СТАНДАРТИЗАЦІЯ ТА МЕТРОЛОГІЧНЕ ЗАБЕЗПЕЧЕННЯ ОВТ

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ANALYSIS OF THE CURRENT STATE OF METROLOGICAL SUPPORT IN THE POWER STRUCTURES OF UKRAINE

Based on the analysis of statistical data on the work of regional metrological military units (RMMU) of the Western and Northern regions for 2006-2022, development trends and directions for improving the state of metrological support have been established, which is the scientific novelty of the work. The established patterns of workload of these institutions allow us to reasonably plan the work of the required number of specialists.

For the first time, a functional dependence of the number of repaired radio measuring instruments on the year of operation was obtained based on the analysis of real statistical data. It is shown that the transition from analog signal processing in modern radio electronic means to digital requires not only the use of the latest digital measuring instruments, but also the improvement of guidelines for their metrological support.

By analyzing the work of regional metrological military units, the least reliable groups of measuring instruments have been identified, which require the creation of additional jobs for their verification and repair. It is proposed to use methods of physical diagnostics of modern digital measuring instruments, which significantly increases the reliability of assessing their technical condition. In this regard, it is necessary to pay attention to the training of highly qualified metrology specialists in higher education institutions.

Keywords: *measuring equipment, metrological support, metrological reliability.*

Formulation of the problem

Metrological support of weapons and military equipment, taking into account modern requirements for the conduct of hostilities, requires new approaches to metrological support of measuring equipment (ME) [1-3], their verification and repair [4]. Also important are the issues of equipping the ME of hardware and technical support for the restoration of operational capability in the field of radio-electronic means (REM) of weapons and military equipment [5, 6]. At the same time, it is important to take into account the peculiarities of the schematic and structural construction of REM objects, their maintenance, ongoing repair, and the elimination of minor combat damage [7-9]. Recently, there has been a transition from analog to digital REM, which also requires new approaches to their maintenance and repair [10-12]. Therefore, an urgent task arises – on the basis of the analysis of statistical data on the work of the inspection and repair facilities of the ME, to substantiate the prospective directions of their further development.

Analysis of recent achievements and publications

Compliance of REM of military use with the necessary requirements for their technical operation is quantitatively assessed during maintenance using ME. But metrological characteristics also change over time, especially in field conditions, which affects the result of assessing the real technical condition of REM. Metrological reliability of ME is their ability to maintain the specified values of metrological characteristics during a specified period of time in specified operating modes and conditions. It is quantified by the intensity of failures, earnings per failure, and the probability of failure-free

operation [4, 13]. Metrological support of technical devices is a complex of scientific and technical activities, as well as the activities of relevant organizations and specialists, aimed at ensuring the unity and accuracy of measurements to achieve the necessary characteristics of the functioning of these devices [14].

According to [4, 14], the value of the probability of failure of the ME, depending on the degree of responsibility of the measurement results, is chosen in the range of $0.85 \le P \le 0.99$.

The predicted value of the metrological reliability of a ME is estimated by expressions [4, 14]:

$$P(\tau) = 1 - m K_M K_s^* \; ; \; m = 720\, \tau K_U / T^* ,$$

where τ – inter-verification interval (months);

K_M – the share of metrological characteristics of ME not covered by built-in control;

K_s^* – statistical estimate of the hidden failure rate;

K_U – coefficient of use of ME;

T^* – statistical estimate of the performance of the ME before failure.

The value of τ depends on the type of ME and is determined by the guiding documents on metrological support.

The value of K_M is determined from the analysis of the technical condition and the schematic diagram of the ME. According to [4, 5, 14], depending on the type of radioelectronic devices and location (stationary conditions, field mobile metrological laboratories, etc.), $0.1 \le K_s \le 0.24$. At stationary points of maintenance and repair of REM $K_U \approx 0.1$, and at specialized bases of ME it significantly increases to the value of $K_U \le 0.3$.

