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Linking the Results of Inter-laboratory Comparisons for DC Electrical Resistance Measures

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Abstract

The article presents the results of the first round of inter-laboratory comparisons of the measures of electric resistance of 1 Ω, 10 Ω and 100 Ω on a direct current. The reference laboratory has studied the measures of electrical resistance as a means of comparison, defined the reference values of comparison with the calculation of their expanded uncertainties. The comparison of the results of measurements obtained during the calibration of the measures of electrical resistance of eight laboratories took place according to the radial scheme from 2018 to 2019.

The linking procedure of inter-laboratory comparisons is described and used for rounds of said inter-laboratory comparisons. The deviations of the corrected results obtained by each laboratory were determined and their correctness was evaluated taking into account the uncertainty of measurements by one of the criteria for performance statistics for the selected electrical resistance ratings. A comparative analysis of the corrected results of the calibration of resistance measures for laboratories that took part in the first and second rounds was carried out.

Keywords: inter-laboratory comparison; assigned value; measurement uncertainty; National Metrology Institute; linking the results.

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1. Introduction

Measurement of small quantities of electrical resistance is an urgent task not only in the field of energy (measurement of the resistance of the protective earth circuit, insulation resistance, etc.), but also in biophysics and medicine (determination of the electrical properties of biological objects, etc.) [1].

Now it is an important task to ensure the recognition of the accreditation certificates issued by the National Accreditation Agency of Ukraine (NAAU) at the European and international level. In this purpose it is necessary to introduce in Ukraine an effective system of inter-laboratory comparisons (ILC) and accreditation of their providers. The issue of organizing and conducting the ILC is a rather pressing issue for NAAU-accredited calibration laboratories (CL) and testing laboratories (TL).

In order to confirm the competence of the CL and TL in accordance with the requirements of national standard DSTU ISO/IEC 17025 [2], accreditation in the field of accreditation is necessary. ILC programs are developed in accordance with the requirements of national standards DSTU ISO/IEC 17025, DSTU EN ISO/IEC 17043 [3] and DSTU ISO 13528 [4].

It is important to conduct periodic ILC rounds with the involvement of an increasing number of calibration laboratories and, accordingly, to establish their competence, which is now quite relevant. For NAAU-accredited CL in Ukraine two rounds of ILC calibration of DC measures of electrical resistance have already been conducted [5, 6].

It is advisable to link all the results obtained in order to compare the results obtained by the ILC of the laboratories that participated in the different rounds of the ILC. For this purpose it is necessary to choose or propose a special method of linking the results of all laboratories [7].

2. Evaluation of inter-laboratory comparisons results

The purpose of the ILC is to verify the quality of the calibration of the measuring instruments by the CL participating in the ILC when performing measurements of the unit of electrical resistance accordance with DSTU ISO/IEC 17025 [2].

At the initiative of the National Metrological Institute of Ukraine SE "Ukrmetrteststandart" as a reference laboratory (RL or Ref), two rounds of ILC calibration of DC measures of electrical resistance for

CLs were organized and conducted. These rounds were performed radially in 2016 and in 2018–2019. Only 12 CLs including the RL participated in these rounds.

Measures of electrical resistance of the direct current of the class of accuracy 0.01: P321 1 Ω, P321 10 Ω and P331 100 Ω was chosen as the RL for comparison. These measures were used in both the first and second rounds of the ILC. Some characteristics of electrical resistance measures P321 and P331 are as follows: rated power of 0.1 W; maximum power value of 1 W; operating temperature range from 15 °C to 30 °C. Measurements were made at 20 °C.

The deviation of laboratory measurement results was determined by:

$$D_{\text{lab}} = R_{\text{lab}} - R_{\text{AV}}, \quad (1)$$

where R_{lab} is the value of the measured DC electrical resistance; R_{AV} is assigned value of direct current electrical resistance, defined as the arithmetic mean from measurements made by the RL.

