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MEASURES OF EFFICIENCY OF DIMENSIONAL CONTROL UNDER TECHNICAL STATE DESIGNATION OF RADIO-TECHNICAL FACILITIES

In the article proponed design methods of the performance factor of parameters dimensional control under technical state designation of radio-technical facilities. These methods are based on the developed mathematical model "Radio-technical facilities – control system". The analysis of methods for controlling the technical state of radio-technical facilities is conducted. The control method based on a comparison of the computed value efficiency indicator of the radio-technical facility with its acceptable value is substantiated. A method is developed for calculating the measures of the dimensional control efficiency in the radio-technical facilities parameters while self-monitoring (before application as intended). The method of calculating the efficiency index of the dimensional control of radio-technical facilities parameters under a complex test is improved. A method is proposed for determining the standard time parameters of the dimensional control of the radio-technical facilities parameters of a radio-engineering device in determining its technical state.

Keywords*: radio-technical facility, control of technical state, measures of efficiency, dimensional control of parameters.*

Introduction

Thematic justification. The decision on the suitability of the radio-technical facilities (RTF) for further use of its intended purpose is based on the results of measurement and control of its parameters. That is why, the main measures of efficiency control technical state of RTF are the probability of its recognition suitable for further appliance, the time for monitoring the parameters of the facility and the reliability of monitoring its parameters [1–3].

Literature route. As a result of measuring the parameters of the control and calculating the measures of efficiency, the decision on the suitability of the RTF to perform its functions by two methods [4–12]. At the first the decision is made on the basis of comparison calculated value of the measures of efficiency with its acceptable value.

At the same time, a method of monitoring by the measures of efficiency is implemented. In the second control method, the decision on the RTF suitability is made on the basis of a comparison of the each RTF control parameter values with its admissible values. In this case, a method of monitoring by parameters is implemented.

In the article it is proposed to use the first method of measuring control of RTF parameters. Its advantages are as follows [2; 5–6]:

– can be used to predict the technical condition of the RTF;

– allows comparative assessment of the technical state of various RTF types, intended for solving the same (similar) task;

– opens wide opportunities for automation of the RTF control process technical condition monitoring system taking into account the actual state of various functional devices, devices, units and elements entering into it.

The purpose of the article is to develop measures of the efficiency of measurement control parameters when determining the technical state of radio-technical facilities.

Main part

Measures of efficiency of RTF parameters dimensional control under self-control (before intended application).

Conducting dimensional control of the RTF parameters during self-controlling makes it possible to determine their suitability for further use. Whereas, after controlling the parameters, the tool is found to be suitable to use, then, according to the mathematical model of the "RTF – control system" (fig. 1), it is in the position d_1. Accordingly, in the way of measures of efficiency of the RTF parameters control under self-control P_{pc}^{s}, take the probability of finding the marker in the position of the mathematical model "RTF – control system". Herewith, if the RTF is not in position d_1, than according to the self-control results was recognized as unfitted for further usage.

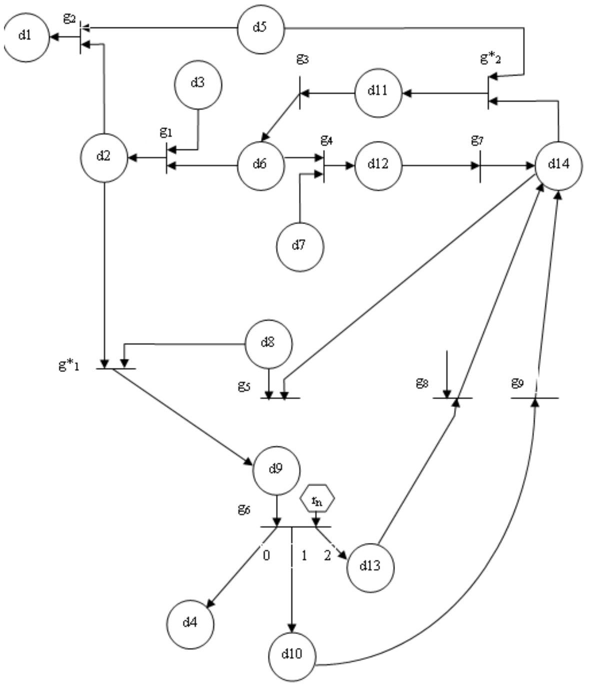


Fig. 1. Petri net graph of "RTF – control system" model

We introduce the notation P_{d_i} – probability of an event consisting in the fact that the RTF is in position d_i, $i = \overline{1,14}$.

