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OPTIMIZATION OF MAINTENANCE COMPLEX OBJECTS OF RADIO ELECTRONIC EQUIPMENT

The article discusses models for optimizing the maintenance eservice process (MS) of complex objects of radio-electronic technics (RET). The statement of the problem determining optimal parameters of objects MS is formulated for the case if the state maintenance strategy MS (MSS strategy) is used.

As a criterion of optimization, the requirement minimum unit cost of operating an object for a given period of its operation is used, provided that the required level of failure-free operation of the object is estimated as estimated by "mean time on failures". The objective functions of the optimization task are determined by modeling the process of MS and repair (MSandR) of the object. This circumstance explains the choice of a search method for an approximately optimal solution to the problem: simplest relaxation method of direct enumeration is used, controlled by a human expert who solves this problem in the interactive dialogue mode between the user and the computer.

The methodology for determining approximately optimal parameters of strategy MSS described in this article is intended for use in the development of object RET. The methodology allows the early stages of development to pre-evaluate possibility of increasing level reliability of the facility due MS. At later stages of development, when all technical solutions have already become known, elements for which there are measurable determining parameters become known, preliminary estimates of the necessary parameters MSS can be refined and corrected design decisions. Corresponding refinement of calculations should be made every time when accurate data on the reliability of component parts appear.

Software (SW) was developed for computer support of the solution search process. SW developed by Delphi programming tools.

Key words: object of radio-electronic technics, maintenance, mean time on failures, unit cost of operation, simulation statistical modeling.

Introduction and statement of the problem. A complex object of radio-electronic technics (RET) is understood to mean a technical device consisting of a large number (tens, hundreds of thousands) of various types components (mechanical, electromechanical, radio and optoelectronic, hydraulic, etc.). Examples of complex RET objects include radar stations, elements of anti-aircraft missile systems, electronic warfare stations, etc. The operation of various components of such objects is based on different physical principles, have significantly different reliability indicators and, therefore, require different terms and volumes of work for their maintenance.

Maintenance (MS) of complex RET facilities is intended to ensure the required level of their failure-free operation. Carrying out maintenance always requires certain costs (time, cost, electricity, etc.), so the task of minimizing these costs naturally arises. To solve this problem, it is necessary to build a mathematical model in which the goals of the optimization problem (objective functions) and the parameters of these functions should be optimized in a formalized form.

With this in mind, we will use the following indicators as objective functions in the problem under consideration:

T_0 - average time between failures of an object [1];

$c_э$ - unit cost of operating RET object at a given time interval.

Using these notations, the problem of optimizing the parameters of the selected MS strategy in a formal form can be written as follows:

$$T_0(\mathrm{P}^*_{\text{то}}) \geq T_0^{\text{тр}};$$
$$c_э(\mathrm{P}^*_{\text{то}}) \to \min\ , \qquad (1)$$

where $\mathrm{P}_{\text{то}}$ - is the designation of the generalized parameter of the maintenance strategy, the specific content of which is determined by the selected maintenance strategy;

$T_0^{\text{тр}}$ – required value of the mean time between failures of the facility.

$\text{Р}_{\text{то}}^{*}$ – is the optimal value for the parameter.

The most common in practice are two fundamentally different MS strategies: the maintenance-by-status strategy (MSS strategy) and the maintenance-by-resource strategy (MSR). The strategy MSS is more effective than strategy MSR (in terms of influencing the facility's failure-free level). However, strategy MSS, as a rule, requires significantly greater economic costs, since it requires the presence of additional hardware necessary to determine the actual technical condition of object during its operation.

In this article we will consider only strategy MSS. Let us denote the set of all structural elements objects, by the state of which the TC of the object is determined $E_{\text{о}}$ ($E_{\text{о}}$ – these are the elements included in the structural diagram of the reliability objects). We assume that only a part of them undergo maintenance during operation. The set of serviced elements is denoted by $E_{\text{то}}$ ($E_{\text{то}} \subseteq E_{\text{о}}$).

