

ВІЙСЬКОВА ТЕХНІКА І ТЕХНОЛОГІЇ ПОДВІЙНОГО ПРИЗНАЧЕННЯ

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COMPARATIVE STUDY OF DIFFERENT MAINTENANCE STRATEGIES

Complex technical objects are understood as objects consisting of a large number of different types elements (tens, hundreds of thousands), each of which can represent a rather complex technical device. Elements can be electronic, mechanical, electromechanical, hydraulic, etc. The diversity of elements leads to the fact that for various elements fundamentally different physical processes (and, consequently, rates) of degradation are characteristic, leading to their failures. Objects can have an arbitrary reliability structure (as a rule, serial-parallel). The structural structure of such objects is usually hierarchical, that is, an object consists of subsystems, subsystems consist of units (cabinets), units - of devices (blocks), etc.

A characteristic feature of complex technical objects for special purposes is the presence in their composition of a large number (tens, hundreds of thousands) of different types of component parts that have different levels of reliability, different patterns of their wear and tear processes. This feature requires a more subtle approach to the organization and planning of maintenance during their operation. The problem is that during the development of such facilities, all issues related to maintainability and maintenance should be addressed already at the early stages of facility design. If you do not provide in advance the necessary hardware and software for the built-in monitoring of the technical condition (TC) of the object, do not develop and “build” the maintenance technology into the object, then it will not be possible to realize in the future a possible gain in the reliability of the object due to maintenance. Since all these issues must be resolved at the stage of object creation (when the object does not yet exist), mathematical models of the maintenance process are needed, with the help of which it would be possible to calculate the possible gain in level of reliability facility due to maintenance, to estimate the cost costs required for this. Then, based on such calculations, make a decision on the need for maintenance for this type of objects and, if such a decision is made, develop the structure of maintenance system, choose the most acceptable maintenance strategy, and determine its optimal parameters.

This paper provides a comparative study of various maintenance strategies. The paper also confirms that the optimal parameters of various maintenance strategies significantly depend on both the reliability and cost structure of object and the specified requirements for the level of reliability of object.

Keywords: maintenance, maintenance strategies, facility availability, component parts.

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

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

- it is possible to compare different maintenance strategies only by the results of their application to the same object;
- test objects (on which a comparison of maintenance strategies is made) should be comparable in terms of the structure time and cost costs for maintenance and maintenance;
- indicators of the quality maintenance process (objective functions), according to which the comparison of various maintenance strategies is made, should be evaluated at the same intervals of

the object's operation and with the same parameters of modeling process (if the comparison of maintenance strategies is made according to the simulation results);

- characteristics of the maintenance process obtained with the optimal parameters of the maintenance strategies should be compared, that is, potential capabilities of various maintenance strategies should be compared.

Analysis of previous studies. The “surge” in the number of theoretical works on the maintenance of complex systems falls on 70s of the last century, which can be explained by the mass production of complex radio-electronic equipment for military and special purposes at that time [1 - 5]. Currently, there is a decline in the number of scientific publications devoted to the maintenance of complex technical objects. One of the reasons for this, in our opinion, is the sharp increase in the level of integration and reliability components. Thanks to this, the developers of sophisticated equipment were able to solve the issues of ensuring required level of reliability without significant maintenance costs (or without maintenance at all). However, the same reason (high integration and reliability of component parts) opened up the possibility of implementing more and more complex technology with new functions, which was impossible with the old element base. This again leads objectively to the problems of ensuring reliability and, therefore, the question of the need for maintenance and choice of optimal strategy for its implementation again becomes relevant.

Unfortunately, the currently known mathematical models and methods for calculating the optimal parameters of MS processes are not very suitable for application to real technical objects. The main disadvantage of these models is that they either do not take into account the complex structure of an object at all, or it is possible to take into account only some of the simplest structures [5-7].

Main part. In this study, 4 test objects are used, which differ in their reliability and structural characteristics. This, among other things, allows you to check and simultaneously demonstrate the "performance" of developed methods for determining the optimal parameters of various maintenance strategies for different initial data.

