Представлено результати міжлабораторних порівнянь результатів калібрування вимірювача часу в точках від 30 с до 3600 с. Порівняння результатів, отриманих під час калібрування вимірювача часу десятьма лабораторіями, відбувалося за радіальною схемою протягом 2016 р. Визначені відхилення отриманих кожною лабораторією результатів та оцінено коректність отриманих результатів з урахуванням невизначеності вимірювань за допомогою критерію за статистикою функціонування для обраних інтервалів часу

Ключові слова: міжлабораторні порівняння, калібрувальна лабораторія, невизначеність вимірювань, вимірювач часу, зразок порівняння

Представлены результаты межлабораторных сравнений результатов калибровки измерителя времени в точках от 30 с до 3600 с. Сравнение результатов, полученных при калибровке измерителя времени десятью лабораториями, происходило по радиальной схеме в течение 2016 г. Определены отклонения полученных каждой лабораторией результатов и оценена корректность полученных результатов с учетом неопределенности измерений с помощью критерия по статистике функционирования для избранных интервалов времени

Ключевые слова: межлабораторные сравнения, калибровочная лаборатория, неопределенность измерения, измеритель времени, образец сравнения

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INTERLABORATORY COMPARISONS OF THE CALIBRATION RESULTS OF TIME METERS

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1. Introduction

The Strategy of development of the National Technical Regulation System for the period up to 2020 (Strategy) envisages the modernization of the Ukrainian economy and ensuring competitiveness. To this end, it is necessary to recognize the national technical regulation system at the European and International levels. One of the directions of the Strategy implementation is to ensure recognition of accreditation Certificates at the European and International level issued by the National Accreditation Agency of Ukraine (NAAU). This is impossible without the appropriate adaptation of national legislation in the field of technical regulation. The Strategy also defines the tasks for the introduction of a system of interlaboratory comparisons (IC) in Ukraine and accreditation of providers of such systems.

The number of calibration (CL) and testing (TL) laboratories accredited by NAAU is increasing annually. By the end of 2017, more than 440 TL and 19 CL have been accredited in Ukraine. These labs can apply the International Laboratory Accreditation Cooperation (ILAC) logo on their certificates and protocols. Such certificates and protocols are recognized by more than 80 countries of the world, since NAAU is a signatory to the Mutual Recognition Agreement (ILAC MRA) in the areas of accreditation of TL and CL. This is one of the important elements for increasing the competitiveness of Ukrainian products in world markets.

National accreditation agencies of laboratories have set strict requirements for the accreditation of CL or TL. Laboratories are required to participate in the relevant ICs:

– CL – in each type of measurement and in each kind of measurable value, which are introduced into the project of accreditation;

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– TL – in each direction of the project of their activity scope, for which they apply for accreditation, and to achieve satisfactory results in IC, if such comparisons are organized, available and appropriate.

IC is one form of experimental verification of laboratories to determine technical competence in a particular activity. Successful results of IC for the laboratory are confirmation of competence in conducting certain types of measurements by a particular specialist on a particular equipment.

Typical tasks of IC are:

– assessment of the performance of laboratories for carrying out certain tests or measurements and continuous monitoring of them;

– detecting problems in laboratories associated with, for example, incorrect measurement or testing procedures, inadequate personnel training and management or inappropriate calibration of equipment and elimination of identified problems;

– establishing the effectiveness and comparability of test methods or measurements and evaluating the characteristics of the method used in certain tests;

– detecting differences between laboratories and providing an additional level of trust from the customers of the laboratory;

– training of personnel of laboratories participating in IC, based on the results obtained;

– confirmation of the measurement uncertainty declared by a laboratory in a particular IC, etc.

Improved methods for processing these results are needed to obtain reliable results of IC of accredited TL and CL. These methods are based on various data processing algorithms according to the requirements of international and regional guidelines and standards [1]. Therefore, it is necessary to choose the optimal method for processing the received data, which would have the minimum number of restrictions on the application and allow obtaining reliable results [2]. Unsatisfactory results of IC may be related not only to a deviation from the normal state of the laboratory's competence, but also to problems with the equipment available in the laboratory or to the lack of competence of the specialist who worked with it [3–5].