Analysis of recent research. Recently, more and more attention has been paid to improving the technical operation of complex equipment. A special "niche" is the issues of optimizing the maintenance parameters long-term use of electronic equipment. For the developer of these processes, it is important to have methodologies for a qualitative assessment of the mechanism influence of individual processes on the degradation and failure of RET.

A lot of research has been devoted to questions of calculating and predicting reliability, as well as creating models (including simulation ones). In work [2], a method has been proposed for developing modern methods for assessing reliability based on numerical modeling. In work [3], a method for calculating reliability based on graphs was proposed. In work [4], MEMS structural reliability modeling method is presented and the FORM method is described for obtaining the reliability index and its sensitivity with respect to input random variables and their parameters, which can not only be used to assess the reliability of an object, but can also help determine key factors for additional structural improvements. In work [5], Weibull – Corrosion extended covariance model is proposed for assessing the reliability of a system that faces operational stresses. A combination method for analyzing the reliability of a multivariate system was proposed in work [6]. The method is based on a combination of BDD and MMDD models. In work [7], it is proposed to use a semi-parametric bayesian approach to obtain reliability indicators of multilevel hierarchical systems, both with parallel and serial connection of components.

In these works, the methodology for determining reliability indicators of system for given set of failing elements and their characteristics is described in detail, but the problem of choosing this set and its effect on reliability indicators is practically not addressed.

где $\{E_{\text{то}}\}$ - множество всех множеств $E_{\text{то}}$;

The main results of study. By *determining parameter* (DP) we mean the physical or functional parameter, value of which determines the operability of element [8].

The normalized DP value of the *i*-th element is denoted by $u_i(t)$ ($u_i(t) \in [0,1], i = \overline{1, |E_{\text{то}}|}$). The value 0 corresponds to the nominal (required) value of the parameter, the value 1 is the boundary value, upon reaching which the element is considered to be failed (inoperative). Random DP values $u_i(t)$ describe the physical process of element degradation. All values $u_i(t) < 1$ correspond to the healthy state of element.

We introduce the concept of a maintenance *level* as $u_{i\text{то}}$ follows ($u_{i\text{то}} < 1$). If the value at a certain point in time (operating time) t reaches a level (level of maintenance), then at this point in time, maintenance (replacement) of this element is required.

Taking into account the introduced concepts and notation, the generalized parameter of the strategy MSS $\text{Р}_{\text{тос}}$ is represented by the following set [9]:

$$\text{Р}_{\text{то}} = \text{Р}_{\text{тос}} = \{E_{\text{то}}, U_{\text{то}}, T_{\text{к}}\}, \quad (2)$$

where $E_{\text{то}}$ – is the set of serviced elements; $U_{\text{то}} = \{u_{i\text{то}}; i = \overline{1, |E_{\text{то}}|}\}$ $T_{\text{к}}$ – a vector of normalized values determining parameters of the serviced elements (vector of MS levels), upon reaching which element MS is required; $T_к$ – frequency of monitoring the vehicle. When monitoring the vehicle's vehicle, the values of all serviced TC elements are measured and, based on the measurement results $u_i(t)$, a decision is made about the need for maintenance.

Taking into account definition (2), the statement of optimization problem (1) can now be written as follows:

$$T_0(E^*_{то}, U^*_{то}, T^*_к) \geq T_0^{тр};$$
$$c_э(E^*_{то}, U^*_{то}, T^*_к) \to \min, \quad (3)$$

where, $E^*_{то}$, $U^*_{то}$ and $T^*_к$ - are the sought optimal values parameters of strategy MSS.

The main features of problem (3) are two: firstly, there are no analytical expressions for the objective functions that would associate their values with the parameters of the functions, and secondly, this is a complex structure of the space optimized parameters $P_{тос}$ (according to (3) this space is three-dimensional and heterogeneous). These features do not allow the use of standard classical optimization methods to solve problem (3).

