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Method of justification of the requirements for metrological support of repair of objects with variable structure

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Abstract

A new method of justification of the requirements for measuring equipment (ME) is proposed. For the first time, the method accounts for the potential variability of the product structure during its intended use, and thus, allows minimizing the requirements concerning the probability of estimating the values of diagnostic parameters of the product during its current repair (CR), thereby reducing the cost of ME. In addition, partial (in particular, time between failures and average recovery time) and multi-component (in particular, the readiness/non-readiness factors) values of the reliability indices are quantitatively estimated and which meet the requirements. The task is solved algorithmically using the approaches of technical diagnostics and metrology. Based on the prescribed requirements for the reliability indices of the product, the justified ME for CR is selected. To achieve the goal, recent advances in modelling the reliability of large-scale facilities and systems with variable structure, as well as metrology methods for assessing the impact of the reliability of the ME on the value of the average recovery time of multimode facilities during their CR are involved. To our best knowledge, the application of these possibilities has not been reported yet. The paper formalizes the procedure for applying the obtained results in the form of an algorithm, which allows increasing the efficiency of the method, benefiting from its advantages. The application of the proposed method is illustrated for a piece of real communication equipment, namely a subsystem controlling the functioning of a high-power radio transmitter. It is demonstrated that, based on the requirements stated in the guidance documents regarding the value of the average recovery time of an object with variable structure, the selection of metrological characteristics and type of ME can be justified. Alternatively, the problem can be solved based on the given value of the reliability index of a multicomponent product, the so-called readiness factor. An example of assessing the efficiency by the proposed method is presented. The proposed method is recommended for the development of metrological support for CR of prospective radio-electronic tools with variable structure.

Keywords: metrological service; technical diagnostics; measuring equipment; object with variable structure.

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1. Introduction

In the process of designing new samples of technical facilities, quantitative values of their reliability indices should be necessarily estimated, namely, partial (in particular, time between failures, average recovery time) and multi-component (the readiness/non-readiness factors) values [1, 2]. In addition, to improve the accuracy of calculations, the specifications of schematic and construction organization of the product should be accounted for [3–5]. Traditionally, in the current repair (CR) process, to reduce the average recovery time, methods of discrete search theory are applied, which is a domain of technical diagnostics that deals with algorithmic methods of assessing the technical condition of installations consisting of individual elements, the failure of each of which leads to the failure of the installation as a whole [6].

The values of diagnostic parameters of measuring equipment (ME) needed for metrological assessment are determined in accordance with the prescribed recommendations [7]. Specifications of developing diagnostic support for multimode technical facilities have been considered in [8]. However, it should be noted that these works do not account for the property of technical facilities to change their structures in the course of their functioning, which consequently underestimates the value of their reliability indices. For the first time, the impact of the variable structure of objects during their operation on their reliability was quantitatively estimated in [9], which significantly improved the accuracy of calculations. Since then, an application model increasing the efficiency of diagnostic support of objects with variable structure was elaborated [10].

Our analysis shows that metrological support of CR accounting for the specifications of multimode facilities is not considered in the literature [11—17]. Therefore, the purpose of this paper is to assess the influence of the quality of metrological support on the reliability indices of metrological objects with variable structure and to scientifically justify the method of selection of ME to support their CR. The requirements for the values of the reliability indices with a minimal probability of correct assessment of diagnostic parameters during the measurement of their values in the CR process should be importantly met in the proposed procedures.

2. Description of the method

The proposed method accounts for recent achievements in the field of the reliability theory [1—5, 9], technical diagnostics [6, 8, 10], and metrology [7—9]. The structure of the method, including initial data, mathematical apparatus, purpose, and essence, as well as limitations, assumptions, and the result of the application of the method are presented in Fig. 1.