According to the "RTF – control system" model and the graph of reachability [8–9], the tag transition to the position (RTF performs the task) from the position determined by the initial marking depends on the following cases: the RTF functioning normally (the position d_6 of the model), the task was received to use the RTF for its intended use (position d_3), according to self-control results, RTF was found as suitable for further usage (position d_5). On the basis of this, write down the probability of the marker transition to the position d_1:

$$P^s_{pc} = P_{d_1} = P_{d_3} P_{d_5} P_{d_6}.$$

Since the use of the RTF is possible only after the receipt of the permissive instruction, then consider $P_{d_3} = 1$, then the expression for determining the probability of marker transition to the position d_1 is:

$$P^s_{pc} = P_{d_5} P_{d_6}. \quad (1)$$

The probability of the case, which is the normal functioning of the RTF at the time of receipt of the command for application, will be calculated on the basis of the mathematical model of operation [6; 12]. The value of probability P_{d_6} (RTF for intended use) matches the probability P_1 of finding RTF in operable condition of S_1 exploitation model, so

$$P_{d_6} = P_1. \quad (2)$$

Correct report about RTF availability for application after dimensional control of parameters depends on serviceability (metrological and technical) control system and on finding control parameters within their tolerances. Then for probability of case that is determined in appeared mark in position d_5, we have:

$$P_{d_5} = P_{cs} P_{cp}, \quad (3)$$

where P_{cs} – probability of metrologically serviceable condition of the control system before and during operations of RTF parameters dimensional control; P_{cp} – probability of finding RTF control parameters within their acceptable deviation.

In the operational manual on the control system reliability characteristics are given (for example, time between failure, increasing failure, etc.), according to which the probability of an operational condition of the control system is calculated [2; 12]. Then the expression for the probability P_s of metrological serviceable condition monitoring system can be written as:

$$P_{cs} = \kappa_s P_s, \quad (4)$$

where κ_s – coefficient characterizing metrological serviceability control system, usually $\kappa_s = 0{,}6 \div 0{,}8$ [2].

We define the probability of finding within the tolerances of the RTF control parameters after the measurement of their control. Let the probability of finding a parameter to control within tolerance is characterized by a priori probability ξ_i RTF suitability of the parameter [5; 7].

To quantify the reliability of test results used a number of different indicators [7; 9]. But most of them do not take into account the specifics in using of RTF maritime transport. Analysis of the peculiarities of RTF maritime transport operation [5; 7] allows to formulate the requirements for analytical expression the indicator of reliability measurement control:

– it should take into account the main components of the control cycle and be used to compare the quality of control different RTF types while using several types of control systems;

– it should be visual and allow the use of a posteriori information to assess the quality of the obtained control results, its numerical value should have a clear physical content.

Requirements listed above fully corresponds to the expression that takes into account the probability of finding a parameter i control within their tolerance to control ξ_i, the probability of finding a parameter control within the tolerance at the time of control P_{x_i}, the absence (presence) of the control errors of the first and second kind. Accordingly, the probability of finding a parameter i within tolerance after the P_i control is proposed to determine the probability of finding it within tolerance before and after the control in the absence of control error of the first kind, i.e. $\xi_i(1-\alpha_i)P_{x_i}(1-\alpha_i)$, or if there is an error of the second kind of control as the sum of the probabilities $P_{x_i}(1-\xi_i)\beta_i + \xi_i(1-P_{x_i})\beta_i$, than

$$P_i = \xi_i(1-\alpha_i)P_{x_i}(1-\alpha_i) + P_{x_i}(1-\xi_i)\beta_i + \xi_i(1-P_{x_i})\cdot$$
$$\cdot\beta_i = \xi_i P_{x_i}(1-\alpha_i)^2 + \beta_i\left[P_{x_i}(1-\xi_i) + \xi_i(1-P_{x_i})\right], \quad (5)$$

where α_i, β_i – respectively, the conditional probability that the RTF control parameter in the tolerance field is recognized outside the tolerance range, and the x_i RTF control parameter that is outside the tolerance is in the tolerance field (the probabilities of control errors of the first and second kind).

