# СТАНДАРТИЗАЦІЯ ТА МЕТРОЛОГІЧНЕ ЗАБЕЗПЕЧЕННЯ ОВТ

# STANDARTIZATION AND METROLOGICAL SUPPORT OF WEAPONS AND MILITARY EQUIPMENT

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## IMPROVED TECHNIQUE FOR IMPLEMENTING CONDITION-BASED MAINTENANCE OF RADIO ELECTRONIC EQUIPMENT

*The object of the study is the process of technical maintenance of radio electronic equipment (REE) to reduce labor costs by the minimum required number of parameter measurements in a certain sequence while ensuring a given probability of assessing the technical condition of the REE. The purpose of the study is to improve the technique of implementing maintenance by eliminating the shortcomings of existing techniques: excessive expenditure of forces and resources, lack of consideration of the impact of metrological support on the time of work and assessment of the real technical condition of the REE. The article proposes improving the technique of technical maintenance by forming a sequence of parameter verification taking into account the metrological characteristics of measuring equipment with a quantitative assessment of the complex indicator of the preferred choice of each REE parameter. The structure of the technique implementation is proposed, a flowchart of its practical use using the initial data depending on the specific operating conditions of the REE. An example of applying the technique is considered, which showed that in some cases there is an increase in the probability of correct assessment of the technical condition of the REE: after maintenance up to 33%; when increasing the number of elements being checked by more than 7% after using the same number of parameter measurements with the prototype. The functional dependences of the relative number of elements of the REE being checked and the probability of correct assessment of the technical condition for existing techniques of implementing maintenance on the number of parameters checked were investigated.*

*The scientific novelty of the technique lies in the exclusion of the subjective factor in determining the order of parameter checking, which, taking into account the quality of metrological and diagnostic support, increases the objectivity of assessing the probability of the real technical condition of the REE after performing the parameter value check. The effect of using the method is achieved by a new approach to ranking the REE parameters for checking their values, taking into account the impact on the quality of the object's functioning, the reliability of the set of elements that affect the parameter value, the time for quantitative assessment of its value and the required recovery time in case of deviation from the norm.*

*The results obtained are advisable to use in promising hardware technical support of modern REE in field conditions to increase the efficiency of their technical maintenance by condition.*

***Keywords:*** *radio electronic equipment, condition-based maintenance, parameter ranking.*

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## Introduction

High-quality maintenance is a prerequisite for maintaining the permanent readiness of the radio-electronic equipment (REE) of weapons and military equipment, including military communications systems. In field conditions, during combat operations, as a rule, there is a shortage of forces, means, and time, and consequently, there is a critical need to minimize the number of measurements of parameter values and the sequence of their execution to establish the real technical condition of the REE with an acceptable probability. Most of the available techniques perfectly fit the civilian needs for quite a long time without any indication of the need for improvement, but show numerous disadvantages in application to military REEs. Progress can be achieved with an account for modern achievements in the theory of metrology, technical diagnostics, and maintenance. To fit the quality of functioning of military REEs to modern requirements, additional studies are demanded. The very such research on the problem of condition-based technical maintenance of military REEs was conducted by the team of authors, and the results are presented in the present paper.

## State of the art of the problem

Maintenance is a set of operations to maintain the serviceability or operability of products during their technical operation. The quality indicators of the maintenance system are duration, complexity, cost, and volume (nomenclature of operations, duration of their execution, and necessary labor, material, and financial costs) [1].

Maintenance is an integral part of operation and includes: regulation, adjustment, verification of completeness, control of technical condition, and verification of compliance of parameters with technical conditions and other operations. During operation, the following types of maintenance are established [2]:

time-based: carried out within the established time frames, taking into account operating conditions, regardless of the operating time;

usage-based: carried out according to the specified operating time, taking into account operating conditions;

preventive (combined): refers to maintenance for products whose malfunctions and failures occur as a result of aging and wear.

A system of principles for organizing and conducting maintenance is called the maintenance strategy [3].

Depending on the availability of information about the technical condition of the REE, the main maintenance strategies are distinguished [4]:

by operating hours: a single volume and frequency of work regardless of the actual need for them for each specific REE;

by condition (condition-based): the list and frequency of maintenance operations is determined by the actual technical condition of the REE.

