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Ensuring the required level of reliability and accuracy of measuring instruments by adjusting the inter-verification intervals

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Abstract

Based on the analysis of the available verification system of measuring instruments, the inexpediency of a fixed value of inter-verification intervals has been established, and recommendations for the implementation of a different approach to changing the values depending on the operation time have been substantiated. Establishing the patterns of changes in the values of reliability and accuracy indicators over time allows one to increase the metrological reliability of measuring instruments, as well as the operational reliability of radio-electronic devices due to correct assessment of their real technical condition during maintenance and current repairs.

The paper for the first time studies the option of reducing the verification intervals of measuring instruments to ensure the required level of their metrological reliability depending on the given value of the complex reliability indicator or the accuracy of measurements of the parameter values of radio-electronic instruments when assessing their technical condition during maintenance or current repairs. The results obtained can be used for versatile determination of verification intervals of both analogue and digital measuring instruments.

Keywords: measuring instrument; inter-verification interval; radio-electronic equipment.

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Statement of the problem

Metrological support (MS) of the operation of modern radio-electronic means (REMs) significantly affects the time of their maintenance (MT) and current repairs (CR) by assessing the real technical condition (TC) based on the measurement results of the parameter values. In real time, the duration of the inter-verification intervals (IVIs) is constant throughout the entire period of operation of the measuring instrument (MI), yet as a result of ageing of electrical and radio elements, as well as metrological failures, their reliability and accuracy deteriorate before the next in turn verification, which leads to incorrect assessment of the REM TC and increase in their MT or CR. Therefore, an urgent scientific task arises: based on the analysis of the MI operation process, the reasons for the deterioration of MI metrological characteristics shall be determined and ways to increase the values of reliability and accuracy indicators throughout the entire period of use for their intended purpose shall be justified by implementing a flexible IVI assignment system.

Analysis of recent achievements and publications

Metrological support of modern REMs significantly affects the time of their maintenance and repairs

$$T_R = T_{TC} / P_{TC} \prod_{i=1}^{M} P_i(\tau), \qquad (1)$$

where T_R is the average recovery time (TC assessment and troubleshooting);

T_{TC} is the average time of TC assessment and troubleshooting;

P_{TC} is the probability of correct TC assessment;

P_i (τ) is the metrological reliability (MR) of the MI type i at IVI τ;

M is the number of MIs for checking the values of the REM parameters during MT or RC.

The reliability of the measurement results of the parameter values of REMs during their MT or CR is determined not only by the accuracy of MIs, but also by the reliability of its maintenance over a certain period of operation, i.e., the MR. In the regulatory and technical documentation for MIs, the MR indicator is recorded, represented by the probability of the absence of hidden failures according to IVI at a given value of the product utilization coefficient $0.1 \leqslant K_B \leqslant 0.24$ [1].

Special features when operating MIs is due to the provision of fault-free operation, mainly due to hidden (metrological) failures. The effects of operating MIs with metrological failures can be extremely large and difficult to predict in the event of incorrect assessment of the real TC of critical infrastructure products (communications, transport, energy, etc.) [1, 2].

The verification of MIs plays a pivotal role in the system maintenance. MIs are verified by metrological centres and verification laboratories in accordance with regulatory legal acts. The duration of a IVI is assigned depending on the actual reliability of a MI, the conditions of its operation, the intensity of use (K_B), and the significance of the results for the operation of specific samples of REMs [1, 2].

But the question arises: why is $P(\tau) < 1$ in IVI? Therefore, the purpose of the paper is not only to determine this effect, but also to substantiate recommendations for increasing the MR of available and promising MIs.

The analysis of the values of τ and $P(\tau)$ of available MIs according to data [3] is given in Table 1, where the values of τ=const and are calculated using the well-known method [1].

Table 1

Information on the inter-verification intervals and metrological reliability of available measuring instruments

Tape of MI	τ, hour	$P(\tau)$
Г4-116	5000	0.989
В3-41	4000	0.978
Ч3-54	3000	0.976
В7-15	4000	0.978
Д-5014	2000	0.899
Г3-102	5000	0.989
СК3-43	5000	0.997
Ц-4353	1500	0.877
М3-45	2000	0.899
Ч3-63	3000	0.976
С6-11	5000	0.997
В3-56	4000	0.978
Г4-151	5000	0.989

Data on modern MIs from the 2017 mobile laboratory set of measuring equipment (TU 34.1-01354485-018:2018) are given in Table 2.