The mean square deviation $P(\tau)$ from the obtained estimate of the probability of failure-free operation of the ME, depending on the conditions of their intended use, is equal to [4, 14]

$$\sigma = m \cdot K_M \sqrt{K_C \left(0.15 \cdot K_C + \frac{1}{m} \right)}.$$

Known functional dependencies, in the presence of reliable initial data, make it possible to assess the metrological reliability of ME with the precision necessary for practice. Failure of ME is the inability to use the required functions. There are non-metrological failures (occur suddenly, do not depend on changes in metrological characteristics and do not require verification for their detection and elimination) and metrological ones, which lead to metrological characteristics going beyond acceptable limits. Analysis of statistical data on failures of ME shows that metrological failures occur more often, their share in the total flow of failures is from 40% to 100%. In all cases, after determining the fact of failure of ME, they require repair at specialized measuring equipment bases [4, 13, 14].

An assessment of the influence of the metrological reliability of ME on the value of the average recovery time of REM during current repair and maintenance [1-3, 8], as well as in connection with the transition to maintenance of REM by condition [9], showed that that taking into account the metrological reliability of ME allows up to 30% to specify the estimated time of restoration of REM.

Currently, the scientific and practical task of creating modern hardware maintenance of REM in the field to perform planned types of maintenance, ongoing repairs, and elimination of minor accident and combat damage [5-7] is very relevant. At the same time, it is necessary to take into account the transition from analog types of REM to digital ones [10-13].

For this, first of all, it is necessary and expedient to analyze real statistical data on the activity of existing metrological bodies.

The purpose of the article

The purpose of the article is to substantiate prospective directions for its further development on the basis of the existing state of metrological support of ME in the power structures of Ukraine.

Presentation of the main material

The authors obtained and analyzed statistical data on the work of RMMU of the Western and Northern regions for 2006-2022.

As a result of refinement, the predictive function of the number of repaired radio measuring analog devices, which is obtained by the method of least squares, and in contrast to the linear dependence proposed in [4], allows to forecast the volume of the repair fund N of ME and to plan the number of specialists required for its implementation (Fig. 1).

It is obvious that due to aging and decommissioning, as well as the transition to digital signal processing, the number of repaired radio measuring devices of the analog fleet is decreasing.

$$N = 200e^{-0.92\,(T-2005)} ,$$

where T – the year for which the number of radio measuring devices to be repaired is predicted.

At the same time, the mean square deviation of the prediction results from the number of actually repaired devices

$$\sigma_N = 27.5 ;$$

that is, at least 68% of the results fall into the interval $N \pm \sigma N$ (Fig. 1),

$$P(|\Delta| < \sigma_N) = 0.68 ,$$

where Δ – the value of the deviation of the actual number of repaired devices from the predicted number.

