UDC 621.396 DOI:

Metrological support of maintenance by the technical state of communication means

Ye. Ryzhov [1], L. Sakovych [2], Yu. Myroshnychenko [2], V. Hrabchak [1], Yu. Nastishin [1], A. Volobuiev [3]

[1] *Hetman Petro Sahaidachnyi National Army Academy, Heroiv Maidanu Str., 32, 79012, Lviv, Ukraine*
zheka1203@ukr.net
[2] *State Institution "Institute of Special Communication and Information Security" of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Verkhnokliuchova Str., 4, 03056, Kyiv, Ukraine*
[3] *Central Researching Institute of the UA Armed Force, Vozdukhoflotsky Ave., 28, 03049, Kyiv, Ukraine*

Abstract

Modern and prospective communication means are among the most knowledge-driven, high-tech types of industrial products, which are subject to enhanced requirements for quality and efficiency of application. The effective functioning of modern communication means is provided by built-in software, including metrological support. In this paper, we consider the specifics of metrological maintenance of large-scale communication facilities (tens and hundreds of thousands of elements) consisting of separate subunits, the serviceability, maintenance, and recovery of which can be performed autonomously. It is proposed to enhance the efficiency of the by-state-maintenance (also called maintenance by the technical state) by accounting for the specifics of metrological support, establishing an optimal sequence of operations, selecting the measuring instruments in accordance with relevant requirements. To do this, one has to use a combined indicator composed of individual parameters of the tests and the probability of their preferred choice. This allows to assess the technical condition of the communication means with a given probability during a minimal time. In addition, one can estimate the time of maintenance, taking into account the metrological reliability and the probability of correct evaluation of the result of checking the parameters by the measuring instruments. The order of implementation of the obtained results is formalized in the form of an algorithm and an example of their realization is presented.

Keywords: communication means; measuring instruments; maintenance by the technical state; metrological support; metrological reliability.

Received: 10.03.2021 Edited: 21.06.2021 Approved for publication: 01.07.2021

1. Introduction

Current development trends require the introduction of the method of maintenance by the technical state (further called by-state-maintenance, BSM) of communication means (CM), which is the most cost-efficient and such that provides a desired level of readiness for exploitation by the prescription. However, at present scientifically justified methodological recommendations for the implementation of this method are not available. The minimum number of testable parameters, the sequence of inspections, requirements for metrological support (MS) depending on the required time of the work still have to be formalized into an algorithm.

In-situ monitoring of measured parameters and the proper selection of necessary measuring instruments (MIs) is of crucial importance for correct assessment of the current technical state (TS) of the CM in the course of BSM, which is the principal task of technical diagnostics. When the values of certain parameters deviate from the norm, the following task of technical diagnostics is performed: search and replacement of a faulty element of the CM. To reduce the number of measurements one employs the so-called conditional diagnostic algorithms (CDAs). The main part of the work on justification of the requirements for the MS consists in the selection of the nomenclature of MI. Therefore, justification of the requirements for MI depending on the required time of BSM of CM, allowing one to determine the actual TS of CM with a given probability at the minimum required number of inspections is in great demand, and thus is the aim of this paper.

2. State-of-the-art and statement of the problem

Maintenance of a device or a system is a set of operations to maintain serviceability or operability during technical operation, which involves verification for compliance of the values of tested parameters with those prescribed by the technical conditions [1]. There are the following principal types of maintenance concerning their scheduling [2]: by the prescribed schedule, by the operating time and BSM. Nowadays, the latter strategy is a priority such that the list and fre-

© ННЦ «Інститут метрології», 2021

quency of maintenance operations are governed by the TS of CM, based the running information during the CM exploitation. The advantage of the BSM is defined by the fact that the verification of the parameters of the CM is performed by a predetermined sequence, and the list of procedures depends on the results of the control. In such a case, one has to select the MI and define the sequence to check the CM parameters to determine the actual TS for the minimum time [3].

