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Evaluation results of COOMET Key Comparison of Power

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Abstract **– The Agreement on Mutual Recognition of the International Committee on Weights and Measures plays a key role for the mutual recognition of the measurement results that are carried out in the National Metrology Institutes from different countries. The COOMET Key Comparison of Power was conducted between thirteen National Metrology Institutes and Designated Institutes from five Regional Metrology Organizations. Traditional results of comparison are published in the Key Comparison Database of International Bureau for Weights and Measures. Results of comparative analysis of this comparison in the context of Regional Metrology Organizations and metrological traceability are presented. For checking consistency of Key Comparison data was used E_n number and z scores. Results for all participants of comparison are satisfactory for E_n number and z scores.**

I. INTRODUCTION

The special agreements on the mutual recognition (MRA) of measurements and tests at the international level are very important to overcome technical barriers to trade between countries. This contributes to the establishment of global metrological traceability [1, 2]. In this case, the main role is have by the National Metrology Institutes (NMIs) and Designated Institute (DIs), in which the national measurement standards are keeping. These measurement standards are subject to periodic international comparisons to establish and further confirm their equivalence to other similar measurement standards.

The Agreement on Mutual Recognition of the International Committee on Weights and Measures (CIPM) [3] plays a key role for the mutual recognition of the measurement results that are carried out in the NMIs of different countries. The main basis for ensuring this process is the results of international comparisons of national measurement standards, which are carried out in accordance with the requirements of the CIPM MRA. The results of such comparisons, in particular of key comparisons (KC), are published in a special key comparison database (KCDB) of the International Bureau of Weights and Measures (BIPM) [4, 5, 6].

KC is conducted both by the consultative committees (CC) of the CIPM, BIPM, and within the regional metrology organizations (RMO), which are distributed on a continental basis, mainly. There are six such RMOs now (EURAMET, APMP, COOMET, SIM, AFRIMET and GULFMET) and all of them organize and conduct KCs according to established procedures. Evaluation of data and results of comparisons includes the establishment of a reference value (RV) of comparisons and it corresponding uncertainty and the degree of equivalence (DoE) of national standards also its corresponding uncertainties [7, 8]. Only Euro-Asian Cooperation of National Metrological Institutions (COOMET) has recommendations for the evaluation of comparison data and results [9, 10].

Comparative analysis of KC results for NMI/DI both in the context of each RMO and metrological traceability to specific NMI/DIs is relevant and important. Carrying out those analysis is connected with the need to take into account the geographical location of the leading institutes. This minimizes the costs of NMI/DIs to achieve the required metrological traceability.

II. THE TRADITIONAL EVALUATION OF KC DATA

CC KC results are interpreted in terms of KC RV and DoE [11, 12]. The RMOs organize the corresponding RMO KCs with a number of common participants and with protocols allowing it results to be linked to the CC KC results after the equivalence of the NMI benchmarks of the participants has been established (calculation of KC RV and DoE). The RMO KC data evaluation procedures are designed to provide linkage to the last CC KC data [7, 13, 14].

Distribution of six RMOs by World map is shown on Fig. 1.

Fig. 1. Distribution of RMOs by World map.

The COOMET KC of active power of low-frequency 50/60 Hz (COOMET.EM-K5) was conducted from 2016 to 2018 between thirteen NMI/DI: State Enterprise (SE) “Ukrmetrteststandard” (UMTS, Ukraine); BelGIM (Belarus); VNIIM (Russia); GEOSTM (Georgia); CMS (Kyrgyzstan); UME (Turkey); SMU (Slovakia); LEM-FEIT (North Macedonia); NIM (China); MASM (Mongolia); QCC EMI (United Arab Emirates); SASO-NMCC (Saudi Arabia), and NIS (Egypt) from five RMOs: COOMET; EURAMET; APMP; GULFMET, and AFRIMET. UMTS was as the pilot laboratory of this KC. The traditional results of KC (DoE) are published in KCDB [4, 15] for power factor (PF) 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, 0.0 Lead at frequencies of 50/53 Hz. Results for PF 1.0 at frequencies of 53 Hz (for example) are shown on Fig. 2. Results for PF (0.5 Lag, 0.5 Lead, 0.0 Lag, 0.0 Lead) at frequencies of 50/53 Hz are similar to those for PF 1.0, so they are not considered further.