The probability of finding the control parameter x_i within the tolerance during the monitoring P_{x_i} can be calculated as follows [8]:

$$P_{x_i} = P(x_{l_i} \le x_i \le x_{u_i}) = \int_{x_{l_i}}^{x_{u_i}} f(x_i)dx_i, \quad (6)$$

where x_{l_i}, x_{u_i} – lower and upper tolerance limits for the monitoring parameter i, respectively; $f(x_i)$ – probability density function of the control parameter i values.

Expression (5) shows that the RTF parameter i will indeed be within its tolerance after the control, if there are no errors of control the first and second kinds and if this parameter is in admission during the control. In the absence of control errors of the first and second kind, expression (5) has the form: $P_i = \xi_i P_{x_i}$, i.e. the probability of finding control x_i parameter i within the tolerance after is dependent on the a priori probability of the RTF suitability for control parameter i and on the probability of finding the control parameter i in the tolerance field under control.

We will take advantage of the widely used assumption that the output parameters of the RTF, and the errors of the control system in most cases are considered to be distributed according to the normal law [2, 7, 11]. Then the probabilities of control errors of the first and second kind and the probability density of the values control parameter i are determined by the formulas:

$$\alpha_i = \frac{1}{2}\sqrt{\frac{1}{1+2\varepsilon_i^2}}\exp\left\{-\frac{\theta_i^2\varepsilon_i}{1+2\varepsilon_i}\right\}\cdot$$
$$\cdot\left[F\left(\frac{\theta_i(1+4\varepsilon_i^2)}{\sqrt{1+2\varepsilon_i^2}}\right) + F\left(\frac{\theta_i}{\sqrt{1+2\varepsilon_i^2}}\right)\right]; \quad (7)$$

$$\beta_i = \frac{1}{2}\sqrt{\frac{1}{1+2\varepsilon_i^2}}\exp\left\{-\frac{\theta_i^2\varepsilon_i}{1+2\varepsilon_i}\right\}\cdot$$
$$\cdot\left[F\left(\frac{\theta_i(1+4\varepsilon_i^2)}{\sqrt{1+2\varepsilon_i^2}}\right) - F\left(\frac{\theta_i}{\sqrt{1+2\varepsilon_i^2}}\right)\right]; \quad (8)$$

$$f(x_i) = \frac{1}{\sigma_{x_i}\sqrt{2\pi}}\exp\left[-\frac{\left(x_i - m_{x_i}\right)}{2\sigma_{x_i}^2}\right],$$

where $\theta_i = \Delta x_i / \sigma_{x_i}$; $\varepsilon_i = \sigma_{x_i}/\sigma_{cs_i}$; σ_{cs_i} – standard error of the mean (SEM) measure of control inaccuracy, that is used under evaluation of x_i parameter's control; Δx_i – the value of the symmetric tolerance for the control parameter x_i; m_{x_i} – mathematical expectation of the control parameter i; F(...) – Tabularize Laplace's function.

Under normal distribution law, the error value of the measured parameter x_i with a probability of 0,997 is within the permissible limits $\pm 3\sigma_{x_i}$ [11]. Therefore, the SEM σ_{x_i}, σ_{cs_i} is assumed to be equal

$$\sigma_{x_i} = \Delta x_i / 3 \text{ and } \sigma_{cs_i} = \Delta_{cs_i} / 3,$$

where Δ_{cs_i} – allowable value (limit) error control system under the parameter is changed x_i.

Formulas (7) and (8) allow us to determine the error probabilities of the first and second kind according to the tolerance values for the control parameter and the error of the control system which is used to control this parameter.

When choosing the control parameters, it is necessary to take into account that the occurrence of dependent control parameters leads to an unjustified increase of timing to perform the measuring control of the parameters, while the reliability of the control is commensurable with the reliability of the independent parameters control.

An independent parameter which is not within the tolerance limit and doesn't involve other parameters to be coming out will be considered, i.e. that parameters are not related to each other. Some control parameters of various PTF units can be related (depend on each other), then it is enough to check one of them to obtain information about other parameters.