Modern publications in the field of technical exploitation of complex systems indicate a need for scientific analysis and justification of specific recommendations for the practical implementation of the BSM for CMs [4–10]. Fundamental theoretical studies of the optimization of maintenance are given in [11]. Further development was performed in works aimed to improve the operational reliability of products [4–10]. In [1] the analysis of specifics of maintenance of systems with time redundancy is presented and the procedures for the enhancement of their reliability are proposed.

In modern publications on technical diagnostics of electronic systems, the notion of the probability of the preferred choice (PPCh) of inspections is widely used to determine the sequence of inspections, which leads to a reduction in the time needed for the fault localization [4, 12]. The dependence of the influence of metrological reliability of MI on the time of maintenance of objects of various purposes, not taken into account in previous works on the optimization of maintenance time, was studied in [13–14].

Our analysis shows that, at present, the BSM of CM appears to be the most efficient maintenance method, and, thus, greatly demanded is the simultaneous account for the reliability, time, and cost indicators for the inspection of separate subsystems, as well as the account for the metrological reliability of MI. To do this, it is necessary to propose a quantitative indicator to assess the PPCh parameters followed by their further ranking in descending order. The purpose of the paper is to derive and analyze the analytical dependences of the time of the BSM of CM on the quality indicators of the MS to algorithmize the process of reasonable choice of MI.

3. Development of the Method

The analysis of publications on the assessment of the impact of the MS on the time of maintenance of a large object [3, 12] allows to quantify the value of the complex coefficient of each inspection, accounting for the reliability and time indicators $u_i = \dfrac{S_i v_i P_i}{\pi_i f_i q_i}$, $P_V = \prod_{j=1}^{N} P_j(\tau)$, where P_i is the metrological reliability of MI in the period τ between inspections; N is the number of MI used during the verification of the parameter i; $P_j(\tau)$ is the metrological reliability of MI of type j; v_i is the significance of the influence of the parameter i on the quality of the functioning of the CM (evaluated as a result of processing the data of the expert survey of specialists according to available methods [15] $\left(\sum_{i=1}^{M} v_i = 1\right)$; M is the total number of parameters of the CM; S_i is the probability of failure of a set of elements that affect the formation of the parameter i

$$S_i = \frac{z_i}{\sum_{i=1}^{M} z_i} = z_i T, \qquad \sum_{i=1}^{M} S_i = 1,$$

where z_i is the failure parameter of the set of elements; T is the operating time of CM to failure; π_i is the relative labor costs for technical diagnosis in case of deviation of the parameter i from its normal value

$$\pi_i = \frac{t_i}{\sum_{i=1}^{M} t_i}, \qquad \sum_{i=1}^{M} \pi_i = 1,$$

where t_i is the execution time of the check of the set of elements that affect the formation of the parameter i; f_i is the relative labor costs for the restoration of CM and proof of the parameter i to the norm

$$f_i = \frac{t_i}{\sum_{i=1}^{M} t_i}, \qquad \sum_{i=1}^{M} f_i = 1,$$

q_i is the value of the probability of error by a specialist in estimating the parameter i depending on MI that is change from 0.0003 to 0.355 [16].

The specifics of the use of MI during the BSM of CM implies ensuring their reliability, primarily for hidden metrological failures. The probability $P_j(\tau)$ of the preservation of the values of metrological characteristics within the specified limits during the inter-inspection interval τ is used as an indicator of metrological reliability of MI [3, 14].

The required level of metrological reliability significantly depends on the application scope of MI and is selected accounting for the condition of ensuring the necessary efficiency of the CM. As a rule, for a serviceable MI this level is in the range 0.85...0.99, and for exemplary ones it is 0.90...0.99 [3, 14]. Quantitatively, the probability of the preservation of the values of metrological characteristics of MI in specific operating conditions is estimated by the expression [3, 12, 13]

$$P_j(\tau) = 1 - K_M K_S K_e,$$

where K_M is the fraction of metrological characteristics of MI not covered by the built-in control; K_S is the statistical estimation of the hidden failure rate, which characterizes the fraction of metrological failures; K_e is the equivalent number of failures at the operation of MI

$$K_e = \tau K_U / T_O,$$

K_U is the average utilization factor of MI; T_O is the operating time of MI on refusal.