The comparative characteristics of the types of maintenance are summarized in Table 1, with the advantages of using condition-based maintenance being highlighted.

However, available techniques for implementing this type of maintenance suffer disadvantages [5-7]:

*Table 1*

**Comparative characteristics of types of maintenance**

| Type of technical maintenance | Advantages | Disadvantages |
|---|---|---|
| Time-based | Easy to schedule | Overspending of effort and resources |
| Usage-based | Saving effort and resources | hard to schedule |
| Combined | Easy to schedule, cost reduction | Variable labor costs |
| Condition-based | Easy to schedule, minimum effort and resources without loss of quality | Variable labor costs |

evaluation of the probability of the established technical condition of the REE based on the relative part of the tested REE segments without taking into account the quality of metrological support;

subjective assessment of the impact of individual parameters on the quality of REE operation;

accounting the use of a single measuring instrument when assessing REE parameters;

evaluation of the relative reliability of REE subsystems based on approximate reliability calculations;

failure to account for the number of uses of each measuring instrument when checking REE parameter values.

The presence of a subjective factor and the need to control the indicators of a set of measuring instruments during maintenance of large-sized objects leads to an erroneous assessment of their real technical condition and, as a result, to possible man-made disasters [8, 9].

Some features of the implementation of technical maintenance are also considered in available publications:

control of the technical condition of radio-electronic systems with redundancy [10];

technical maintenance of telecommunication and radio-electronic systems based on the results of forecasting their technical condition [11];

analysis of possible approaches to the implementation of technical maintenance of energy industry equipment by condition [12];

optimization of parameters of technical maintenance strategies by condition with a constant monitoring frequency (according to the time-based (calendar) principle) [13];

analysis of the effectiveness of current procedures for assessing the technical condition of aviation radio equipment [14].

**The purpose of the paper** is to improve the technique of implementing technical maintenance by eliminating the identified defects.

## Results and discussion

The essence of technical condition-based maintenance is periodic monitoring of the values of the REF parameters, with the performance of work depending on the results of instrumental testing: if necessary, bringing the parameter values to the norm.

When using technical maintenance of products in field conditions, it is necessary to first check the REE subsystems that form the most important indicators of the quality of its functioning, are the least reliable, require minimal time to check the parameters and bring them to the norm, since the time for performing the work is limited and, depending on the maintenance conditions, can end at any time.

The scheme of implementation of the improved technique is shown in Fig. 1, where its purpose and the essence of the improvement are defined together with limitations and assumptions that correspond to real conditions of technical maintenance.

