METROLOGY, QUALITY, STANDARDIZATION AND CERTIFICATION

LINKING OF ROUNDS RESULTS OF INTERLABORATORY COMPARISONS ON CALIBRATION OF ELECTRICAL RESISTANCE MEASURES ON A DIRECT CURRENT

Oleh Velychko, Dr.Sc., Prof., Vasyl Dovhan, PhD, Denys Nikitenko, Jaroslav Brezytskyi
State Enterprise "Ukrmetrteststandard", Ukraine; e-mail: velychko@hotmail.com

https://doi.org/10.23939/istcmtm2024.02.046

Abstract. Interlaboratory comparisons (ILC) are used to evaluate and confirm measurements' accuracy, reliability, and reproducibility. ILCs are conducted for both testing and calibration laboratories (CL). They are comparing the results of measurements or calibrations obtained by different laboratories. The main stages of confirming the competence of laboratories include accreditation as the first step of such confirmation, as well as periodic participation in the ILCs. This is the basis for confirmation of the competence of laboratories and contributes to increasing confidence in the data obtained in these laboratories. The proposed approach to linking the results obtained by the laboratories in different rounds made it possible to jointly evaluate the CL results of two rounds of the ILC on the calibration of measures of electrical resistance on direct current. This provided confirmation of the competence of a larger number of CLs in the calibration of resistance measures. This approach can be applied to the evaluation of the laboratory results and a larger number of ILC rounds, but under the condition that the same CL is chosen as the reference laboratory. The majority of CLs, which participated in two rounds of the ILC for the calibration of resistance measures of nominal values of 1 Ω, 10 Ω, 100 Ω, received positive evaluation results using a modified criterion based on functioning statistics – the E_n number. They have confirmed their qualification in performing calibration for this measurand in accordance with the requirements of ISO/IEC 17025 standard. Several CLs do not meet the requirements for the value of E_n, so they need to implement the necessary corrective measures.

Key words: Measure of electrical resistance, direct current, interlaboratory comparisons, calibration, uncertainty.

1. Introduction

Measurement of electrical resistance on direct current is important for ensuring the safety, quality, and reliability of electrical systems, as well as for their effective management and maintenance. Electrical resistance is an important characteristic of materials, especially conductors and insulators. Resistance measurements are performed to assess the quality of materials and their suitability for specific applications. Measurand resistance can detect electrical conduction problems in electrical systems, help identify problems with electrical connections such as poor welds or defects in connections between conductors, and can indicate potential problems such as short circuits or leakage currents that may lead to fire or electric shock [1–4].

Interlaboratory comparisons (ILC) are designed to evaluate and confirm measurements' accuracy, reliability, and reproducibility. ILCs are conducted for both testing and calibration laboratories (CL) [5, 6]. They are the process of comparing the results of measurements or calibrations obtained by different laboratories. ILCs help determine the reproducibility of laboratory measurement standards and measuring instruments. They also help improve data quality control and help identify discrepancies in laboratory measurements. This is the basis for confirming the competence of laboratories and contributes to increasing confidence in the data obtained in these laboratories.

National accreditation agencies set a requirement for periodic confirmation by the CL of ensuring the quality and reliability of the results of the performed calibrations. The main stages of confirming the competence of laboratories include accreditation as the first step of such confirmation, as well as periodic participation in the ILCs. To prove their competence, laboratories must maintain a quality system at an appropriate level, carry out periodic calibration of their standards and measuring instruments, evaluate the qualifications of their personnel, conduct internal and external audits, etc.

2. Drawbacks

The scientific publications mainly consider the peculiarities of calibration for certain types of measurements or calibration in laboratories and the evaluation of ILC results. Improvement of calibration methods and uncertainty assessment of laboratories participating in ILC for various types of calibrations is considered in [7–10]. Peculiarities of evaluating the results of ILC for CL are reflected in [11–13]. Algorithms for evaluating the results of ILC are given in [14–18]. These works do not consider such an important issue as linking the laboratory results in different rounds with each other.

3. Goal

Aim of current research is to evaluate the laboratory results of two rounds of ILC on the calibration of electrical resistance measures and to link their results with each other. This can prove the competence of a greater number of CLs on the direct current calibration.