Table 1

Quantitative indicators of metrological reliability of measuring instruments

No.	Measuring instrument	T_O, hours	K_M	K_S	$P_j(\tau)$	δ
1	Electric multifunctional device	1500	1.0	0.21	0.877	0.353
2	Power meter	2000	1.0	0.23	0.899	0.319
3	Frequency meter	3000	0.5	0.16	0.976	0.217
4	Meter of nonlinear distortions	5000	0.1	0.16	0.997	0.054
5	Millivoltmeter	4000	1.0	0.10	0.978	0.148
6	High frequency signal generator	5000	0.3	0.20	0.989	0.187

Value τ is obtained from the guiding documents of the MS of the serviced CM or from the technical description of the MI. Taking that the master performing the maintenance spends 900 hours during the year for the BSM and recovery of CM, we find $K_U = 0.103$ for one year of operation of CM [12]. The value of K_M is determined based on the results of the analysis of the technical description and operating instructions of MI. Depending on the operation scope of MI in the absence of current statistical data for the given conditions of operation of CM, the value of K_S can be determined by the average indicators, where $0.1 \le K_S \le 0.24$ [3, 12, 14].

Operating time for failure of MI is also taken from statistical data, and in their absence it can be found in the technical description of devices. The standard deviation of the estimate of the probability of the preservation of the values of the metrological characteristics of the MI is calculated as following [3, 12]

$$\delta = K_e K_M \sqrt{K_S (0.15 K_S + 1/K_e)}.$$

Quantitative indicators of metrological reliability of MI, which are used during the BSM of radio stations for $\tau = 8760$ hours (for example), according to [3, 12, 14], are given in Table 1. The value of the coefficient u_i is dimensionless; it allows one to identify the least reliable subsystems of CM, which require minimal time to test and restore, but generally have the greatest impact on the quality of operation of CM.

It varies in a quite wide range and, thus, to rank the order of verification of the parameters of the CM, it is advisable to use the value of PPCh [3, 17]

$$U_i = \frac{u_i}{\sum_{i=1}^{M} u_i}, \qquad \sum_{i=1}^{M} U_i = 1.$$

The parameters of the CM are checked in descending order of value U_i. For a given value of probability P_{perm} of the determination of the TS of the CM, the parameters are checked according to the predetermined rank before the condition is fulfilled

$$\frac{\sum_{i=1}^{n} u_i}{\sum_{i=1}^{M} u_i} \ge P_{\text{perm}}, \qquad n = \overline{1, M},$$

where n is the number of parameters that are checked during the BSM. In such a case, the minimum time of inspection of the CM is required $T_n = \sum_{i=1}^{n} t_i$, and the relative gain in time in comparison with that for the complete verification of all parameters of the CM is of the form

$$\eta = \frac{\sum_{i=1}^{M} t_i - T_n}{\sum_{i=1}^{M} t_i} \cdot 100\%.$$

In [3, 17], it is shown that the considered approach to the ranking of CM parameters during the BSM allows to reduce up to 10% the number of parameters to be checked using the predetermined value of P_{perm} or up to 37% using the known value of the operating time on the failure of the CM after checking the main parameters that affect the quality of operation. Below we consider the influence of the MS on the value of the coefficient u_i, where

$$C_i = \frac{S_i v_i}{\pi_i f_i}, \qquad u_i = C_i \frac{P_i}{q_i}.$$

Since $P_i \approx 1$ and $q_i < 1$, we have $P_i / q_i > 1$, which means that the quality of the MS is the main factor affecting the value u_i, which changes linearly with this ratio. At $v_i = 0.025$; $S_i = 0.04$; $\pi_i = 0.054$; $f_i = 0.055$ we find $C_i = 0.3367$. The corresponding dependences $u_i(q_i)$ are directly proportional to P_i and shown in Fig. 1.