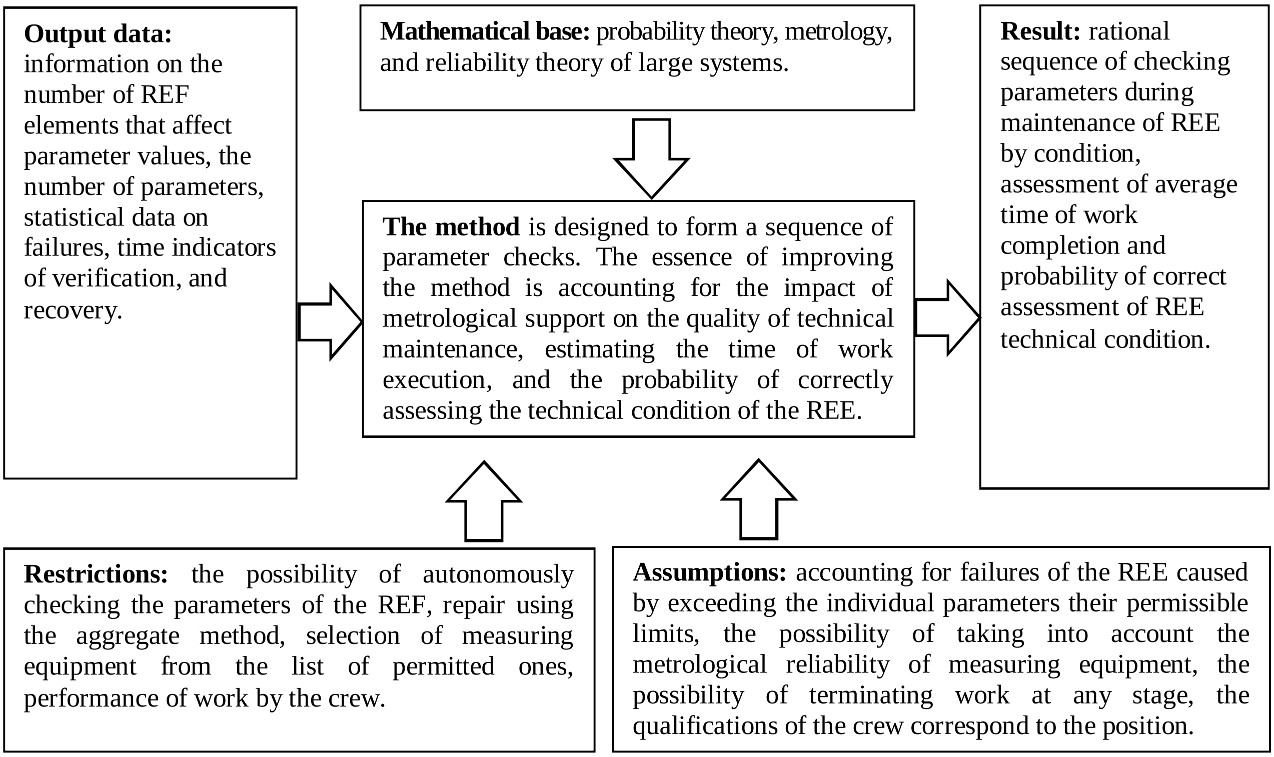


*Fig. 1.* **Scheme of implementation of an improved technique of implementing condition-based technical maintenance of radio electronic equipment in field and stationary conditions**

The technique presented in [5-7] is considered as a prototype.

**Mathematical base of the technique.**

The probability of failure of the REF due to the parameter value exceeding the permissible limits in the prototype is determined from an approximate calculation of the reliability of the sets of elements that affect the formation of the parameter. However in reality, depending on the operating conditions, this value varies within quite wide limits and is not an objective assessment. Therefore, it is proposed to determine this characteristic based on the results of experimental or controlled operation of REE samples as the ratio of the number of REE failures due to the parameter $i = \overline{1,K}$ exceeding the permissible limits $Q_i$ to the total number of failures for this period of operation $Q$:

$$g_i = \frac{Q_i}{Q}; Q = \sum_{i=1}^{K} Q_i;$$

where $K$ is the number of REF parameters that affect its operation.

This indicator is more objective and fully corresponds to real operating conditions.

The significance of the parameter's influence on the quality indicators of the REE's work $\gamma_i$ in the prototype is determined by an expert survey of specialists, which is subjective in nature and depends on the qualifications of the experts. Therefore, when improving the technique, it is proposed to define this indicator as the relative part of the REE that affects the formation of the parameter $i = \overline{1,K}$:

$$\gamma_i = L_i/L;\ L = \sum_{i=1}^{K} L_i;$$

where $L_i$ is the number of elements influencing the $i$-th parameter; $L$ is the total number of elements in the REE elements.

The relative time cost (consumption) for performing the checking of parameter $i = \overline{1,K}$ in the prototype does not account for the metrological reliability of measuring equipment ($P_{3i}$) and the probability of correct assessment of the verification results ($p_i$), thus, to take into account the quality of metrological support, it is proposed to apply the indicator:

$$\tau_i = \frac{t_i}{\prod_{i=1}^{m_i} p_i P_{3i}} \Big/ \sum_{j=1}^{K} \frac{t_j}{\prod_{j=1}^{m_j} p_j P_{3j}},$$

where $t_i$ is the time for checking without taking into account the quality of metrological support; $m_i$ is the number of measuring instruments for estimating the value of the parameter $i = \overline{1,K}$ .

The relative labor costs for bringing the value of the parameter $i = \overline{1,K}$ to the norm are determined as in the prototype:

$$f_i = \frac{t_{ri}}{\sum_{j=1}^{K} t_{rj}};$$

where $t_{ri}$ time of restoration of REF performance after failure of parameter $i = \overline{1,K}$, depends on the quality of diagnostic support. Since the required number of checks according to the diagnostic program is unknown in advance, the value of this indicator should be specified for each specific case.