Expanded measurement uncertainty in determining the true value of DC electrical resistance is defined as

$$U\left(R_{\text{AV}}\right) = 2 \cdot \sqrt{u^2(R_{\text{ref}}) + u^2(R_{\text{stab}})}, \quad (2)$$

Results of calibration of electrical resistance measures for CLs, Ω

Laboratory	R_{lab}	d_{lab}	$U(d_{\text{lab}})$	E_n
1 Ω				
Ref	1.0000210	0.000000	0.000006	
Lab 1	1.0005610	0.000540	0.002166	0.25
Lab 2	1.0000166	-0.000005	0.000021	0.23
Lab 3	0.9998200	-0.000201	0.023940	0.01
Lab 4	0.9999790	-0.000042	0.000007	4.56
Lab 5	1.0000200	-0.000001	0.000008	0.10
Lab 6	1.000059	0.000038	0.000015	2.35
Lab 7	0.999987	-0.000034	0.001600	0.02
Lab 8*	1.000030	0.000001	0.000002	0.16
Lab 9*	1.000032	0.000003	0.000009	0.28
Lab 3**	1.001508	0.001463	0.027500	0.05
Lab 4**	1.000273	0.000228	0.007440	0.03
10 Ω				
Ref	9.999420	0.000000	0.000050	
Lab 1	9.998564	-0.000856	0.000435	1.95
Lab 2	9.999733	0.000313	0.000013	6.06
Lab 3	9.998900	-0.000500	0.029200	0.02
Lab 4	9.999350	-0.000070	0.000070	0.81
Lab 5	9.999440	0.000020	0.000060	0.26
Lab 6	9.999330	-0.000090	0.000130	0.65
Lab 7	9.998900	-0.000520	0.016000	0.03
Lab 8*	9.999430	0.000010	0.000036	0.16
Lab 9*	9.999423	0.000003	0.000061	0.04
Lab 3**	10.001600	0.002180	0.033500	0.07
Lab 4**	9.999806	0.000386	0.007583	0.05
100 Ω				
Ref	99.9988	0.0000	0.0007	
Lab 1	99.9900	-0.0088	0.0098	0.90
Lab 2	100.0040	0.0052	0.0010	4.26
Lab 3	99.9950	-0.0038	0.0440	0.09
Lab 4	99.9990	0.0002	0.0009	0.18
Lab 5	99.9983	-0.0005	0.0008	0.47
Lab 6	100.0002	0.0014	0.0013	0.95
Lab 7	99.9950	-0.0038	0.0650	0.06
Lab 8*	99.9981	-0.0002	0.0007	0.20
Lab 9*	99.9982	-0.0001	0.0008	0.09
Lab 3**	100.0046	0.0063	0.0510	0.12
Lab 4**	100.0003	0.0020	0.0076	0.26

where $u(R_{ref})$ is standard uncertainty obtained from calibration of electrical resistance measurements P321 and P331 by the RL for the appropriate nominal (1 Ω, 10 Ω and 100 Ω); $u(R_{stab})$ is standard uncertainty from instability of electrical resistance measures P321 and P331 as comparison samples during comparisons:

$$u(R_{stab}) = \Delta R_{max} / \sqrt{3}. \quad (3)$$

The evaluation of the results of each participating laboratory was performed using a criterion based on performance statistics – the E_n number, which was defined by:

$$E_n = |D_{lab}| / \sqrt{U(R_{lab})^2 + U(R_{ref})^2}, \quad (4)$$

where $U(R_{lab})$ is expanded measurement uncertainty in determining the value of DC electric resistance by the participant; $U(R_{ref})$ is expanded uncertainty obtained by calibrating electrical resistance measurements P321 and P331 by the RL for the appropriate nominal (1 Ω, 10 Ω and 100 Ω).

In this case, if:

$|E_n| \leqslant 1$ – the result does not require corrective action or reaction;

$|E_n| > 1$ – the result requires corrective action or reaction.

The first and second rounds of the ILC were anchored in terms of expression:

$$d_{lab} = D_{lab} + \Delta, \quad (5)$$

where the correction factor is determined by:

$$\Delta = R_{ref1} - R_{ref2}, \quad (6)$$

R_{ref1} and R_{ref2} are measured values of direct current electrical resistance by RL in the first and second rounds respectively.

Expanded measurement uncertainty of correction factor is determined by:

$$U(\Delta) = 2 \cdot \sqrt{\frac{u^2(R_{ref1}) + u^2(R_{ref2})}{2} + u^2(R_{stab})}, \quad (7)$$

where $u(R_{ref1})$ and $u(R_{ref2})$ are standard uncertainty of measuring the value of electrical resistance by a reference laboratory in the first and second rounds, respectively.

