UDC 001.4:389.14:621.317

Main Results of COOMET.EM-K5 Key Comparison of Power

O. Velychko, S. Karpenko

State Enterprise "All-Ukrainian state research and production center for standardization, metrology, certification and consumers' rights protection" (SE "Ukrmetrteststandart"), Metrologichna Str., 4, 03143, Kyiv, Ukraine
velychko@ukrcsm.kiev.ua
s.r.karpenko86@gmail.com

Abstract

The COOMET.EM-K5 Key Comparison of Power was carried out in the CIPM–MRA framework from 2016 to 2018. The main aims of this project were to compare national measurement standards of low-frequency 50/60 Hz power and to link with the CCEM-K5 Key Comparison. This comparison was carried out between 13 National Metrology Institutes which are the members of five Regional Metrology Organisations: COOMET, EURAMET, APMP, GULFMET and AFRIMET. The selected travelling standard of low-frequency 50/60 Hz power was compared at: UMTS (Ukraine), BelGIM (Belarus), VNIIM (Russia), GeoSTM (Georgia), CMS (Kyrgyzstan), UME (Turkey), SMU (Slovakia), LEM-FEIT (R. Macedonia), NIM (China), MASM (Mongolia), QCC EMI (UAE), SASO-NMCC (Saudi Arabia), and NIS (Egypt). UMTS was a pilot laboratory. NIM (China) and VNIIM (Russia) were linking National Metrology Institutes for the linking process between CCEM-K5 Key Comparison and COOMET.EM-K5 Key Comparison due of participating in CCEM-K5 Key Comparison.

The paper is devoted to the discussion of issues concerning the participation and further evaluation of measurement data of COOMET.EM-K5 Key Comparison of Power. Main results of participating laboratories measuring the same power of travelling standard of low-frequency 50/60 Hz power in a framework of COOMET.EM-K5 Key Comparison of Power are presented. Besides, the paper describes some problems concerning the evaluation of travelling standard drift effect and its further influence on evaluation of Key Comparison Reference Value during a Key Comparison. Degrees of Equivalence and Expanded Uncertainties of National Metrology Institutes participants are set. In addition, E_n number was calculated for each National Metrology Institute participating in COOMET.EM-K5 Key Comparison of Power with the aim of determining data consistency.

Keywords: drift effect, key comparison, electric power, key comparison reference value, travelling standard, degree of equivalence.

Received: 14.02.2019 Edited: 11.03.2019 Approved for publication: 18.03.2019

Introduction

Key comparisons (KCs) are the special comparisons for National Metrology Institutes (NMIs) in a frame of Constative Committee (CC) and Regional Metrology Organizations (RMOs) around the world, which are carried out within the framework of the International Committee for Weights and Measures (CIPM) of Mutual Recognition Arrangement (MRA) [1, 2]. The main purpose of KCs is the determination of the equivalence between laboratories of different NMIs.

The unilateral degree of equivalence (DoE) of a laboratory is obtained as the deviation of its measurement result from the KC reference value (KCRV), together with the uncertainty associated with this deviation according to the CIPM MRA [3].

The CIPM MRA describes in general how the data of KC should be evaluated but it does not provide enough specifics to define an unambiguous analysis. Consequently many different ways of evaluating KC data have been suggested over the years [4, 5].

Brief review of performed Key Comparisons of Power

To support CIPM MRA [1] between laboratories of different NMIs, CIPM Consultative Committee for Electricity and Magnetism (CCEM) was a sponsor of international comparisons of electromagnetic units between NMIs [6]. CCEM organized international KC of 50/60 Hz electric power (EP) (CCEM-K5) in 1995. The NIST was selected as the pilot laboratory [7].

In 1994 it was agreed at a meeting of EURAMET AC power experts at the Swedish National Testing and

Research Institute (SP) to perform EURAMET KC of 50/60 Hz EP (EURAMET.EM-K5) to support CIPM MRA [1] between members of European Community. The PTB was proposed as the pilot laboratory. EURAMET.EM-K5 KC was carried out from 1996 to 2001 [8].

At the end of the EURAMET.EM-K5 KC some more European NMIs showed their interest to the comparison of EP and were willing to participate in the measurements. It was decided to start a new EURAMET.EM-K5.1 KC, but at the same measurement points and using the same kind of travelling standard (TS) [9]. The UME was a pilot laboratory. EURAMET.EM-K5.1 KC was carried out from 2003 to 2008. Moreover, some NMIs participated in the KC were improved their capabilities for EP measurements and their measurement uncertainties. The link between the CCEM-K5 and EURAMET.EM-K5.1 was established by following the example [10] as in EURAMET. EM-K5. SE "Ukrmetrteststandart" (UMTS) took part as the participant in EURAMET.EM-K5.1 KC with the aim of publishing Calibration and Measurement Capabilities (CMCs) for EP unit in the of the International Bureau for Weights and Measures (BIPM) Key Comparison Database (KCDB).

The SIM Electromagnetic Working Group (WG) under the auspices of the CCEM carried out a KC of EP measurement standards at 50/60 Hz. The pilot laboratory was CENAM. This KC was assigned the number SIM.EM-K5 [11]. The main aim was to provide a link to various NMIs in the SIM region to the CCEM-K5 KC on 50/60 Hz EP [7].

In 1996, an APMP.EM-K5 KC (the NMIA was a pilot laboratory) and in 2006, an APMP.EM-K5.1 KC (the NIM was a pilot laboratory) of 50/60 Hz EP were organized to link with the CCEM-K5 KC.