4. Calibration object and participants

State Enterprise (SE) "Ukrmetrteststandard" (Kyiv, Ukraine), as a national metrological institute, initiated and conducted two rounds of ILC on the calibration of electrical resistance measures according to the requirements of the ISO/IEC 17025 standard [5]. The main purpose of the ILC rounds was to check the qualification of calibration laboratories in measuring electrical resistance. Conduction of ILCs was carried out with ISO/IEC 17043 [6] and ISO 13528 [19] standards. The qualification verification program was implemented with the requirements of the ISO/IEC 17043 standard [6].

Electrical resistance measures P321 (1 Ω, 10 Ω), and P331 (100 Ω) with an accuracy class of 0.01 were chosen as calibration objects for qualification testing. The high stability of these measures over a fairly long period is confirmed by continuous calibrations. These measures are a component of precision measurement setup for calibration of resistance measures of less preci- sion, electrical resistance meters, multimeters, and cali- brators of electrical quantities. As calibration points for ILCs, electrical resistance ratings corresponding to the selected measures were chosen: 1 Ω, 10 Ω, 100 Ω.

Calibration was performed under normal conditions:

- ambient air temperature – (20 ± 0.1) °C;
- relative air humidity – (55 ± 25) %;
- atmospheric pressure – (100 ± 6) kPa.

8 CL took part in the 1st round of the ILC, and 5 CLs – in the 2nd round of the ILC. The laboratories carried out calibration with their methods. The reference laboratory (RL) – SE "Ukrmetrteststandard" prepared the transported comparison objects, and determined their values before and after the comparisons, the stability of the sample, and the corresponding uncertainties.

The general view of the precision measurement setup for the calibration of RL is shown in Fig. 1, and its block diagram is in Fig. 2. To calibrate precision measures with this measurement setup, the method of comparison measure to be calibrated and a reference measure, the P3015 bridge-comparator is applied.

The electrical resistance value of the measure R_x being calibrated is determined by the equation [20–22]:

$$R_x = R_{nom} + \Delta R_x + \Delta_{Rc} + \Delta_{Rres} + \Delta_{s+} + \Delta_{dr}\,, \qquad (1)$$

where R_{nom} is nominal value of electrical resistance; ΔR_x is deviation of the measured value of electrical resistance from the nominal value; ΔR_c is correction that occurs when measuring electrical resistance with a comparator; ΔR_{res} is the correction that occurs when measuring electrical resistance due to the finite resolution of the comparator; Δ_s is correction for the value of the reference measure; Δ_{dr} is correction for reference measure drift since its last calibration.

Uncertainty budget for 10 Ω of RL is given in Table 1.

Fig. 1 The general view of the precision measurement setup for the calibration of RL

Table 1. Uncertainty budget of RL for 10 Ω

Quantity, X_i	Estimate, x_i	Standard uncertainty, $u(x_i)$	Probability distribution	Sensitivity coefficient, c_i	Uncertainty contribution, $u_i(y)$
R_{nom}	10.00000 Ω				
ΔR_x	-0.00058 Ω				
ΔR_c	0	0.00000025 Ω	Rectangular ($k = \sqrt{3}$)	1.0	0.00000025 Ω
ΔR_{res}	0	0.00000289 Ω	Rectangular ($k = \sqrt{3}$)	1.0	0.00000289 Ω
Δ_s	0	0.0000045 Ω	Normal ($k = 2$)	1.0	0.00000450 Ω
Δ_{dr}	0	0.0000173 Ω	Rectangular ($k = \sqrt{3}$)	1.0	0.00001730 Ω
R_x	9.99942 Ω				0.0000187 Ω

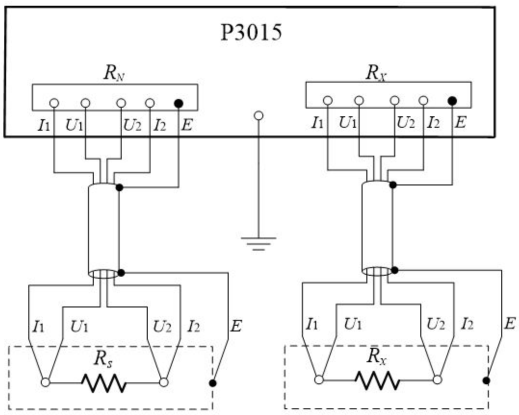

Fig. 2 Block diagram of the precision measurement setup for the calibration of resistance measures.
R_x is a calibrated measure; R_s is a reference measure.