Expanded measurement uncertainty in the corrected deviation of laboratory measurement results is determined by:

$$U(d_{lab}) = 2 \cdot \sqrt{u^2(D_{lab}) + u^2(\Delta)}. \quad (8)$$

3. Evaluation of results of inter-laboratory comparisons

The related results of calibration of electrical resistance measures (resistance measures P321 and P331) for electrical resistance of 1 Ω, 10 Ω and 100 Ω by participating CLs of two rounds of ILC (obtained value of electrical resistance R_{lab}, deviation of measurement results of d_{lab} laboratories, their the uncertainties $U(d_{lab})$ and the values of the E_n number) are indicated, which are denoted respectively by RL and Lab i (i = 1...9) is shown in Table and Fig. 1–3. Second-round participating CLs are marked with "*" and two-round participating CLs are marked with "**". The drawings in the red dashed lines show the boundaries that are set in view of the expanded

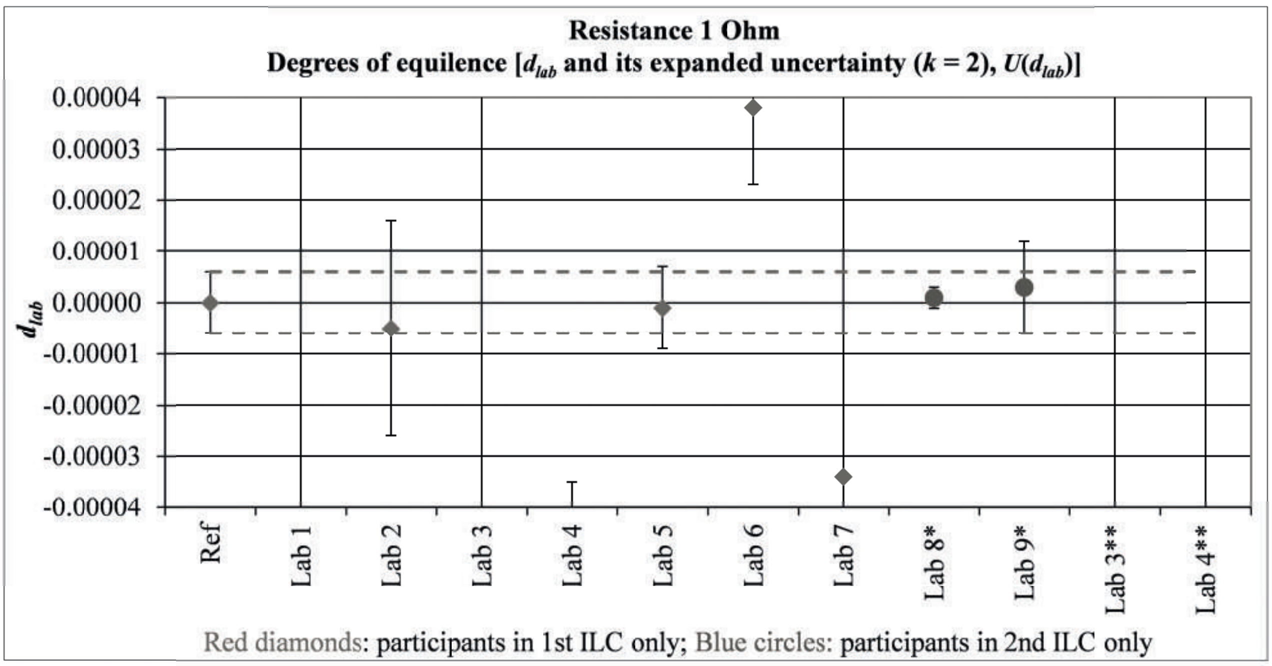

Fig. 1. Results of the calibration of the comparison sample by CLs for electrical resistance of 1 Ω