To determine the dependent parameters from the total set of control parameters, it is necessary to construct the structural and logical scheme of the under study RTF on the basis of which will be creating a matrix having the same number of rows and columns which is equal to the total number of parameters of the RTF control. The presence of a unit in the corresponding row and column shows the dependence of the control parameters among each other. In the following, the case of independent control parameters which is typical for the practice of RTF operation will be considered. Under the control of RTF according to independent control parameters we take the event of finding all control parameters within their tolerances as the criterion of their suitability for use, and for the criterion of unsuitability – if at least one control parameter is within its tolerance limit. Taking into account formula (5), the formula for the probability of the RTF suitability for applying all parameters N to the control results is:

$$P_{RTF} = \prod_{i=1}^{N} P_i, \qquad (9)$$

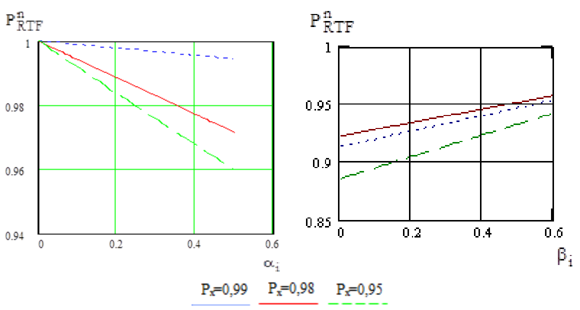
where P_{RTF} – the probability of the RTF suitability for the application according to results of the all parameters control.

The number of parameters of the RTF, which fully describes its technical condition can be very large. Therefore in practice, according to a number of limitations (for example control time, cost, etc.), the number of control parameters n should be limited, where $n << N$.

The probability of finding control parameters n within the tolerance limits (the probability of RTF working condition) is determined by the probability P^n_{RTF} for which, taking into account relations (5) and (9), formula is:

$$P^n_{RTF} = \prod_{i=1}^{n} P_i = \prod_{i=1}^{n} \left\{ \begin{array}{c} \xi_i P_{x_i} \left(1-\alpha_i\right)^2 + \beta_i \cdot \\ \cdot \left[P_{x_i}\left(1-\xi_i\right) + \xi_i \left(1-P_{x_i}\right) \right] \end{array} \right\}. \qquad (10)$$

Formula (10) determines the probability of RTF working condition according to the results of measuring control n of the control parameters. The dependencies of probabilities of RTF working condition which were obtained with the help of relation (10), according to the probabilities of the first and second kind control errors (fig. 2). With increase of the probability of the first kind control error (fig. 2, a) and the probability of the second kind error (fig. 2, b) the probability of RTF working condition increases.



a b

Fig. 2. Graf probability on of the kind control error

Therefore in order to increase the probability P^n_{RTF} the reliability of the control should be increased; i.e. probability of errors of the first α_i and second kinds β_i RTF should be reduced.

Taking into account formulas (2–4; 10), formula (1) for the performance factor of measuring control of the RTF control parameters according to self-control takes the form:

$$P^s_{ps} = \frac{\kappa_s P_s P_1 P^n_{RTF}\left(1-\alpha\right)}{\kappa_s P_s P_1 P^n_{RTF}\left(1-\alpha\right) + \left(1-\kappa_s P_s P_1 P^n_{RTF}\right)\beta}. \qquad (11)$$

The analysis of the obtained performance factor (11) of measuring control of RTF P^s_{ps} parameters should be performed. For successful implementation of the RTF task the probability of the marker transition to the model position d_1 of the "RTF – control system" should be of the order of unity, i.e. strive for maximum. This requires values which are included in the exponent P^s_{ps} to be strived to maximum:

– the probability of RTF working condition according to control of parameters P^n_{RTF}, which can be increased by reduction of control errors of the first and second kind and increase of composition of the control parameters (10);

– the probability of finding RTF in working condition P_1, which depends on the parameters of the operational process [2; 12];

– the probability of a metrologically working condition of the control system P_s and a coefficient κ_s. The probability value P_s depends on the selected parameters of operational process of control system, which can be determined, for example according to the procedure [2]. The coefficient κ_s can be increased in two ways:

– using of control systems with self-checking and calibration functions, i.e. using of digital control systems especially if in the existing control and verification equipment the number of such control systems is very small;

– reduction of the calibration period of the control system, which will lead to an increase of material costs on operating process.

Obtained indicator of performance factor of RTF technical condition according to self-control P^s_{ps} depends on the parameters of the operational process of the RTF and on the parameters of the operational process of the control system; on control parameters (values x_i and their tolerances) and on the metrological characteristics of the control system used in their control according to formulas (7–8).

This conclusion is natural but the obtained formula (11) allows to obtain a quantitative judgment of the effectiveness of the measuring control of the RTF parameters.

Performance factor of measuring control of RTF parameters under comprehensive inspection.