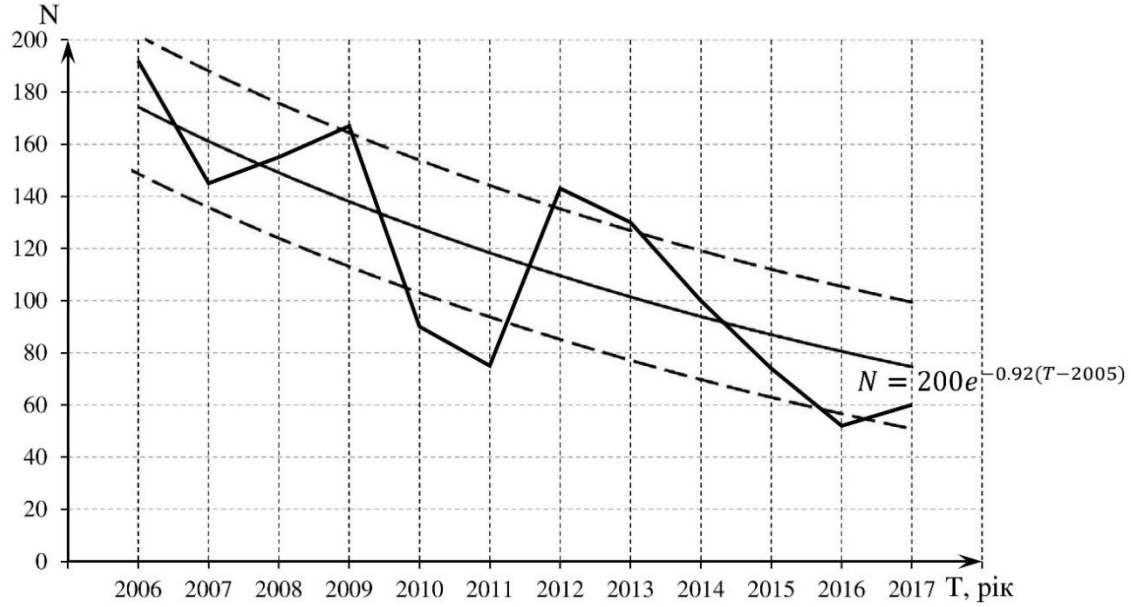

Fig. 1. **Statistical data on the number of repaired analog radio measuring devices and approximation results**

The department of verification and regulation of radio measuring devices of the RMMU of the Northern region was taken as a sample of the study. In this department, there are 340 radio measuring devices in operation, of which 298 are Soviet-made (before 1992), 20 are Ukrainian-made (1994-2016), as well as more than 25 of the latest foreign-made models (2014-2023). Of the mentioned Soviet-made samples, more than half (at least 160 units) are used on a permanent basis (at least 1-2 times a week) and have a service life of 11 to 23 thousand hours. The other part (about 140 units) is used less often (no more than once or twice a month) and has a working life of 4 to 10 thousand hours.

In the department of verification and regulation of radio-measuring devices of the RMMU of the Northern region, out of the specified number of Soviet-made devices (298 units), according to the entry in the passports (forms), over the past 10 years, 52 devices failed and were repaired. It is worth considering that during the specified time period, at least 40 units of ME failed in the department, which were later recognized as beyond repair, and which were written off with subsequent transfer to processing of precious metals.

Department of repair of measuring equipment of the RMMU of the Northern region, which performs current repair (of the entire nomenclature of ME, which is operated and checked in the RMMU of the Northern region) and medium repair (limited range according to the available documentation and repair kits). The average time to repair a radio measuring device is 12 man-hours (excluding those ME that cannot be repaired).

The military unit did not summarize the data on failures during such a period of time, but taking into account the data from the repair logs of ME and information from engineers repairing ME, it is possible to state that radio measuring devices of groups РЧ6, С6, СК3, Ч3, Ч1 failed most often during this period (for the last For 10 years, more than a third (up to 40%) of the devices of the specified groups, which are operated in the RMMU of the Northern region, have passed through the measuring equipment repair department), less often - С1, СК4, Г4, В3, Ч7, К2, И1, И2, Д1, Б5, В7 (about 20% were repaired or could not be repaired), at all rarely - Р1, Р2, В1, В4, В6, С8, Ч2, Б3, Б2, ЯЗЧ, Г3, Х1, М3, У3, С7 (no more than 10%, but here it is worth considering that devices of these types are used somewhat less often than the previous ones).

The number of failures in the inter-credit period was not recorded, because as soon as the creditor suspects a breakdown in the device, measures are taken to repair it, that is, in fact, most of the breakdowns of devices that are directly operated in the department occur in the inter-credit period and precisely during their operation.

The actual labor costs for the repair of devices in an absolute perspective coincide with the norms of time for verification (calibration), adjustment and repair of ME used in the Armed Forces of Ukraine (order of the head of the Central Department of Metrology and Standardization - the chief metrologist of the Armed Forces of Ukraine dated 20.11.2007 No. 6). If we conditionally take three installations for checking voltmeters В1-8 (according to the norm, 16 man/hours are set for current repair), then one is repaired in 12 hours, one in 15-16, and another in 20 hours (in case of problematic issues in during the repair), that is, in fact, taking into account the real experience of the work, the labor costs coincide with those indicated in the order.

Annual report on repair and verification of devices. During 2022, the RMMU of the Northern

region: authorized – 10595 units of ME (including 782 own units); repaired – 623 units of ME (including 56 of our own units).