Fig. 1 shows that with the increase of P_i on 0.2 the value u_i grows by 1.27 times. Accordingly, coefficient u_i

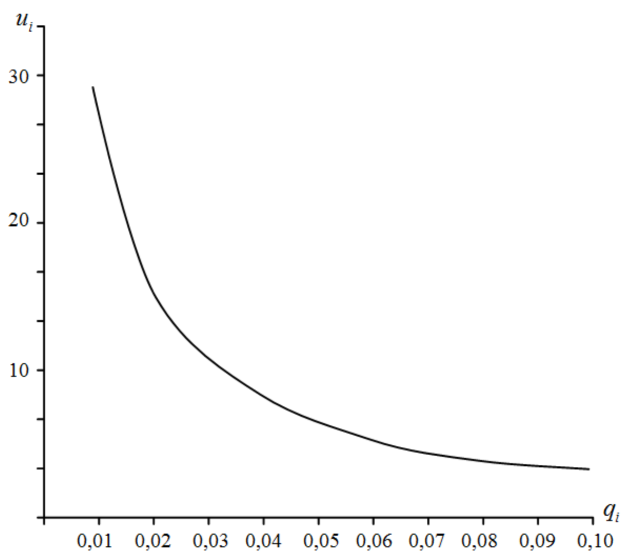

Fig. 1. Dependence $u_i(q_i)$ at C_i = 0.3367 and P_i = 0.85

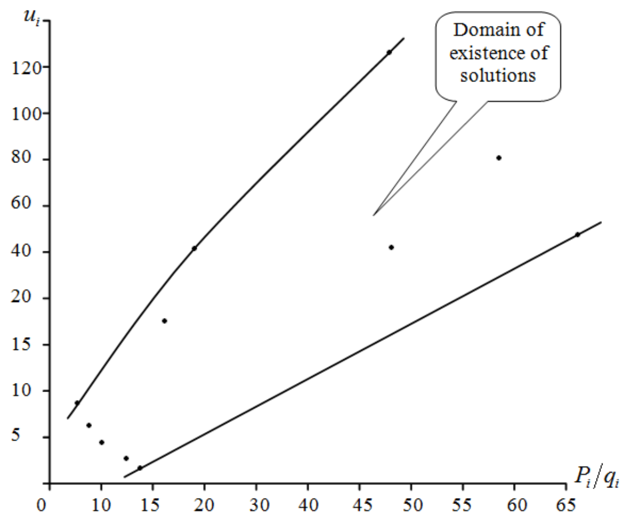

Fig. 2. Dependence $u_i(P_i/q_i)$

decreases approximately by 10 times when q_i increases by 0.09. Generally, one has a linear dependence of value u_i on the quality of MS (Fig. 2 plotted according to data from [3]).

The employment of the parameter u_i for the calculation of PPCh parameters and their ranking allows one by checking, primarily, the least reliable sets of elements n, to evaluate with the desirable accuracy the following quality indicators of BSM of the CM:

- the probability of trouble-free operation of the tested part of the CM for the time $t = 720$ hours (month of work)

$$P_{\text{perm}} \le P(n) = \exp\left(-t\sum_{i=1}^{n} z_i\right), \quad 1 \le n \le M,$$

where P_{perm} is the permissible value of $P(n)$;

- the operating time of the checked part of CM on failure

$$T_{\text{perm}} \le T(n) = \left(\sum_{i=1}^{n} z_i\right)^{-1}, \quad 1 \le n \le M,$$

where T_{perm} is permissible value of $T(n)$.

Next, we consider the influence of the quality of the MS on the restoration of the CM for the case when the values of the parameters are out of the allowable limits of their change. Since at the BSM one uses the same set of MI for the checking of the parameters and for the search of the failed element, the metrological reliability will be $P_i = P$. For n values of tested parameters checked to be within the norm, the total time of the BSM will be

$$T_{\text{MAC}} = \frac{1}{P} \cdot \sum_{i=1}^{n} \frac{t_i}{(1-q)^i}, \quad 1 \le n \le M,$$

where $q = 1 - \prod_{j=1}^{N} (1 - q_j)$ is the probability of erroneous evaluation of the result of the parameter check using N MIs (q_j is the probability of erroneous evaluation of the test result by the device j); $(1-q)^n$ is the probability of a correct assessment of the technical condition of the object.