Realization of the measuring control of RTF parameters according to the comprehensive inspection allows to determine its suitability for further application. If after control of parameters RTF will be confess as usable then according to the mathematical model of the RTF control system it will be in position d_{11}. Therefore as a performance factor of the measuring control of RTF parameters during the comprehensive inspection P_{pc}^{c} we will take the probability of finding the marker in the position d_{11} of the mathematical model of the "RTF – control system", and if the RTF is rejected then after carrying out the reconstruction operations it can pass into a working condition.

According to the "RTF – control system" model and the graph of reachability [8], the marker transition to the position d_{11} (if RTF based on the inspection results is suitable for further exploitation) from the position determined by the initial marking takes place in two ways which depend on the following events:

– the RTF functions normally (the position d_6 of the model), the task for control of the technical condition (position d_7) was received, all operations of connecting the RTF and the control system (position d_{12}) were performed, and the RTF was found as practicable (position d_5) by the results of parameters check;

– the events of positions d_6, d_7, d_{12} of "RTF – control system" models are executed, RTS was found impracticable for application (position d_8) by the results of parameters check, it is necessary to perform restoration works (position d_{10} or d_{13}).

Based on this the probability of the marker moving to the position d_{11} is written as:

$$P_{pc}^{c} = P_{d_{11}} = P_{d_5}P_{d_6}P_{d_7}P_{d_{12}} + \\ +P_{d_6}P_{d_7}P_{d_8}P_{d_{10}}P_{d_{12}}, \quad (12)$$

where $P_{d_{10}}$ is probability of recovering of broken RTF (it means either recovery by adjusting the RTF parameters – position d_{10}, or replacing the faulty block in it – position d_{13}).

The control of the technical condition is possible only after the command is received and depends on the frequency of the RTF testing. Operations of RTF connection with the control system do not introduce defects, then $P_{d_7} = P_{d_{12}} = 1$ and formula (12) takes the form:

$$P_{pc}^{c} = P_{d_5}P_{d_6} + P_{d_6}P_{d_8}P_{d_{10}}. \quad (13)$$

Taking into account formulas (2–3) and taking into account that $P_{d_5} = 1 - P_{d_8}$ formula (13) can be represented as:

$$P_{pc}^{c} = P_1\left[P_{cs}P_{cp} + (1 - P_{cs}P_{cp})P_{d_{10}}\right]. \quad (14)$$

Using formula (4) and (10) for the probabilities P_{cs} and P_{cp}, formula (14) can be represented as:

$$P_{pc}^{c} = P_1\left[\kappa_s P_s P_{RTF}^{n} + (1 - \kappa_s P_s P_{RTF}^{n})P_{d_{10}}\right]. \quad (15)$$

Formula (15) defines the quality indicator of the RTF measuring control during comprehensive inspection P_{pc}^{c}. The probability of successful recovery of the RTF $P_{d_{10}}$ depends on the complexity of the defect, the availability of replacement parts, qualification of repairmen values must be in the range from 0 to 1.

This value is determined on the basis of the analysis of recondition that was done with similar RTF. If we accept $P_{d_{10}} = 1$, then $P_{d_{11}} = P_1$, i.e. the probability of recognizing RTF as suitable for further exploitation after the technical condition control depends on a priori probability of working condition before the control.

Due to the fact that if as a result of the control the device was found as impracticable it will be repaired with the probability 1. When $P_{d_{10}} = 0$ we have $P_{d_{11}} = P_{d_1}$, i.e. without repairing broken RTF the probability of finding it in working condition after a comprehensive check and self-control are equal.

Identification of regulatory timing RTF dimensional control.

The composition of the control parameters depend on the time required to conduct the dimensional control of RTF parameters. The greater the number of control parameters, the longer duration of the dimensional control. This explains the need for introducing time parameters into the indicators used in optimizing the composition of the RTF control parameters. We obtain expressions for evaluation.

As noted [8], the matrix T characterizes the time spending of the "RTF – control system" model. Let us consider time spending that is immediate depends on number n control parameters.

The regulatory and technical documentation on any RTF sample indicates the time valuation of certain measurement and control parameters operations. The time spent on monitoring each parameter of the RTF depends on the time for connecting the control system and the RTF, as well as on the speed of the monitoring system used to monitor it.