The value R_x of the resistance measure of 10 Ω of RL at a temperature of 20 ˚C is (9.999420 ± 0.000037) Ω.

The expanded uncertainties for the nominal of 1 Ω and 100 Ω for RL are values of 0.000002 Ω and 0.00071 Ω, respectively.

RL tracked the drifts of the calibration objects that were set for both rounds of ILC. From the beginning of round 1 to the end of round 2 of the ILCs, the drift of the 1 Ω measure was 0.000001 Ω, the 10 Ω – 0.00005 Ω, and the 100 Ω – 0.0001 Ω. The values of these drifts were so small that their contribution to the combined standard uncertainty during the calibration of the calibra- tion object can be neglected.

5. Laboratory calibration results

Table 2 and Figs 3–5 show the calibration results of the laboratories that participated in the ILC rounds (the deviation of the measurement results of the D_{lab} laboratories, their expanded uncertainties $U(x_{lab})$. The graphical interpretation of the results obtained by the laboratories was carried out with the help of the special software "IntLab 1.0", developed by the specialists of the SE "Ukrmetrteststandard" [23].

Table 2. Laboratory results for measure of nominals of 1 Ω, 10 Ω, and 100 Ω

	Ref-Lab 1	Lab 1-1	Lab 1-2	Lab 1-3	Lab 1-4	Lab 1-5	Lab 1-6	Lab 1-7
				1 Ω				
R_x	1.000021	1.000561	1.0000156	0.999820	0.999979	1.000020	1.000059	0.999987
D_{lab1}	0.000000	0.000540	-0.0000054	-0.000201	-0.000042	-0.000001	0.000038	-0.000034
$U(x_{lab1})$	0.000006	0.002166	0.0000212	0.023940	0.0000068	0.000008	0.000015	0.001600
	Ref-Lab 2	Lab 2-1	Lab 2-2	Lab 2-3	Lab 2-4			
R_x	1.000029	1.000022	1.001500	1.000024	1.000265			
D_{lab2}	0.000000	-0.000007	0.001471	-0.000005	0.000236			
$U(x_{lab2})$	0.000002	0.000002	0.027500	0.000009	0.007440			
				10 Ω				
	Ref-Lab 1	Lab 1-1	Lab 1-2	Lab 1-3	Lab 1-4	Lab 1-5	Lab 1-6	Lab 1-7
R_x	9.99942	9.998564	9.9997334	9.9989	9.99935	9.99944	9.99933	9.99890
D_{lab1}	0.00000	-0.000856	0.0003134	-0.0005	-0.00007	0.00002	-0.00009	-0.00052
$U(x_{lab1})$	0.00005	0.000435	0.0000130	0.0292	0.00007	0.00006	0.00013	0.01600
	Ref-Lab 2	Lab 2-1	Lab 2-2	Lab 2-3	Lab 2-4			
R_x	9.999420	9.999430	10.001600	9.999423	9.999806			
D_{lab2}	0.000000	0.000010	0.002180	0.000003	0.000386			
$U(x_{lab2})$	0.000037	0.000036	0.033500	0.000061	0.007583			
				100 Ω				
	Ref-Lab 1	Lab 1-1	Lab 1-2	Lab 1-3	Lab 1-4	Lab 1-5	Lab 1-6	Lab 1-7
R_x	99.9988	99.98997	100.00397	99.995	99.9990	99.9983	100.00024	99.9950
D_{lab1}	0.0000	-0.00883	0.00517	-0.0038	0.0002	-0.0005	0.00144	-0.0038
$U(x_{lab1})$	0.0007	0.00980	0.00102	0.044	0.00094	0.0008	0.00130	0.0650
	Ref-Lab 2	Lab 2-1	Lab 2-2	Lab 2-3	Lab 2-4			
R_x	99.99830	99.99860	100.00510	99.99869	100.00076			
D_{lab2}	0.00000	0.00030	0.00680	0.00039	0.00246			
$U(x_{lab2})$	0.00071	0.00070	0.05100	0.00079	0.00760			