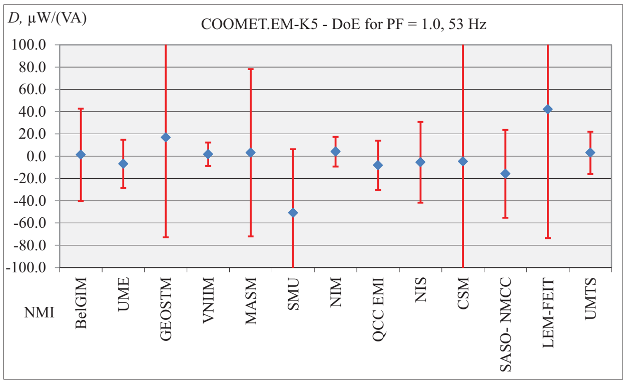

Fig. 2. DoE for NMI/DI participants for PF = 1.0, 53 Hz.

The correlations in traceability between the NMI/DI participants have been neglected for calculating the KC RV. Because three NMI/DIs have the lowest standard uncertainties then they determine the KC RV. NIM and VNIIM was participants of CCEM-K5 KC [16], and UME was pilot laboratory of EURAMET.EM-K5.1 KC [17] and they have different traceability source.

The KC RV x_{ref} is calculated as the mean of NMI/DI participant results with COOMET.EM-K5 data and is given by formula:

$$x_{ref} = \sum_{i=1}^{N} \frac{x_i}{u_c^2(x_i)} \Bigg/ \sum_{i=1}^{N} \frac{1}{u_c^2(x_i)} \tag{1}$$

and combine standard uncertainties

$$u_c^2(x_{ref}) = 1 \Bigg/ \sum_{i=1}^{N} \frac{1}{u_c^2(x_i)}, \tag{2}$$

where x_i is result of i-th NMI/DI participant; $u_c(x_i)$ is standard uncertainty of i-th NMI/DI participant; N is the total number of NMI/DI participants.

KC RV and expanded uncertainties (k = 2) for PF 1.0, 53 Hz are x_{ref} = -2.1 µW/(VA) and U_{ref} = 5.8 µW/(VA).

The DoE of i-th NMI/DI D_i and its combined standard uncertainties $u_c(D_i)$ with respect to the KC RV are estimated as

$$D_i = x_i - x_{ref}, \tag{3}$$

$$u_c^2(D_i) = u_c^2(x_i) + u_c^2(x_{ref}). \tag{4}$$

NMI/DI participant results of RMO KCs of power (EUROMET.EM-K5&K5.1, SIM.EM-K5, and COOMET.EM-K5) are linked to those of CCEM-K5 KC and shown on Fig. 3 for PF 1.0, 53 Hz [4].

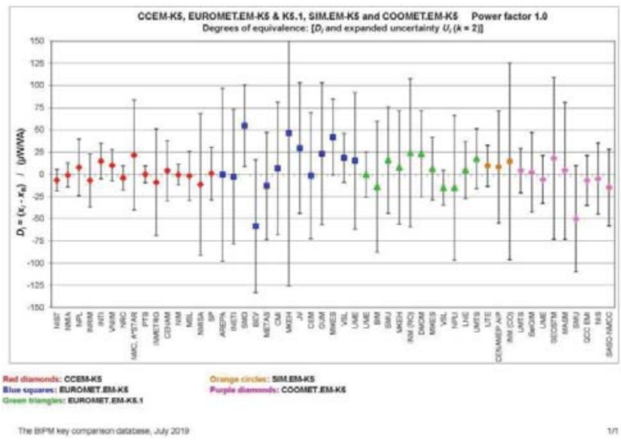

Fig 3. Linked DoE for NMI/DI participants of RMO KCs of power for PF = 1.0, 53 Hz.