The urgency of the study stems from the ever-increasing need for IC to ensure the recognition of the results of product testing at the national, regional and international levels. Publications devoted to the organization of IC and methods for data processing in specific types of testing or measurement are of considerable interest. The issue of determining the competence of CL is extremely relevant given the absence of ICs conducted in Ukraine for widespread measurements of time during the testing of various products.

2. Literature review and problem statement

IC is an obligatory and integral part of the external quality control of the obtained measurement results in the overall quality system of CL and TL. IC plays an important role in assessing the technical competence of the laboratory both during the validation and control of the laboratory during the accreditation period. The IC program is developed taking into account the requirements of the national standards DSTU ISO/IEC 17025 [6], DSTU EN ISO/IEC 17043 [7], DSTU ISO 13528 [8], which are harmonized with the relevant International and European standards. IC should be performed from time to time in accordance with the standard DSTU ISO/IEC 17025, in order to confirm the competence of the laboratories in the field of accreditation.

ICs should be run by competent providers (coordinators). To assess the results of participation in a particular test program, the criteria established by the test coordinators (reference laboratories) regarding the quality of calibrations or tests for a specific type of measurement or test are used. The main task of the provider is to set the reference value of the measured value and the uncertainty of the reference value. The provider carries out the processing of the received results and forms the conclusion for each participating laboratory.

There are various algorithms for processing IC results based on statistical methods. The choice of a specific method for evaluating the test results depends on the type of test sample (comparison sample), the peculiarities of the test and the number of laboratories participating in the tests. However, statistical methods usually impose restrictions on the permissible number of laboratories participating in IC. In addition, they usually show a low ability to distinguish between really unreliable laboratories and the labs whose results can be trusted.

Most scientific publications on the topic of the study relate to the characteristics of conducting an IC for TL, primarily analytical (physical and chemical) laboratories. Only a small number of scientific publications relates to the issues of IC for CL, which mainly relate to the issues of the calibration for certain types of measurements.

A thorough analysis of normative documents and standards for the processing of data obtained in IC, based on statistical methods, was the subject of previous studies of the authors [1, 2]. In [3, 4], the peculiarities of assessing the competence of experts in the field of metrology and measurement were researched. The state of professional training for laboratories staff was considered in [5].

Two ways of IC data processing, which consist in the application of the same procedure are considered in [9]. The algorithms and results of IC to assess the measurement capabilities of the laboratories and obtain high-accuracy data were presented in [10–12]. However, these works do not take into account such an important element as the time and temperature drift of the comparison samples, which greatly affects the results of the tests.

A number of papers are devoted to general issues on the processing of IC data: in [13] the application of different methods for the estimation of inconsistent data is proposed; in [14] the methods of data analysis of IC of accredited CL to check the quality of measurements on the example of IC of mass values are considered; in [15] approaches to validation of measurement results for CL are considered; in [16] a Bayesian approach to the processing of IC results is proposed; in [17] testing of software applications for the evaluation of IC results is proposed.

A number of papers are devoted to the results of IC and the study of the features of IC: in [18–21] approaches to improving the measurement and evaluation methods of uncertainty of participating laboratories of IC for different types of measurements (pressure, water flow, active power, temperature, electricity) are considered; in [22–24] an evaluation of the results of laboratories that participated in IC on specific types of measurements, with calculations of uncertainties of measurement results (reactive power, length, pressure) is conducted.

Researches carried out by the authors continue to develop and improve the existing methods of IC data processing, and also aim at obtaining IC results for such a common type of measurement as time measurement. Virtually all improvements are aimed at increasing the accuracy of the comparison sample study to reduce the uncertainty of measurements conducted by participating laboratories.

3. Aims and objectives

The research was aimed at developing a universal algorithm for processing IC results for CL. In this case, it is necessary to take into account the provision of metrological traceability of various levels in relation to the used transmission samples, minimization of the uncertainty of the reference value during the IC when processing the data obtained from the participating laboratories.