In both cases, regardless of the MI operation time and the year of manufacture, the value τ=const for the entire period of use for its intended purpose until decommissioning.

Table 2

Modern measuring instruments from the set of a mobile laboratory

Name	Inter-verification interval, years
Universal frequency counter Keysight 53220A, USA	2
Analogue signal generator Keysight E8257D, USA	2
Signal generator Г4-301, Ukraine	2
Comparator Ч7-39, Ukraine	2
Rubidium frequency standard, F8725, USA	2
Resistance store Р4831, Ukraine	2
Electronic frequency counter, Ч3-101, Ukraine	2
Non-linear distortion meter, СК 6-13, SU	2
Signal generator Keysight 33511B, USA	2
Digital multimeter Keysight 34461A, USA	2
Signal analyser Keysight №9000B, USA	2
Modulation meter СК3-45, SU	2
Digital oscilloscope Keysight DSOX3032A, USA	3
Power sensor Keysight U2000H USB, USA	2
Electronic scales ТВЕ-30-0.5, Ukraine	2

It is known that the presence of a subjective factor and the need to control a set of MIs during MT of large-sized objects leads to incorrect assessment of their real TC and, as a result, to possible human-made disasters [2, 4].

MS of modern REMs requires new approaches to make a solid choice of MIs for their MT and CR, as well as considering MR in the process of assessing the reliability indicators. Recently, there has been a transition from analogue to digital REMs, which also requires new approaches to assess their real TC during MT and CR, which is in turn affected by the MR of the MI. At the same time, the IVIs of these, according to the guiding documents, remains unchanged, which leads to a deterioration in the MR values of modern MIs at the final stage of IVIs [5–10].

The purpose of the paper is to obtain functional dependencies of the length of IVIs of MIs on the conditions of their operation and the requirements for the values of the reliability indicators of the REMs for a practical transition to a versatile determination of IVIs of modern analogue and digital MIs, which will allow maintaining the value of their MR throughout the entire period of operation.

Presentation of the main material

Considering the intensity of use of the MIs throughout the entire IVI to be constant, a linear dependence of the complex reliability indicator – the readiness coefficient (*Krc*) – on time is obtained,

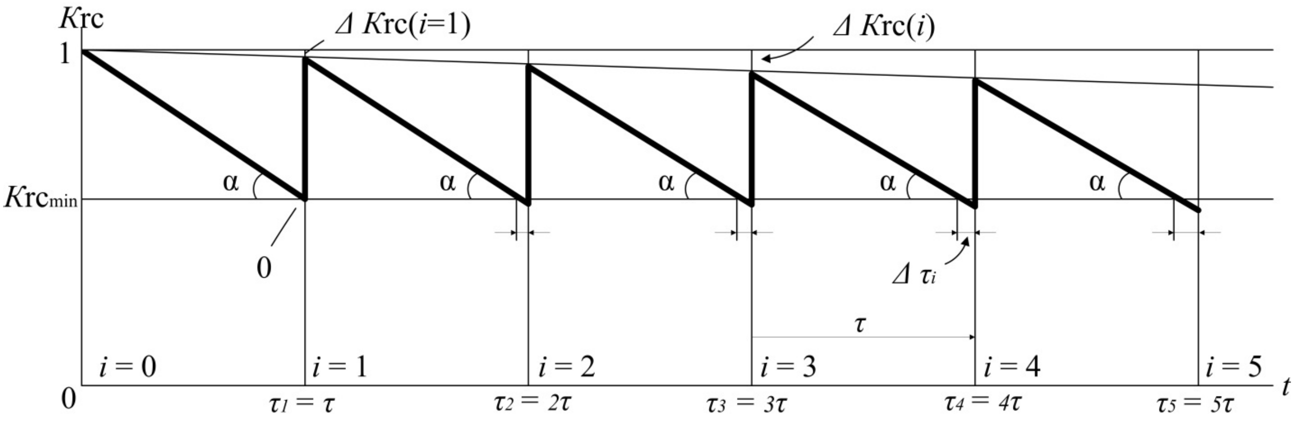

Fig. 1. Change in the readiness coefficient of a measuring instrument depending on the time of operation and the number of next in turn verifications

which is shown in Fig. 1. Due to the ageing of the MI electrical and radio elements, restoring its reliability to the initial level during verification is impossible, therefore, with each next verification, the value of the readiness coefficient decreases by

$$\Delta\, Krc(i) = 1 - \beta\, Krc(i-1),$$

where β is the relative part of the restoration of the readiness coefficient to the previous value of $Krc(i-1)$.