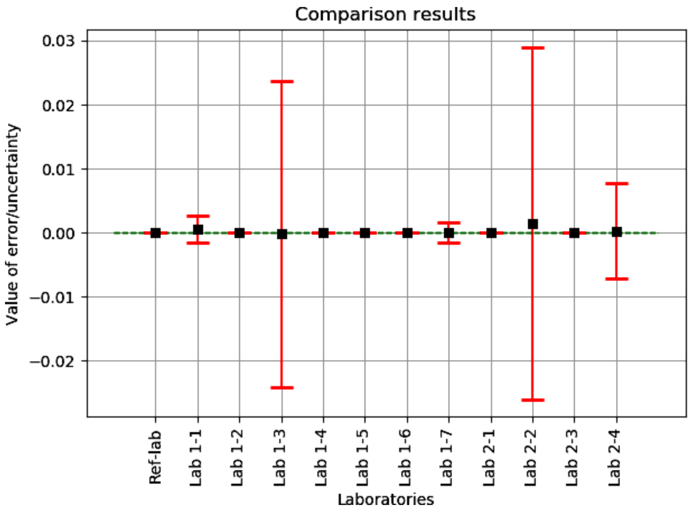

Fig. 3. Laboratory results for a measure with a nominal value of 1 Ω.

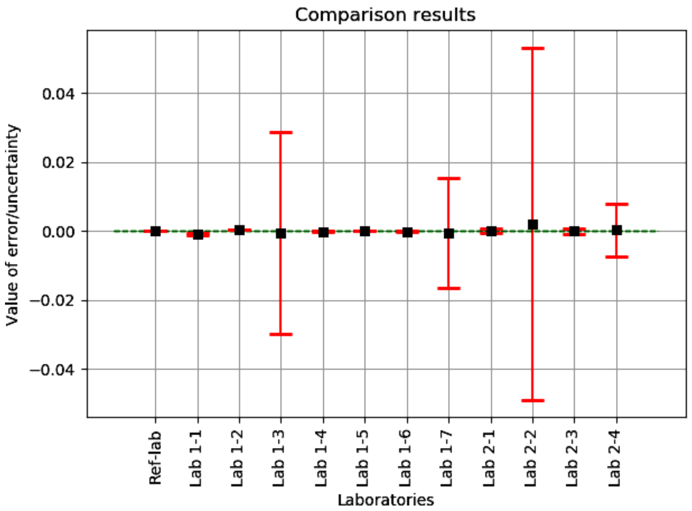

Fig. 4. Laboratory results for a measure with a nominal value of 10 Ω.

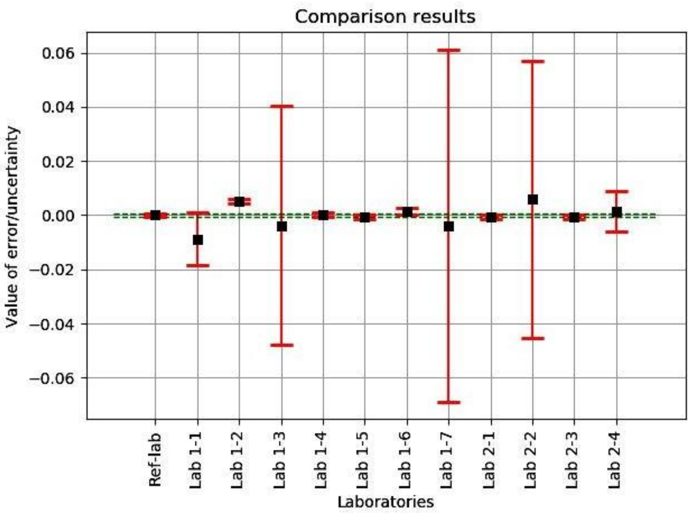

Fig. 5. Laboratory results for a measure with a nominal value of 100 Ω.