The mathematical apparatus of the method is based on the following previous results of ours [7—10]:

- the average number of checks needed at the failure of a subset of L_i elements is

$$K_i = \log_2 L_i;$$

- the average number of checks needed in the CR process of an object with variable structure is

$$K = \frac{1}{n}\sum_{i=0}^{n} K_i;$$

- the failure flow parameter of a subset of i elements is

$$Z_i = 1/T_i;$$

- relative runtime of a subset of i elements

$$u_i = \frac{T_{pi}}{T_p};$$

- failure flow parameter of the product as a whole

$$Z = \sum_{i=1}^{n} n_i Z_i;$$

- runtime of the product between failures

$$T = \frac{1}{Z};$$

- average recovery time for CR without accounting for the metrological reliability of ME and correct estimation of the parameter values

$$T_{BP} = t_y + \frac{t}{Z}\sum_{i=1}^{n} u_i Z_i K_i;$$

- probability of failure-free operation of the ME in the period between verifications

$$P(\tau) = \prod_{j=1}^{M} \underline{P}_j(\tau);$$

- average recovery time of the product in the case of CR, accounting for the metrological reliability of ME and the probability of correct assessment of the check result

$$T_B = \frac{T_{BP}}{p^K P(\tau)};$$

- the factor of non-readiness of the product

$$U = \frac{T_B}{T_B + T};$$

- the factor of readiness of the product

$$A = 1 - U.$$

The flowchart of the implementation of the method is shown in Fig. 2, where the value of p gradually increases with a step Δp to satisfy inequalities $T_B \le T_{rp}$ and $A \ge A_v$. Otherwise, the source data should be changed. After determining the minimum required value p according to the data in Table 1, the ME instrument is selected [7—9].

Table 1

General information about failure-free performance of measuring operations

№	Measuring operations	p
1	Perception to the assessment of the readings of a single arrow device: - multiscale; - simple; - with a vertical linear scale; - with a horizontal linear scale; - with a circular scale; - with a semicircular scale; - with a scale in the form of a window	 0.840…0.852 0.944…0.960 0.645 0.725 0.891 0.834 0.995
2	Determination of the “Norm” value by the sector of the scale	0.971
3	Search, perception, and evaluation of indices: - from one to seven; - from five to fifteen	0.995 0.990
4	Perception and evaluation of the readings of a digital device with the following number of digits: - from one to three; - from four to six; - from seven or more	 0.9997 0.9993 0.9985
5	Decision-making under several logical conditions: - one, two; - three, four; - five or more	0.995 0.950 0.900