The figure shows that with each verification for the time value $\Delta\tau_{i+1}$, the readiness coefficient of the MI decreases below the permissible $Krc_{\min}$. Due to the fact that $\Delta\tau_{i+1} > 0$, the scope of work during the next in turn verification of the MI increases, and this also leads to a decrease in the indicators of the MR, namely $P(\tau)$ (Table 1). During these periods, there is a risk of incorrect TC assessment during MT or CR of the REM, as well as a risk of an increase in the time required to perform the work, which follows from expression (1).

Let us consider the quantitative indicators of the MI operation process, which are shown in Fig. 1. Under the previously defined conditions, the following is obtained:

$$\operatorname{tg}\alpha = \frac{1 - Krc_{\min}}{\tau}.$$

In this case, when a = const, there is always the following:

$$\frac{\beta^{i-1} - Krc_{\min}}{\tau - \Delta\tau_i} = \frac{1 - Krc_{\min}}{\tau},$$

that is, every time the IVI exceeds the permissible value by

$$\Delta\tau_i = \tau\left[1 - \frac{\beta^{i-1} - Krc_{\min}}{1 - Krc_{\min}}\right].$$

For example, when $\beta = 0.99$; $Krc_{\min} = 0.9$; $\tau = 2$ years, there is an increase $\Delta\tau_i$ with each next verification, as shown in Fig. 2, when $Krc < Krc_{\min}$.

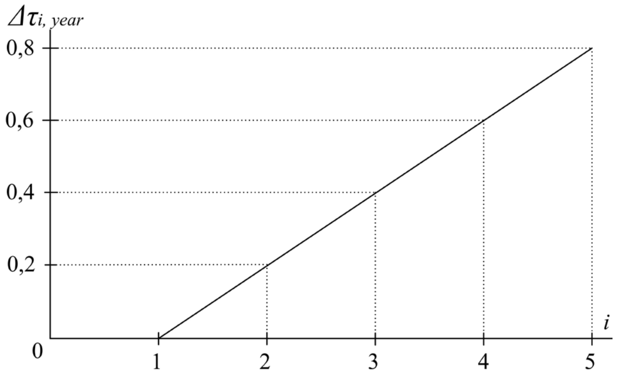

Fig. 2. Dependence of the increase in time when the readiness coefficient of the measuring instrument is below the permissible value

That is, the reason for the decrease in the MR of available MIs is explained by the fact that τ = const regardless of the MI operation time, and the longer it is, the smaller the MR is. This situation arose due to the difficulty of accounting the operating time of individual samples of MIs in the absence of a computer. Today, information technologies are rapidly developing, which makes it possible to create an automated system of REM MS for critical infrastructure, which can operate as part of metrological centres or metrological laboratories. This allows for the recording of works individually for each sample of MIs. In this case, it is possible to exclude periods of the MI operation when their $Krc < Krc_{\min}$ (Fig. 3).

With the previously mentioned assumptions, the length of the IVI depending on its number is obtained:

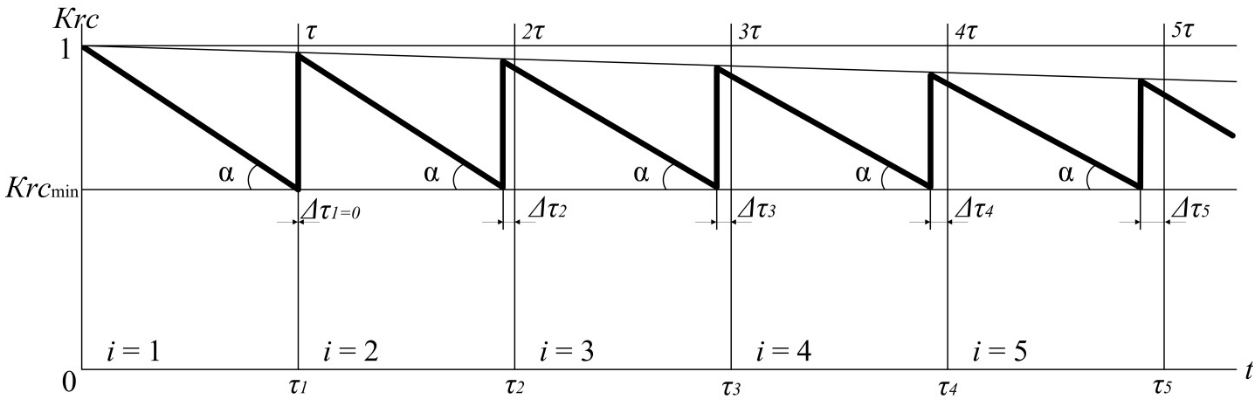

Fig. 3. Operation of measuring instruments with variable inter-verification intervals

$$\tau_i = \tau - \Delta\tau_i = \tau \frac{\beta^{i-1} - Krc_{\min}}{1 - Krc_{\min}}.$$

The total reduction in the IVI time after performing n verifications is equal to

$$\sum_{i=1}^{n} \Delta\tau_i = \tau \left[n + \frac{nKrc_{\min} - \sum_{i=1}^{n} \beta^{i-1}}{1 - Krc_{\min}} \right],$$

that is, for the previously considered example of using a MI, it is necessary to perform one additional verification over 10 years of operation, while the scope of works is reduced, the MR of the MI increases and always corresponds to the standard one.

Let us consider the influence of controlled variables on the value of the IVI reduction:

- when τ increases by 2 times, $\Delta\tau_i$ also increases by two times;
- when β_i decreases by only 1%, the value of $\Delta\tau_i$ doubles;
- when the permissible value $Krc_{\min}$ is reduced by 11%, the value $\Delta\tau_i$ decreases by two times (Fig. 4).

If the accuracy of measurement of the REM parameters is crucial for using the MI, then as a criterion for sending the MI for verification, it is possible to apply an increase in the relative measurement error (δ) to the maximum permissible value $\delta_{\max}$ (Fig. 5).

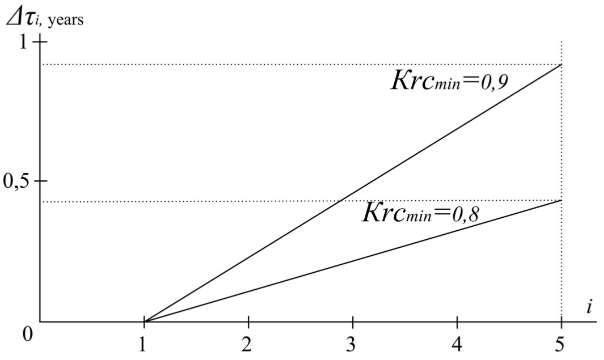

Fig. 4. Dependence of the reduction of inter-verification intervals on the minimum permissible decrease in the readiness coefficient (τ = 2; β = 0.99)

In this case, the length of the IVI is obtained as follows:

$$\tau_i = \tau \left[1 - \frac{(i-1)\Delta_1}{\delta_{\max} - \delta_{\min}} \right] + \tau_{i-1},$$

where τ_i is the time until the next in turn verification from the start of operation of the MI;
$\Delta_1 = \delta_{\max}(1-\gamma)$, γ is the degree of recovery of relative accuracy of measurements of the REM parameter values.

Let us consider the use of the obtained results using the example of the frequency meter Ч3-101 with the following initial data: τ = 2 years; β = 0.99; $Krc_{\min}$ = 0.85. In this case, over 12 years of operation,