The deviation of laboratory measurement results in round 1 was determined as:

$$D_{lab1} = x_{lab\ i1} - X_{ref-lab1}, \quad (2)$$

where x_{lab1} is the value of the electrical resistance measured by the i-th laboratory in round 1 of the ILC; $X_{ref\text{-}lab1}$ is the value of electrical resistance, determined as the arithmetic mean value of the values of measurements performed by RL in round 1 of the ILC.

The deviation of laboratory measurement results in round 2 of the ILC was set as follows:

$$D_{lab2} = x_{lab\ i2} - \left(X_{ref-lab1} - X_{ref-lab2}\right), \quad (3)$$

where x_{lab2} is the value of the electrical resistance measured by the i-th laboratory in round 2 of the ILC; $X_{ref\text{-}lab2}$ is the value of electrical resistance, determined as the arithmetic mean value of the values of measurements performed by RL in round 2 of the ILC.

The expanded uncertainty of RL measurements when setting the value of electrical resistance, taken as the assigned value of ILC in each of the rounds of ILC, given the value:

$$U_{ref-lab} = 2\sqrt{u^2\left(X_{ref-lab}\right) + u^2\left(X_{stab}\right)}, \quad (4)$$

where $u(X_{ref\text{-}lab})$ is the combined standard uncertainty obtained during the calibration of the electrical resistance measure of the RL at the corresponding nominal value; $u(X_{stab})$ is the combined standard uncertainty from the instability of the transported measure during the ILC.

6. Discussion of the obtained results

The results of each laboratory for each of the rounds with modified criteria according to the functioning statistics – E_n indicator are shown in Table 3 and Figs 6–8.

Table 3. Laboratory results according to the E_n number for measure of nominals of 1 Ω, 10 Ω, and 100 Ω

1 Ω							
Ref-Lab 1	Lab 1-1	Lab 1-2	Lab 1-3	Lab 1-4	Lab 1-5	Lab 1-6	Lab 1-7
-	0.25	-0.25	-0.01	-4.63	-0.10	2.35	-0.02
Ref-Lab 2	Lab 2-1	Lab 2-2	Lab 2-3	Lab 2-4			
-	-1.51	0.05	-0.55	0.03			
10 Ω							
Ref-Lab 1	Lab 1-1	Lab 1-2	Lab 1-3	Lab 1-4	Lab 1-5	Lab 1-6	Lab 1-7
-	-0.20	2.25	-0.02	-0.78	0.26	-0.65	-0.03
Ref-Lab 2	Lab 2-1	Lab 2-2	Lab 2-3	Lab 2-4			
-	0.12	0.07	0.03	0.05			
100 Ω							
Ref-Lab 1	Lab 1-1	Lab 1-2	Lab 1-3	Lab 1-4	Lab 1-5	Lab 1-6	Lab 1-7
-	-0.90	4.19	-0.09	0.17	-0.47	0.98	-0.06
Ref-Lab 2	Lab 2-1	Lab 2-2	Lab 2-3	Lab 2-4			
-	0.22	0.13	0.37	0.32			

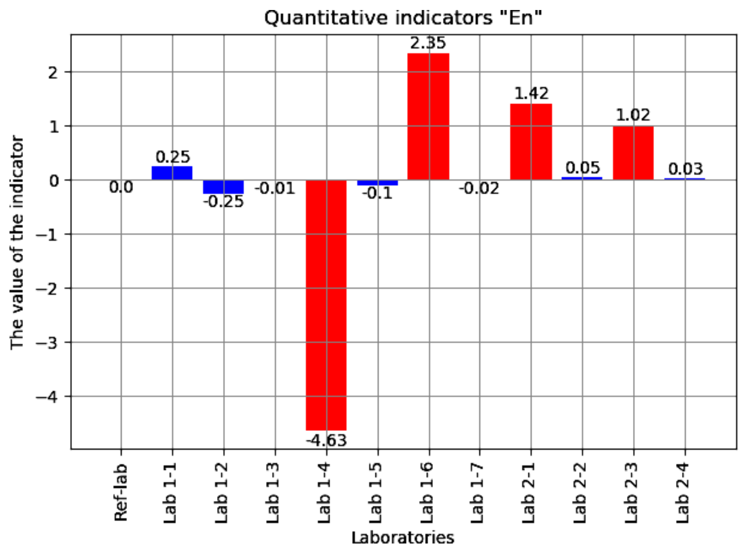

Fig. 6. Laboratory results according to the E_n number for the measure of nominals of 1 Ω