Upon detection of $0 < m \leqslant n$ parameters that do not fit the norm, one performs the search for failures in subsets of elements that form these subsets, according to the CDA followed by re-checking the parameter after troubleshooting (Fig. 3).

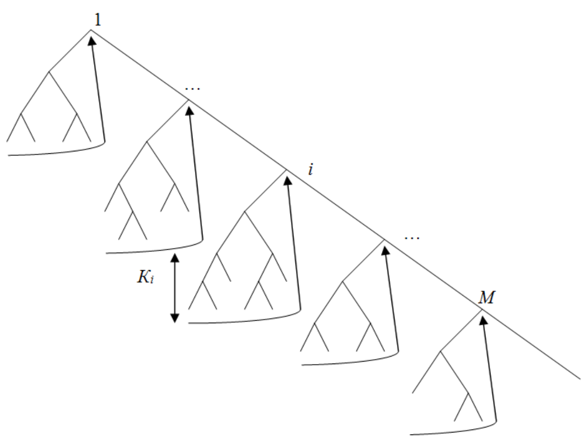

Fig. 3. Algorithm for the BSM inspections of an object with its troubleshooting

$$T_{\mathrm{MAC}}\left(n,m\right)=\frac{1}{P}\left[\sum_{i=1}^{n}\frac{t_i}{\left(1-q\right)^i}+T\left(\frac{\sum_{i=0}^{m}t_i z_i}{\left(1-q\right)^m}+\sum_{i=0}^{m}\frac{\left(K_i t+t_{yi}\right)z_i}{\left(1-q\right)^{K_i}}\right)\right],$$

where $K_i = \log_2 L_i$ is the number of checks indicating that parameter i does not fit the norm; t is average time for the execution of the check; t_{yi} is the average troubleshooting time; $z_i T$ is the probability of object failure because of parameter i.

The maximum value of time needed for the BSM we have at $m = n$. The obtained results alluded to above allow one to formalize the order of selection of MI for BSM of CM in the form of algorithm shown in Fig. 4.

For example, for $0.85 \le P_i \le 0.99$ we find $P_i = P = 0.92$. The employment of digital MI during the BSM provides the probability of correct assessment of the test result $1 - q_i = 0.9993$, which corresponds to $q_i = q = 0.0007$. According to the initial data [3] if all the parameters of the CM are in the norm we obtain $T_{\mathrm{MAC}} = 202$ min, which is by 9% more than that without taking into account the probability of error of the master: at $q = 0$ $T_{\mathrm{BSM}} = 185$ min.