The metrological reliability of measuring instruments in the prototype was calculated separately, and thus it is proposed to calculate its value for all measuring instruments, since its value is taken into account when calculating $\tau_i$. In this case, the complex indicator of the choice of parameter $i = \overline{1,K}$ takes the form:

$$u_i = \frac{\gamma_i g_i}{f_i \tau_i}.$$

Obtained analytical expressions are summarized in Table 2.

*Table 2*

**Comparison of the prototype and technique**

| Parameter | Prototype | Technique |
|---|---|---|
| Probability of REE failure due to the parameter exceeding the permissible limits | $P_i = \frac{Z_i}{\sum_{j=1}^{K} Z_j}$ | $g_i = \frac{Q_i}{Q}; Q = \sum_{i=1}^{\pi K} Q_i$ |
| The significance of the impact on the quality indicators of REE | Expert survey of specialists $\sum_{i=1}^{K} \gamma_i$ | $\gamma_i = \frac{L_i}{L}$ *Relative part of the REE affecting the parameter i* |
| Relative time cost to perform the check of the $i$ parameter | $\tau_i = \frac{t_i}{\sum_{j=1}^{K} t_j}$ | $\tau_i = \frac{t_i}{\prod_{i=1}^{m_i} p_i P_{3i}} \Big/ \sum_{j=1}^{K} \frac{t_j}{\prod_{j=1}^{m_i} p_j P_{3i}}$ |
| Relative labor costs for bringing parameter $i$ to the norm | $f_i = \frac{t_{ri}}{\sum_{j=1}^{K} t_{rj}}$ | $f_i = \frac{t_{ri}}{\sum_{j=1}^{K} t_{rj}}$ |
| Metrological reliability of measuring instruments | $P_{3i} = \prod_{j=1}^{m_i} P_{3j}$ | $P_{ME} = \prod_{i=1}^{K} P_{3i}$ |
| Complex indicator of the selection of the $i$ parameter | $u_i = \frac{P_{3i}\gamma_i P_i}{\tau_i f_i}$ | $u_i = \frac{\gamma_i g_i}{f_i \tau_i}$ |

The value of $u_i$ is dimensionless and varies greatly for various REE parameters. For this reason, to rank parameters, it is advisable to use, as above, the probability of the preferred choice:

$$U_i = \frac{u_i}{\sum_{j=1}^{\pi} u_j};\ \sum_{i=1}^{K} U_i = 1.$$

In addition, in contrast to the prototype, it is proposed to quantitatively assess the time for performing condition-based maintenance, taking into account the possibility of individual parameter values exceeding the permissible limits:

$$T_M = \sum_{i=1}^{K} \left[ \frac{t_i}{\prod_{j=1}^{m_i} p_j P_{3j}} + t_{ri} g_i \right].$$

It is also proposed to assess the probability of the technical condition of the REE after maintenance not by the relative part of the tested REE, but actually taking into account the quality of metrological support, that is, the probability of a correct assessment of the result of measuring the value of the parameter by means of measuring equipment:

$$P_M = \prod_{i=1}^{K} P_i;\ P_i = \prod_{j=1}^{m_i} p_j.$$

Thus, the improved technique allows for a more objective assessment of the quality of condition-based maintenance and to perform ranking of the order of parameter checking.

The formalization of the implementation of the improved technique for implementing condition-based maintenance of modern REE in the form of a flowchart of the algorithm is shown in Fig. 2, where $T_n$ is the allowable time for technical maintenance, $P_n$ is the allowable probability of a correct assessment of the technical condition of RES.