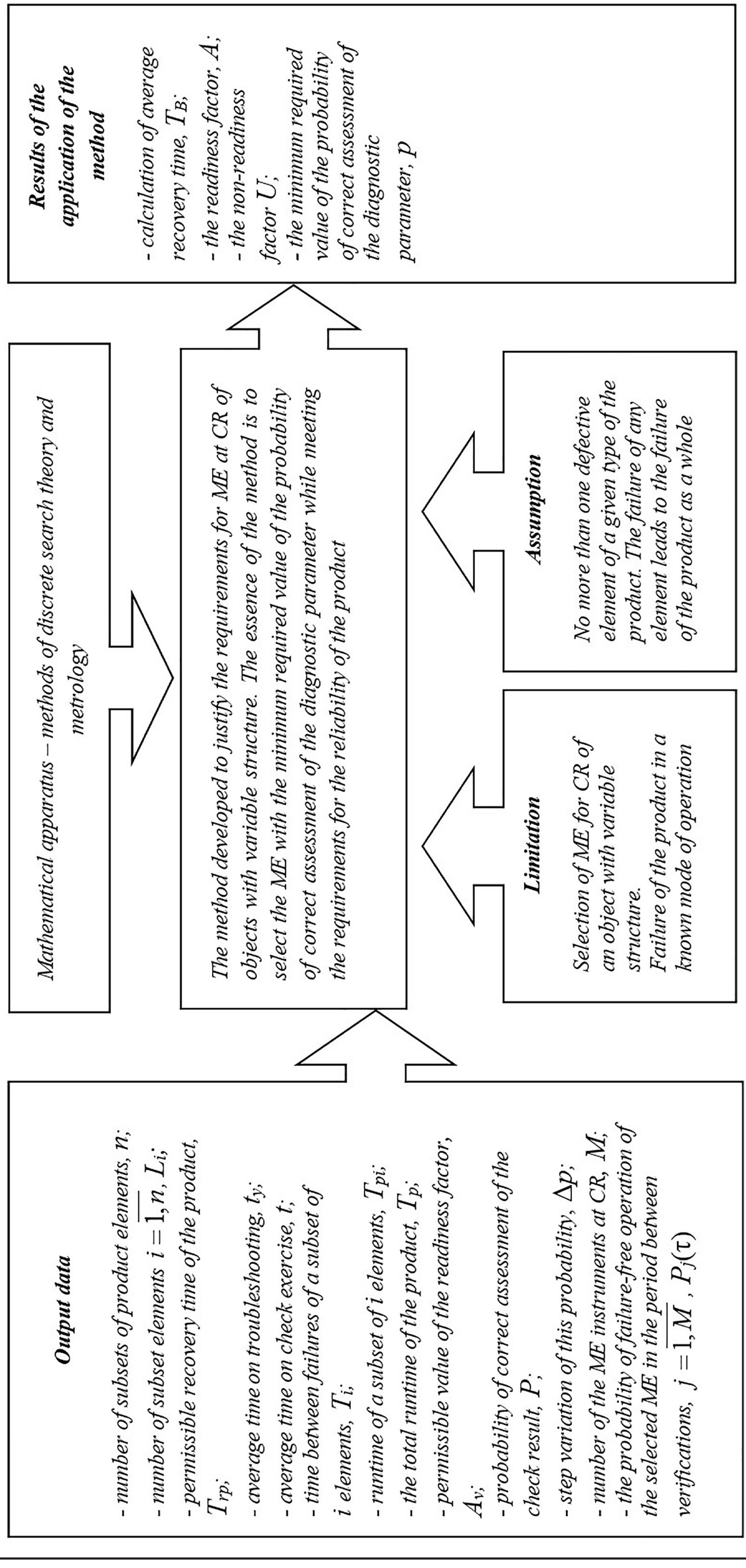

Fig. 1. Structure of the method of justification of the requirements for metrological support of current repair of objects with variable structure