To achieve this aim, it is necessary to accomplish the following objectives:

– to choose the methodology for processing the IC results and to offer a universal algorithm for processing the primary data of IC;

– to explore the transmission sample for IC on the calibration of time meters, define the reference value and its expanded uncertainty for this IC;

– to evaluate the results of the study of the sample of comparisons of participating laboratories of IC on the calibration of time meters taking into account the criteria of performance statistics;

– to determine the competence of the staff of the laboratories of the calibration of time meters involved in IC and to investigate the influence of staff competence on the obtained results of IC.

4. Materials and methods of researching the approaches to the evaluation of interlaboratory comparison of the calibration results

According to the results of the IC for CL, the processing of the primary data received from the participating laboratories is carried out. It will be necessary to check the consistency of IC data. In the case of data inconsistency, an analysis is conducted for the purpose of rejecting these data or for further harmonization by clarifying the applied indicators. A comparative analysis of the relevant criteria for performance statistics is performed to verify the data consistency and the most effective one for use in processing the data obtained is selected.

Deviations of CL measurement results are determined by the formula:

$$D_{lab} = x_{lab} - X_{ref}, \qquad (1)$$

where x_{lab} is the value of the time interval measured by the participant; X_{ref} is the valid (reference) value of the time interval defined as the arithmetic mean of the measurement values performed by the reference laboratory.

In some cases, the percentage deviation of the measurement results $D_{lab\%}$ of CL can also be determined, which is calculated by the formula:

$$D_{lab\%} = \frac{x_{lab} - X_{ref}}{X_{ref}} \cdot 100. \qquad (2)$$

The data evaluation for each of participating laboratories is carried out using several criteria for performance statistics:

– E_n index, which is determined by the formula:

$$E_n = \frac{x_{lab} - X_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}}, \qquad (3)$$

where U_{lab} is the expanded uncertainty of measurements of the parameter value of the comparison sample by the participating laboratory; U_{ref} is the expanded uncertainty of measurements in determining the valid value of the parameter of the comparison sample, which is determined by the formula:

$$U_{ref} = 2 \cdot \sqrt{u^2(X_{ref}) + u^2(X_{stab})}, \qquad (4)$$

where $u(X_{ref})$ is the standard uncertainty obtained when calibrating the comparison sample with the reference laboratory; $u(X_{stab})$ is the standard uncertainty from the instability of the comparison sample during comparisons:

$$u(X_{stab}) = \frac{\Delta X_{\max}}{\sqrt{3}}; \qquad (5)$$

– z index, which is calculated by the formula:

$$z = \frac{x_{lab} - X_{ref}}{\sigma}, \qquad (6)$$

where σ is the standard deviation for qualification assessment;

– ζ index, which is calculated by the formula:

$$\xi = \frac{x_{lab} - X_{ref}}{\sqrt{u_{lab}^2 - u_{ref}^2}}, \qquad (7)$$

where u_{lab} is the total standard uncertainty associated with the result of the laboratory participating in the IC; u_{ref} is the standard uncertainty of the reference value of IC.

The value of σ can be calculated based on:

– estimates from a statistical model (main model) or results of a precision experiment;

– estimates from previous IC rounds or assumptions based on experience;

– results of participating laboratories, that is, normal or robust standard deviation, based on the results of participating laboratories, etc.

The criteria for evaluating the performance characteristics shall be established after taking into account whether the methods for evaluating the performance characteristics consider the main features, namely:

– statistical determination of indicators, i. e. when the criteria must be suitable for each indicator;

– compliance with the purpose, given criteria that take into account, for example, the technical specifications for the characteristics of the method and the recognized level of work of the participants, etc.

For the E_n index:

– $|E_n| \le 1.0$ – indicates a satisfactory performance characteristic and does not require adjustment or response measures;

– $|E_n|>1.0$ – indicates an unsatisfactory performance characteristic and requires special adjustment or response measures.

For the z index and ζ index:

– $|z|\leq 2.0$ and $|\zeta|\leq 2.0$ – indicates a satisfactory performance characteristic and does not require adjustment or response measures;

– $2.0<|z|<3.0$ and $2.0<|\zeta|<3.0$ – indicates a dubious performance characteristic and requires precautionary measures;

– $|z|\geq 3.0$ and $|\zeta|\geq 3.0$ – indicates an unsatisfactory performance characteristic and requires adjustment or response measures.