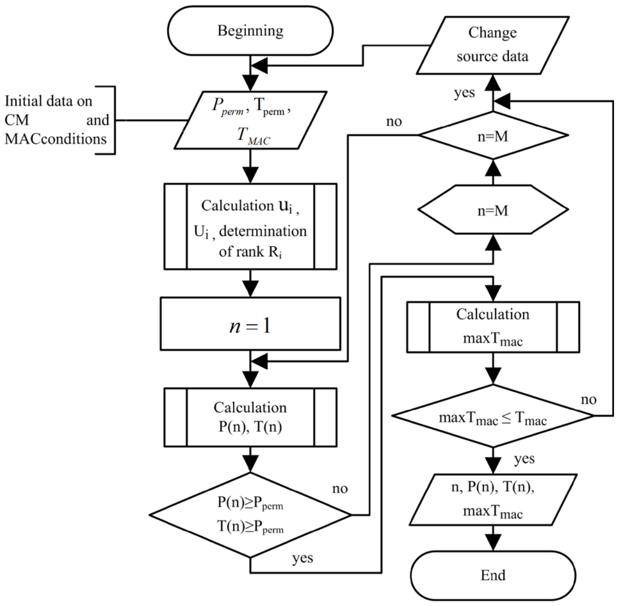

Fig. 4. Block diagram of the algorithm for selecting MI for BSM of CM

In the worst case, when $m = n = M$ at $t = 3$ min, we obtain $\max T_{\mathrm{BSM}} = 247$ min taking into account the probability of failure of subsets of elements, i.e. by 22.3% more than for $m = 0$. Thus at $n = 9$ we find $P(n) = 0.85 = P_{\mathrm{perm}}$, $T(n) = 11300$ hours $>$ T $= 10000$ hours, as well as $\max T_{\mathrm{BSM}} = 247$ min $< T_{\mathrm{MAC}} = 250$ min, which confirms that the MI is selected correctly and the MS fits the requirements.

4. Conclusions

We have analyzed the influence of metrological support on the quality of the by-state maintenance of communication means. The functional dependences of indicators of quality of BSM of CMs on metrological reliability of measuring instruments and probability of correct estimation of checking result for the CM parameters by the specialist are derived and analyzed. Obtained results are used to formulate feasible recommendations for the choice of measuring instruments depending on the requirements for the quality of BSM for a CM in the form of a formalized algorithm followed by an example illustrating its application. The results presented in this paper can be used for justification of the reasonable choice of measuring instruments of the minimum cost as well for computerization of the process of selection of measuring instruments, reducing the time for the development of technical documentation for maintenance of advanced CMs.

Метрологічне забезпечення технічного обслуговування за станом засобів зв'язку

Є.В. Рижов [1], Л.М. Сакович [2], Ю.В. Мирошниченко [2], В.І. Грабчак [1], Ю.А. Настишин [1], А.П. Волобуєв [3]

[1] *Національна академія сухопутних військ імені гетьмана Петра Сагайдачного, вул. Героїв Майдану, 32, 79012, Львів, Україна*
zheka1203@ukr.net
[2] *Інститут спеціального зв'язку та захисту інформації КПІ імені Ігоря Сікорського, вул. Верхньоключова, 4, 03056, Київ, Україна*
[3] *Центральний науково-дослідний інститут Збройних Сил України, просп. Повітрофлотський, 28, 03049, Київ, Україна*

Анотація

Сучасні та перспективні засоби зв'язку належать до найбільш наукомістких і високотехнологічних видів промислової продукції, до яких висуваються підвищені вимоги за якістю та ефективністю застосування. Ефективне функціонування сучасних засобів зв'язку базується на основних видах забезпечення, до яких належить і метрологічне забезпечення.

Розглянуто особливості метрологічного забезпечення технічного обслуговування за станом засобів зв'язку великої розмірності (десятки і сотні тисяч елементів), що складаються з окремих підсистем, перевірку працездатності яких, технічне обслуговування та відновлення працездатності можливо виконувати автономно. Пропонується для підвищення ефективності технічного обслуговування за станом врахувати особливості метрологічного забезпечення, встановлювати раціональну послідовність виконання операцій, залежно від вимог обґрунтовано вибирати необхідні засоби вимірювань. Для цього використовують комплексний показник, що об'єднує окремі параметри перевірок та ймовірність їх переважного вибору. Це дозволяє за мінімальний час із заданою вірогідністю оцінити технічний стан засобу зв'язку. Крім того, можливо кількісно оцінити час виконання технічного обслуговування з урахуванням метрологічної надійності та ймовірності правильної оцінки результату перевірки параметрів засобами вимірювань.

Уперше проаналізовано вплив метрологічного забезпечення на якість технічного обслуговування за станом засобів зв'язку. Отримано і досліджено функціональні залежності показників якості технічного обслуговування за станом засобів зв'язку від метрологічної надійності засобів вимірювань та ймовірності правильної оцінки результату перевірки значення параметру засобу зв'язку виконавцем. Формалізовано порядок використання отриманих результатів і наведено приклад реалізації.