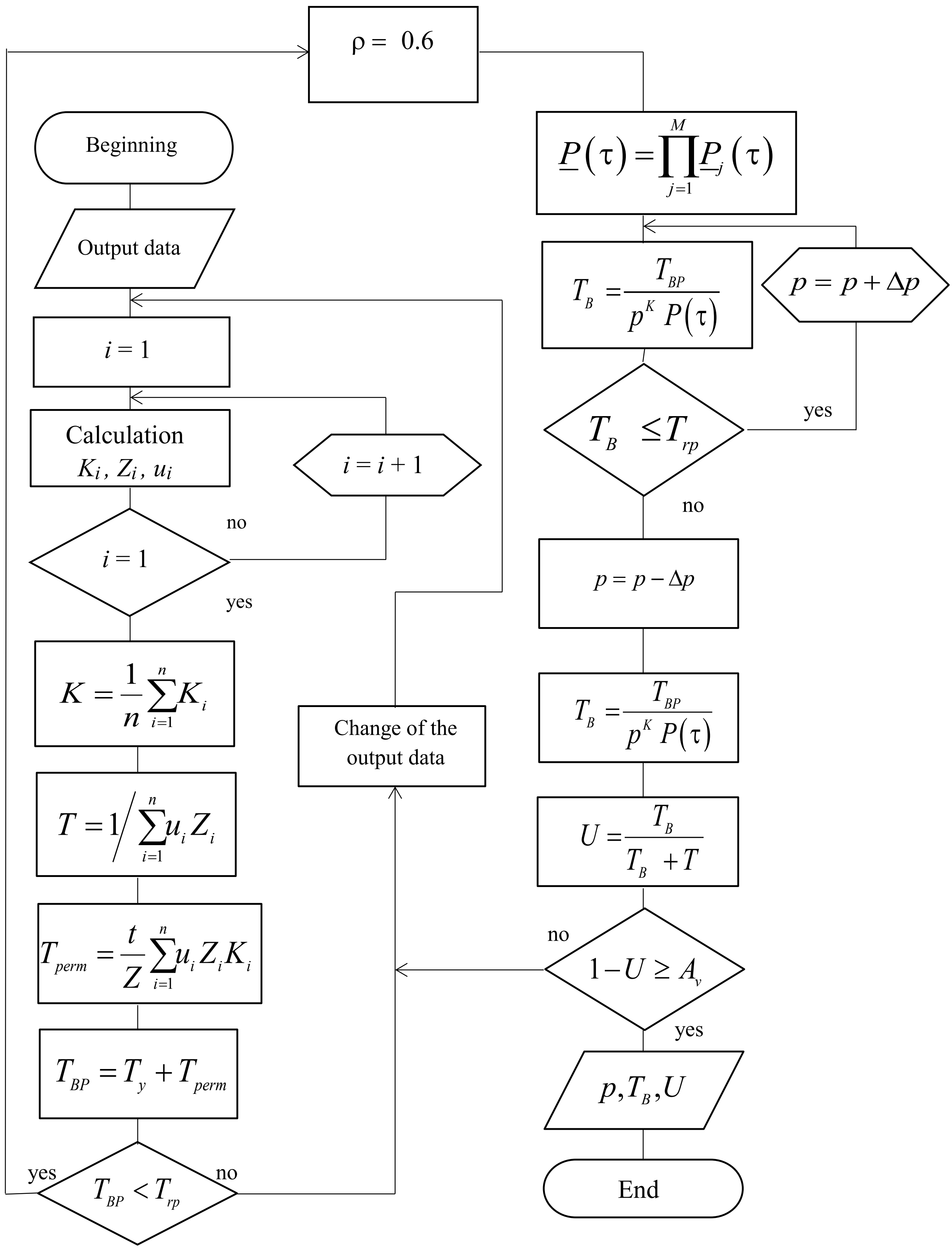

Fig. 2. Flowchart of the algorithm for determining the minimum required value of the probability of correct assessment of the diagnostic parameter

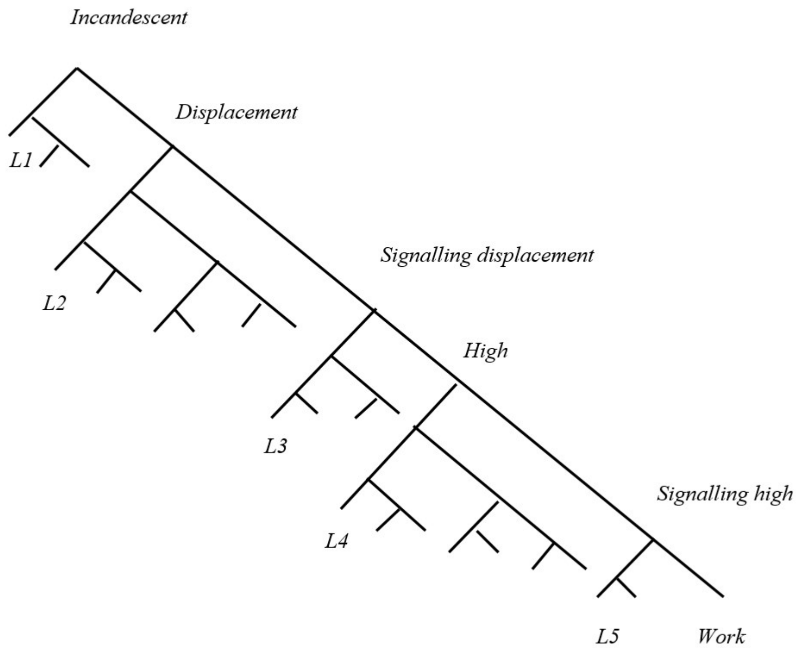

Fig. 3. Algorithm for technical condition of a control subsystem of the operation of a radio transmitter

Table 2

Output data for the device

i	L_i	K_i	u_i	T_i	Z_i
1	3	1.7	1.00	200	0.0050
2	7	2.9	0.95	150	0.0067
3	4	2.0	0.95	175	0.0057
4	8	3.1	0.05	125	0.0080
5	2	1.0	0.05	300	0.0333

3. Application of the method

Let us consider an example of the application of the method for the selection of ME for CR of a control subsystem of the operation of a high-power radio transmitter which has $n = 5$ subsets of elements. The conditional diagnosis algorithm [8] is shown in Fig. 3. The radio transmitter is controlled remotely. The initial data are presented in Table 2.