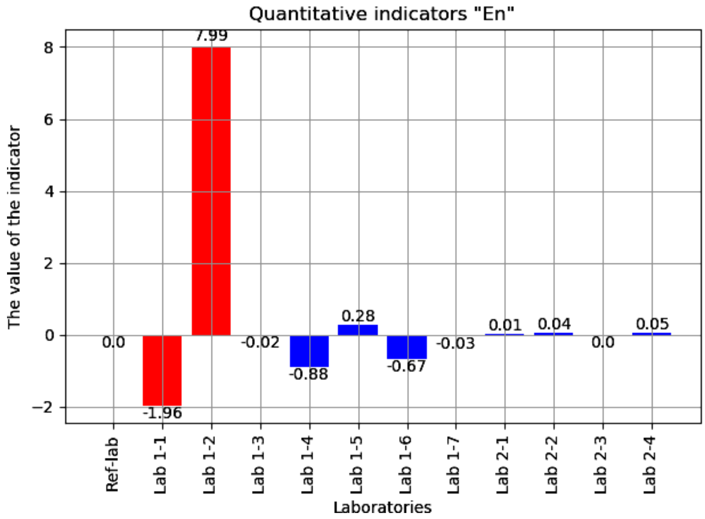

Fig. 7. Laboratory results according to the E_n number
for a measure of nominals of 10 Ω

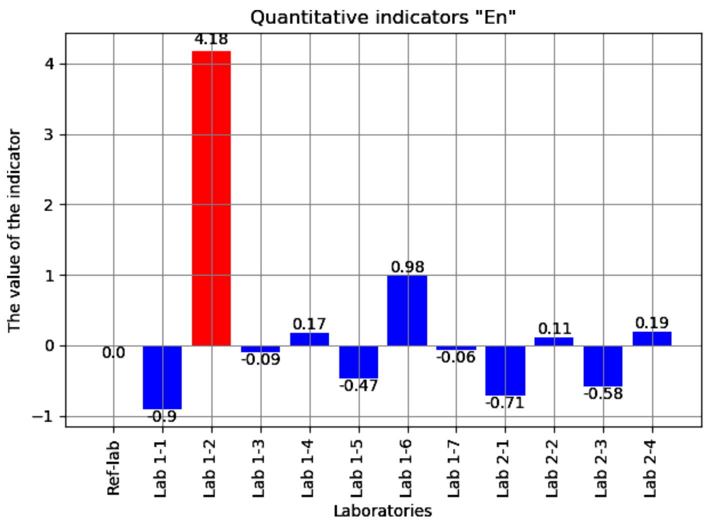

Fig. 8. Laboratory results according to the E_n number
or a measure of nominals of 100 Ω

Evaluation of the results of the *i*-th laboratory for each of the rounds ILC according to the E_n number was defined as:

$$E_{n\,i} = \frac{x_{lab\ i} - X_{ref-lab}}{\sqrt{u^2\left(x_{lab\ i}\right) + u^2\left(X_{ref-lab}\right)}}, \qquad (5)$$

where $u(x_{lab\ i})$ is the combined standard uncertainty of measurements when determining the value of electrical resistance by each laboratory.

At the same time, if: $E_n \le 1$ is the laboratory result that does not require correction; $E_n > 1$ is the laboratory result that requires corrective or response action.

Lab 1-3, Lab 1-5, and Lab 1-7 for nominals of 1 Ω, 10 Ω, and 100 Ω, Lab 1-1 and Lab 1-2 for 1 Ω, Lab 1-4 and Lab 1-6 for 10 Ω, Lab 1-1, Lab 1-4 and Lab 1-6 satisfy the criterion requirements for the value of E_n number for 10 Ω. Those laboratories confirm their qualification in performing calibration with the requirements of the ISO/IEC 17025 standard. The results of Lab 1-1, Lab 1-3, and Lab 1-7 are significantly different from the RL value, and their uncertainty is much larger than the values of other laboratories, so they are recommended to enter corrections to the method of calculating corrections to reduce the overall uncertainty. Lab 1-4 and Lab 1-6 received unsatisfactory results regarding the value of E_n

number for all nominals, so they need to implement the necessary corrective action.

