling, is proposed.

The best strategy in terms of mean time between failures (MTBF) and unit cost of operation is the "adaptive TM" strategy. Then comes the "condition-based TM" strategy. The worst is the "TM by lifetime" strategy. The strategies "TM on condition" and "adaptive TM" are very close to the obtained indicators. This is due to their common essence - when TM is used information on the actual current state of the object. The effectiveness of various TM strategies depends significantly on the reliability-value structure of the object. If the distribution of the cost of renewable elements about correlates with the distribution of their uptime indicators, the difference in the efficiency of different TM strategies is reduced.

The optimal parameters of different TM strategies depend significantly on both the reliability-value structure of the object, and on the given requirements to the object's failure-free operation level.

Key words: complex engineering objects, maintenance strategy, change of inspection frequency, maintenance and repair.

Introduction and problem statement. The process of maintenance of complex technical objects is very necessary to improve their reliability and extend their technical life, especially when these objects are impossible or impractical to replace with new ones. This is usually due to economic, social, hazard and other some difficulties [1-3].

Despite the fact that complex objects in modern conditions have in their composition built-in systems of technical diagnosis (STD), means of which are carried out continuous or periodic control of the technical condition, as well as the search for faults and failures, to restore the resource is possible only by conducting maintenance and repair (MAR).

The content of the MAR process depends on the complexity of the object, the design features of the component and element composition, the presence and degree of development of the built-in STD, the purpose of the object and the modes of its application. The content of the MAR process is determined by the following main components:

- maintenance work;
- repairs (current, scheduled, preventive, etc.);
- conducting analyses and tests;
- providing TM and repair of spare parts for tools and accessories (SPTA).

Maintenance according to [4-6] is "a set of operations or operations to maintain the serviceability or operability of the object during its intended use, downtime, storage and transportation". Further we will consider only TM when used as intended. TM consists in periodic inspection of the technical condition of the object and replacement of its individual elements that are in a pre-failure state. Maintenance is carried out when the object is in good or serviceable condition.

Thanks to carrying out TM there is a "rarefaction" of a stream of failures of object and at the expense of it raises level of its reliability.

Repair according to [4] is "a set of operations to restore serviceability or operability of the object and restore the resource of the object or its components. A distinction is made between routine and scheduled repairs.

Current repair (CR) is designed to restore the performance of a complex object, carried out at random moments of time, each time a failure of the object occurs. During maintenance, as a rule, replacement of one or more components or elements, the failure of which led to the failure of the object as a whole, is carried out.

Scheduled repair (SR) is designed to replenish the resource of the object, it is carried out at pre-scheduled points in time. In the case of a planned repair, a large part of the elements of the object are usually replaced. The greater the number of replaced elements, the greater the value of the resource, which is accumulated as a result of the planned repair. In practice, for the convenience of planning and organization of planned repair, the notion of type of planned repair is introduced. With the help of the notion of type of repair the scope of repair is specified and the rules of assignment of terms of their performance and ensuring. Most often two types of planned repairs are defined - major (MJR) and medium (MR). In this case, it is assumed that the volume of overhaul is significantly greater than the volume of medium repairs. As a result of performance of MJR is carried out close to full restoration of the resource of the object. At performance of MR there is only a partial restoration of a resource.

The MAR process is carried out according to the appropriate system, which is understood as a set of interrelated means, documentation, and performers required to maintain the required level of reliability of complex radioelectronic objects [7]. The elements (subsystems) of MAR system are [8-12]:

- technical maintenance system,
- system of current maintenance,
- system of repair organizations,
- system of providing spare parts, tools and accessories;
- control system.

Figure 1. shows a typical schematic structure of the MAR process with the definition of the person (operator) in the process.

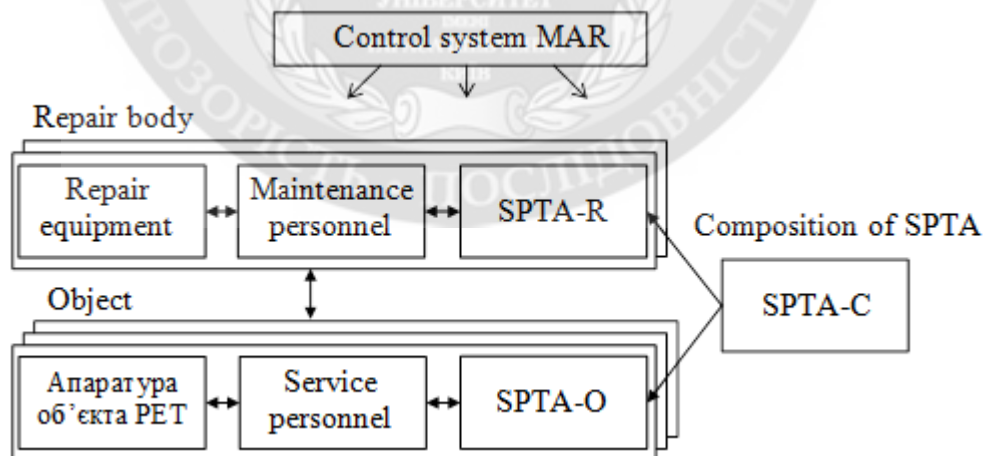


Figure 1 – Typical structure of the MAR process of complex objects

In general, there are several TM strategies for complex objects [3-13]. Of these, we will consider comparisons of the following TM strategies:

- condition maintenance;
- adaptive TM;
- resource maintenance (durability restoration);

- without TM.