The general algorithm for processing the primary data of IC is shown in Fig. 1. This algorithm allows the reference laboratory to take into account all the features of reporting during ICs. The main steps for all ICs are: the definition of the reference value for the transmission sample with the corresponding expanded uncertainty, the preliminary determination of the instability of the transmission sample for the IC, the calculation of the performance statistics with the evaluation of these characteristics.

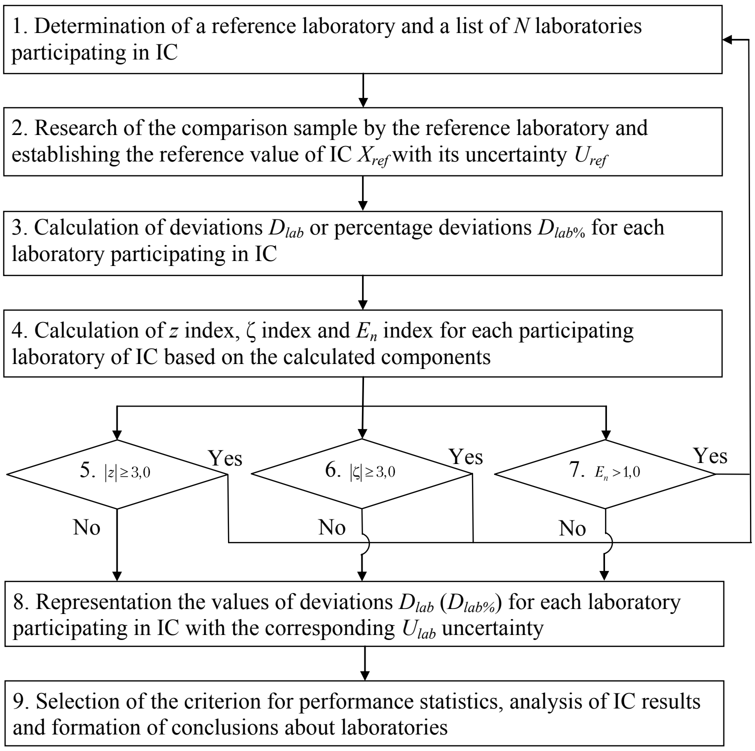

Fig. 1. The general algorithm for processing the primary data of IC

Statistical outliers are processed as follows:

– obvious mistakes, such as data with errors in the decimal point, the results belonging to different samples for IC should be removed from the data set and processed separately;

– when the results of the participating laboratories are used to determine the reference value, statistical methods should be used to minimize the impact of outliers;

– if the results are removed as outliers, they should be removed only from the calculations of the final statistics.

Obvious mistakes and erroneous data should not be verified by the outliers criterion or by robust statistical methods. In IC programs, automatic filtering of outliers can be used if the effectiveness of this approach is confirmed by objective data. Outliers should be evaluated within the IC program and, based on the results obtained, an appropriate assessment of the performance characteristics should be determined.

5. Discussion of the results of the interlaboratory comparison of the calibration of the time meter

5. 1. Results of the study of the comparison sample, determination of the reference value and its expanded uncertainty

Definition of the reference value and its expanded uncertainty includes the application of:

– reference values determined during measurements or comparisons of a sample for IC using a working standard traceable to a national standard;

– certified reference values determined using common measurement methods;

– agreed values from participants using statistical methods, etc.

The reference laboratory – SE ''Ukrmetrteststandard'' (Kyiv, Ukraine) as the National Metrology Institute (NMI) of Ukraine has identified a comparison sample. As the comparison sample for IC, an electronic stopwatch HS-45 manufactured by Citizen Watch Co., Ltd. (Japan) was chosen. The basic metrological characteristics of the HS-45 stopwatch are: time measurement range of up to 10 hours; resolution – 0.01 s. The reference laboratory determined the characteristics of the instability of the comparison sample before and after the research in participating laboratories of IC.