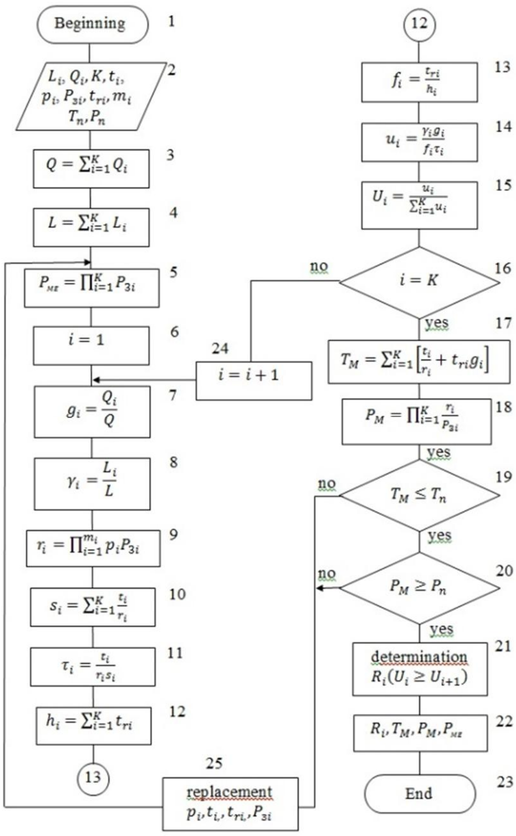


*Fig. 2.* **Flow-chart of the algorithm for implementing an improved technique for implementing condition-based maintenance of radio-electronic equipment**

Initial data are obtained from the analysis of the REE schemes, the results of its experimental or controlled operation, metrological and diagnostic support for technical maintenance, and the qualifications of specialists.

If the estimated time of maintenance $T_M$ exceeds the permissible value $T_n$ or the estimated probability of assessing the technical condition of the RES $P_M$ is lower than the permissible value $P_n$, then it is necessary to replace the measuring equipment (increasing $p_i$ and $P_{3i}$) or improve the qualifications of the performers (decreasing $t_i$ and $t_{ri}$).

Let us consider an example of using the proposed technique in comparison with the prototype [7], the results of which are summarized in Table 3. With the same initial data, the results of ranking the REE parameters according to the proposed technique are summarized in Table 4, which significantly differ from the prototype.

Fig. 3 shows the dependence of the relative part of the tested elements of the REE on the rank of the parameter with 1 corresponding to the prototype and 2 to the proposed technique.

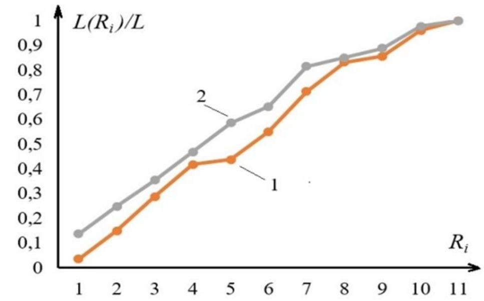


*Fig. 3.* **Dependences of the relative part of the tested elements of the REE on the rank of the parameters (1 – prototype, 2 – proposed technique)**

Analysis of data shown in Fig. 3 indicates that with the proposed technique the relative number of checked elements increases on average on 7.4% at the same number of measurements of the REE parameters.

With an increase in the number of parameter measurements, the probability of an error in evaluating the results also increases, which leads to a decrease in the probability of a correct assessment of the technical condition of the REE as a whole (Fig. 4), while compared to the prototype (dependence 1), with the proposed technique the value of $P_M$ increases by 33% when analog measuring instruments (dependence 2).

*Table 3*

**Results of parameter ranking according to the prototype technique**

| $i$ | $L_i$ | $p_i$ | $P_{3i}$ | $t_i$ | $t_{вi}$ | $Z_i \cdot 10^{-6}$, *hour*$^{-1}$ | $\tau_i$ | $f_i$ | $u_i$ | $U_i \cdot 10^2$,% | $R_i$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 80 | 0,942 | 0,85 | 15 | 10 | 4 | 0,0811 | 0,0221 | 1229 | 0,765 | 9 |
| 2 | 120 | 0,931 | 0,88 | 15 | 12 | 4 | 0,0811 | 0,02652 | 2492 | 1,551 | 8 |
| 3 | 370 | 0,910 | 0,81 | 20 | 15 | 10 | 0,0108 | 0,03315 | 68907 | 42,899 | 1 |
| 4 | 410 | 0,988 | 0,79 | 20 | 20 | 10 | 0,0108 | 0,0442 | 41993 | 26,144 | 2 |
| 5 | 350 | 0,945 | 0,91 | 10 | 11 | 6 | 0,0054 | 0,0243 | 7039 | 4,401 | 6 |
| 6 | 430 | 0,956 | 0,88 | 10 | 8 | 7 | 0,0054 | 0,0177 | 9336 | 5,812 | 4 |
| 7 | 330 | 0,912 | 0,93 | 10 | 16 | 6 | 0,0054 | 0,0353 | 7411 | 4,614 | 5 |
| 8 | 110 | 0,980 | 0,95 | 30 | 25 | 25 | 0,01621 | 0,05525 | 5386 | 3,350 | 7 |
| 9 | 70 | 0,982 | 0,89 | 15 | 22 | 4 | 0,0081 | 0,04862 | 786 | 0,490 | 11 |
| 10 | 510 | 0,901 | 0,87 | 15 | 18 | 4 | 0,0081 | 0,03978 | 1095 | 0,682 | 10 |
| 11 | 360 | 0,985 | 0,88 | 25 | 24 | 20 | 0,01351 | 0,05304 | 14955 | 9,311 | 3 |