Lab 2-1, Lab 2-2, Lab 2-3, and Lab 2-4 for nominal 10 Ω and 100 Ω, Lab 2-2 and Lab 4 for measures of nominal 1 Ω meet the requirements for the value of E_n number, which confirms the qualification of CLs when they perform calibration with the established requirements. Lab 2-1 and Lab 2-3 for 1 Ω do not meet the requirements for the value of E_n number, so they need to implement the necessary corrective measures. However, it is recommended for Lab 2-2, and Lab 2-4 to apply more accurate of calibration methods.

7. Conclusions

The proposed approach linking the laboratory results obtained in different rounds allows jointly evaluating the CL results of two rounds of the ILC of the calibration of measures of electrical resistance on direct current. This confirmed the competence of a larger number of CLs in the calibration of resistance measures. The approach can be applied to the evaluation of the laboratory results and a larger number of ILC rounds, but under the condition that the same CL is chosen as the RL.

The majority of CLs, which participated in two rounds of the ILC for the calibration of resistance measures of nominal values of 1 Ω, 10 Ω, and 100 Ω, re- ceived positive evaluation results using a modified crite- rion based on functioning statistics – the E_n number. They have confirmed their qualification in performing calibration for this measurand under the requirements of ISO/IEC 17025 standard. Several CLs do not meet the requirements for the value of E_n, so they need to imple- ment the necessary corrective action.

8. Gratitude

The authors thank their colleagues and the Staff of the Journal “Measuring Equipment and Metrology” for their help and assistance.

9. Mutual claims of authors

The authors have no claims against each other.

References

[1] R. Radetić, M. Pavlov-Kagadejev, D. Brodić and N. Milivojević, “An Approach to the Low-Resistance Measurement,” Serbian Journal of Electrical Engineering, vol. 10, 2013, no. 2, pp. 293–307. DOI: https://doi.org/10.2298/SJEE130411005R.

[2] D. Böhm et al., “Analysis of electrical resistance measurements as a potential determination method for coating thickness on powders,” Surface and Coatings Technology, vol. 473, 2023, 129931. DOI: https://doi.org/10.1016/j.surfcoat.2023.129931.

[3] V. Pleština, V. Boras and H. Turić, “The Measurement Uncertainty in Determining of Electrical Resistance Value by Applying Direct-Comparison Method,” Energies, vol. 15, 2022, no. 6, pp. 2115. DOI: https://doi.org/10.3390/en15062115.

[4] Landry M., Turcotte O., Brikci F., “A complete strategy for conducting dynamic contact resistance measurements on HV circuit breakers,” IEEE Transactions on Power Delivery, vol. 2, 2008, pp. 710–716. DOI: 10.1109/TPWRD.2008.917694.

[5] ISO/IEC 17025, “General requirements for the competence of testing and calibration laboratories,” 2017. https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html

[6] ISO/IEC 17043, “Conformity assessment – General requirements for the competence of proficiency testing providers,” 2023 https://www.iso.org/standard/80864.html

[7] L. G. Bermanec, D. Zvizdic, “Interlaboratory comparison in the pressure range from 0 to 2 MPa for accredited calibration laboratories,” Int. J. Metrol. Qual. Eng., vol. 6, 2015, no. 3, 307. DOI: https://doi.org/10.1051/ijmqe/2015021.

[8] N. Furuichi et al., “Inter-laboratory comparison of small water flow calibration facilities with extremely low uncertainty,” Measurement, vol. 91, 2016, pp. 548-556. DOI: https://doi.org/10.1016/j.measurement.2016.05.088

[9] M. M. Poenaru et al., “Active power quality assessment through interlaboratory comparison,” 21st IMEKO TC4 International Symposium “Understanding the World through Electrical and Electronic Measurement”, Budapest, Hungary, 2016, pp. 224-228. https://www.imeko.org/publications/tc4-2016/IMEKO-TC4-2016-42.pdf