Exact data on failures were not summarized, but taking into account the experience of use and taking into account the analysis of the ratio of suitable / unsuitable ME based on the results of the verification (analyzed monthly), it is possible to state the following (in total for the RMMU of the Northern region and other military units that provided the means measuring equipment for verification):

as of 2014, out of 1000 authorized radio measuring devices, 71 were rejected, and out of 1000 certified electric measuring devices, 92 were rejected;

as of 2022, 98 out of 1000 certified radio measuring devices were rejected (that is, one in ten), and 106 out of 1000 certified electric measuring devices were already rejected.

Thus, over 8 years, the number of radio measuring devices rejected during verification increased from 7.1% to 9.8%, and electric measuring devices, respectively, from 9.2% to 10.6%. This is explained by the use of the resource and the aging of the element base of ME.

In fact, all ME that cannot be repaired or whose repair is economically impractical, become donors for ME of the second category of technical condition, the repair of which can be carried out by replacing component parts (boards, nodes, etc.). In the military unit, there are at least 700 ME on balance, which can be used as a repair fund for the repair of other ME.

If the metrological characteristics do not meet the requirements, then the repair is mainly carried out by the aggregate method by replacing boards, nodes and parts from "donors" (that is, the method of technical cannibalism).

Analysis of the causes of failures of ME showed that they include physical obsolescence of electronic components, loss of emission of radio elements, failure of reference frequency generators, etc. At the same time, 16 to 32 man-hours are spent on testing and repairing new ME.

The RMMU of the Northern region are being replenished with new model equipment. For example, we received a mobile laboratory of measuring equipment (MLME) manufactured in 2017. The list of modern measuring equipment that is included in the (MLME) and their interverification interval is given in the table. 1, and additional equipment – in table. 2.

Table 1

Modern measuring equipment from a set of mobile measuring equipment laboratory

Name	Calibration interval between verification	Units of measure	Quantity	Year of manufacture, country of origin
Stabilizer Б2-3	is not verified	kit	6	2014, Refurbished Soviet Union
Keysight 53220A Universal frequency meter, 350 MHz with 115 option: 3rd additional channel, 15 GHz	1 time in 2 years	kit	1	2016, USA
Keysight E8257D Analog signal generator PSG series (option 520: up to 20GHz)	1 time in 2 years	kit	1	2016, USA
Signal generator UA Г4-301	1 time in 2 years	kit	1	2014, Ukraine
Comparator Ч7-39	1 time in 2 years	kit	1	2014, Ukraine
Power amplifier UA-У6-2000	1 time in 2 years	kit	1	2014, Ukraine
FS725 Rubidium frequency standard	1 time in 2 years	kit	1	2016, USA
Resistance store P4831	1 time in 2 years	kit	2	2016, Ukraine
Electronic frequency meter Ч3-101	1 time in 2 years	kit	1	2014, Ukraine
Nonlinear distortion meter СК6-13	1 time in 2 years	kit	1	2014, Refurbished Soviet Union
Keysight 33511B single-channel signal generator of standard and arbitrary waveforms 20MHz	1 time in 2 years	kit	1	2016, USA
Keysight 34461A digital multimeter	1 time in 2 years	kit	1	2016, США
Keysight N9000B CXA series signal analyzer (option 507: 9 kHz-3 GHz range)	1 time in 2 years	kit	1	2016, USA
Modulation meter СК3-45	1 time in 2 years	kit	1	Refurbished Soviet Union
Keysight DSOX3032A 2-channel digital oscilloscope, 350 МГц	1 time in 2 years	kit	1	2016, USA
Electronic laboratory scales ТВЕ-30-0,5	1 time in 2 years	kit	1	2016, Ukraine
Keysight U2000H USB Power sensor 10 MHz-18 GHz, range - 50dBm+30dBm	1 time in 2 years	kit	1	2016, USA

Increasing the reliability of measuring instruments is one of the important ways to increase the quality of their metrological support. Reliable measurement results depend on the accuracy of the devices, as well as the conditions of their preservation for a certain period of operation, which determines metrological reliability, which, in turn, depends on the indicators of failure of the device, one of which is the average failure rate.

It is worth noting that the required level of metrological reliability depends on the scope of application of the measuring tools and is chosen under the condition of ensuring the necessary efficiency of the technical devices being serviced. As a rule, this level for military ME is 0.85-0.9 [4, 14, 15].