To ensure the comparability of structure time and cost costs for maintenance and current repairs, the same for all elements and objects characteristics of maintainability and cost were set:

- average recovery time of an element $\tau_{bi} = 1$ h;
- average duration of maintenance $\tau_{toi} = 1$ h;
- item cost $C_i = 10$ c.u.;
- cost of operation current repair (replacement) of the element $C_{tpi} = 1$ c.u. ;
- cost of MS operation elements $C_{toi} = 1$ c.u.

Technical diagnostics systems characteristics for test objects are set as follows:

- duration of diagnostics at MS $\tau_d = 0.5$ h;
- cost of the diagnostic operation at MS $C_d = 1$ c.u.

The same for all test objects are also set the indicators depending on the purpose of object – specific cost losses incurred by the external system (in which this object is used) in the object failure state $c_{отк} = c.u./h$, and in MS state $= 1$ c.u./h.

For all test objects, according to the developed methods, optimal parameters for three maintenance strategies were determined. For brevity, as before, we will call them: “MS by state”, “adaptive MS” and “MS by resource”.

All calculations were made for the duration of operation $T_s = 20$ years with continuous operation of the facilities.

The optimal parameters of various maintenance strategies were determined under the idealized assumption of existence for test objects of measurable determining parameters for the least reliable elements related to the set of recoverable elements E_b . The subsets of potentially serviced items $E_{то}$

were specified in such a way that they included all the least reliable items. The test objects do not contain elements whose reliability would be lower than the reliability of any elements E_{to} ($E_{to} \subset E_B$). Obviously, under this condition, with the optimal parameters of maintenance strategies, the maximum, potentially possible efficiency of maintenance is provided, which is most likely unattainable in practice.

Table 1 - 4 presents final results of calculating the optimal parameters of various maintenance strategies. In fig. 1 - 4 show the graphs of the mean time between failures T_0 and the unit cost c_{yd} of operation versus the number of serviced elements, obtained with the optimal parameters of corresponding maintenance strategies.

Table 1

Comparative evaluation of indicators T_0 , c_{yd} and K_{TH} for object Test-1 with different maintenance strategies

Maintenance strategy		MS condition	Adaptive MS	MS by resource	Without MS
Indicators (target functions)	T_0 , h	1660	1662	1609	1236
	c_{yd} , c.u./h	0,01461	0,01408	0,01695	0,02187
	K_{TH}	0,99851	0,99877	0,99689	0,99919
	ε	0,180	0,179	0,184	0,085
Optimal maintenance strategy parameters ($T_0^{TP} = 1500$ h)		$ E_{to}^* = 3$ $U_{to}^* = \{0,5; 0,4; 0,5\}$ $T_k^* = 1200$ h	$ E_{to}^* = 3$ $U_{to}^* = \{0,5; 0,4; 0,5\}$ $\gamma^* = 0,45; \beta = 0,$	$N_{to}^* = 1$ $ E_{to1}^* = 3$ $T_{to}^* = 1400$ h	-

Table 2

Comparative evaluation of indicators T_0 , c_{yd} and K_{TH} for object Test-2 with different maintenance strategies

Maintenance strategy		MS condition	Adaptive MS	MS by resource	Without MS
Indicators (target functions)	T_0 , h	695	702	676	294
	c_{yd} , c.u./h	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
Optimal maintenance strategy parameters ($T_0^{TP} = 600$ 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	-

Table 3

Comparative evaluation of indicators T_0 , c_{yd} and K_{TH} for object Test-3
with different maintenance strategies

Maintenance strategy		MS condition	Adaptive MS	MS by resource	Without MS
Indicators (target functions)	T_0 , h	15194	15136	15009	9458
	c_{yd} , c.u./h	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
Optimal maintenance strategy parameters ($T_0^{tp} = 15000$ 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	-

Table 4

Comparative evaluation of indicators T_0 , c_{yd} and K_{TH} for object Test-4
with different maintenance strategies

Maintenance strategy		MS condition	Adaptive MS	MS by resource	Without MS
Indicators (target functions)	T_0 , h	6575	5566	4879	914
	c_{yd} , c.u./h	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
Optimal maintenance strategy parameters ($T_0^{tp} = 5000$ 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	-