*Table 4*

**Results of parameter ranking according to the proposed technique**

| $i$ | $g_i$ | $\gamma_i \cdot 10^2$ | $\tau_i \cdot 10^2$ | $u_i$ | $U_i \cdot 10^2$,% | $R_i$ | $L(R_i)/L$ | $P_M$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 0,04 | 2,55 | 8,42 | 0,220 | 1,70 | 10 | 0,978 | 0,565 |
| 2 | 0,04 | 3,82 | 8,23 | 0,281 | 2,20 | 9 | 0,888 | 0,600 |
| 3 | 0,10 | 11,78 | 12,19 | 1,164 | 9,10 | 5 | 0,586 | 0,740 |
| 4 | 0,10 | 13,06 | 11,52 | 1,031 | 8,00 | 6 | 0,653 | 0,730 |
| 5 | 0,06 | 11,15 | 5,23 | 2,097 | 16,30 | 2 | 0,248 | 0,903 |
| 6 | 0,07 | 13,69 | 5,34 | 4,078 | 31,80 | 1 | 0,137 | 0,956 |
| 7 | 0,06 | 10,50 | 5,30 | 1,351 | 10,50 | 3 | 0,353 | 0,824 |
| 8 | 0,25 | 3,50 | 14,48 | 0,438 | 3,40 | 8 | 0,850 | 0,644 |
| 9 | 0,04 | 2,23 | 7,71 | 0,096 | 0,75 | 11 | 1,000 | 0,555 |
| 10 | 0,04 | 16,24 | 8,60 | 0,763 | 5,90 | 7 | 0,815 | 0,657 |
| 11 | 0,20 | 11,48 | 12,98 | 1,310 | 10,30 | 4 | 0,468 | 0,811 |

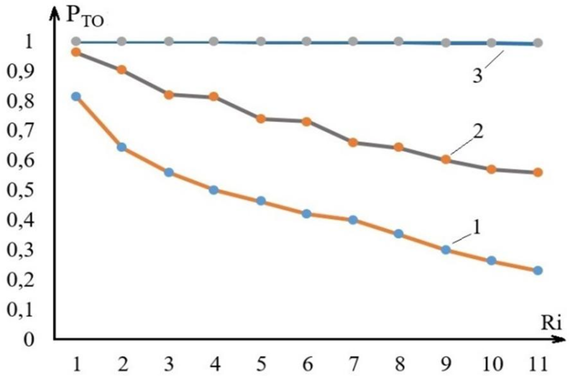


*Fig. 4.* **Dependences of the probability of correct assessment of the technical condition of the REE on the number of checked parameters for the prototype (1) and proposed technique with analog (2) and digital (3) measuring instruments**

However, when employing modern digital measuring instruments with $p_i \geq 0.9993$ [15] of a mobile measuring instrument laboratory of 2017 release according to TU 34.1 – 01354485 – 018:2016, which is fully equipped with digital measuring instruments produced in both Ukraine and the USA, at the same conditions the corresponding value increases to $P_M = 0.9923$ (dependence 3, Fig. 4).

