Linking results of RMO comparisons and inter-laboratory comparisons for AD/DC voltage transfer difference

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Abstract – **The global metrological traceability fully depends on the implementation of international mutual recognition agreements in field of metrology.**
The linked results of international comparisons of national standards and national inter-laboratory comparison for AD/DC voltage transfer difference measurementswas presented.

Keywords – inter-laboratory comparison, calibration laboratory, measurement uncertainty, comparison of national standards

I. INTRODUCTION

The global metrological traceability fully depends on the implementation of two mutual recognition agreements (MRAs): the International Committee on Weights and Measures (CIPM) and the International Laboratory Accreditation Cooperation (ILAC) [1].

The results of international comparisons of standards of National Metrology Institutes (NMIs) of different countries [2-4] are used to implement the provisions of the CIPM MRA. Key comparisons (KCs) are made by the CIPM Consultative Committees (CCs) and six Regional Metrology Organizations (RMOs) using agreed technical protocols for participients.

The results of calibration of working standards and measuring instruments (MIs), which are conducted by accredited calibration laboratories (CLs) for accredited test laboratories [4], are used to implement the provisions of the ILAC MRA. Inter-laboratory comparisons (ILCs) are widely used to confirm the technical competence of accredited CLs [5].

An important task is to establish a linkingof results of the comparisons of national standards and the calibration results of accredited CLs within the framework of national ILCs for technical confirmation of metrological traceability. The basis for establishing such a linking should be provide by NMI.

II. RELATED RESULTS IN THE LITERATURE

The results of COOMET.EM-S1 supplementary comparison (2 participants) [7] can be expressed in terms of the reference value (RV) of COOMET.EM-K6.a key comparison (6 participants) [8]. VNIIM (Russia) took part both in COOMET.EM-K6.a and COOMET.EM-S1 comparisons therefore it can serve as a linking NMI for these two comparisons. The degrees of equivalence (DoE) of standards of COOMET.EM-K6.a and COOMET.EM-S1 comparisons are presented [9].

To evaluation of data of the RMO comparisons determine: RV comparisons and its uncertainty and the DoE and uncertainty for all participants. To evaluation the data of the RMO key comparisons are also determined: transformed participant data and their uncertainties; DoE and uncertainty for all participants with the exception of the linking NMIs.

To evaluation of ILC data with CR participation, the following is determined: assigned value (AV) and its uncertainty; inter-laboratory differences– DoE and their uncertainties; data consistency characteristics. There are various options for the establishment of AV, in particular, the measured value by the reference laboratory, which is metrological traceability to the national standard. When conducting ILC for CL, it is necessary to ensure the stability of the reference sample [10].

To establish the linking between the results of international comparisons of standards and the results of inter-laboratory comparisons, the most optimal is the participation of the NMI as a reference laboratory (RL).

III. DESCRIPTION OF THE METHOD

The general approach used for evaluation of RMO comparison data and ILCs data is providing in [9, 11].

Inter-laboratory differences for i-th CL traditionally defined by [5, 11, 12]:

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

where: $x_{lab\,i}$ is measured value for i-th CL; X_{AV} is AV which determined by the RL.

The extended uncertainty of U_{AV} measurements is determined by:

$$U_{AV} = k\sqrt{u^2(X_{AV}) + u^2(X_{stab})}, \qquad (2)$$

where: k is coverage factor (traditionally k=2); $u(X_{AV})$ is standard uncertainty obtained during the calibration of the MIs of RL; $u(X_{stab})$ is the standard uncertainty about the instability of the MIs during the ILC.

The extended uncertainty U_{AV} of i-th CL from ILC is determined by:

$$U(D_{lad\,i}) = k\sqrt{u^2(X_{AV}) + u^2(X_{lab\,i})}. \qquad (3)$$

The results of the ILC are to be expressed in relation to the RMO comparisons: $D_{NMIj} = x_{NMIj} - X_{RV}$. For this purpose the DoE of the ILC (indicated $D_{lab\,i}$), will be corrected by a correction factor d, which is determined from the results of the participant laboratory in both comparisons (NMIj – Lab 1):

$$d = D_{NMIj} - D_{lab1}, \qquad (4)$$

where: D_{NMIj} is DoE of NMIi in RMO comparison; $D_{lab\,i}$ is DoE of Lab 1 (NMI i) in ILC, with the uncertainty:

$$U(d) = k\sqrt{\left[u^2(D_{NMIj}) + u^2(D_{lab1})\right]/2}. \qquad (5)$$

The corrected DoE for i-th Lab participant in ILC with respect to linking to RMO comparison are estimated as

$$D'_{lab\,i} = D_{lab\,i} + d \qquad (6)$$

with the uncertainty:

$$U(D'_{lab\,i}) = k\sqrt{u^2(D_{lab\,i}) + u^2(d)}. \qquad (7)$$

The corrected DoE for i-th Lab participant in ILC1 with respect to linking to RMO comparison are estimated as