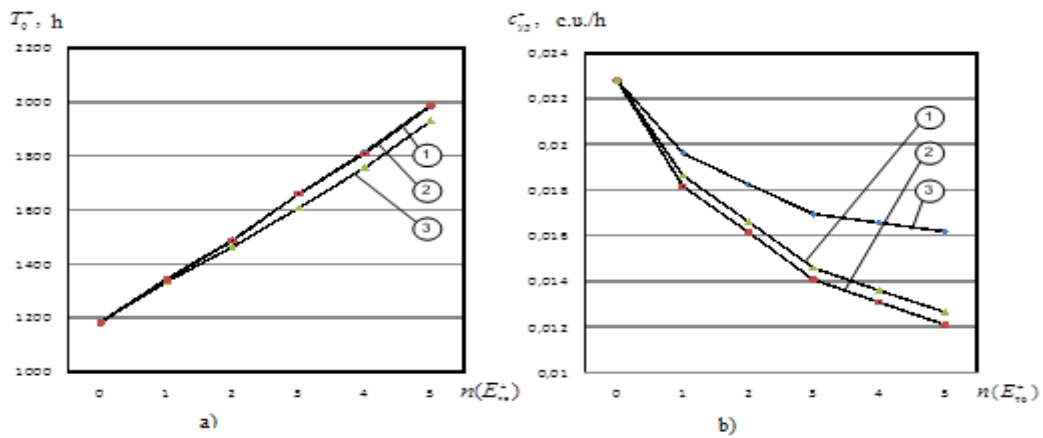


Figure 1 – Graphs of dependence indicators T_0^+ and c_{yd}^+ on the number of serviced elements for various maintenance strategies (object Test-1):
 1 - maintenance by condition; 2 - adaptive maintenance; 3 - maintenance by resource

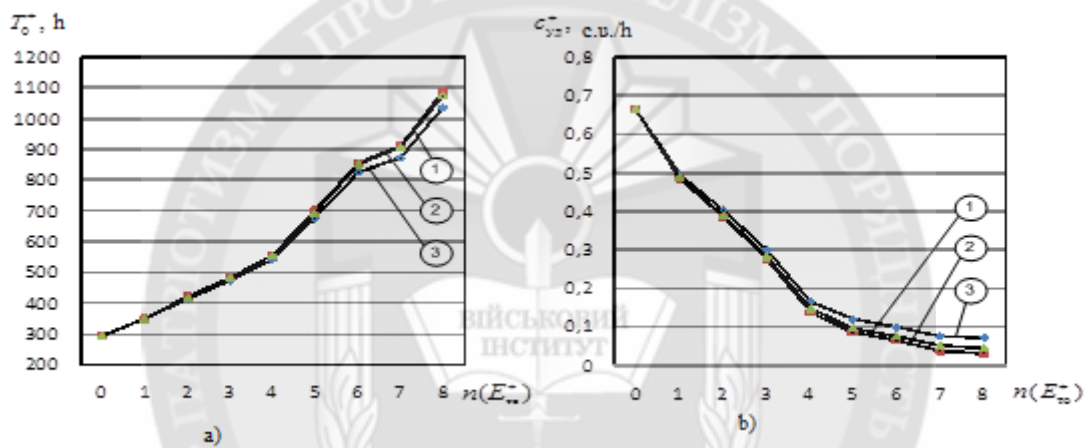


Figure 2 – Graphs of dependence indicators T_0^+ and c_{yd}^+ on the number of serviced elements for various maintenance strategies (object Test-2):
 1 - maintenance by condition; 2 - adaptive maintenance; 3 - maintenance by resource