A comparative study of different TM strategies

The complexity of TM processes and the variety of factors affecting them significantly complicate the choice between different TM strategies. For an objective comparison of the advantages and disadvantages of various TM strategies, it is necessary to ensure the approximate equality (sameness) of the conditions in which they are applied.

When comparing different TM strategies, we will be guided by the following principles:

- it is possible to compare various TM strategies only by results of their application to the same object;

- test objects on which comparison of strategies TM, should be comparable (identical) on structure of time and cost of TM and CR;

- quality indicators of process TM (target functions) on which comparison of various TM strategies, should be estimated on equal intervals of operation of object and at the identical parameters of process of modeling (if comparison of strategies TM is carried out by results of modeling)

- characteristics of process TM received at optimum parameters of TM strategies should be compared, that is potential possibilities of various TM strategies should be compared.

This study uses 4 test objects differing in their structural and reliability characteristics (the characteristics of the test objects are given in [12,13]). This, among other things, makes it possible to test and simultaneously demonstrate the "workability" of the developed methods for determining the optimal parameters of different TM strategies with different initial data.

To ensure the comparability of the structure of time and cost of TM and SR, the same for all elements and objects characteristics of maintainability and cost were set:

- average element recovery time = 1 h;

- average duration of TM = 1 h;

- cost of the element = 10 c.u. ;

- cost of the operation of current repair (replacement) of the element = 1 c.u. ;

- cost of element TM operation = 1 c.u. ;

The STD characteristics for the test objects are proposed as follows:

- duration of diagnostics at TM = 0.5 h ;

- cost of diagnostics operation at TM = 1 c.u.

The same for all test objects are also set and indicators, which depend on the purpose of the object - the specific loss of value, which is incurred by the external system (in which this object is used) in the object failure state = 10 c.u. / hour, and in the TM state = 1 c.u. / hour.

For all test objects, the optimal parameters for the three TM strategies are determined using the developed techniques. For brevity, as before, we will call them: "condition TM "adaptive TM" and "resource TM ".

All calculations were performed for the duration of operation = 20 years at continuous operation of the objects.

The optimal parameters of different TM strategies were determined under the idealized assumption of the existence for test objects of measurable determinants for the least reliable elements belonging to the set of renewable elements E_B . Subsets of potentially serviceable elements E_{T_0} were specified such that all less reliable elements were included [14-15]. There were no elements in the test objects whose reliability was lower than the reliability of any of the elements E_{T_0} ($E_{T_0} \subset E_B$). Obviously, under this condition with the optimal parameters of TM strategies provides the maximum, potentially possible efficiency of TM, most likely unattainable in practice.

Table 1-4 shows the final results of calculations of the optimal parameters of different TM strategies. Figures 2-5 show the corresponding graphs of average MTBF T_0 and specific cost of operation c_{yt} on the number of serviced elements, obtained with the optimal parameters of the corresponding TM strategies. All detailed calculations, on the basis of which these tables and graphs

are constructed, were given by this time in [16] (for object Test-1) and in the appendices (for objects Test-2,3,4).

Table 1

Comparative estimates of the indicators T_0 , c_{yd} , and $K_{ти}$ for the object Test-1 at different TM strategies

TM strategy		Condition TM	Adaptive TM	Resource maintenance	Without TM
Indicators (target functions)	T_0, h	1660	1662	1609	1236
	$c_{yd}, c.u./hour$	0,01461	0,01408	0,01695	0,02187
	$K_{ти}$	0,99851	0,99877	0,99689	0,99919
	ε	0,180	0,179	0,184	0,085
Parameters of the optimal strategy TM ($T_0^{TP} = 1500 h$)		$ E_{то}^* = 3$ $U_{то}^* = \{0,5; 0,4; 0,5\}$ $T_K^* = 1200 h$	$ E_{то}^* = 3$ $U_{то}^* = \{0,5; 0,4; 0,5\}$ $\gamma^* = 0,45; \beta = 0,5$	$N_{то}^* = 1$ $ E_{то1}^* = 3$ $T_{то}^* = 1400 h$	-