$$D'_{ILC1i} = D_{ILC1i} + d_{S1} \qquad (8)$$

with the uncertainty:

$$U(D'_{ILC1\,i}) = k\sqrt{u^2(D_{ILC1\,i}) + u^2(d_{S1})}. \qquad (9)$$

IV.   RESULTS AND DISCUSSIONS

The results from all laboratories of participants in COOMET.EM-K6.a and COOMET.EM-S1 comparisons and in ILC1(5 participants) in terms of $RV_{K6.a}$(1 kHz, 20 kHz, 100 kHz, 1 MHz) are shown in Table 1. D_{K6a} is DoE from COOMET.EM-K6.a [8], D_{S1} is DoE from COOMET.EM-S1 [7]; $U(D_{K6a})$ is NMI expanded uncertainty from COOMET.EM-K6.a [8], $U(D_{S1})$ is NMI expanded uncertainty from COOMET.EM-S1 [7], $U(D_{ILC1})$ is expanded uncertainty of i-th CL from ILC1 are shown on Table 1.

In accordance with the proposed procedure and using the data in Table 1, DoE for all laboratories in COOMET.EM-K6.a, COOMET.EM-S1 comparisons and in ILC1 in terms of $RV_{K6.a}$ with the expanded uncertainty at 1 kHz, 20 kHz, and 100 kHz was calculated, which are shown on Fig. 1-3. UMTS (Ukraine) took part both in COOMET.EM-K6.a and COOMET.EM-S1 comparisons and national ILC1 therefore it can serve as a linking Lab (RL).
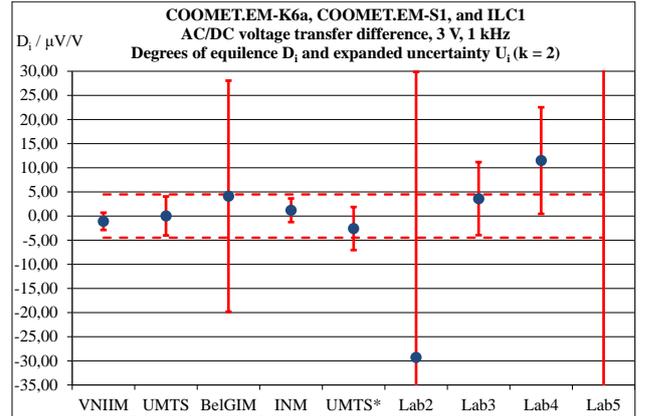

Fig. 1. DoE of all laboratories in COOMET.EM-K6.a, COOMET.EM-S1 comparisons and in ILC1 in terms of $RV_{K6.a}$ with the expanded uncertainty at 1 kHz
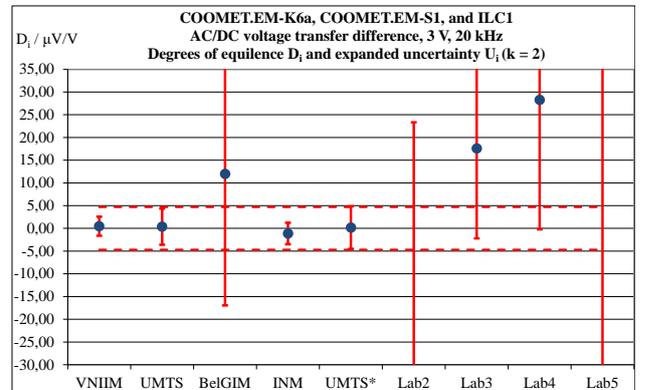

Fig. 2. DoE of all laboratories in COOMET.EM-K6.a, COOMET.EM-S1 comparisons and in ILC1 in terms of $RV_{K6.a}$ with the expanded uncertainty at 20 kHz

Table 1.DoE of laboratories in COOMET.EM-K6.a, COOMET.EM-S1 comparisons and ILC1
in terms of $RV_{K6.a}$ with the expanded uncertainty.