The measurement model in the calibration of the time meter (stopwatch) in absolute form as a deviation of the measured value from the reference value, has the following form:

$$\Delta T = T_{CL} - T_S + T_{S\Gamma} + \Delta T_{CLD} + \Delta T_0, \qquad (8)$$

where T_{CL} is the average reading of the HS-45 stopwatch; T_S is the time deducted by the Secondary standard of time and frequency (SSTF), which is stored in the reference laboratory; $\Delta T_{S\gamma}$ is the correction caused by the SSTF drift since its last calibration; ΔT_{CLD} is the correction due to the discreteness of the HS-45 stopwatch readings; ΔT_0 is the correction caused by the operator's error when pressing the ''start''/''stop'' button of the HS-45 stopwatch.

The uncertainty budgets for the reference values of the comparison sample for the intervals of 30 s, 1800 s and 3600 s, compiled according to the requirements [25], are shown in Table 1.

The reference laboratory has the following reference values with the corresponding uncertainties for the time intervals regulated by the IC Program:

– $X_{ref1}=(-0.024\pm 0.0097)$ s for the time interval of 30 s;

– $X_{ref2}=(-0.028\pm 0.0056)$ s for the time interval of 1800 s;

– $X_{ref3}=(-0.036\pm 0.0064)$ s for the time interval of 3600 s.

Table 1

Uncertainty budgets for the reference values of the comparison sample

Input value, X_i	Input value-estimate, x_i	Standard uncertainty, $u(x_i)$	Distribution law	Sensitivity factor, c_i	Contribution to uncertainty, $u_i(y)$
Time interval of 30 s					
T_{CL}	29.976 s	0.008 c	normal	1.0	0.008 s
T_S	30 s	2.4×10^{-8} c	normal	1.0	2.4×10^{-8} s
$\Delta T_{S\gamma}$	0	6.6×10^{-14} c	rectangular	1.0	6.6×10^{-14} s
ΔT_{CLD}	0	0.003 c	rectangular	1.0	0.003 s
ΔT_0	0	0.004 c	rectangular	1.0	0.004 s
ΔT	–0.024 s	–	–	–	0.0097 s
Time interval of 1800 s					
T_{CL}	1799.972 s	0.003 c	normal	1.0	0.003 s
T_S	1800 s	2.4×10^{-8} c	normal	1.0	2.4×10^{-8} s
$\Delta T_{S\gamma}$	0	6.6×10^{-14} c	rectangular	1.0	6.6×10^{-14} s
ΔT_{CLD}	0	0.003 c	rectangular	1.0	0.003 s
ΔT_0	0	0.004 c	rectangular	1.0	0.004 s
ΔT	–0.028 s	–	–	–	0.0056 s
Time interval of 3600 s					
T_{CL}	3599.964 s	0.004 s	normal	1.0	0.004 s
T_S	3600 s	2.4×10^{-8} s	normal	1.0	2.4×10^{-8} s
$\Delta T_{S\gamma}$	0	6.6×10^{-14} s	rectangular	1.0	6.6×10^{-14} s
ΔT_{CLD}	0	0.003 s	rectangular	1.0	0.003 s
ΔT_0	0	0.004 s	rectangular	1.0	0.004 s
ΔT	–0.036 s	–	–	–	0.0064 s

5. 2. Results of the study of the comparison sample by the participating laboratories

The first round of IC on the calibration of the HS-45 electronic stopwatch was conducted between February and November 2016 in accordance with the requirements of DSTU ISO/IEC 17025 [6]. The IC organization was performed in accordance with the IC Program, which complies with the requirements of DSTU EN ISO/IEC 17043 [7] and DSTU ISO 13528 [8].

The main goal of the first round was to conduct a qualification check of the CL during the measurement of time. In this round of IC, ten CLs (one of them referent) participated in the calibration, according to their own calibration methods by the radial scheme.

Calibration was performed for intervals of 30 s, 1800 s and 3600 s under normal conditions in accordance with the requirements:

– ambient temperature – (22±3) °C;
– relative humidity – up to 80 %;
– atmospheric pressure – from 84 kPa to 106 kPa.