Let us denote with τ_i the time spent on the control of the RTF parameter. Then the duration τ_{sm} of the self-monitoring according to the n control parameters is determined by the expression:

$$\tau_{sm} = \sum_{i=1}^{n} \tau_i . \quad (16)$$

Similarly, we define the duration of a comprehensive RTF τ_{cc} check, herewith $n = m$, where $n = m$ – the number of the RTF parameters control during its comprehensive verification.

The time parameters of the RTF will be used in future when formulating and solving the problem of control parameters optimal choice. It should be noted that the optimal values of the time parameters τ_{sm} and τ_{cc} obtained during the selection of parameters for the operation of the RTF are related to the parameters τ_{sm}^{o} and τ_{cc}^{o} the following relationship:

$$\tau_{sm} \le \tau_{sm}^{o}, \ \ \tau_{cc} \le \tau_{cc}^{o} . \quad (17)$$

Therefore, in determining the optimal composition of the control parameters should be considered the optimal parameters of the vector χ obtained in the study of mathematical models of the RTF operation.

To indicators of the effectiveness of the RTF parameters measuring control during the monitoring technical state, the reliability of the parameters control should also be included. However, in order to clarify the analytical expression for determining the reliability of the dimensional control of the RTF parameters under control, first of all it is necessary to clarify the methodology for expert determination the coefficients of the RTF control parameters significance.

Conclusions

With the use of the developed model "RTF – control system" analytical expressions were obtained to determine the values of the efficiency indicators of the RTF parameters monitoring for two types of their maintenance: self-monitoring (before the intended use) and complex testing. The peculiarities of these indicators are that they take into account the parameters of the control and operation of the RTF and the parameters of the control system used in servicing the RTF. It is shown that to increase the probability of finding RTF in operational condition after measuring its control parameters necessary to reduce control errors of the first and second kind, which is achieved by using digital control systems serving RTF, and to determine the optimal value of such maintenance frequency.

A method for determining the standard time parameters of the dimensional control of the RTF parameters in determining its technical state is proposed.

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ПОКАЗНИКИ ЕФЕКТИВНОСТІ ВИМІРЮВАЛЬНОГО КОНТРОЛЮ ПАРАМЕТРІВ ПРИ ВИЗНАЧЕННІ ТЕХНІЧНОГО СТАНУ РАДІОТЕХНІЧНИХ ЗАСОБІВ

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У статті запропоновані методи розрахунку показників ефективності вимірювального контролю параметрів при визначенні технічного стану радіотехнічних засобів. Дані методи базуються на розробленій математичній моделі "радіотехнічний засіб – система контролю". Проведено аналіз методів контролю технічного стану радіотехнічних засобів. Обґрунтовано метод контролю на основі порівняння обчисленого значення показника ефективності радіотехнічного засобу з його допустимим значенням. Розроблено метод розрахунку показника ефективності вимірювального контролю параметрів радіотехнічних засобів при самоконтролі (перед застосуванням за призначенням). Удосконалено метод розрахунку показника ефективності вимірювального контролю параметрів радіотехнічних засобів при комплексній перевірці. Запропоновано метод визначення нормативних часових параметрів вимірювального контролю параметрів радіотехнічного засобу при визначені його технічного стану.

***Ключові слова**: радіотехнічний засіб, контроль технічного стану, показник ефективності, вимірювальний контроль параметрів.*

ПОКАЗАТЕЛИ ЭФФЕКТИВНОСТИ ИЗМЕРИТЕЛЬНОГО КОНТРОЛЯ ПАРАМЕТРОВ ПРИ ОПРЕДЕЛЕНИИ ТЕХНИЧЕСКОГО СОСТОЯНИЯ РАДИОТЕХНИЧЕСКИХ СРЕДСТВ

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В статье предложены методы расчета показателей эффективности измерительного контроля параметров при определении технического состояния радиотехнических средств. Данные методы базируются на разработанной математической модели "радиотехническое средство – система контроля". Проведен анализ методов контроля технического состояния радиотехнических средств. Обоснован метод контроля, основанный на сравнении вычисленного значения показателя эффективности радиотехнического средства с его допустимым значением. Разработан метод расчета показателя эффективности измерительного контроля параметров радиотехнических средств при самоконтроле (перед применением по назначению). Усовершенствован метод расчета показателя эффективности измерительного контроля параметров радиотехнических средств при комплексной проверке. Предложен метод определения нормативных временных параметров измерительного контроля параметров радиотехнического средства при определении его технического состояния.

***Ключевые слова**: радиотехническое средство, контроль технического состояния, показатель эффективности, измерительный контроль параметров.*