| Lab	D_{K6a},μV/V	$U(D_{K6a})$, μV/V	D_{S1},μV/V	$U(D_{S1})$, μV/V	D_{ILC1},μV/V	$U(D_{ILC1})$, μV/V	D'_{K6a},μV/V	$U(D'_{K6a})$, μV/V
1 kHz								
VNIIM	-1.10	1.79	-0.50	1.50			-1.10	1.79
UMTS	0.00	4.04					0.00	4.04
BelGIM	4.10	23.94					4.10	23.94
INM	1.20	2.44					1.20	2.44
UMTS* (Lab 1)			-2.00	4.10	0.00	4.47	-2.60	4.47
Lab 2					-26.70	59.00	-29.30	59.17
Lab 3					6.20	6.10	3.60	7.56
Lab 4					14.10	10.10	11.50	11.04
Lab 5					-48.70	260.00	-51.30	260.04
20 kHz								
VNIIM	0.48	2.11	-1.20	1.50			0.48	2.11
UMTS	0.38	3.99					0.38	3.99
BelGIM	11.98	28.94					11.98	28.94
INM	-1.12	2.37					-1.12	2.37
UMTS* (Lab 1)			-1.50	4.20	0.00	4.50	0.18	4.70
Lab 2					-42.00	65.00	-41.82	65.17
Lab 3					17.40	19.20	17.58	19.77
Lab 4					28.10	28.10	28.28	28.49
Lab 5					68.20	3140.00	68.38	3140.00
100 kHz								
VNIIM	1.81	2.06	-3.80	3.00			1.81	2.06
UMTS	-3.19	7.67					-3.19	7.67
BelGIM	25.80	139.00					25.80	139.00
INM	-5.99	11.50					-5.99	11.50
UMTS* (Lab 1)			-5.00	5.80	0.00	8.50	0.61	6.15
Lab 2					-14.00	95.00	-13.39	95.20
Lab 3					11.00	45.50	11.61	45.91
Lab 4					10.20	78.70	10.81	78.94
Lab 5					1419.00	3140.00	1419.61	3140.01
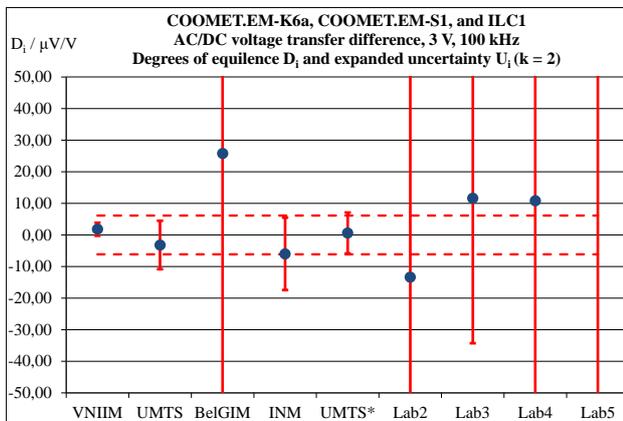
Fig. 3.DoE of all laboratories in COOMET.EM-K6.a, COOMET.EM-S1 comparisons and in ILC1 in terms of $RV_{K6.a}$ with the expanded uncertainty at 100 kHz

$E_n$numbers are calculated using equation

$$E_n = \frac{x_{lab\,i} - X_{AV}}{\sqrt{U_{lab\,i}^2 - U_{AV}^2}} \,, \qquad (10)$$

where $U_{lab\,i}$ is the expanded uncertainty of a participant's result.

According to [3] on the basis of measurement results and associated uncertainties presented by participants of RMO comparisons of national measuring standards, calculate the value of the χ^2 test.

The same formula from [3] can be applied to evaluation of consistency of the results of ILCs for CLs:

$$\chi^2 = \sum_{i=1}^{n} \frac{D_{lab\,i}^2}{u^2(x_{lab\,i})} \,. \qquad (11)$$

To checks consistency of ILCs for CLs were used criterion value, calculated from data provided by the CLs does not exceed the critical value χ^2 for confidence level 0.95 and the number of degrees of freedom $n - 1$ (n is number of CL-participants of ILC):

$$\chi^2 \, p \, \chi^2_{0.95}(n-1). \qquad (12)$$

The results of estimation of E_n numbers and χ^2-test of all participant laboratories in COOMET.EM-K6.a and COOMET.EM-S1 comparisons and in national ILC1 are shown in Table 2.

Table 2. The results of estimation of E_n numbers and χ^2-test

Lab	E_n	χ^2	$\chi^2_{0.95}(n-1)$
1 kHz			
VNIIM	0.61		
UMTS	0.00		
BelGIM	0.17		
INM	0.49		
UMTS* (Lab 1)	0.58	2.58	3.33
Lab 2	0.50		
Lab 3	0.48		
Lab 4	1.04		
Lab 5	0.20		
20 kHz			
VNIIM	0.23		
UMTS	0.10		
BelGIM	0.41		
INM	0.47		
UMTS* (Lab 1)	0.04	2.65	3.33
Lab 2	0.64		
Lab 3	0.89		
Lab 4	0.99		
Lab 5	0.02		
100 kHz			
VNIIM	0.88		
UMTS	0.42		
BelGIM	0.19		
INM	0.52		
UMTS* (Lab 1)	0.09	1.57	3.33
Lab 2	0.14		
Lab 3	0.25		
Lab 4	0.14		
Lab 5	0.45		

All laboratories meet the requirements of the E_n numbers and χ^2-test at all frequencies (1 kHz, 20 kHz, and 100 kHz) except Lab 4 at frequency 1 kHz for E_n number. Lab 5 has a very large expanded uncertainty at frequencies of 20 kHz and 100 kHz, so it needs to re-estimation own of measurement uncertainty.

V. CONCLUSIONS

The procedure for linking the results of international comparisons of national standards and ILC results was applied for AD/DC voltage transfer difference measurements. The presented linked results showed good agreement between all participating laboratories. To check the consistency of the linked results, we used the E_n number and the χ2 test.

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