The space in which the search for optimal values $E^*_{то}$, $U^*_{то}$ and $T^*_к$ should be carried out is a cartesian product of the following form (Fig. 1)

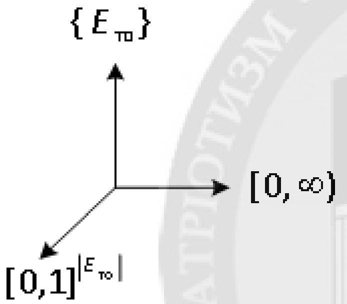

Fig .1. The search space for optimal solution

$$\{E_{то}\} \times [0,1]^{|E_{то}|} \times [0, \infty), \quad (4)$$

where $\{E_{то}\}$ - is the set of all sets $E_{то}$;

$[0,1]^{|E_{то}|}$ - hypercube, each point in which is a vector of dimension $|E_{то}|$, elements of the vector are numbers belonging to a segment;

$[0, \infty)$ - numerical axis containing all positive numbers.

Searching in such a space for a "point" representing an optimal solution $P^*_{тос} = \{E^*_{то}, U^*_{то}, T^*_{то}\}$ is a difficult task requiring use of non-standard approaches.

The article discusses the methodology for approximate solution of problem (3), based on the application of the ISM, which is implemented in the ISMPN program [10]. With the help of the ISM, the estimates of the objective functions T_0 and $c_э$ taking into account the maintenance are determined by modeling. The problem is solved in the mode of interactive user dialogue with a personal computer (PC).

The idea of the methodology consists in the sequential (step-by-step) formation of set $E^*_{то}$ by including in it at each step one element taken from the base set $E^*_{то}$ of all potentially serviced elements. The set $E^*_{то}$ is set by the user ($E'_{то} \subseteq E_о$) [11,12]. It is assumed that before starting to solve the problem, a database (DB) was created (using the ISMPN program), into which all the necessary information about object RET for which this problem is solved is entered. The content of the methodology is most conveniently stated by presenting it in the form of an algorithm (Fig. 2). Let us briefly consider the operation of this algorithm.