DoE of i-th NMI/DI participants of COOMET.EM-K5 with respect to linking to CCEM-K5 is estimated as

$$d_i = D_i + \Delta, \tag{5}$$

where: d_i is best estimate of result from i-th NMI/DI to linking to CCEM-K5; D_i is DoE from COOMET.EM-K5 for NMI/DI participant in COOMET.EM-K5 only; Δ is correction factor with respect to linking to CCEM-K5.

Measurements from the linking NMIs provide estimates

$$\Delta_{iLINK} = d_{iLINK} - D_{iLINK}, \quad (6)$$

where Δ_{iLINK} is correction factor for i-th linking NMI/DI; d_{iLINK} is DoE for i-th linking NMI/DI from CCEM-K5; D_{iLINK} is DoE for i-th linking NMI/DI from COOMET.EM-K5.

NIM and VNIIM were linking NMIs (see Fig. 3). The correction factor Δ is 0.9 for PF 1.0, 53 Hz (for example) [4, 15].

III. THE EVALUATION OF KC RESULTS IN THE CONTEXT OF RMOS

COOMET.EM-K5 KC was conducted between NMI/DI participants from five RMOs: COOMET; EURAMET; APMP; GULFMET, and AFRIMET. NMI/DI participant results (D_i is DoE of i-th NMI/DI participant, $U(D_i)$ is expanded uncertainty of D_i) in the context of RMOs are shown in Table 1 and on Fig. 4 for PF 1.0, 53 Hz.

TABLE 1. NMI/DI RESULTS OF COOMET.EM-K5 IN THE CONTEXT OF RMOS FOR PF 1.0, 53 HZ.

NMI	**D_i, 10^{-6}**	**$U(D_i)$, 10^{-6}**	**E_{ni}**	**z_i**
		COOMET		
VNIIM	1.7	10.6	0.16	0.08
BelGIM	1.2	41.5	0.03	0.06
GEOSTM	16.7	89.6	0.19	0.81
CSM	-4.9	158.1	0.03	0.24
UMTS	3.0	19.0	0.16	0.15
		EURAMET		
UME	-6.9	21.7	0.32	0.34
SMU	-50.9	57.2	0.89	2.48
LEM-FEIT	42.0	115.6	0.36	2.04
		APMP		
NIM	4.0	13.3	0.30	0.19
MASM	3.1	75.1	0.04	0.15
		GULFMET&AFRIMET		
QCC EMI	-8.2	22.2	0.37	0.40
SASO-NMCC	-15.9	39.4	0.40	0.78
NIS	-5.5	36.3	0.15	0.27

E_{ni} number and z_i scores [18-20] are most often used to check the consistency of KC data, which are presented in Table 1 and on Fig. 5 (for E_{ni} number) and Fig. 6 (for z_i score).

E_{ni} number is calculated as:

$$E_{ni} = |D_i| / 2u_c(D_i). \quad (7)$$

z scores are calculated by the formula:

$$z_i = |D_i| / \sigma, \quad (8)$$

where σ is the standard deviation for qualification assessment.

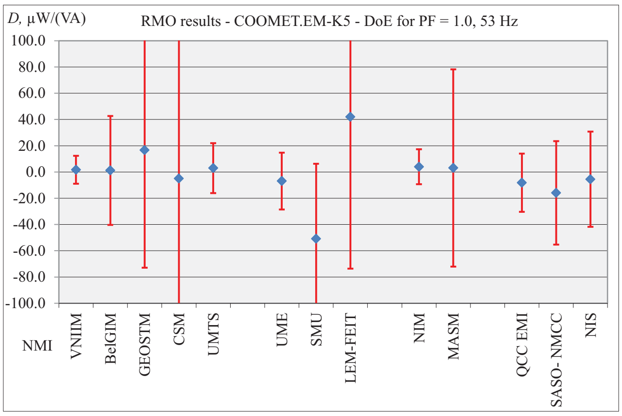

Fig. 4. DoE for NMI/DI participants in the context of RMOs for PF 1.0, 53 Hz.