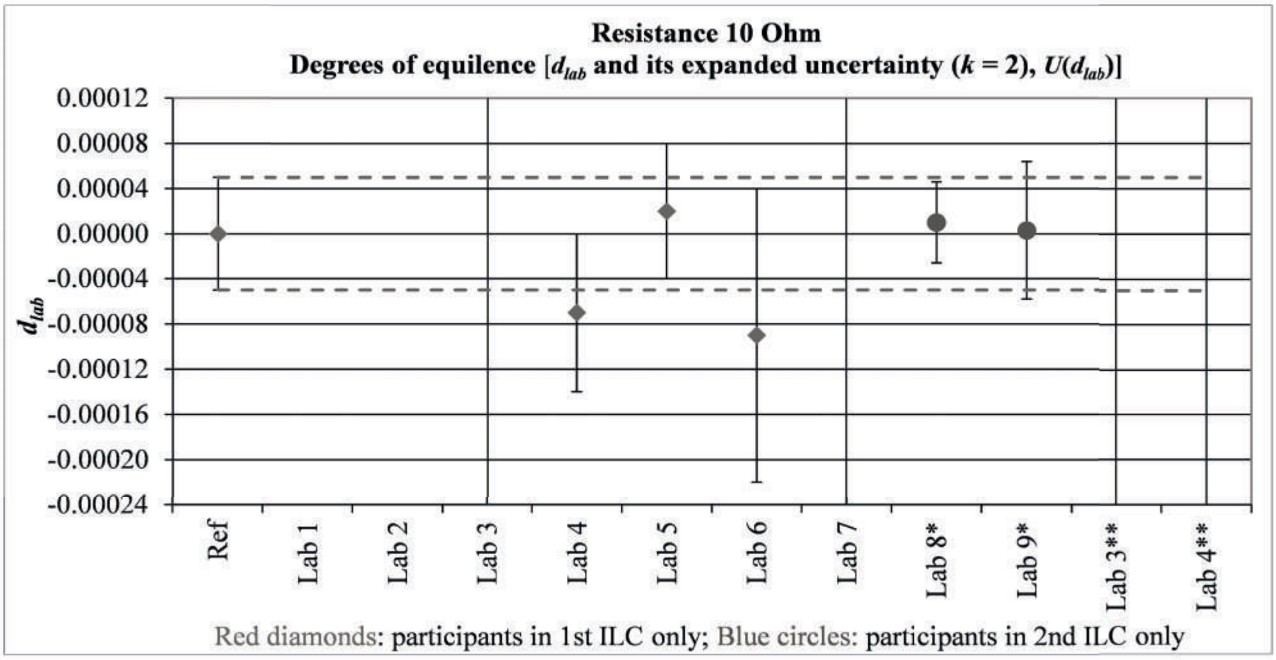

Fig. 2. Results of the calibration of the comparison sample
by CLs for electrical resistance of 10 Ω