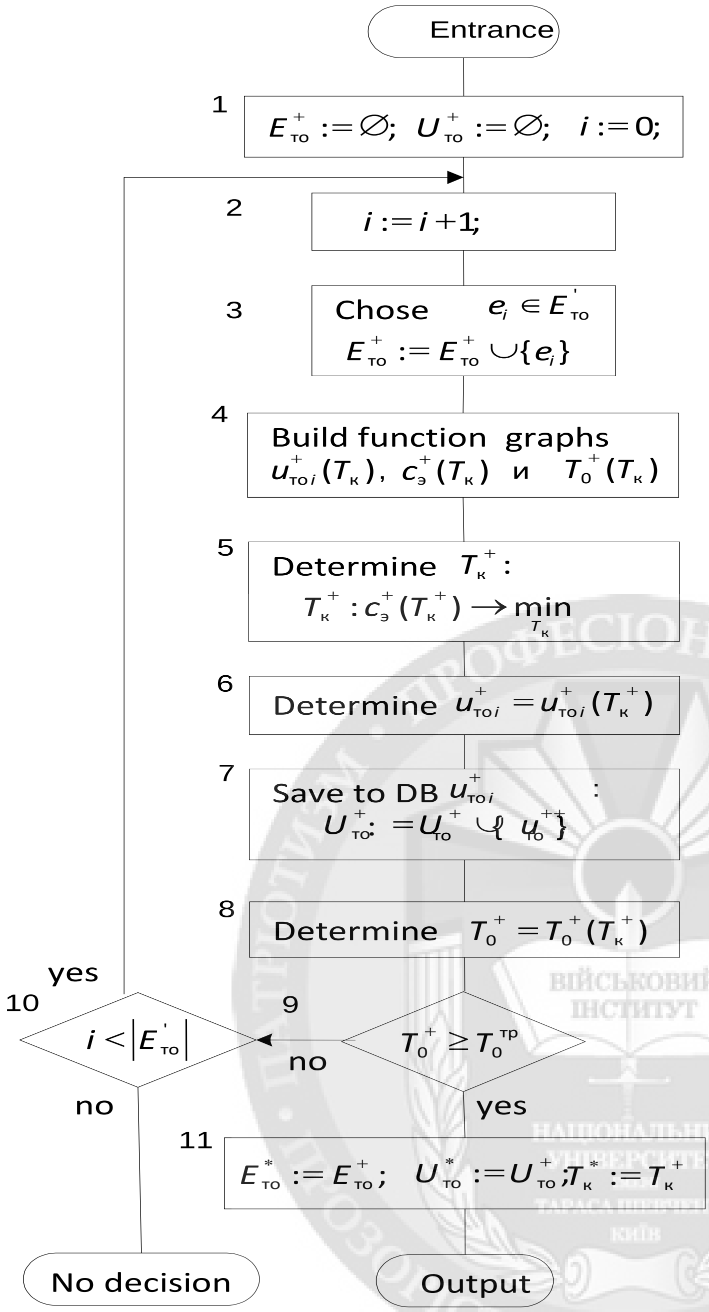

Figura 2. Algorithm for determining pameters with a constant freguency of control

Operator 1 indicates preparatory operations: auxiliary sets $E^{+}_{\text{то}}$ и $U^{+}_{\text{то}}$ are created (in the PC memory) and in which the corresponding elements of the future solution $E^{+}_{\text{то}}$ и $U^{+}_{\text{то}}$ will be formed and. At first they are empty. The variable i is initiated, with the help of which the number of completed steps in the process of solving the problem will be calculated. Operator 2 generates number of the next step.

At the beginning of each step, one element e_i must be added to the set $E^{+}_{\text{то}}$, taken from the set $E^{'}_{\text{то}}$ (operator 3). These actions are performed by the user "manually" in the **Database** mode of the ISMPN program. The choice of elements to include them in the set is recommended to be made in order of increasing level of reliability.

After adding a new element to set $E^{'}_{\text{то}}$, calculations are carried out using the ISMPN program (in **Optimization TO | TO "by state"** mode). In fig. 2, these actions are presented by operator 4. As a result of the calculations, function $u^{+}_{\text{то}i}(T_{\text{к}})$, $c^{+}_{\text{э}}(T_{\text{к}})$ and $T^{+}_{0}(T_{\text{к}})$ schedules are generated, and in a given range of control $D(T_{\text{к}})$ periodicity values.

The results obtained during the modeling process always contain a random component, therefore, these graphs are formed as average estimates accumulated by the results repeated repetitions of calculations. The user monitors calculation process and interrupts calculations as soon as he considers achieved accuracy of the graphs sufficient for practical solutions. The form of obtained graphs for example considered below is shown in Fig.3.

Each point on the graphs $u^{+}_{\text{то}i}(T_{\text{к}})$, $c^{+}_{\text{э}}(T_{\text{к}})$ and $T^{+}_{0}(T_{\text{к}})$, and it turns out as the accumulated average, obtained by varying parameter $u_{\text{то}i}$ (level of MS element e_i), added in $E^{+}_{\text{то}}$ in current step. As a conditionally optimal value of MS $u^{+}_{\text{то}i}$ level, value corresponding to minimum of indicator is selected $c_{\text{э}}(E^{+}_{\text{ТО}\,i}, U^{+}_{\text{ТО}\,i}, T_{\text{К}})$:

$$u^{+}_{\text{ТО}\,i}(T_{\text{К}}) : c_{\text{э}}(E^{+}_{\text{ТО}\,i}, U^{+}_{\text{ТО}\,i}, T_{\text{К}}) \to \min_{u_{\text{ТО}\,i} \in [0,1]}, \tag{5}$$

where $U^{+}_{\text{то}i} = \{u^{+}_{\text{то}1}, ..., u^{+}_{\text{то}i-1}, u_{\text{то}i}\}$ – is vector in which $u^{+}_{\text{то}1}, ..., u^{+}_{\text{то}i-1}$ – are conditionally optimal values of MS $u_{\text{то}i}$ – levels found in the previous steps and stored in database, is value of MS level of *i*-th element varied in the current step.