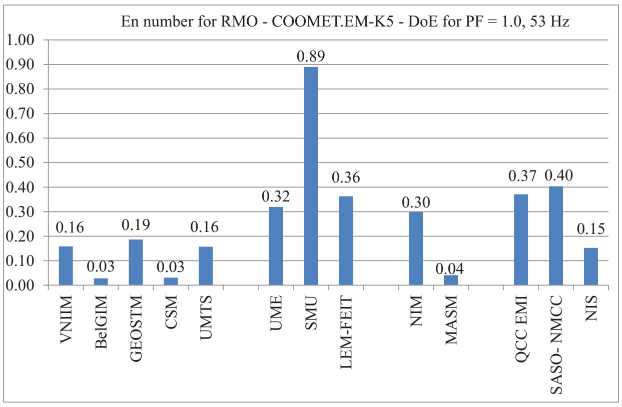

Fig. 5. E_{ni} number for NMI/DI participants in the context of RMOs for PF 1.0, 53 Hz.

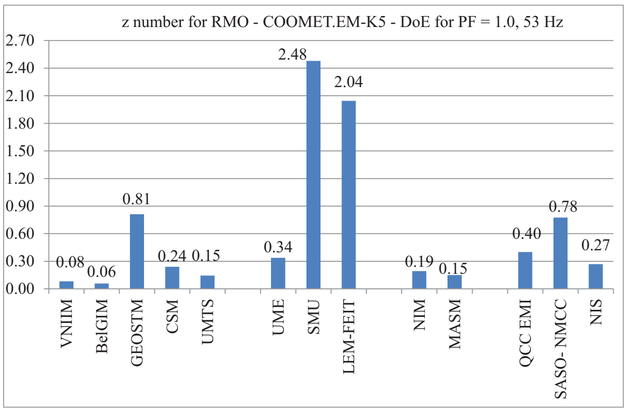

Fig. 6. z score for NMI/DI participants in the context of RMOs for PF 1.0, 53 Hz.

Values of E_{ni} number for COOMET NMI/DI participants of COOMET.EM-K5 are vary from 0.03 to 0.19, EURAMET – from 0.32 to 0.89, APMP – from 0.04 to 0.30, GULFMET&AFRIMET – from 0.15 to 0.40.

The highest values of E_{ni} number are fixed for EURAMET NMI/DI participants, and the smallest – for COOMET. Results for all NMI/DI participants of COOMET.EM-K5 are satisfactory for E_{ni} number (< 1.0), but value of E_{ni} number for SMU from EURAMET several times more than values for all other NMI/DI participants.

Values of z_i scores for COOMET NMI/DI participants are vary from 0.06 to 0.81, EURAMET – from 0.34 to 2.48, APMP – from 0.15 to 0.19, GULFMET&AFRIMET – from 0.27 to 0.78.

The highest values of z_i scores are fixed for EURAMET NMI/DI participants, and the smallest – for COOMET and APMP. Results for all NMI/DI participants of COOMET.EM-K5 are satisfactory for z_i scores (< 3.0), but value of z_i scores for SMU and LEM-FEIT from EURAMET ($2.0 < z_i < 3.0$) indicate a dubious performance characteristic and require precautionary measures.

IV. THE EVALUATION OF KC RESULTS IN THE CONTEXT OF METROLOGICAL TRACEABILITY

In KC of power took part NMI/DIs, which had metrological traceability to the three main NMIs: PTB (Germany), UME, and NIM. PTB, NIM and VNIIM had own traceability as CCEM-K5 KC participants. PTB was a pilot laboratory for EUROMET.EM-K5 KC also. QCC EMI traceabile to NMIA (Australia), which was a pilot laboratory for APMP.EM-K5.

Fig. 7 shows the traceability of NMI/DI participants of COOMET.EM-K5 KC. Cells on Fig. 6 with a dashed line show NMI that did not participate in COOMET.EM-K5 KC.