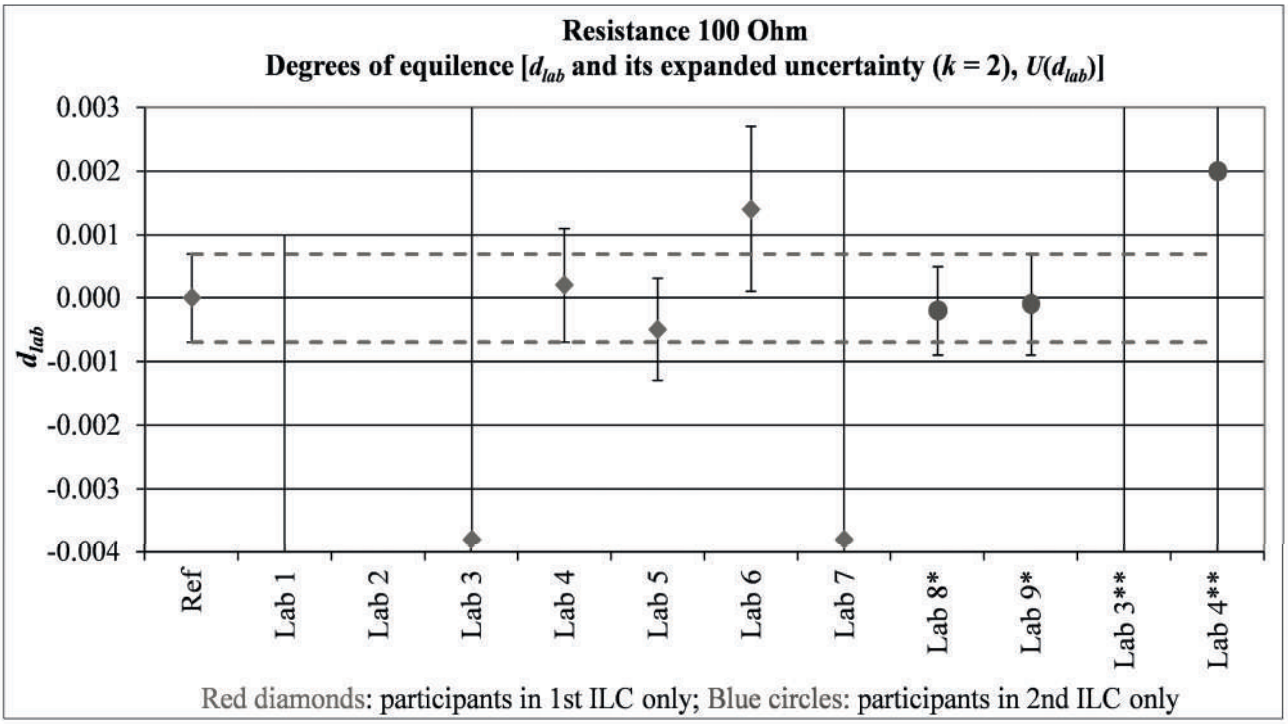

Fig. 3. Results of the calibration of the comparison sample
by CLs for electrical resistance of 100 Ω

uncertainty of the assigned value for each of the denominations.

To analyze the results of the ILC and to formulate conclusions regarding the CLs participating in the ILC calibration of electrical resistance measures of all determined denominations, the E_n number (Fig. 4–6) determined by (4) was used.

Studies of the RL showed that the participating CLs in ILC used their own measurement methods and their own working standards. The obtained values of E_n numbers for both rounds show that for all the CLs participating in the ILC they satisfy the established criterion, except for the results of the next CLs from first round (E_n > 1.00):

Lab 4 (E_n = 4.56) and Lab 6 (E_n = 2.35) for electrical resistance of 1 Ω;

Lab 1 (E_n = 1.95) and Lab 2 (E_n = 6.06) for electrical resistance of 10 Ω;

Lab 2 (E_n = 4.26) for electrical resistance of 100 Ω.

Although Lab 1 and Lab 6 received satisfactory results in the first round of the ILC for electrical