On graphs $c^{+}_{\text{э}}(T_{\text{к}})$ and $T^{+}_{0}(T_{\text{к}})$ displays estimates of the corresponding indicators and found as a result of modeling are displayed $c_{\text{э}}(E^{+}_{\text{то}i}, U^{+}_{\text{то}i}, T_{\text{к}})$ and $T_{0}(E^{+}_{\text{то}i}, U^{+}_{\text{то}i}, T_{\text{к}})$. Varying frequency of control $T_{\text{к}}$ is carried out in a user-defined range of values $D(T_{\text{к}})$. The range of variation $D(T_{\text{к}})$ is selected by the user in such a way as to ensure that a minimum of function $c^{+}_{\text{э}}(T_{\text{к}})$ (if one exists) falls within him and an acceptable accuracy of solution.

Based on obtained schedule $c^{+}_{\text{э}}(T_{\text{к}})$, conditionally optimal value of the monitoring periodicity is determined $T^{+}_{\text{к}}$ (operator 5):

$$T^{+}_{\text{к}} : c^{+}_{\text{э}}(T^{+}_{\text{к}}) = \min_{T_{\text{к}} \in D(T_{\text{к}})} c^{+}_{\text{э}}(T_{\text{к}}). \qquad (6)$$

For the found value $T^{+}_{\text{к}}$ from graph $u^{+}_{\text{то}i}(T_{\text{к}})$, determine the conditionally optimal value of level MS $u^{+}_{\text{то}i} = u^{+}_{\text{то}i}(T^{+}_{\text{к}})$ (operator 6). Save obtained value $u^{+}_{\text{то}i}$ in database (operator 7). This operation is performed by the user "manually" in **Database** mode [10]. After that, value $u^{+}_{\text{то}i}$ is stored as *i*-th element of vector $U^{+}_{\text{то}i}$.

Then, according to schedule $T^{+}_{0}(T_{\text{к}})$, determine value T^{+}_{0} - mean time between failures achieved in current step (operator 8).

Check compliance with the requirement $T^{+}_{0} \geq T^{\text{тр}}_{0}$ (operator 9). If this requirement is fulfilled, process of solving problem is completed, conditionally optimal parameter values are obtained, $E^{+}_{\text{то}}$, $U^{+}_{\text{то}}$ and $T^{+}_{\text{к}}$ are accepted as approximately optimal values $E^{+}_{\text{то}}$, $U^{+}_{\text{то}}$ and $T^{+}_{\text{к}}$ (operator 11), an approximate solution is obtained $\text{P}^{*}_{\text{тос}} = \{E^{*}_{\text{то}}, U^{*}_{\text{то}}, T^{*}_{\text{то}}\}$.

If condition $T^{+}_{0} \geq T^{\text{тр}}_{0}$ is not fulfilled, it is necessary to check if there are more elements that can be included in set $E^{+}_{\text{то}}$ (operator 10). If there are any, it is necessary to continue the process of searching (forming) a solution to the problem, proceed to the next step of solving the problem (operator 10 transfers control to operator 2). Otherwise, if all potentially serviced elements $E^{+}_{\text{то}}$ have been exhausted, it is concluded that there is no solution to problem (3) under given conditions.

In fig. 3 shows the view of the PC screen after completion of the simulation at the next step of solving the problem (after executing operator 4).