In the considered example, the estimated time for measuring the values of $K = 11$ parameters is 3.7 hours, and the predicted time for bringing the parameter values to the norm is 0.25 hours, i.e., the total time for performing technical maintenance according to the condition $T_M \approx 4$ hours. At the same time, the metrological reliability of measuring equipment (ME) $P_{ME}$=0,748. The latter is the probability of all measuring equipment for technical maintenance of the facility will be operational within a year (inter-verification period).

Therefore, the proposed technique increases the checked part of the inspected object, when the parameter values are checked in the certain established sequence. The latter is important for field conditions, when the inspection process can be interrupted at any time. In addition, the technique enhances the probability of correct assessment of the technical condition of the REE (at least by 33% in the example under consideration).

## Conclusions

The scientific novelty of the technique lies in assessing the probability of the preferred choice of the REE parameter, taking into account the quality of metrological and diagnostic support while excluding the subjective factor that influences this process. This allows for using the obtained results in perspective hardware technical support of modern REE applying information technologies to increase the efficiency of maintenance by condition.

The effect of using the developed technique is achieved by a new approach to ranking REE parameters to check their values in extreme field conditions, namely: with limited time for performing work, when the first-checked parameters that reflect the most important indicators of the quality of the object's functioning are the least reliable, require minimal time for checking and restoring if necessary. As a result, the technique allows for increasing the probability of correct assessment of the technical condition of REE

Compared to checking subsets of REE elements in order of decreasing their power, the proposed technique increases the average probability of a correct technical condition assessment by 33%.

The research results are depicted in the form of a flow-chart of an algorithm that can be implemented based on electronic computers with promising hardware technical support.

We believe that further research directed towards the introduction of information technology techniques into the process of technical diagnostics of modern digital information processing REE will be in great demand.

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## УДОСКОНАЛЕНИЙ МЕТОД ВПРОВАДЖЕННЯ ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ ЗА СТАНОМ РАДІОЕЛЕКТРОННИХ ЗАСОБІВ

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*Об'єктом дослідження є процес технічного обслуговування за станом радіоелектроних засобів (РЕЗ) для скорочення працевитрат за рахунок мінімально необхідної кількості вимірювань параметрів у визначеній послідовності при забезпечені заданої ймовірності оцінювання технічного стану РЕЗ. Метою дослідження є удосконалення методу впровадження технічного обслуговування за станом усуненням недоліків існуючих методів: перевитрати сил і засобів, відсутність врахування впливу метрологічного забезпечення на час виконання робіт і оцінювання реального технічного стану РЕЗ.*

*В статті пропонується удосконалення методу технічного обслуговування за станом формуванням послідовності перевірки параметрів з врахуванням метрологічних характеристик засобів вимірювальної техніки із кількісною оцінкою комплексного показника переважного вибору кожного параметра РЕЗ. Запропоновано структуру реалізації методу, блок-схема його практичного використання із застосуванням вихідних даних залежно від конкретних умов експлуатації РЕЗ. Розглянуто приклад використання методу, який показав, що в окремих випадках має місце підвищення ймовірності правильної оцінки технічного стану РЕЗ: після обслуговування до 33%; при збільшенні кількості елементів, що перевіряються, більше 7% після використання однакової кількості вимірювань параметрів із прототипом.*

*Досліджено функціональні залежності відносної кількості елементів РЕЗ, що перевіряються та ймовірності правильного оцінювання технічного стану для існуючих методів реалізації технічного обслуговування від кількості перевірених параметрів.*

*Наукова новизна методу полягає у виключенні суб'єктивного фактора при визначенні порядку перевірки параметрів, що із врахуванням якості метрологічного і діагностичного забезпечення підвищує об'єктивність оцінювання ймовірності реального технічного стану РЕЗ після виконання перевірки значень параметрів. Ефект від застосування методу досягається новим підходом до ранжування параметрів РЕЗ для перевірки їх значень із врахуванням впливу на якість функціонування об'єкта, надійності сукупності елементів, які впливають на значення параметра, часу кількісної оцінки його значення і необхідного часу відновлення при відхиленні від норми.*

*Отримані результати доцільно використовувати в перспективних апаратних технічного забезпечення сучасних РЕЗ в польових умовах для підвищення ефективності їх технічного обслуговування за станом.*

***Ключові слова**: радіоелектронні засоби, технічне обслуговування за станом, ранжування параметрів.*