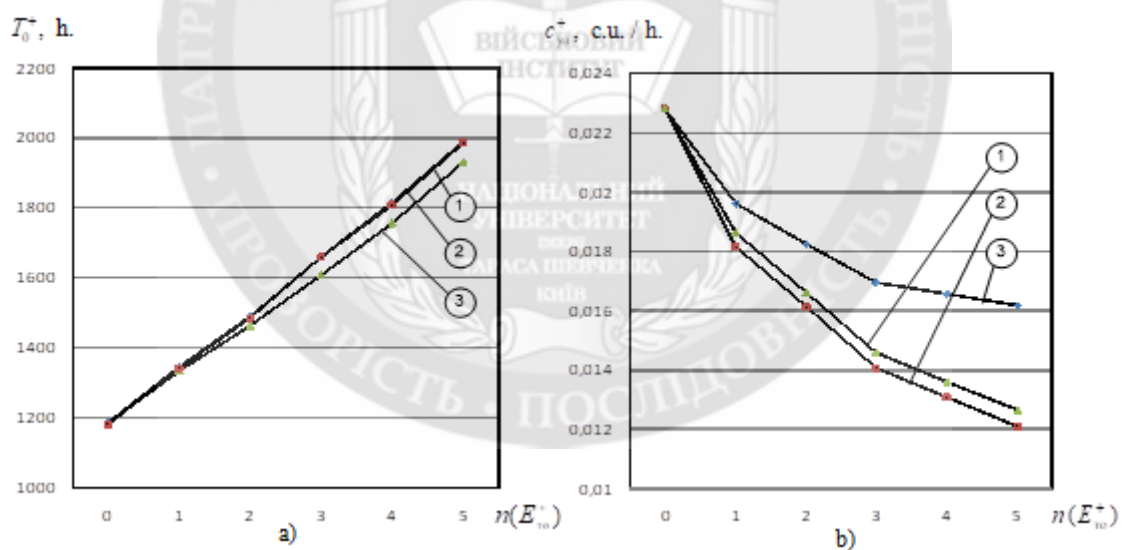


Figure 2 – Plots of dependence of indicators T_0^+ (a) and c_{yd}^+ (b) on the number of elements served under different TM strategies (Test-1 object):

- 1 - condition TM;
- 2 - adaptive TM;
- 3 - resource maintenance.

Table 2

Comparative estimates of the indicators T_0 , c_{yd} , and K_{TH} for the object Test-2 at different TM strategies

TM strategy		Condition TM	Adaptive TM	Resource maintenance	Without TM
Indicators (target functions)	T_0 , h	695	702	676	294
	c_{yd} , c.u./hour	0,09852	0,08801	0,12009	0,66572
	K_{TH}	0,98610	0,99374	0,97564	0,99708
	ε	0,111	0,112	0,113	0,069
Parameters of the optimal strategy TM ($T_0^{TP} = 600$ h)		$ E_{To}^* = 5$ $U_{To}^* = \{0,55; 0,45; 0,25; 0,6; 0,5\}$ $T_k^* = 250$ h	$ E_{To}^* = 5$ $U_{To}^* = \{0,6; 0,55; 0,6, 0,5; 0,6\}$ $\gamma^* = 0,45; \beta = 0,5$	$N_{To}^* = 1$ $ E_{To1}^* = 5$ $T_{To}^* = 240$ h	-