Зазначено, що подальші дослідження доцільно спрямувати на автоматизацію процесу вибору засобів вимірювань за допомогою ЕОМ, що дозволить скоротити час розробки технологічної документації технічного обслуговування перспективних засобів зв'язку за станом та обґрунтовано обирати для цього засоби вимірювань мінімальної вартості.

Ключові слова: засоби зв'язку; засоби вимірювань; технічне обслуговування за станом; метрологічне забезпечення; метрологічна надійність.

Метрологическое обеспечение технического обслуживания по состоянию средств связи

Е.В. Рыжов [1], Л.Н. Сакович [2], Ю.В. Мирошниченко [2], В.И. Грабчак [1], Ю.А. Настишин [1], А.П. Волобуев [3]

[1] Национальная академия сухопутных войск имени гетмана Петра Сагайдачного, ул. Героев Майдана, 32, 79012, Львов, Украина
zheka1203@ukr.net
[2] Институт специальной связи и защиты информации КПИ имени Игоря Сикорского, ул. Верхнеключевая, 4, 03056, Киев, Украина
[3] Центральный научно-исследовательский институт Вооруженных Сил Украины, просп. Воздухофлотский, 28, 03049, Киев, Украина

Аннотация

Рассмотрены особенности метрологического обеспечения технического обслуживания по состоянию средств связи большой размерности (десятки и сотни тысяч элементов), состоящих из отдельных подсистем, проверку работоспособности которых, техническое обслуживание и восстановление работоспособности можно выполнять автономно. Предлагается для повышения эффективности технического обслуживания по состоянию учесть особенности метрологического обеспечения, устанавливать рациональную последовательность выполнения операций, в зависимости от требований обоснованно выбирать необходимые средства измерений. Для этого используют комплексный показатель, объединяющий отдельные параметры проверок и вероятность их преимущественного выбора. Это позволяет за минимальное время с заданной вероятностью оценить техническое состояние средств связи. Кроме того, возможно количественно оценить время выполнения технического обслуживания с учетом метрологической надежности и вероятности правильной оценки результата проверки параметров средствами измерений. Формализован порядок использования полученных результатов и приведен пример их реализации.

Ключевые слова: средства связи; средства измерений; техническое обслуживание по состоянию; метрологическое обеспечение; метрологическая надежность.