Results of the calibration of the time meter (HS-45 stopwatch) for the laboratories participating in IC, designated, respectively, Ref and Lab *i* (*i*=1…9) for time intervals of 30 s, 1800 s and 3600 s are shown in Table 2 and Fig. 2–4.

Table 2

Results of calibration of the laboratories participating in IC

Characteristic	Results				
Time interval of 30 s					
Laboratory	Ref	Lab 1	Lab 2	Lab 3	Lab 4
D_{lab}	0.000	0.144	–0.006	0.040	0.024
U_{lab}	0.0197	0.201	0.020	0.035	0.060
E_n	–	0.713	–0.214	0.996	0.380
Laboratory	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9
D_{lab}	0.040	0.029	0.258	–0.014	0.033
U_{lab}	0.040	0.086	0.287	0.044	0.027
E_n	0.897	0.329	0.897	–0.290	0.987
Time interval of 1800 s					
Laboratory	Ref	Lab 1	Lab 2	Lab 3	Lab 4
D_{lab}	0.000	0.208	–0.022	0.032	0.048
U_{lab}	0.0118	0.208	0.020	0.042	0.220
E_n	–	0.998	–0.947	0.734	0.218
Laboratory	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9
D_{lab}	0.052	0.033	0.111	–0.018	0.093
U_{lab}	0.076	0.204	0.579	0.046	0.101
E_n	0.676	0.161	0.192	–0.379	0.915
Time interval of 3600 s					
Laboratory	Ref	Lab 1	Lab 2	Lab 3	Lab 4
D_{lab}	0.000	0.146	–0.014	0.034	0.066
U_{lab}	0.0135	0.205	0.020	0.073	0.420
E_n	–	0.711	–0.580	0.458	0.157
Laboratory	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9
D_{lab}	0.034	0.021	0.219	–0.012	0.115
U_{lab}	0.114	0.323	0.272	0.042	0.152
E_n	0.296	0.065	0.804	–0.272	0.754

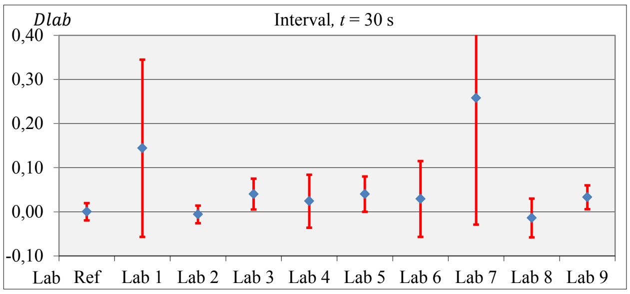

Fig. 2. Results of calibrations in the laboratories for the time interval of 30 s

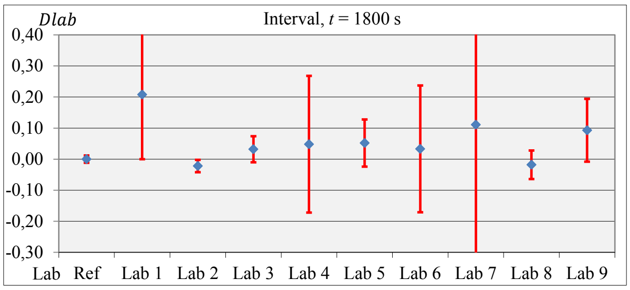

Fig. 3. Results of calibrations in the laboratories for the time interval of 1800 s

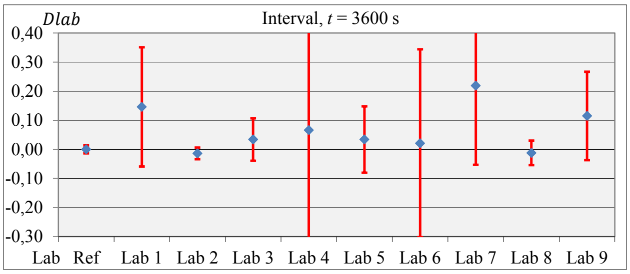

Fig. 4. Results of calibrations in the laboratories for the time interval of 3600 s

The x-axis in Fig. 2–4 shows the laboratories, and the y-axis – the deviation values D_{lab} for the laboratories-participant of IC. Blue rhombs denote the value of deviations D_{lab} for each of the laboratories participating in IC, and the red lines – the corresponding expanded uncertainties U_{lab}.