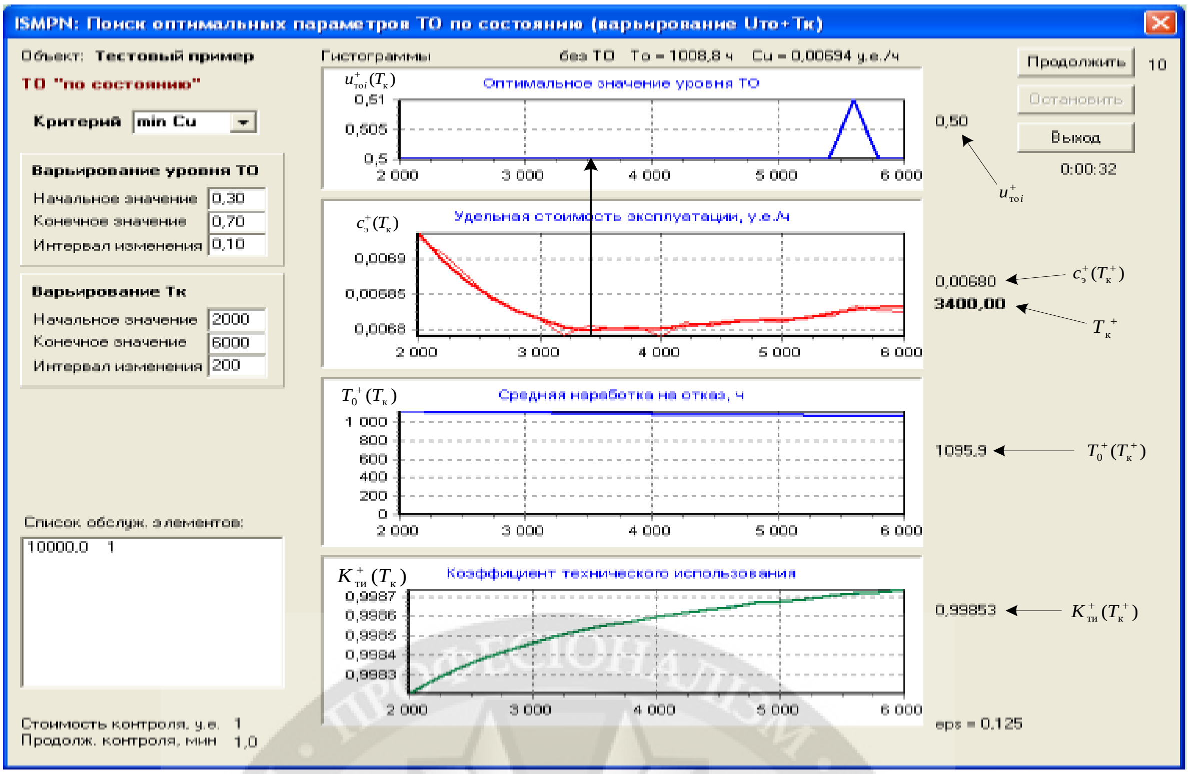

Figure 3 - The view of PC screen after completing calculations in the 1-st step

Findings. The methodology for determining approximately optimal parameters of strategy MSS described in this article is intended for use in the development process of RET object. The technique allows the early stages of development to pre-evaluate the possibility of increasing the level of reliability of an object due to maintenance. At later stages of development, when all technical solutions have already become known, elements for which there are measurable determinative parameters become known, preliminary estimates of the necessary parameters of MSS can be refined and corrected design decisions. Corresponding refinements to calculations should be made each time when accurate data on the reliability of component parts appear. Thus, the developed technique and its supporting software can be an effective means of reliable analysis of the RET object at all stages of its creation.