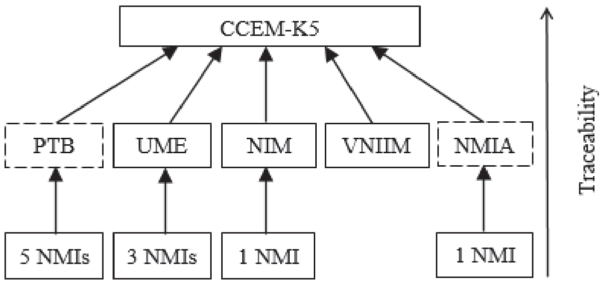

Fig. 7. The metrological traceability for NMI/DI participants.

NMI/DI results of COOMET.EM-K5 in the context of metrological traceability are shown in Table 2 and on Fig. 8. E_{ni} score and z_i score for NMI/DI participants are presented in Table 2 and on Fig. 9 (only for E_{ni} number) and Fig. 10 (for z_i score).

Values of E_{ni} number for NMI/DI participants which traceable to PTB from EURAMET are vary from 0.03 to 0.89, UME from EURAMET – from 0.03 to 0.40, NIM from APMP – from 0.04 to 0.30, other NMI – from 0.16 to 0.37.

The highest values of E_{ni} number are fixed for NMI/DI participants which traceable to PTB, and the smallest – for NIM and UME. Results for all NMI/DI participants are satisfactory for E_{ni} number (< 1.0), but value of E_{ni} number for SMU may indicate the time drift of the power standard since its last calibration in the PTB. In general, NMI/DI participants of comparison may be encouraged to calibrate it standards immediately before of comparison.

Table 2. NMI/DI results in the context of metrological traceability to NMI/DI.

NMI	D_i, 10^{-6}	$U(D_i)$, 10^{-6}	E_{ni}	z_i
PTB				
UMTS	3.0	19.0	0.16	0.15
BelGIM	1.2	41.5	0.03	0.06
GEOSTM	16.7	89.6	0.19	0.81
SMU	-50.9	57.2	0.89	2.48
LEM-FEIT	42.0	115.6	0.36	2.04
UME				
UME	-6.9	21.7	0.32	0.34
SASO- NMCC	-15.9	39.4	0.40	0.78
NIS	-5.5	36.3	0.15	0.27
CSM	-4.9	158.1	0.03	0.24
NIM				
NIM	4.0	13.3	0.30	0.19
MASM	3.1	75.1	0.04	0.15
Other NMI/DI				
VNIIM	1.7	10.6	0.16	0.08
QCC EMI	-8.2	22.2	0.37	0.40

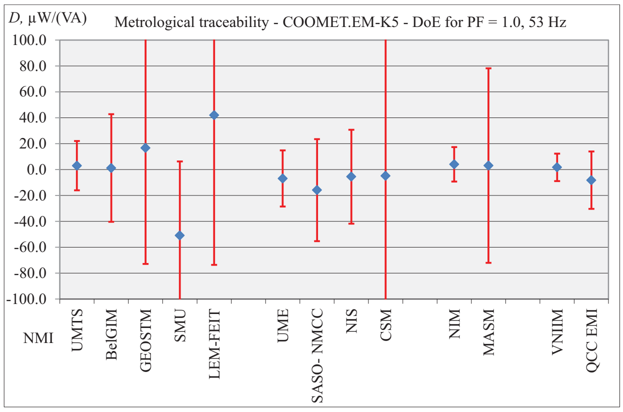

Fig. 8. DoE for NMI/DI participants in the context of traceability for PF 1.0, 53 Hz.

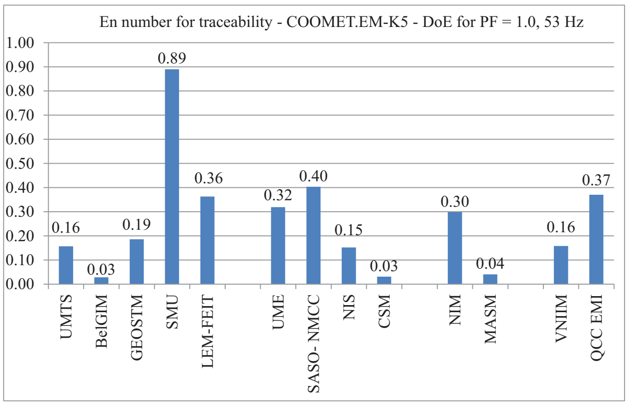

Fig. 9. E_{ni} number for NMI/DI participants in the context of traceability for PF 1.0, 53 Hz.