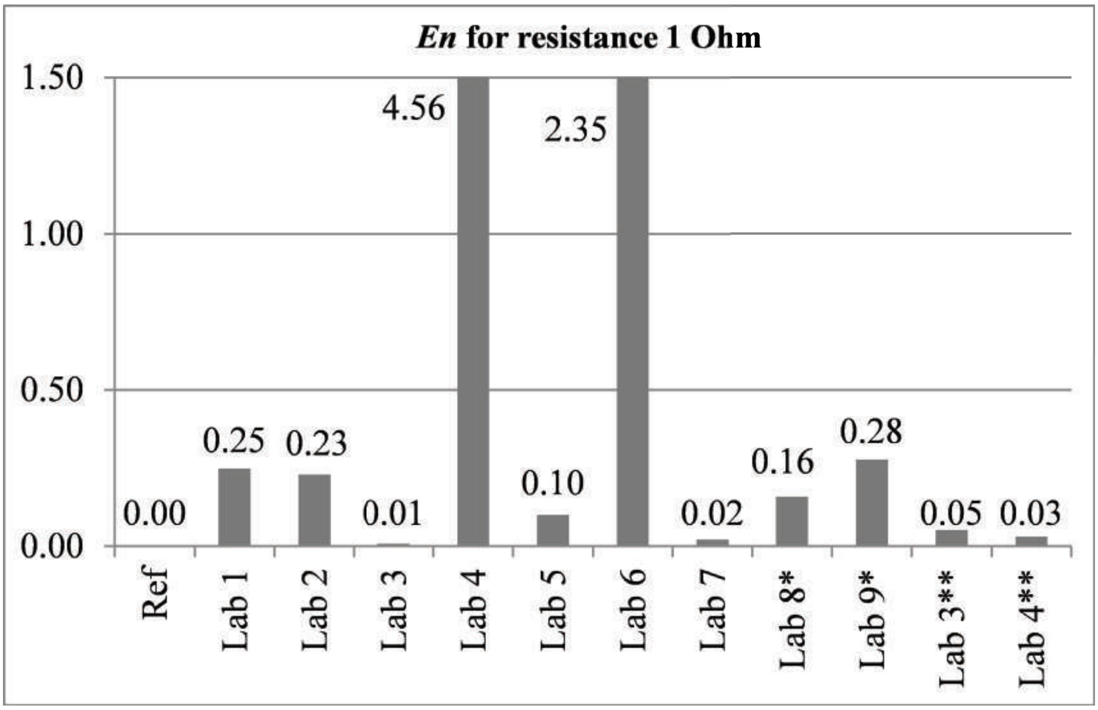

Fig. 4. Value E_n number of CL for 1 Ω electrical resistance

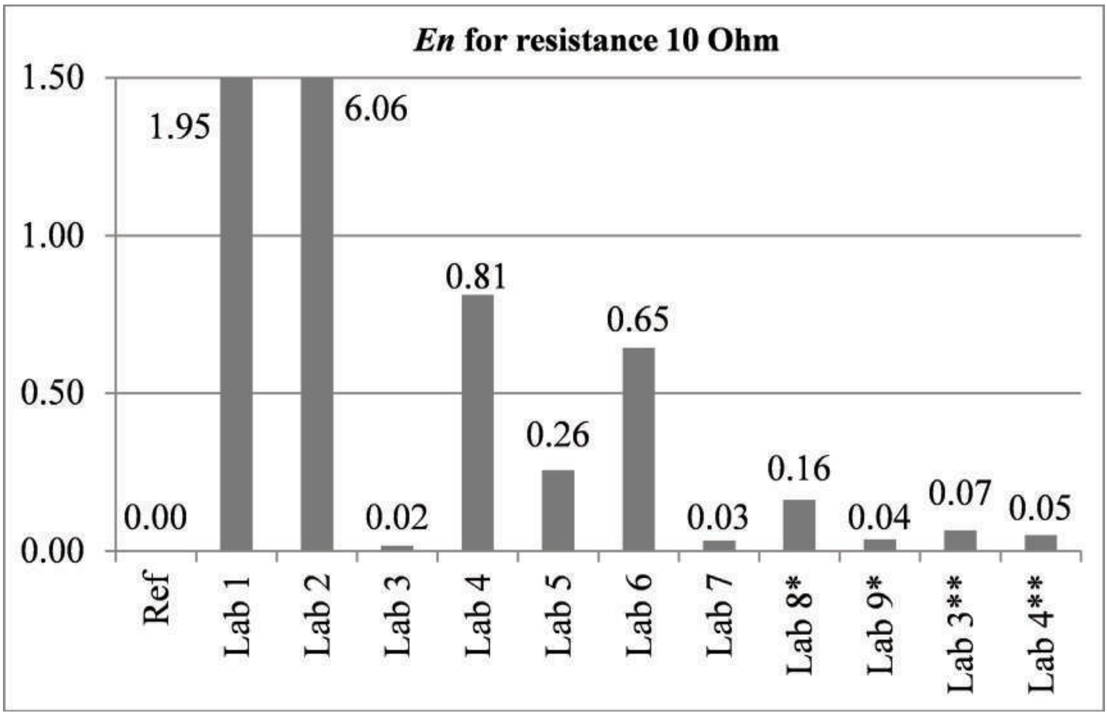

Fig. 5. Value E_n number of CL for 10 Ω electrical resistance

resistance of 100 Ω, their values of E_n numbers were on the brink the established requirements.

An analysis of the comparison of Lab 3 and Lab 4, which participated in both the first [5] and second [6] rounds of ILC, showed the following:

Lab 3 showed satisfactory results in both rounds of ILC for all electrical resistance values;

Lab 4 showed more accurate measurement results in the second round of the ILC, compared to the first round of the ILC, for electrical resistance of 1 Ω and 10 Ω;

Lab 4 received satisfactory results from both rounds of ILC for electrical resistance of 100 Ω only. Lab 4 and Lab 6 should use more accurate measurement methods and working standards to obtain less uncertainty for electrical resistance of 1 Ω. Lab 1 and Lab 2 for electrical resistance of 10 Ω and 100 Ω need to use more accurate measurement methods and working standards that have significantly less measurement uncertainty.