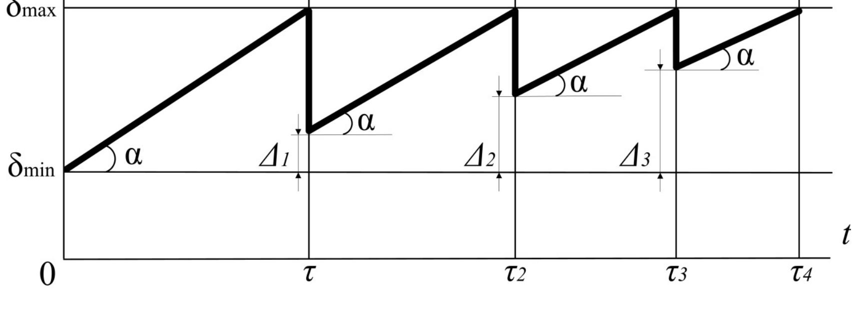

Fig. 5. Determination of inter-verification intervals depending on the value of the relative measurement error of the radio electronic equipment parameter

it is proposed to perform 8 verifications according to a flexible schedule instead of 6 according to the fixed one as established, but during this period of operation, the value of the complex reliability indicator will always be no less than the required one (in the existing state, for 8 months before the sixth verification $Krc < Krc_{min}$).

Another example of calculating the inter-verification intervals is depending on the minimum permissible error of measurements of the parameters values of radio electronic devices. Keysight DSOX3032A digital oscilloscope made in the USA was used, with the following initial data: $\tau = 3$ years; $\delta_{max} = 4\%$; $\delta_{min} = 1\%$; $\gamma = 0.9$. At the same time, over 12 years of operation, it is necessary to perform 6 calibrations instead of 4, which ensures the minimum required value of the relative error of the parameter measurements during this period of operation of the oscilloscope (in the existing state, before performing 4 calibrations, the relative error of parameter measurements exceeds 5%).

It should be noted that the results were obtained assuming stable operating conditions and a linear nature of the change in the readiness coefficient and the relative error of the MI measurements over time.

Therefore, the proposed approach to determining the IVI will be flexible and different from the available one, in which this time is deterministic. To increase the value of the readiness coefficient and accuracy of MIs, especially those that have been in operation for a long time, it is necessary to reduce the IVI (Fig. 3, 5). This allows ensuring the required level of operational reliability of REMs without significant costs for their MS: despite the increase in the number of MI verifications during their operation, the scope of work is reduced and, in addition to the scheduled MT, does not require CR.

Conclusions

1. For the first time, the possibility of reducing the inter-verification intervals of measuring instruments to increase their metrological reliability and reduce the relative measurement error was studied.
2. It is advisable to use the obtained results in the creation of promising automated systems for metrological support of radio-electronic means of critical infrastructures.
3. The collection and processing of statistical data on changes in the reliability and accuracy of measuring instruments over time shall be studied to pass real laws depending on the operating conditions of promising digital instruments.

Забезпечення необхідного рівня надійності й точності засобів вимірювальної техніки регулюванням міжповірочних інтервалів

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Анотація

На основі аналізу наявної системи повірки засобів вимірювальної техніки встановлено недоцільність постійного значення міжповірочних інтервалів і обґрунтовано рекомендації щодо впровадження іншого підходу до зміни їх значення залежно від часу експлуатації. Встановлення закономірності зміни значень показників надійності й точності з часом дозволяє підвищити метрологічну надійність засобів вимірювальної техніки, а також експлуатаційну надійність радіоелектронних засобів за рахунок правильного оцінювання їх реального технічного стану при технічному обслуговуванні та поточному ремонті.

У статті вперше досліджено можливість скорочення міжповірочних інтервалів засобів вимірювальної техніки для забезпечення необхідного рівня їх метрологічної надійності залежно від заданого значення комплексного показника надійності або точності вимірювання значень параметрів радіоелектронних засобів під час визначення їх технічного стану в процесі технічного обслуговування або поточного ремонту. Отримані результати можливо використовувати для гнучкого визначення міжповірочних інтервалів як аналогових, так і цифрових засобів вимірювальної техніки. Їх практичне використання можливо реалізувати при створенні перспективних автоматизованих систем метрологічного забезпечення радіоелектронних засобів критичних інфраструктур у метрологічних органах на базі сучасних ЕОМ. Це дозволить не тільки розраховувати міжповірочні інтервали індивідуально для засобів вимірювальної техніки, а й корегувати їхні значення залежно від умов експлуатації (стаціонарних або польових) з метою забезпечення необхідного рівня метрологічної надійності на весь період експлуатації.

Ключові слова: засоби вимірювальної техніки; міжповірочний інтервал; радіоелектронні засоби.

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