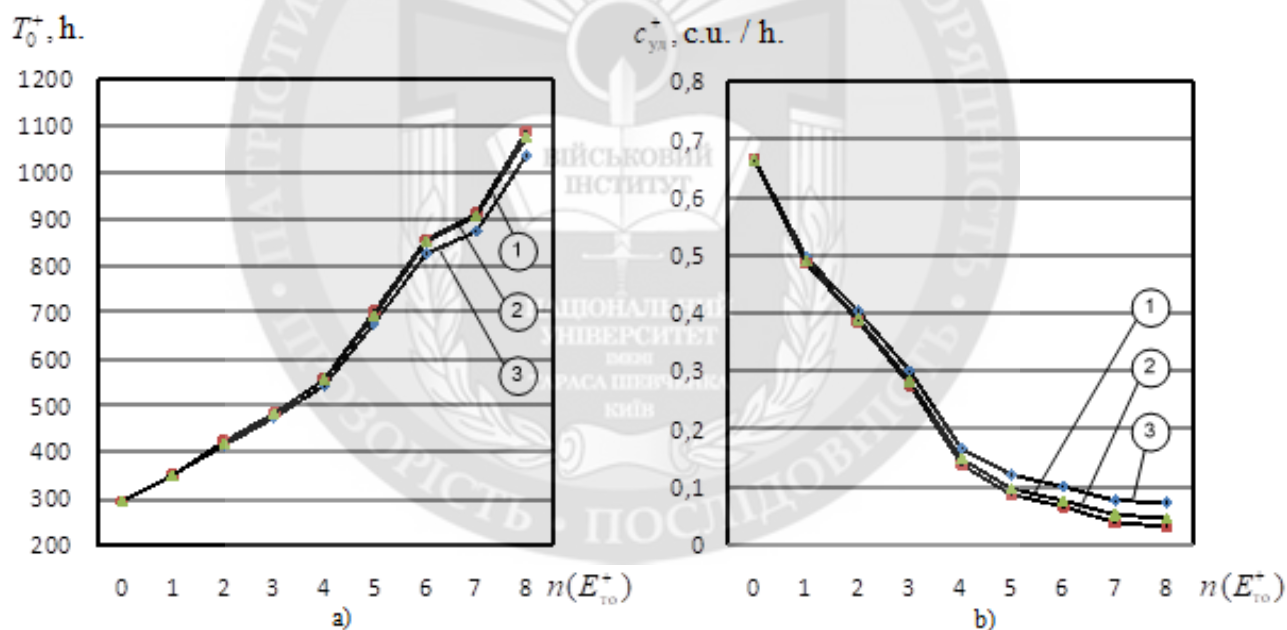


Figure 3 – Plots of dependence of indicators T_0^+ (a) and c_{yd}^+ (b) on the number of elements served under different TM strategies (Test-2 object):

- 1 - condition TM;
- 2 - adaptive TM;
- 3 - resource maintenance.

Table 3

Comparative estimates of the indicators T_0 , c_{yd} , and K_{TH} for the object Test-3 at different TM strategies

TM strategy		Condition TM	Adaptive TM	Resource maintenance	Without TM
Indicators (target functions)	T_0 , h	15194	15136	15009	9458
	c_{yd} , c.u./hour	0,00154	0,00151	0,00169	0,00232
	K_{TH}	0,99982	0,99984	0,99967	0,99978
	ε	0,487	0,448	0,493	0,367
Parameters of the optimal strategy TM ($T_0^{TP} = 15000$ h)		$ E_{To}^* = 3$ $U_{To}^* = \{0,5; 0,5; 0,5\}$ $T_k^* = 10500$ h	$ E_{To}^* = 3$ $U_{To}^* = \{0,7; 0,6; 0,5\}$ $\gamma^* = 0,4; \beta = 0,5$	$N_{To}^* = 1$ $ E_{To1}^* = 4$ $T_{To}^* = 16000$ h	-

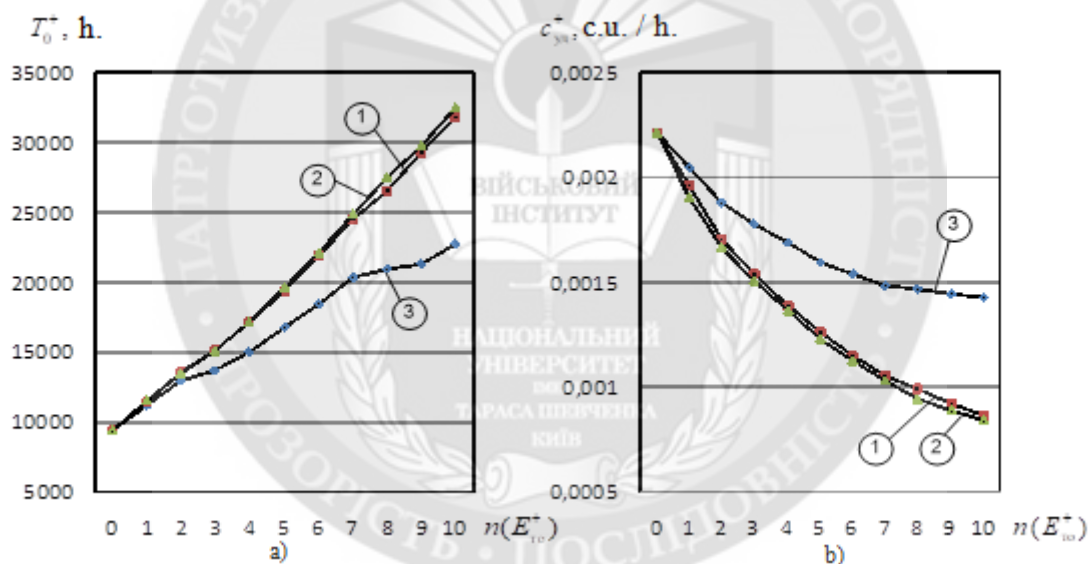


Figure 4 – Plots of dependence of indicators T_0^+ (a) and c_{yd}^+ (b) on the number of elements served under different TM strategies (Test-3 object):

- 1 - condition TM;
- 2 - adaptive TM;
- 3 - resource maintenance.