Further, according to the algorithm shown in Fig. 2, for $T_{rp} \leq 20$ min; $A \geq 0.994$; $t = 1$ min; $t_y = 5$ min; $M = 1$; $P(\tau) = 0.95$ we obtain the following: $K = 2.14$; $Z = 0.0188$ hours^{-1}; $T = 53.2$ hours; $T_{BP} = 7.2$ min; $T_B = \dfrac{7.54}{p^{2.14}}$.

Calculation results for T_B with the step $\Delta p = 0.1$ are shown in Fig. 4.

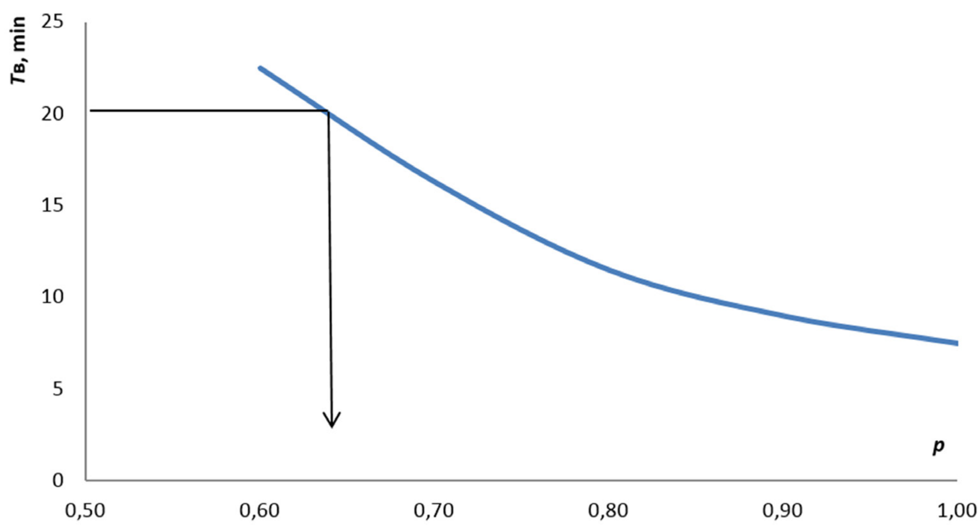

Fig. 4. Calculation results for the average recovery time depending on the probability of correct estimation of the value of the diagnostic parameter

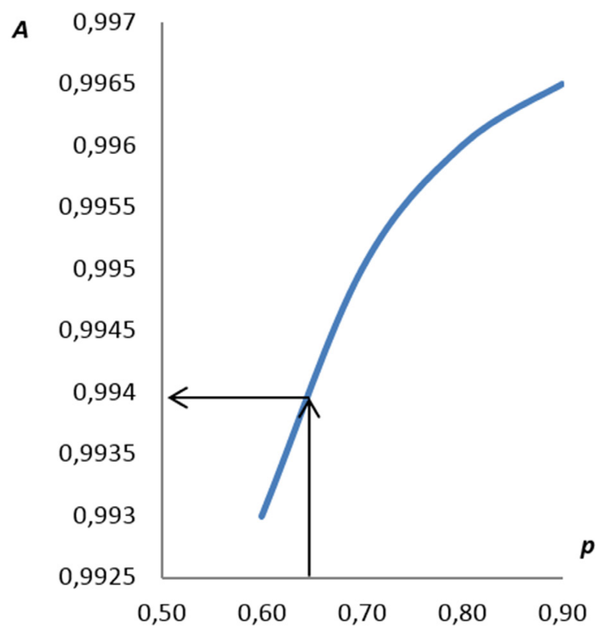

Fig. 5. Dependence of the readiness factor on the probability of correct assessment of the diagnostic parameter