For the analysis of the IC results and the formation of conclusions about laboratories participating in IC, the criterion for performance statistics – E_n index was chosen.

Laboratories Lab 1-9 meet the requirements of the criterion ($|E_n|\leq 1$) for all time intervals (30 s, 1800 s and 3600 s). This confirms the qualification (technical competence) of participating laboratories of IC during the calibration in accordance with the requirements of the standard DSTU ISO/IEC 17025.

In general, all laboratories have received satisfactory accuracy. In laboratories Lab 2 and Lab 8, the measured values of time intervals are below the reference IC values (reference laboratory values).

In laboratories Lab 1 and Lab 7, the values of deviations D_{lab} are particularly large, and the uncertainty for the intervals of 30 s and 1800 s is much greater than the values of other laboratories participating in IC. These laboratories are advised to make adjustments to the time correction calculation methodology. Laboratories Lab 4 and Lab 6 are recommended to review the time correction in calculating the measurement uncertainty for the 3600 s interval.

5. 3. Results of the assessment of competence of staff of calibration laboratories

The competence of staff for all laboratories participating in the IC on the calibration of time meters was estimated. The data on the specified staff collected through a special questionnaire were processed using the universal Microsoft Excel software (USA).

The values of coefficients of competence (k_k) for the staff of all CL who participated in IC on the calibration of time meters are shown in Table 3. The indicated coefficients of competence are obtained using the method described in [4].

Table 3

The coefficients of CL staff competence

Laboratory	Ref	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9
k_k	0.97	1.00	0.95	0.76	0.84	0.43	0.97	0.92	0.86	0.95

Results of the assessment of the CL staff competence are shown in Fig. 5.

The column graph displays the ranking of participating laboratories in order of decreasing values of the coefficients staff competency. The x-axis shows the labs participating in IC, on the y-axis – the values of the coefficients of the CL staff competence (in points).

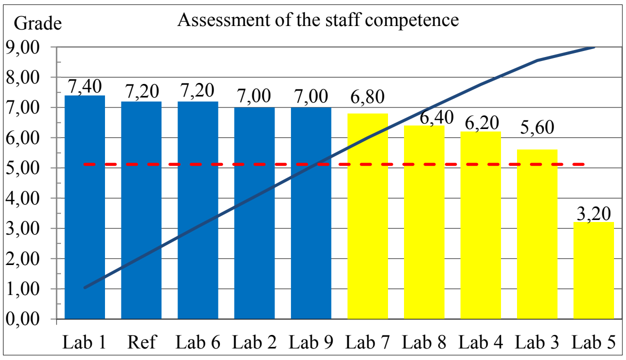

Fig. 5. Results of the assessment of the CL staff competence

The graph uses the Pareto principle, or the "20/80" principle, which generally means that 20 % of the effort gives 80 % of the result (yellow columns), and the remaining 80 % of the effort – only 20 % of the result (blue columns) [26, 27]. The blue columns indicate the CL staff, which has high competence by the Pareto principle and yellow columns – low competence. That is, the staff of laboratories Ref, Lab 1, Lab 2, Lab 6 and Lab 9 has a high level of competence, and the staff of laboratories Lab 3, Lab 4, Lab 5 Lab 7 and Lab 8 has a low level of competence. For the latter laboratories, it will be required to take measures to increase the staff competence.

During the research of the staff of the laboratories participating in IC, it was suggested that they carry out their own assessment of their competence. According to the results, the staff of laboratories Lab 3 and Lab 5 overestimated their competence compared with the obtained objective estimates. The staff of laboratories Ref, Lab 1, Lab 2, Lab 4 and Lab 6–8 underestimated own competence in comparison with the obtained objective estimates.

The research of the reference laboratory showed that the laboratories participating in IC used their own measurement methods and working standards. Laboratories Lab 1, Lab 3, Lab 5 and Lab 7–9 used the same equipment – stopwatch timers STTS-1 (2) as working standards. Laboratories Lab 2, Lab 4 and Lab 6 used special plants for calibration of stopwatches.