Table 4

Comparative estimates of the indicators T_0 , c_{yd} , and K_{TH} for the object Test-3 at different TM strategies

TM strategy		Condition TM	Adaptive TM	Resource maintenance	Without TM
Indicators (target functions)	T_0, h	6575	5566	4879	914
	c_{yd} , c.u./hour	0,00668	0,00637	0,01180	0,02296
	K_{TH}	0,99736	0,99776	0,99323	0,99890
	ε	0,268	0,209	0,311	0,113
Parameters of the optimal strategy TM ($T_0^{TP} = 5000 h$)		$ E_{TO}^* = 4$ $U_{TO}^* = \{0,5; 0,55; 0,65; 0,85\}$ $T_K^* = 500 h$	$ E_{TO}^* = 3$ $U_{TO}^* = \{0,55; 0,55; 0,55\}$ $\gamma^* = 0,5; \beta = 0,5$	$N_{TO}^* = 3$ $ E_{TO1}^* = 3$ $T_{TO1}^* = 600 h$ $ E_{TO2}^* = 3$ $T_{TO2}^* = 6000 h$ $ E_{TO3}^* = 4$ $T_{TO3}^* = 22000 h$	-

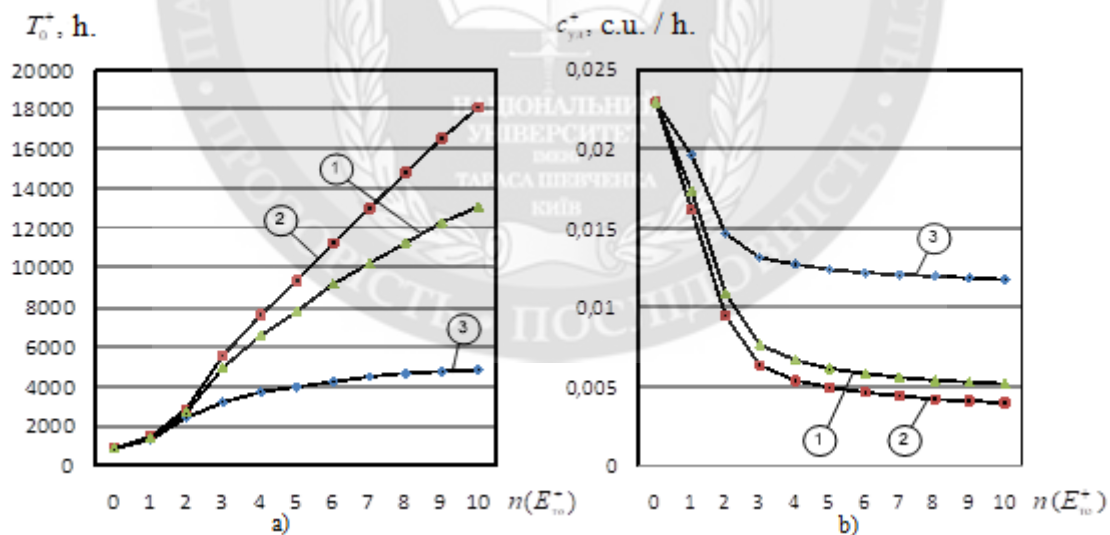


Figure 5 – Plots of dependence of indicators T_0^+ (a) and c_{yd}^+ (b) on the number of elements served under different TM strategies (Test-4 object):

- 1 - condition TM;
- 2 - adaptive TM;
- 3 - resource maintenance.

For the object Test-4 given requirement $T_0^{TP} = 5000$ hours at the optimal strategy "resource maintenance" is not provided. Despite the fact, that all potentially serviceable elements are used.

The "adaptive TM" strategy was not investigated separately. The adaptive TM β parameter (exponential smoothing constant) was set to 0.5 for all test objects. This corresponds to a neutral situation, when the "weight" of the initial data about the reliability performance of the elements (always a priori information) and the data about the actual measured values of the determining parameters (a posteriori information) is about the same.

Without going into the study of the "adaptive TM" strategy, we can assume that adaptive TM is more advantageous in the case of unreliable initial information about the fault tolerance rates of the object elements. Let us check this assumption as follows.

Let's calculate indicators T_0 and c_{yd} for the test objects in the case when the average time to failure of all renewable elements T_{cpi} is 2 times less in comparison with the indicators, at which the parameters of the optimal TM strategy were calculated.

Obviously, in this case the indicators obtained in T'_0 and c'_{yd} should be worse, in comparison with the indicators T_0 and c_{yd} , obtained at the initial values of T_{cpi} . Tables 5 and 6 show the values of the coefficients of relative losses in the level of no-failure δ_{T_0} and in the unit cost of operation $\delta_{c_{yd}}$, which were determined by the formulas:

$$\delta_{T_0} = \frac{T_0 - T'_0}{T_0} \cdot 100; \quad \delta_{c_{yd}} = \frac{c'_{yd} - c_{yd}}{c_{yd}} \cdot 100,$$

where T_0 (c_{yd}) - is the average MTBF (unit cost of operation), obtained with the optimal parameters, provided that the indicators T_{cpi} correspond to the values set for the test objects in the test examples;

T'_0 (c'_{yd}) - the same indicators obtained with the optimal parameters, but provided that the indicators T_{cpi} in the original data are reduced by 2 times.