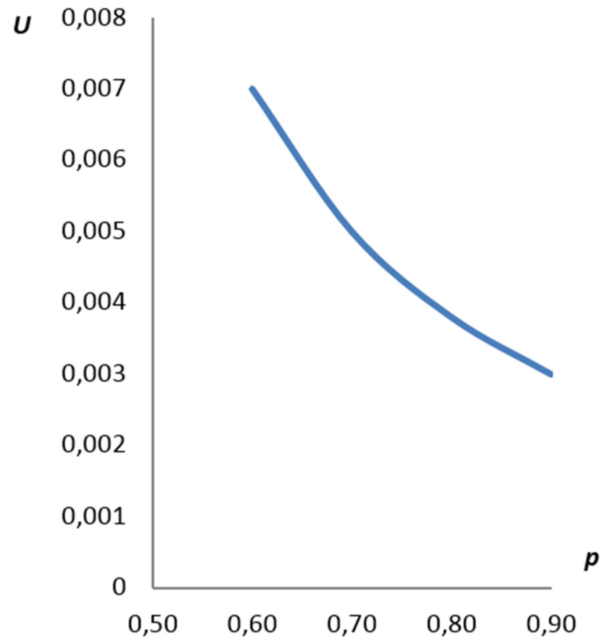

Fig. 6. Dependence of the factor of non-readiness on the probability of correct assessment of the diagnostic parameter

These results suggest that a built-in voltmeter with a vertical linear scale, for which $p=0.645$ (Table 1), is preferable at the given conditions. Probability dependencies of multi-component reliability indices $A(p)$ and $U(p)$ are shown in Fig. 5 and Fig. 6, respectively.

Fig. 5 shows that for $p = 0.645$ we obtain $A = 9.994 = A_v$, which in turn confirms that the ME instrument is selected correctly.

4. Conclusions

A method for selecting measuring equipment for current repair of objects with variable structure is developed and scientifically justified with accounting for the first time the limitations on the value of the average recovery time and the readiness factor based on the assessment of the impact of the quality of metrological support on the reliability indices of such complex objects, according to the criteria of the minimum probability of correct assessment of the result of the evaluation of diagnostic parameters.

A specific example of the application of the developed method is presented. It is demonstrated that increasing the value of the probability of correct assessment of the diagnostic parameter from 0.6 to 0.9 reduces the average recovery time of the product at the current repair by 44% (Fig. 4) and the non-readiness factor by 2.3 times (Fig. 6).

In our opinion, it is highly desirable to direct further research to the improvement of metrological support of objects with variable structure in the events of accidental and combat damage, with the aim to recover their operability in the field conditions.

Метод обґрунтування вимог до метрологічного забезпечення ремонту об’єктів зі змінною структурою

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Анотація

Запропоновано новий метод обґрунтування вимог до засобів вимірювальної техніки, який вперше враховує можливість зміни структури виробу під час його використання за призначенням. Це дозволяє мінімізувати вимоги щодо ймовірності оцінки значень діагностичних параметрів виробу під час його поточного ремонту, тобто зменшити вартість засобів вимірювальної техніки. При цьому кількісно оцінюються часткові (наробіток на відмову і середній час відновлення) і комплексні (коефіцієнт готовності та неготовності) значення показників надійності, що задовольняють вимоги. Задача вирішується алгоритмічно з використанням математичного апарату методів технічної діагностики й метрології. При цьому, зважаючи на потрібні вимоги до показників надійності виробу, обґрунтовано вибирають потрібні для поточного ремонту засоби вимірювальної техніки.

Для розв'язання поставленої задачі використовують сучасні досягнення теорії надійності великих об'єктів і систем зі змінною структурою, а також методи метрології з оцінки впливу надійності засобів вимірювальної техніки на значення середнього часу відновлення багаторежимних об'єктів під час їхнього поточного ремонту з використанням результатів останніх досліджень у галузі технічної діагностики. У відомих наукових публікаціях перераховані методи комплексно не використовувалися.

У статті формалізовано порядок використання запропонованих результатів у вигляді алгоритму, що дозволяє підвищити ефективність застосування методу за допомогою ЕОМ.

Наведено конкретний приклад використання методу на реальній техніці зв'язку – підсистемі керування функціонуванням радіопередавача великої потужності. Показано, що відповідно до вимог настановчих документів щодо значення середнього часу відновлення об'єкта зі змінною структурою можливо обґрунтовано обрати метрологічні характеристики й тип засобів вимірювальної техніки. Або, зважаючи на задане значення комплексного показника надійності виробу – коефіцієнта готовності. Наведено оцінку ефективності використання запропонованого методу.

Метод доцільно використовувати при розробці метрологічного забезпечення поточного ремонту перспективних радіоелектронних засобів зі змінною структурою.

Ключові слова: метрологічне обслуговування; технічна діагностика; засоби вимірювальної техніки; об'єкт зі змінною структурою.

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