Table 2

Additional equipment of the mobile laboratory of measuring equipment

Name	Calibration interval between verification	Units of measure	Quantity	Year of manufacture, country of origin
Keysight 82357B USB/GPIB Adapter	is not verified	kit	1	2016, USA
Wrench set Pro'sKit HW-609B/608B	is not verified	kit	1	2016, PRC
Screwdriver set Pro'sKit 1PK-9402	is not verified	kit	1	2016, PRC
Rub down set Pro'sKit 8PK-605A	is not verified	kit	1	2016, PRC
Pincette set Pro'sKit 808-389	is not verified	kit		2016, PRC
Set of sockets STANLEY "Expert" 1/4" and 1/2" with tools, 96 шт.	is not verified	kit	1	2016, PRC
Set of scalpels Pro'sKit PD-398	is not verified	kit	1	2016, PRC
Angle meter 2-2	1 time in 2 years	pcs.	1	2016, Ukraine
High precision ruler ЛД-320	1 time in 2 years	pcs.	1	2016, Ukraine
Smooth micrometer 0-25 mm, price of division 0,01мм	1 time in 2 years	pcs.	1	2016, Ukraine
Micrometer МРП 0-25мм	1 time in 2 years	pcs.	1	2016, Ukraine
Roulette Р5У3К	1 time in 2 years	pcs.	1	2016, Ukraine
Dipstick № 2 (0,02-0,5) 70мм.	1 time in 2 years	pcs.	1	2016, Ukraine
Dipstick № 3 (0,5-1мм)	1 time in 2 years	pcs.	1	2016, Ukraine
Soldering station Lukey868	is not verified	kit	1	2016, PRC
Soldering iron Polish 230 В 150/300 Вт	is not verified	pcs.	1	2016, PRC
Capacitor set P5025	1 time in 2 years	kit	1	2016, Ukraine
Tool set Pro'sKit 1PK-1700	is not verified	pcs.	1	2016, PRC
ПКПО	1 time in 2 years	kit	1	2016, Ukraine
Power supply ЕП3.3005.1.3	is not verified	kit	1	2016, Ukraine
Pressure calibrator CPN6000 complete with a case for transportation, pump CPP1000-L with pressure transmitter CPT600 measuring range (0 - 6000) bar	1 time in 2 years	kit	1	2016, Germany
Power supply APS-9102	is not verified	kit	1	2016, PRC
Power supply BVP-30-50A	is not verified	kit	1	2016, Ukraine
Vernier caliper 1000-III (0,1 мм)	1 time in 2 years	pcs.	1	2016, Ukraine

Fulfillment of the requirements for maintaining the reliability indicators of radio-electronic equipment objects at the proper level is possible under the condition of using high-quality diagnostic and metrological support, as well as modern information technologies.

Solving the task of diagnosing measuring instruments and predicting their resource with higher reliability is possible under the condition of using physical diagnostics, which involves the use of energy-static, energy-dynamic and electromagnetic methods of diagnosis and the possibility of their use to determine the technical condition of digital devices [16-18].

The reliability of the standard verification of ME is 0.85-0.9, the reliability of the energy-dynamic method is 0.95, the energy-static method is 0.97, and the electromagnetic method is 0.97. In the case of using a complex approach using several methods of physical diagnosis, reliability increases. The results of calculations [15] indicate that when using one of the methods of physical diagnosis during verification of measuring instruments, the reliability is 0.95-0.97, when using two methods it is from 0.9991 to 0.99985, when using three methods is 0.99995. The use of a complex method of diagnosis based on data obtained during the simultaneous iterative application of methods of physical diagnosis and verification of ME allows to increase the reliability of the results of diagnosis of digital measuring devices. It is important to note that the use of predictive functions [19] allows you to determine the remaining resource, that is, to perform the third function of technical diagnostics.

Conducting physical diagnostics during the verification of ME slightly increases the time of work, but allows, in addition to increasing the dependence of the probability of trouble-free operation of the devices, to predict the condition of the ME, the probability of failure of its individual components, to plan the time of the next repair, etc.