4. Conclusion

On the whole, the results of the second round of the ILC demonstrated a sufficient level of competence of the CLs and confirmed the qualification of the participating CLs to perform their calibration in

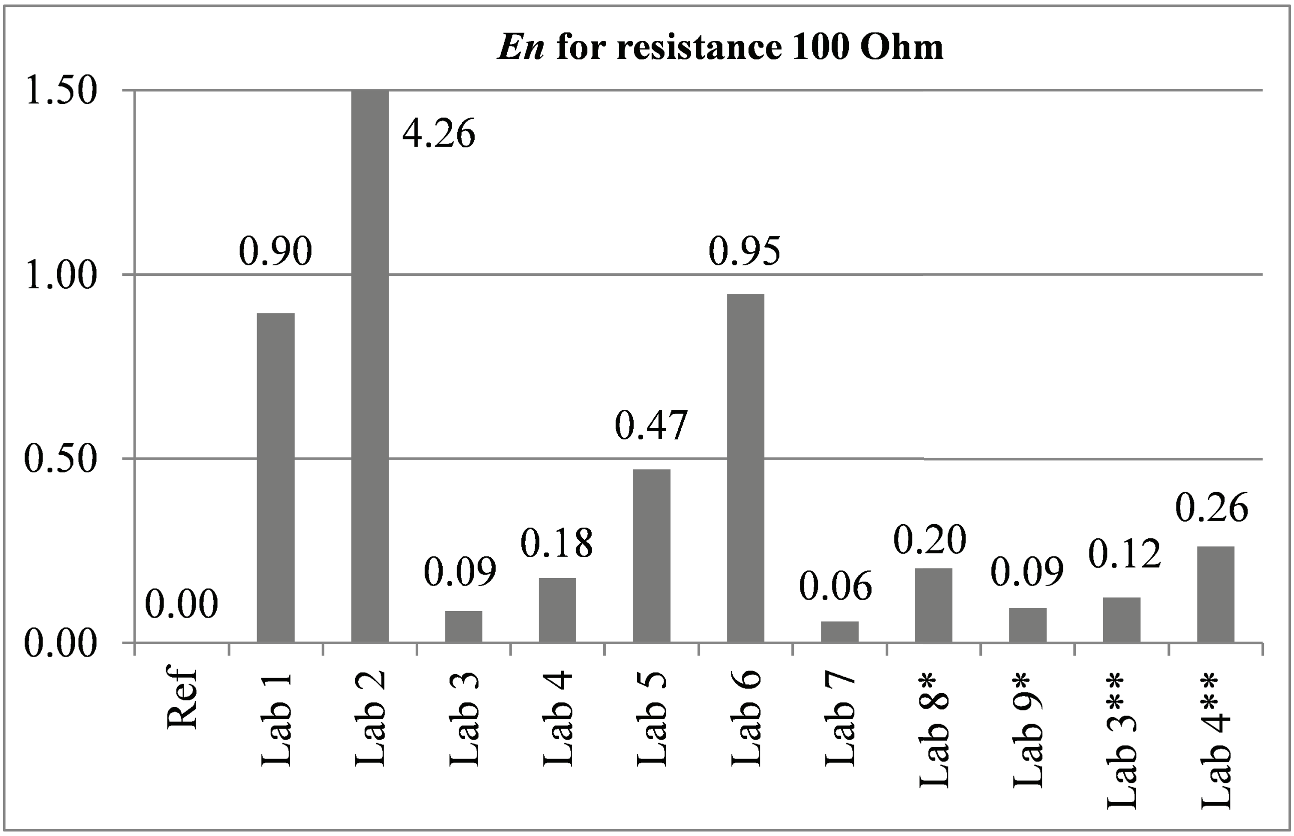

Fig. 6. Value E_n number of CL for 100 Ω electrical resistance

accordance with the requirements of DSTU ISO/IEC 17025, with some exceptions.

Labs 1 and Lab 6 meet the requirements for the E_n numbers for all electrical resistance par values, confirming their qualification when performing calibration in accordance with the requirements of DSTU ISO/IEC 17025. However, Lab 1 and Lab 6 are recommended to use more accurate measurement methods and working standards.

Lab 1 calibration results meet the requirements for En number for electrical resistance of 1 Ω and 100 Ω, but do not meet this indicator for electrical resistance of 10 Ω. Uncertainty for Lab 1 for electrical resistance of 1 Ω and 100 Ω is very large. Therefore, Lab 1 needs to use more accurate measurement methods and working standards that have much less measurement uncertainty.