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ОПТИМІЗАЦІЯ ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ СКЛАДНИХ ОБ'ЄКТІВ РАДІОЕЛЕКТРОННОЇ ТЕХНІКИ

У статті розглянуті моделі оптимізації процесу технічного обслуговування (ТО) складних об'єктів радіоелектронної техніки (РЕТ). Сформульовано постановку задачі визначення оптимальних параметрів системи ТО об'єкта для випадку, якщо застосовується стратегія ТО за станом (стратегія ТОС).

В якості критерію оптимізації використовується вимога мінімуму питомої вартості експлуатації об'єкта на заданому періоді його експлуатації за умови забезпечення необхідного рівня безвідмовності об'єкта, що оцінюється показником «середнє напрацювання на відмову». Цільові функції задачі оптимізації визначаються шляхом моделювання процесу ТО і ремонту (ТОіР) об'єкта. Цією обставиною пояснюється вибір методу пошуку наближено оптимального рішення задачі: використовується найпростіший релаксаційний метод прямого перебору, керований людиною-експертом, вирішальним це завдання в режимі інтерактивного діалогу користувача з комп'ютером.

Викладена в даній статті методика визначення наближено оптимальних параметрів стратегії ТОС призначена для застосування в процесі розробки об'єкта РЕТ. Методика дозволяє на ранніх стадіях розробки попередньо оцінити можливості підвищення рівня безвідмовності об'єкта за рахунок проведення ТО. На більш пізніх стадіях розробки, коли вже стають відомими все технічні рішення, стають відомими елементи, для яких є вимірювані визначають параметри, попередні оцінки необхідних параметрів ТОС можна уточнювати і коректувати конструкторські рішення. Відповідні уточнення розрахунків слід проводити кожен раз при появі уточнених даних про надійність комплектуючих елементів.

Розроблено програмне забезпечення (ПО) для комп'ютерної підтримки процесу пошуку рішення. ПО розроблено засобами програмування Delphi.

Ключові слова: об'єкт радіоелектронної техніки, технічне обслуговування, середнє напрацювання на відмову, питома вартість експлуатації, імітаційне статистичне моделювання.

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ОПТИМИЗАЦИЯ ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ СЛОЖНЫХ ОБЪЕКТОВ РАДИОЭЛЕКТРОННОЙ ТЕХНИКИ

В статье рассмотрены модели оптимизации процесса технического обслуживания (ТО) сложных объектов радиоэлектронной техники (РЭТ). Сформулирована постановка задачи определения оптимальных параметров системы ТО объекта для случая, если применяется стратегия, ТО по состоянию (стратегия ТОС).

В качестве критерия оптимизации используется требование минимума удельной стоимости эксплуатации объекта на заданном периоде его эксплуатации при условии обеспечения требуемого уровня безотказности объекта, оцениваемый показателем «средняя наработка на отказ». Целевые функции задачи оптимизации определяются путем моделирования процесса ТО и ремонта (ТОиР) объекта. Этим обстоятельством объясняется выбор метода поиска приближенно оптимального решения задачи: используется простейший релаксационный метод прямого

перебора, управляемый человеком-экспертом, решающим данную задачу в режиме интерактивного диалога пользователя с компьютером.

Изложенная в данной статье методика определения приближенно оптимальных параметров стратегии ТОС предназначена для применения в процессе разработки объекта РЭТ. Методика позволяет на ранних стадиях разработки предварительно оценить возможности повышения уровня безотказности объекта за счет проведения ТО. На более поздних стадиях разработки, когда уже становятся известными все технические решения, становятся известными элементы, для которых имеются измеряемые определяющие параметры, предварительные оценки необходимых параметров ТОС можно уточнять и корректировать конструкторские решения. Соответствующие уточнения расчетов следует производить каждый раз при появлении уточненных данных о надежности комплектующих элементов.

Разработано программное обеспечение (ПО) для компьютерной поддержки процесса поиска решения. ПО разработано средствами программирования Delphi.

Ключевые слова: объект радиоэлектронной техники, техническое обслуживание, средняя наработка на отказ, удельная стоимость эксплуатации, имитационное статистическое моделирование.