[10] T. P. Petkova, et al., “Assessing technical competence through participation in interlaboratory mergers,” Information processing systems, 2013, no. 3 (110), pp. 82-85. http://www.irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/cgiirbis_64.exe?I21DBN=LINK&P21DBN=UJRN&Z21ID=&S21REF=10&S21CNR=20&S21STN=1&S21FMT=ASP_meta&C21COM=S&2_S21P03=FILA=&2_S21STR=soi_2013_3_21

[11] F. Iacobescu, M. M. Poenaru, M.-A. Anghel, “Reactive Power Quality Assessment through Interlaboratories Comparison,” 22th IMEKO TC 4 Symposium “Supporting World development through electrical and electronic measurements”, Iasi, Romania, 2017, pp. 13-19. https://www.imeko.org/publications/tc4-2017/IMEKO-TC4-2017-003.pdf

[12] M. M. Poenaru, F. Iacobescu, M.-A. Anghel, “Length Calibration Quality Assessment through Interlaboratories Comparison,” 22nd IMEKO TC 4 Symposium “Supporting World development through electrical and electronic measurements”, Iasi, Romania, 2017, pp. 20-26. https://www.imeko.org/publications/tc4-2017/IMEKO-TC4-2017-004.pdf

[13] M. M. Poenaru, F. Iacobescu, M.-A. Anghel, “Pressure Calibration Quality Assessment through Interlaboratories Comparison,” 22nd IMEKO TC 4 Symposium “Supporting World development through electrical and electronic measurements”, Iasi, Romania, 2017, pp. 27-32.

https://www.imeko.org/publications/tc4-2017/IMEKO-TC4-2017-005.pdf

[14] J. Claudio, M. Costa, “Brazilian energy interlaboratory program applicative,” XX IMEKO World Congress “Metrology for Green Growth”, 2012, Busan, Republic of Korea, 6 p. https://www.imeko.org/publications/wc- 2012/IMEKO-WC-2012-TC4-P5.pdf

[15] I. Sandu, L. Dragomir, B. Pantelimon, “Interlaboratory comparison,” 15th IMEKO TC 4 Symposium on Novelties in Electrical Measurements and Instrumentations, Iasi, Romania, 2007, 4 p. https://www.imeko.org/ publications/tc4-2007/IMEKO-TC4-2007-179.pdf

[16] Sousa J.J.L., Leitão L.T.S., Costa M. M., Faria M. C., “Considerations on the influence of traveling standards instability in an interlaboratory comparison program,” XX IMEKO World Congress “Metrology for Green Growth”, Busan, Republic of Korea, 2012, 4 p. https://www.imeko.org/publications/wc-2012/IMEKO-WC-2012-TC8-O2.pdf

[17] Velychko O., et al., “Interlaboratory comparisons of the calibration results of time meters,” Eastern-European Journal of Enterprise Technologies, Information and Controlling Systems, 2018, no. 1/9 (91), pp. 4–11. DOI: https://doi.org/10.15587/1729-4061.2018.121089

[18] Velychko O., Gordiyenko T.: The Data Evaluation of Interlaboratory Comparisons for Calibration Laboratories, Applied Aspects of Modern Metrology, IntechOpen. (2022). DOI: https://doi.org/10.5772/intechopen.99489

[19] ISO 13528, “Statistical methods for use in proficiency testing by interlaboratory comparison,” 2022. https://www.iso.org/standard/78879.html

[20] JCGM 100, “Uncertainty of measurement. Part 3: Guide to the expression of uncertainty in measurement (GUM),” 2008, https://www.bipm.org/documents/20126/ 2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf- 3f85-4dcd86f77bd6.

[21] EA-04/02 M, “Evaluation of the Uncertainty of Measurement in Calibration,” 2013. https://www.enac.es/ documents/7020/635abf3f-262a-4b3b-952f-10336cdfae9e.

[22] UKAS M3003, “The Expression of Uncertainty and Confidence in Measurement,” UKAS, 2024. https://www.ukas.com/wp- content/uploads/2023/05/M3003-The-expression-of- uncertainty-and-confidence-in-measurement.pdf.

[23] Velychko O., Kursin S., and Haman V., “Automation of evaluation of the interlaboratory comparisons results employing software,” Measurements Infrastructure, 2023, no. 5. https:// DOI.org/10.33955/v5(2023)-039