Lab 2 calibration results meet the requirements for the E_n number only for electrical resistance of 1 Ω, but do not meet the requirements for this number for electrical resistance of 10 Ω and 100 Ω values. However, the expanded uncertainty of calibration does not correspond to the measurement result, so these CLs are advised to make adjustments to the calibration methodology in terms of calculating the required corrections when measuring electrical resistance.

The uncertainties for Lab 7, Lab 4 in the second round and Lab 3 in both rounds are very large for all denominations of electrical resistance. These CLs need to use more accurate measurement methods and working standards that have much less measurement uncertainty.

Comparison of the results of Lab 3 and Lab 4, which participated in both rounds of ILC, showed satisfactory results. However, for these CLs are recommended by the RL to use more accurate measurement methods and working standards to obtain less measurement uncertainty.

Прив’язка результатів міжлабораторних порівнянь для мір електричного опору електричному струму

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Анотація

Вимірювання невеликих кількостей електричного опору є актуальним завданням не тільки в галузі енергетики (вимірювання опору захисного заземлення, опору ізоляції тощо), але й у біофізиці та медицині (визначення електричних властивостей біологічних об'єктів тощо).

Для підтвердження компетентності калібрувальних і випробувальних лабораторій відповідно до вимог стандарту ISO/IEC 17025 необхідна відповідна акредитація. Питання організації та проведення міжлабораторних порівнянь результатів є досить нагальним питанням для акредитованих калібрувальних і випробувальних лабораторій. Важливо проводити періодичні раунди міжлабораторних порівнянь результатів із залученням все більшої кількості лабораторій та, відповідно, встановити їх компетентність.

У статті надано результати другого раунду міжлабораторних порівнянь результатів калібрування мір електричного опору номіналів 1 Ом, 10 Ом та 100 Ом на постійному струмі. Референтною лабораторією (ДП "Укрметртестстандарт") здійснено дослідження мір електричного опору як засобу порівняння, визначені опорні значення порівняння із розрахунком їхніх розширених невизначеностей. Порівняння результатів вимірювань, отриманих під час калібрування мір електричного опору п'ятьма лабораторіями, відбувалося за радіальною схемою протягом 2018–2019 рр.

Доцільно пов'язати всі результати кожної лабораторії, яка брала участь у двох раундах міжлабораторних порівнянь результатів. Описано процедуру прив'язки міжлабораторних порівнянь, яку використано для раундів зазначених міжлабораторних порівнянь. Визначені скореговані відхилення отриманих результатів кожною лабораторією. Оцінено їхню коректність з урахуванням невизначеності вимірювань за допомогою одного із критеріїв за статистикою функціонування для обраних номіналів електричних опорів. Проведено аналіз міжлабораторних порівнянь результатів калібрування мір електричного опору всіх лабораторій.

Ключові слова: міжлабораторні порівняння; приписане значення; міра електричного опору; невизначеність вимірювань; національний метрологічний інститут; зв'язування результатів.

Привязка результатов межлабораторных сравнений для мер электрического сопротивления

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Аннотация

Представлены результаты второго раунда межлабораторных сравнений мер электрического сопротивления 1 Ом, 10 Ом и 100 Ом на постоянном токе. Референтной лабораторией проведено исследование мер электрического сопротивления как средства сравнения, определены опорные значения сравнений с расчетом их расширенных неопределенностей. Сравнение результатов измерений, полученных при калибровке мер электрического сопротивления пятью лабораториями, проходило по радиальной схеме в течение 2018–2019 гг.

Описана процедура привязки межлабораторных сравнений, которая использована для раундов указанных межлабораторных сравнений. Определены откорректированные отклонения полученных результатов каждой лабораторией. Оценена их корректность с учетом неопределенности измерений при помощи одного из критериев по статистике функционирования для избранных номиналов электрических сопротивлений. Проведен сравнительный анализ результатов калибровки мер сопротивления для лабораторий, которые принимали участие в первом и втором раундах.

Ключевые слова: межлабораторные сравнения; приписанное значение; мера электрического сопротивления; неопределенность измерений; национальный метрологический институт; связывание результатов.

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