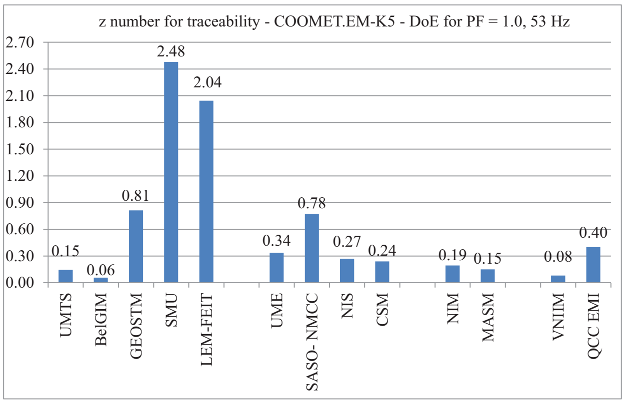

Fig. 10. z_i number for NMI/DI participants in the context of metrological traceability for PF 1.0, 53 Hz.

Values of z_i scores for NMI/DI participants which traceable to PTB from EURAMET are vary from 0.06 to 2.48, UME from EURAMET – from 0.24 to 0.78, NIM from APMP – from 0.15 to 0.19, other NMI – from 0.08 to 0.40.

The highest values of z_i scores are fixed for NMI/DI participants which traceable to PTB, and the smallest – for NIM. Results for all NMI/DI participants are satisfactory for z_i scores (< 3.0). Value of z_i scores for SMU and LEM-FEIT ($2.0 < z_i < 3.0$), which traceable to PTB, indicate a dubious performance characteristic and require precautionary measures. In both cases, the specified NMI/DI participants also need to pay attention to improving the level of practical training of staff.

V. THE POSSIBILITY OF IMPLEMENTATION OF THE CIPM MRA

BelGIM, UME, SMU, and UMTS checked COOMET.EM-K5 KC results against CMC entries in the KCDB and confirmed that the results support these CMC entries for active power.

GEOSTM, MASM, QCC EMI, SASO-NMCC, and NIS are had not CMC entries in the KCDB. COOMET.EM-K5 results of these NMI/DIs may be basis for preparing of CMC entries draft for active power.

NMIs Kyrgyzstan and North Macedonia are not signatories of the CIPM MRA, therefore, CSM and LEM-FEIT do not have possibility to prepare CMC entries draft for AC active power.

Results this KC can become the basis for recognizing quality management systems of NMI/DI participants (MASM, QCC EMI, and SASO-NMCC) for internationally recognized calibration service – CMC in field of electrical and magnetism.

VI. CONCLUSION

In general, there is good agreement of results of NMI/DI participants of KC for AC active power from five RMOs. This comparative analysis of KC results in the context of each RMO is shown the geographical context of NMI/DI participants.

All NMI/DI participants of this KC reported metrological traceability of the unit of AC active power. Traceabile of NMI/DI participants was provided through the NMIs that participated in the CCEM-K5 KC (PTB, NIM, and VNIIM), and NMIs, which was pilot laboratories of KC RMOs (UME, and NMIA). This comparative analysis can make it possible to minimize the cost of NMI/DI to achieve the required metrological traceability for AC active power. For such RMOs as COOMET, EURAMET, APMP, and GULFMET the results of this KC can become the basis for conducting a peer-review of NMIs/DIs in order to recognize its quality management systems for calibration service in framework of the CIPM MRA. It is expected that this comparison will be able to provide support for NMI/DI participants' entries in Appendix C of the CIPM MRA. Five NMI/DI participants KC (GEOSTM, MASM, QCC EMI, SASO-NMCC, and NIS) which do not have CMC entries in the KCDB got such opportunity.

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