Table 5

Coefficient of relative loss of reliability level δ_{T_0} (in %)

Type of TM strategy	Technical object			
	Test-1	Test-2	Test-3	Test-4
Condition TM	52	53	67	79
Adaptive TM	49	49	63	56
Resource TM	55	59	69	82

Table 6

Coefficient of relative losses of unit cost of operation $\delta_{c_{yd}}$ (in %)

Type of TM strategy	Technical object			
	Test-1	Test-2	Test-3	Test-4
Condition TM	110	144	187	192
Adaptive TM	98	100	167	117
Resource TM	121	712	185	166

In Figure 6 and 7, the same coefficients are shown in the form of graphs.

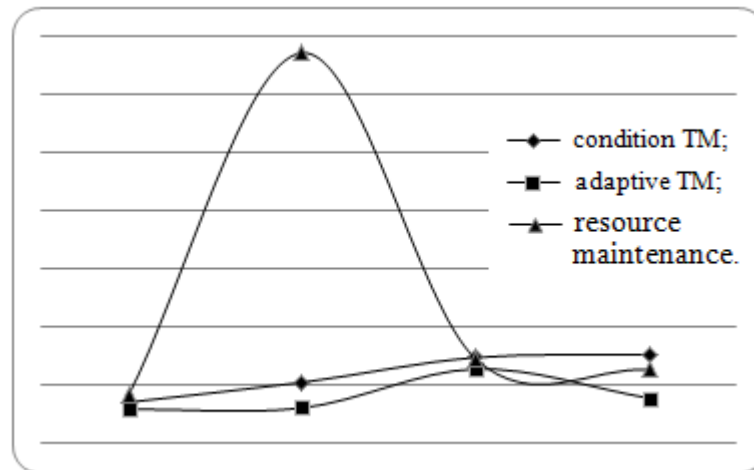


Figure 6 – Coefficient of relative loss of reliability level δ_{T_0} (in %)

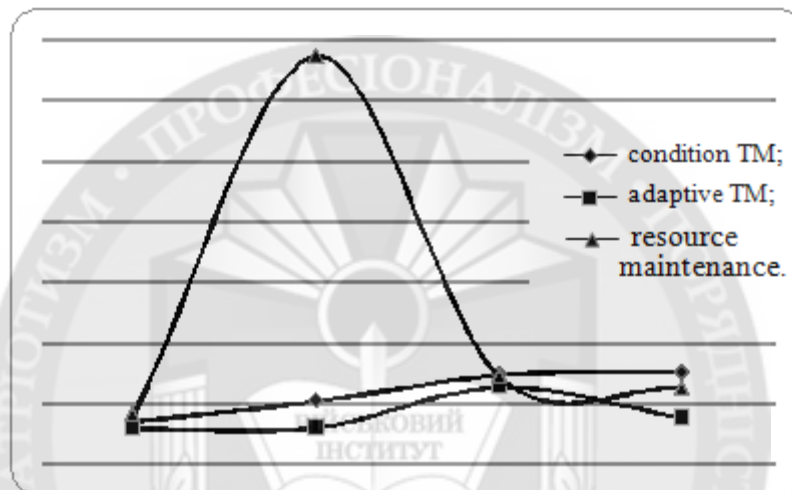


Figure 7 – Coefficient of relative losses of unit cost of operation $\delta_{C_{yn}}$ (in %)

The obtained data fully confirm the proposed assumption that the strategy of "adaptive TM" is more preferable in the case of unreliable (inaccurate) information about the reliability indicators of the elements of the object.

The value of loss rate $\delta_{C_{yn}} = 712\%$ obtained for the Test-4 object is not a random outlier or an error. Such large losses in the unit cost at "resource maintenance" are explained by the high cost of less reliable elements of the Test-4 object. This result is an additional confirmation of the critical sensitivity of the optimal parameters of the "resource maintenance" strategy in the case of inaccurate initial data about the reliability of the object.

Conclusions

The following conclusions can be drawn from the results:

1. This article considers one of the important and not fully solved problems: ensuring the reliability of operation of complex objects of technology and the continuation of their technical life by comparing the effectiveness of various TM strategies.

2. The best strategy in terms of average failure time T_0 and unit cost of operation C_{yn} is the "adaptive TM" strategy. This is followed by the "condition-based TM" strategy. The worst is the "TM by resource" strategy. The TM strategy is considered better if the graph of function T_0^+ is located higher (for function C_{yn}^+ , lower) with respect to the corresponding graph for the comparable strategy.