An important place in the maintenance system is the verification of measuring devices, the general procedure of which is regulated at the legislative level. Verification is carried out periodically (once every 1-2 years) and does not depend on the age of the product, intensity of use,

external conditions of use, etc. A new device that is used as intended once a week and that is located in an air-conditioned room (heated in winter) is believed to be the same as a device more than 10 years old that is used daily in difficult conditions, which is not practical.

Conclusions

1. Specialists of RMMU believe that the order of the Minister of Defense of Ukraine No. 278 of 26.11.1994 (nomenclature and calibration intervals of military measuring equipment used in the Armed Forces of Ukraine) needs improvement in connection with the commissioning of the latest digital ME techniques that are not in this order. Interverification intervals of the state metrological service (metrological centers and institutes, Ukrmetrteststandard, etc.) should also not be used in the Armed Forces of Ukraine, because these institutions are aimed at making a profit, and the absolute majority (more than 90% of the total number) recommend an interverification interval of one year . Taking as a basis the stability of indicators of the newest samples of measuring equipment of the world's leading manufacturers, it is possible to state that an inter-verification interval of three years will be sufficient to control the parameters of working and auxiliary means of ME, and with regard to working standards, an interval of two years can be considered quite sufficient.

2. The results of the analysis indicate the need to replace the existing ME with modern models in connection with the completion of the period of their normal operation and the development of the resource as the power structures of Ukraine are re-equipped with new models of REM for military purposes.

3. The introduction of physical diagnostics during the verification of digital ME will increase the value of their reliability indicators. This will have a positive impact on the reliability of the results of measurements of physical quantities, will allow determining the actual technical condition of measuring instruments, will make it possible to predict their residual life and perform maintenance according to their condition, and will reduce the amount of replacement stock and the load on it. In addition, it will reduce transportation costs (logistics component).

4. Specialists of the metrological services of the law enforcement agencies of Ukraine should be trained in advance to carry out verification and repair of ME for maintenance and repair of promising digital REM that are delivered to units.

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АНАЛІЗ ІСНУЮЧОГО СТАНУ МЕТРОЛОГІЧНОГО ЗАБЕЗПЕЧЕННЯ В СИЛОВИХ СТРУКТУРАХ УКРАЇНИ

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На основі аналізу статистичних даних щодо роботи регіональних метрологічних військових частин (РМВЧ) Західного та Північного регіонів за 2006-2022 роки встановлені тенденції розвитку і напрями поліпшення стану метрологічного забезпечення, в цьому і полягає наукова новизна роботи. Встановлені закономірності завантаження цих закладів, що дозволяє обґрунтовано планувати роботу необхідної для цього кількості фахівців.

Вперше отримана функціональна залежність кількості відремонтованих засобів радіовимірювальних приладів від року роботи на основі аналізу реальних статистичних даних. Показано, що перехід від аналогової обробки сигналів в сучасних радіоелектронних засобах на цифрову вимагає не тільки використання новітніх цифрових засобів вимірювальної техніки, а й удосконалення керівних документів щодо їх метрологічного забезпечення.

Зазначено, що підвищення надійності засобів вимірювань є одним із важливих шляхів збільшення якості їх метрологічного забезпечення. Достовірні результати вимірювання залежать від точності приладів, а також умов їх збереження за деякий період експлуатації, що визначає метрологічну надійність, яка, в свою чергу, залежить від показників безвідмовності приладу, одним з яких є середній наробіток на відмову. Необхідний рівень метрологічної надійності залежить від сфери застосування засобів вимірювань і обирається за умови забезпечення необхідної ефективності технічних пристроїв, що обслуговуються. Як правило, цей рівень для військових засобів вимірювальної техніки становить 0,85-0,9.

Завдяки аналізу роботи регіональних метрологічних військових частин встановлені найменш надійні групи засобів вимірювальної техніки, що потребують створення додаткових робочих місць для їх повірки і ремонту. Запропоновано використання методів фізичного діагностування сучасних цифрових засобів вимірювальної техніки, що суттєво підвищує достовірність оцінювання їх технічного стану. У зв'язку з цим необхідно приділяти увагу підготовці висококваліфікованих фахівців метрологів у вищих навчальних закладах.

Ключові слова: *засоби вимірювальної техніки, метрологічне забезпечення, метрологічна надійність.*