References

1. Kredentser B.P. Tekhnicheskoe obsluzhivanie i nadyozhnost sistem s vremennym rezervirovaniem [Maintenance and reliability of systems with temporary redundancy: monograph]. Kiev, Phoenix Publ., 2016. 382 p. (in Russian).
2. DSTU V 3577-97. Types of maintenance. Replacement of components. Terms. Kyiv, 1998. 9 p. (in Ukrainian).
3. Ryzhov Ye., Sakovych L. Metod vyznachennia poslidovnosti perevirky parametriv pid chas tekhnichnoho obsluhovuvannia viiskovoi tekhniky zviazku za stanom [Method of determining sequence of checking parameters at maintenance of military communication means by the state]. *Weapons and military equipment*, 2017, no. 4(16), pp. 70–72 (in Ukrainian). doi: https://doi.org/10.34169/2414-0651.2017.4(16).70-72
4. Ksenz S.P., Poltarzhickij M.I., Alekseev S.P., Mineev V.V. Borba s diagnosticheskimi oshibkami pri tehnicheskom obsluzhivanii i remonte sistem upravlenija svjazi i navigacii [Combating diagnostic errors in the maintenance and repair of communication and navigation control systems]. Saint Petersburg, VAS Publ., 2010. 240 p. (in Russian).
5. Herasimov S., Pavlii V., Tymoshchuk O., Yakovlev M.Yu. et al. Testing Signals for Electronics: Criteria for Synthesis. *Journal of Electronic Testing*, 2019, vol. 35, no. 3, pp. 349–357. doi: https://doi.org/10.1007/s10836-019-05798-9
6. Hlotov V.M., Fys M.M., Pashchetnyk O.D. Development of a methodics for improving the accuracy of determination of spatial coordinates of object points during air surveillance from a UAV. *Geodesy, cartography and aerial photography*, 2020, vol. 92, pp. 45–54. doi: http://doi.org/10.23939/istcgcap2020.92.045
7. Sakovych L., Ryzhov Ye., Sobolev A. Method of time distribution for repair of radio electronic means with multiple defects. *Military Technical Collection*, 2019, no. 21, pp. 72–77. doi: https://doi.org/10.33577/2312-4458.21.2019.72-77
8. Romanenko V.P., Sakovych L.N., Ryzhov Ye.V., Gnatyuk S.E., Rozum I.Y. Methodology of justification the type and evaluation of quality group search of defects in the repair radio-electronic means. *Radio Electronics, Computer Science, Control*, 2019, no. 1, pp. 18–28. doi: https://doi.org/10.15588/1607-3274-2019-1-2
9. Ryzhov Ye., Sakovych L., Puchkov O., Nebesna Ya. Evaluation of reliability of radio-electronic devices with variable structure. *Radio Electronics, Computer Science, Control*, 2020, no. 3(54), pp. 31–39. doi: https://doi.org/10.15588/1607-3274-2020-3-3
10. Ryzhov Ye., Sakovych L., Romanenko V., Khaustov D., Nastishin Yu. Model of conjoint faults detection at metrological service of electronics. *Ukrainian Metrological Journal*, 2020, no. 2, pp. 18–26. doi: https://doi.org/10.24027/2306-7039.2.2020.208671
11. Barzilovich E.Yu. Modeli tekhnicheskogo obsluzhivaniya slozhnyh sistem [Maintenance models for complex systems]. Moscow, Vysshaya shkola Publ., 1982. 231 p. (in Russian).
12. Ryzhov Ye., Sakovych L., Vankevych P., Yakovlev M., Nastishin Yu. Optimization of requirements for measuring instruments at metrological service of communication tools. *Measurement*, 2018, vol. 123, pp. 19–25. doi: https://doi.org/10.1016/j.measurement.2018.03.055
13. Kononov V.B., Vodolazhko O.V., Koval O.V., Naumenko A.M., Kondrashova I.I. Osnovy ekspluatatsii zasobiv vymiriuvalnoi tekhniky viiskovoho pryznachennia v umovakh provedennia ATO [Fundamentals of operation of means of measuring equipment for military purposes in the conditions of ATO]. Kharkiv, KhNUPS Publ., 2017. 288 p. (in Ukrainian).
14. Kononov V., Ryzhov Ye., Sakovych L. Dependence of parametrs of repaire of military communication means on the quality of metrological support. *Advanced Information Systems*, 2018, vol. 2, no. 1, pp. 91–95. doi: http//doi.org/10.20998/2522-9052.2018.1.17
15. Kovalenko I.I., Dragan S.V., Rykhalsky M.A. Ekspertnye ocenki v upravlenii informacionnymi proektami [Expert assessments in information project management]. Nikolaev, NUK Publ., 2007. 168 p. (in Russian).
16. Yakovlev M., Ryzhov Ye. Pidkhid do vyboru zasobiv vymiriuvalnoi tekhniky viiskovoho pryznachennia dlia metrolohichnoho obsluhovuvannia viiskovoi tekhniky zviazku [Approach to selection of military measurement means for metrological maintenance of military communication means]. *Military Technical Collection*, 2014, no. 1(10), pp. 115–121 (in Ukrainian). doi: https://doi.org/10.33577/2312-4458.10.2014.115-121
17. Sakovych L.M., Ryzhov Ye.V., Nastishin Yu.A., Miroshnichenko Yu.V., Korotchenko L.A. Metodyka vyznachennya poslidovnosti perevirky radioelektronnykh kompleksiv pry tekhnichnomu obsluhovuvanni za stanom [Methodology for determining the sequence of checking radio electronic complexes at maintenance]. *Military Technical Collection*, 2020, no. 22, pp. 66–73 (in Ukrainian). doi: https://doi.org/10.33577/2312-4458.22.2020.66-73