The TM strategy that is best behind the indicator T_0^+ is usually also best behind the indicator c_{yd}^+ , and vice versa.

3. The strategies "condition TM" and "adaptive TM" are very close to the indicators obtained. This is due to their common essence - when performing TM, information about the actual current state of the object is used.

4. The effectiveness of different TM strategies depends significantly on the reliability-value structure of the facility. If the distribution of the cost of the renewable (including maintained) elements closely correlates with the distribution of their no-failure rates, the difference in the efficiency of different TM strategies is reduced. This is well seen on the example of the Test-2 object, for which the least reliable elements are simultaneously the most expensive.

5. The optimal parameters of different TM strategies depend essentially both on the reliability-cost structure of the object, and on the given requirement to the level of the object fault-tolerance T_0^{TP} . The greater the given value T_0^{TP} , the greater the number of serviceable elements should be included in the optimal TM strategy.

LITERATURE:

1. Lanetskii B.N., Luk'yanchuk V.V., Terebukha I.N. (2011) Kompleksnaya model' kontrolya tekhnicheskogo sostoyaniya i vosstanovleniya rabotosposobnosti slozhnoi tekhnicheskoi sistemy s mnogourovnevoi strukturoi [An integrated model for monitoring the technical condition and restoring the operability of a complex technical system with a multi-level structure]. Kharkiv: Weapons systems and military equipment, 4, 73-75 p. [in Ukraine]

2. Forecasting reliability of complex technology objects. Parameters optimization of their technical exploitation: [monography] in English / Sergey Lenkov, Igor Tolok, Vadim Tsitsarev, Genadiy Zhyrov, Evgen Lenkov, Yuriy Khlaponin, Bohdan Borowik; under edition S.V. Lenkov. – Poland, Bielsko-Biala: Publishing house «BEL », 2018. – 253 p.

3. Lanets'kii, B.M., Burtsev, V.V., Karpenko, V.I., Lisovenko, V.V. (2006) Naukovo-tekhnichne suprovodzhennya ekspluatatsii i remontu zasobiv zenitnikh raketnikh sistem: osnovni polozhennya, suchasni stan ta propozitsii shchodo udoskonalennya. [Scientific and technical support of operation and repair of anti-aircraft missile systems: basic provisions, current status and suggestions for improvement]. Kharkiv: Information processing systems, 3, 75 – 80 p. [in Ukraine],

4. DSTU 3576-97. (1998) Ekspluatatsiya ta remont viis'kovoï tekhniki. Termini ta viznachennya [Operation and repair of military equipment. Terms and definitions]. Kyiv: Ukrainian national standardization system, 59 p.

5. DSTU 2860-94. (1996) Nadiinist' tekhniki. Termini ta viznachennya [Reliability of equipment. Terms and definitions.]. Kyiv: Ukrainian national standardization system, 96 p.

6. DSTU 3577-97. (1998) Vidi tekhnichnogo obslugovuvannya. Zamina komplektual'nykh virobiv. Zagal'ni polozhennya [Types of maintenance. Replacement of components. General provisions]. Kyiv: Ukrainian national standardization system, 9 p.

7. Berezovskaya YU.V., Boryak K.F., Braun V.O., Lenkov S.V. (2012) Modelirovanie i optimizatsiya protsessov tekhnicheskogo obsluzhivaniya slozhnykh ob"ektov radioelektronnoi tekhniki [Modeling and optimization of maintenance processes for complex objects of radio electronic equipment] Lenkova S.V. (Ed.). Nikolaev: Saint Gross, 1, 150 p. [in Ukraine]

8. Barzilovich E.YU., Belyaev YU.K., Kashtanov V.A. (1983) Voprosy matematicheskoi teorii nadezhnosti [Questions of the mathematical theory of reliability] Gnedenko B.V. (Ed.). Moscow: Radio and communication, 376 p.

9. Lanetskii B.N., Luk'yanchuk V.V., Artemenko A.A. (2016) Kompleksnoe otsenivanie pokazatelei bezotkaznosti i ostatochnoi dolgovechnosti slozhnykh tekhnicheskikh sistem, ehkspluatiruemykh po tekhnicheskomu sostoyaniyu [Comprehensive assessment of indicators of reliability and residual durability of complex technical systems operated by technical condition] Basic provisions of the Information Processing System, 2, 40-43 p.