According to the results of the research, it can be concluded that the competence of the staff of the participating laboratories of IC did not significantly affect the results of the conducted IC. On the contrary, the results of laboratories Lab 1 and Lab 7 were affected by the equipment used by these CLs.

6. Conclusions

1. The choice of methodology for processing the IC results is made. A universal algorithm for processing the IC data obtained is proposed, which allows the reference laboratory to take into account all the reporting peculiarities during IC and to make a selection of the methodology of processing the primary data of IC.

2. The study of the transmission sample for IC on the calibration of time meters by the reference laboratory was

carried out. The reference value and its expanded uncertainty for IC were defined. Uncertainty budgets for all reference values of the comparison sample for the time intervals of 30 s, 1800 s and 3600 were made up.

3. The reference laboratory of IC carries out the selection of the required criterion for performance statistics and evaluates the results of the study of the comparison sample of the participating laboratories of IC. The results of ICs on the calibration of time meters show that all participating laboratories of IC received the results, which fully satisfy the requirements for the selected criterion for performance statistics – E_n index. This confirms the technical competence of the indicated CL in the course of their calibration in accordance with the requirements of the standard DSTU ISO/IEC 17025.

4. The competence of the staff of the laboratories participating in IC was evaluated. According to the results of the objective assessment, it can be concluded that the competence of the staff of the laboratories participating in IC on the calibration of time meters did not significantly affect the results of IC. According to the results of self-evaluation, it is determined that the staff only of two CL from ten overestimated their competence in comparison with the obtained objective estimates.

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DEVELOPMENT OF A SELF-DIAGNOSTICS SUBSYSTEM OF THE INFORMATION-MEASURING SYSTEM USING ANFIS CONTROLLERS

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Досліджено можливість розробленої підсистеми самодіагностики інформаційно-вимірювальної системи випробувань гідравлічних передач тепловозів. Запропоновано використання нейро-фаззі контролерів для прогнозування окремих параметрів гидропередачі з подальшим порівнянням прогнозованих даних з даними, отриманими від датчиків вимірювання цих параметрів. Істотна відмінність даних прогнозу і вимірювання говорить про можливу несправність датчиків. Результати дослідження підсистеми на реальних даних випробування показали ефективність

Ключові слова: гідравлічна передача тепловоза, інформаційно-вимірювальна система, датчики вимірювання параметрів, нейро-фаззі контролер

Исследована возможность разработанной подсистемы самодиагностики информационно-измерительной системы испытаний гидравлических передач тепловозов. Предложено использование нейро-фаззи контроллеров для прогнозирования отдельных параметров гидропередачи с последующим сравнением спрогнозированных данных с данными, полученными от датчиков измерения этих параметров. Существенное различие данных прогноза и измерения говорит о возможной неисправности датчиков. Результаты исследования подсистемы на реальных данных испытания показали ее эффективность

Ключевые слова: гидравлическая передача тепловоза, информационно-измерительная система, датчики измерения параметров, нейро-фаззи контроллер

1. Introduction

Information-measuring systems (IMS) are used in many industries. Numerous object parameters are measured by these systems using specialized sensors. Any information-measuring system requires diagnostic tools. Usually, these are additional hardware and software means. In order to cut costs, it is necessary to avoid additional costs of hardware diagnostics.

To reduce the cost of specialized equipment, a mechanism of indirect diagnosis with analysis of measurement results can be used. Self-diagnostic algorithms will detect malfunction using only the data sets obtained from existing sensors. Such a method of self-diagnostics can be used in the process of the working cycle of the information-measuring system. This ensures high speed of obtaining diagnostic data.

The problem of such indirect mechanisms of self-diagnostics involves development of some mechanisms for analyzing measurement results, especially in the event of a possible large scatter of measurement results. The measurement results can be compared with theoretical calculations based on the results of measuring other system parameters. However, the functional relationship between system parameters is weak or not known at all in some cases. Therefore, it is relevant to study the possibilities of predicting values of one

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