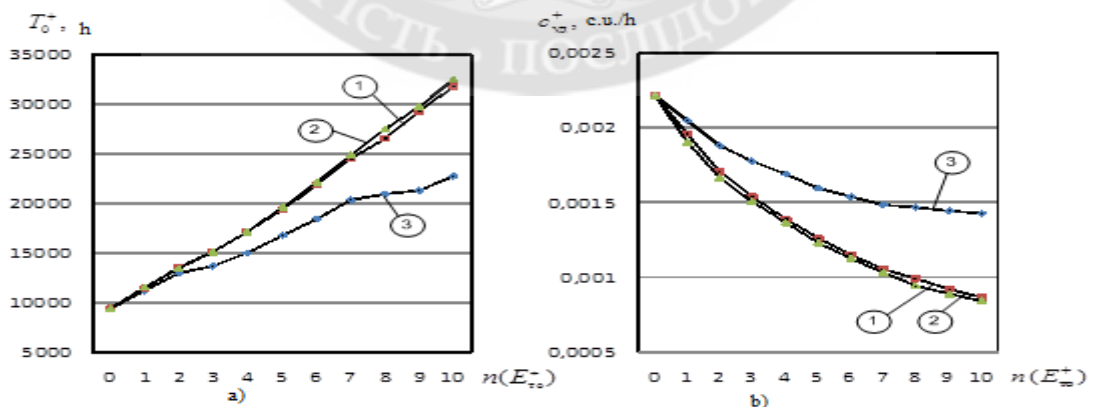


Figure 3 – Graphs of dependence indicators T_0^+ and c_{yd}^+ on the number of serviced elements for various maintenance strategies (object Test-3):
 1 - maintenance by condition; 2 - adaptive maintenance; 3 - maintenance by resource

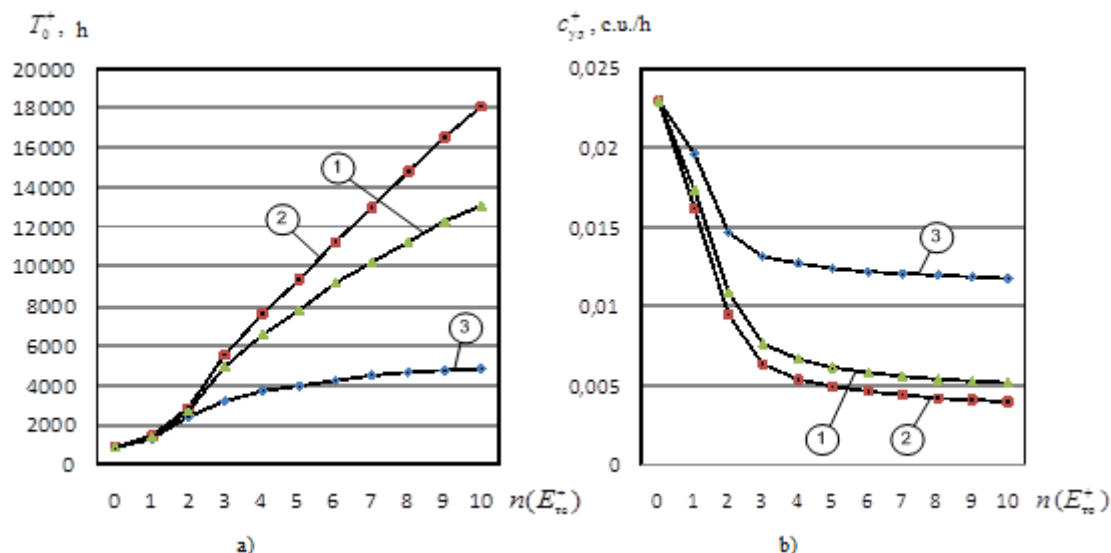


Figure 4 – Graphs of dependence indicators T_0^+ and c_{yd}^+ on the number of serviced elements for various maintenance strategies (object Test-4):
 1 - maintenance by condition; 2 - adaptive maintenance; 3 - maintenance by resource

Based on the results obtained, following **conclusions** can be drawn:

1. The best in terms of mean time between failures T_0^+ and unit cost of operation c_{yd}^+ is the “adaptive maintenance” strategy. This is followed by “maintenance by condition” strategy. The worst is the “TO by resource” strategy. The maintenance strategy is considered the best if graph of the function T_0^+ is located higher (for the function c_{yd}^+ – lower) in relation to the corresponding graph for compared strategy. The maintenance strategy, the best in terms of performance T_0^+ , is usually the best in terms of performance c_{yd}^+ , and vice versa.