10. Strel'nikov V.P., Fedukhin A.V. (2002) Otsenka i prognozirovanie nadezhnosti ehlektronnykh ehlementov i sistem. [Assessment and prediction of the reliability of electronic components and systems] Kyiv: Logos, 486 p. [in Ukraine]

11. Shishanov M.O., Veretnov A.O., (2019) Metodichni osnovi doslidzhennya remontopridatnosti viis'kovoii avtomobil'noii tekhniki. [Methodical bases of research of maintainability of military automobile equipment] Kyiv: Weapons and military equipment, 23, 53-58 p. [in Ukraine]
12. S. Lenkov, G. Zhyrov, D. Zaytsev, I. Tolok, E. Lenkov, T. Bondarenko, Y. Gunchenko, V. Zagrebnyuk, O. Antonenko/ Features of modeling failures of recoverable complex technical objects with a hierarchical constructive structure // Skhidno-Evropeis'kii zhurnal peredovikh tekhnologii. – Kharkiv, 2017. - №4/4(88) – С. 34 – 42. DOI:10.15587/1729-4061.2017.108395.
13. Genadiy Zhyrov, Serhii Lienkov, Yurii Husak, Hennadii Banzak, Igor Tolok. Analysis of problem optimization of parameters maintenance process according to state with constant periodicity of control. // International Journal of Emerging Trends in Engineering Research Available. ISSN 2347-3983. Volume 8. No. 6, June 2020, P.2605-2611. DOI:10.30534/ijeter/2020/63862020.
13. Zhiron G.B. (2017) Algorimt modelyuvannya protsesiv tekhnichnogo obslugovuvannya za resursom skladnikh radioelektronnikh ob'ektiv [Algorithm for modeling maintenance processes based on the resource of complex electronic objects] Kyiv: MIKNU, XIII International Scientific and Practical Conference "Military Education and Science: Present and Future", 36 p. [in Ukraine]
14. Lenkov E.S., Zhiron G.B., Bondarenko T.V. (2016) Formalizovannaya matematicheskaya model' protsesa adaptivnogo tekhnicheskogo obsluzhivaniya po sostoyaniyu slozhnoi radioehlektronnoi tekhniki [Formalized mathematical model of the process of adaptive maintenance on the state of complex electronic equipment]. Odessa: Informatics and mathematical methods in modeling 2, 365-371 p. [in Ukraine]
15. Zhiron G.B., Lenkov E.S., Bondarenko T.V. (2017) Algoritmichna model' protsesu tekhnichnogo obslugovuvannya za stanom z postiinoyu periodichnistyu kontrolyu [Algorithmic model of maintenance process according to the state with constant periodicity of control] Kyiv: Modern special equipment 1, 26-29 p. [in Ukraine]
16. Forecasting to reliability complex object radio-electronic technology and optimization parameter their technical usage with use the simulation statistical models: [monography] in English / Sergey Lenkov, Konstantin Borjak, Gennady Banzak, Vadim Braun, etc.; under edition S. V. Lenkov. – Odessa: Publishing house «BMB», 2014. – 252 p.

**д.т.н., проф. Ленков С.В., к.т.н. Зінчик А.Г., к.т.н. Ленков Є.С., Бондаренко Т.В.
ПОРІВНЯННЯ ЕФЕКТИВНОСТІ МЕТОДИК ОПТИМІЗАЦІЇ ПАРАМЕТРІВ СТРАТЕГІЇ
ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ СКЛАДНИХ ОБ'ЄКТІВ ТЕХНІКИ**

Стаття присвячена проведенню порівняння ефективності методик оптимізації параметрів стратегії технічного обслуговування складних об'єктів техніки. Перш за все, це стосується методик оптимізації параметрів стратегії технічного обслуговування за станом, за ресурсом та адаптивного технічного обслуговування (ТО). Крім цього зроблено порівняльні оцінки показників цільових функцій об'єкту без технічного обслуговування. Тобто стаття присвячена одній із важливих і до кінця не розв'язаних задач: забезпеченню надійності експлуатації складних об'єктів техніки звичайної та високої відповідальності.

Розглянуті основні принципи та елементи побудови методики, застосована технологія виконання завдання оптимізації відповідної стратегії, що розроблена авторами раніше. Запропоновано розрахунок параметрів за умовою оптимальними методами вирішення задач, а саме імітаційно статистичним моделюванням.

Кращою за показниками середнього напрацювання на відмову і питомої вартості експлуатації є стратегія "адаптивне ТО". Потім йде стратегія "ТО за станом". Найгіршою є стратегія "ТО за ресурсом". Стратегії "ТО за станом" і "адаптивне ТО" дуже близькі до отримуваних показниками. Це пояснюється їх загальною сутністю - при проведенні ТО використовується інформація про фактично поточний стан об'єкта. Ефективність різних стратегій ТО істотно залежить від надійнісно-вартісної структури об'єкта. Якщо розподіл вартості відновлюваних елементів близько корелюється з розподілом їх показників безвідмовності, відмінність в ефективності різних стратегій ТО скорочується.

Оптимальні параметри різних стратегій ТО істотно залежать як від надійнісно-вартісної структури об'єкта, так і від заданої вимоги до рівня безвідмовності об'єкта.

Ключові слова: складні об'єкти техніки, стратегія технічного обслуговування, зміна періодичності контролю, технічне обслуговування і ремонт.