2. The strategies “maintenance by condition” and “adaptive maintenance” are very similar in terms of the obtained indicators. This is due to their common essence – during maintenance, information about the actual current state of the object is used.

3. The effectiveness of various maintenance strategies depends significantly on the reliability and cost structure of the object. If distribution of the cost restored (including serviced) elements is closely correlated with the distribution of their reliability indicators, difference in effectiveness of different maintenance strategies is reduced. This is clearly seen on the example of Test-2 object, for which the least reliable elements are also the most expensive.

4. The optimal parameters of various maintenance strategies substantially depend on both the reliability and cost structure of the facility and the specified requirement for the facility's reliability T_0^{tp} . The higher the specified value T_0^{tp} , more serviced items should be included in the optimal maintenance strategy.

For Test-4 object, the specified requirement $T_0^{tp} = 5000$ h with the optimal strategy of “maintenance by resource” is not provided (despite the fact that all potentially serviced elements have been used).

The “adaptive maintenance” strategy has not been studied separately. The adaptive maintenance parameter β (exponential smoothing constant) was set equal to 0.5 for all test objects. This corresponds to a neutral situation, when the “weight” of initial data on the reliability indicators of elements (a priori information) and data on the actual measured values of determining parameters (posteriori information) is approximately the same.

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ПОРІВНЯЛЬНЕ ДОСЛІДЖЕННЯ РІЗНИХ СТРАТЕГІЙ ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ

Під складними технічними об'єктами розуміються об'єкти, що складаються з великого числа різнотипних елементів (десятки, сотні тисяч), кожен з яких може являти собою досить складний технічний пристрій. Елементи можуть бути радіоелектронними, механічними, електромеханічними, гідравлічними, і т.д. Різнотипність елементів призводить до того, що для різних елементів характерні принципово різні фізичні процеси (і, отже, швидкості) деградації, що призводять до їх відмов. Об'єкти можуть мати довільну надійнісну структуру (як правило - послідовно-паралельну). Конструктивна структура таких об'єктів зазвичай ієрархічна, тобто, об'єкт складається з підсистем, підсистеми складаються з агрегатів (шаф), агрегати - з пристроїв (блоків), і т.д. Характерною особливістю складних технічних об'єктів спеціального призначення є наявність в їх складі великої кількості (десятки, сотні тисяч) різнотипних комплектуючих елементів, які мають різний рівень надійності, різні закономірності процесів їх зносу і старіння. Ця особливість вимагає більш тонкого підходу до організації і планування ТО в процесі їх експлуатації.

Проблема полягає в тому, що при розробці таких об'єктів всі питання, пов'язані з ремонтпридатністю і технічним обслуговуванням повинні вирішуватися вже на ранніх етапах проектування об'єкта. Якщо не передбачити заздалегідь необхідні апаратні і програмні засоби вбудованого контролю технічного стану (ТС) об'єкта, якщо не розробити і не "вбудувати" в

об'єкт технологію проведення ТО, то реалізувати в майбутньому можливий виграш в безвідмовності об'єкта за рахунок проведення ТО не вдасться. Оскільки всі ці питання повинні вирішуватися на етапі створення об'єкта (коли об'єкта ще немає), необхідні математичні моделі процесу ТО, за допомогою яких можна було б прорахувати можливий виграш в рівні безвідмовності об'єкта за рахунок проведення ТО, оцінити необхідні для цього вартісні витрати. Потім на підставі таких розрахунків прийняти рішення про необхідність проведення ТО для даного типу об'єктів і, якщо таке рішення прийнято, розробити структуру системи ТО, вибрати найбільш прийнятну стратегію ТО, визначити її оптимальні параметри.

У даній роботі проводиться порівняльне дослідження різних стратегій технічного обслуговування. Також в роботі підтверджується, що оптимальні параметри різних стратегій ТО істотно залежать як від надійностно-вартісної структури об'єкта, так і від заданої вимоги до рівня безвідмовності об'єкта.

Ключові слова: технічне обслуговування, стратегії технічного обслуговування, безвідмовність об'єкта, комплектуючі елементи