To support the published CMCs, UMTS organized Supplementary Comparison COOMET.EM-S2 (SC) [12] and was a pilot laboratory. It was decided to perform the comparison at 120 V, 5 A, 50 Hz and 53 Hz, power factors 1, 0.5 Lead/Lag in order to be in line with EURAMET.EM-K5.1 KC. The procedure was proposed for linking results of EURAMET.EM-K5.1 KC and COOMET.EM-S2 SC to those NMIs which have also taken part in both comparisons [13].

Participants of COOMET.EM-K5 Key Comparison of Power

The COOMET.EM-K5 KC of Power was carried out in the CIPM–MRA framework from 2016 to 2018. The main aims of this project were to compare national measurement standards of EP of low-frequency 50/60 Hz power and to link with the CCEM-K5 KC. COOMET.EM-K5 KC was carried out between 13 NMIs which are the member of five RMOs: COOMET, EURAMET, APMP, GULFMET and AFRIMET. TS of low-frequency 50/60 Hz power was compared at: UMTS (Ukraine), BelGIM (Belarus), VNIIM (Russia), GeoSTM (Georgia), CMS (Kyrgyzstan), UME (Turkey), SMU (Slovakia), LEM-FEIT (R. Macedonia), NIM (China), MASM (Mongolia), QCC EMI (UAE), SASO-NMCC (Saudi Arabia), and NIS (Egypt). UMTS was a pilot laboratory responsible for providing the TS, coordinating the schedule, collecting and analysing the comparison data, and preparing the draft report, etc.

NIM (China) and VNIIM (Russia) was linking NMIs for the linking process between CCEM-K5 KC and COOMET.EM-K5 KC due to participating in CCEM-K5 [13, 14]. Relevance of the comparison results are expected at the level better than 0.005 %.

General review of the travelling standard

Selected TS is of Radian Research type RD-33-332 (serial number 301308) (RD-33-332). The RD-33-332 has a guaranteed accuracy of 0.01 %. Appearance of RD-33-332 is shown in Fig. 1.

Fig. 1. Travelling standard RD-33-332

RD-33-332 is three-phase electric power meter that works on principles of digital processing of electrical current and voltage signals and measurement principle is based upon the fundamentals of a high-speed charge-balance integrating analogy to digital signal converter. To carry out measurements on COOMET. EM-K5 KC of power all the participating NMIs needed to use a single-phase switching circuit (only phase A). And as the reference of output signal, frequency output is used. Main characteristics of RD-33-332 are: input voltage: from 30 V to 525 V (RMS); input current: from 0.2 A to 120 A (RMS); frequency of the input voltage and current signals: from 45 Hz to 65 Hz; constant of the frequency output: 125000 pulse/Wh; supply voltage: from 60 V to 525 V (RMS); working range of the temperature: from minus 20 °C to 40 °C; keeping range of the temperature: from minus 25 °C to 80 °C; working range of the humidity: from 0 % to 95 %; dimensions: 444.5×172.0×131.0 mm; weight: 6.2 kg.

Before starting measurements the RD-33-332 must be warmed up for 24 hours (connected to the main power supply). Current and voltage signals must be connected for 4 hours before measurement. Only following these procedures, short-term shutdown signal current or voltage from TS will not lead to loss of the TS's characteristics. But if the power supply of TS will be turned off, then the procedure of warming up must be made over again. Main measurements should be performed with the input signals: voltage 120 V ± 0.2 %; current 5 A ± 0.2 %; power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, 0.0 Lead deviation from the nominal value not exceeding ± 0.1 %; frequency 50 Hz ± 0.05 Hz and 53 Hz ± 0.05 Hz.

Behaviour of the travelling standard

During KC all the participating laboratories should measure the identical TS, which often is not perfectly stable. So it is necessary to take into account the instabilities arising from the ageing of the TS or by several physical or mechanical changes during the transportation process or from the time. The presence of drift of TS directly influences the quality of KC [15].

If preliminary analysis of the KC data points out the presence of TS drift, it is necessary to evaluate this one. This evaluation has significance for a final assessment KCRV and the degrees of equivalence of the NMIs standards.

The UMTS as pilot laboratory has performed repeated measurements over the duration of the KC in order to monitor the stability of the TS and also the correction to compensate the drift can be evaluated. The evaluated correction which depends on both the stability of the TS and the long term stability of the measurements and its standard uncertainty will be included in the model describing the measurement process of the KC [16]. The different approaches for evaluation drift effect to the COOMET.EM-K5 KC were applied [17].

TS RD-33-332 provides extreme linearity coupled with extreme stability. In addition, high resolution and repeatability permit rapid and accurate single revolution testing both in the field and in the lab with the appropriate optical pickup [18, 19]. The RD-33-332 is well-suited for test applications that require multiple measurements with high accuracy and as well as long term and short term stabilities. The drift effect was calculated during the course of this KC. From these measurements after analysing specified that the behaviour of TS is the linear fit [20]. As the example the drift values δP_{drift} are given in Table 1 only for frequency 50 Hz and PF = 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead. As was calculated, the drifts effect was linear and small for all measurement points, so it can be neglected.

Table 1

The drift values δP_{drift}, μW/(VA)

Frequency	Power factor	δP_{drift}
50 Hz	1.0	-0.14
	0.5 Lag	-0.14
	0.5 Lead	0.80
	0.0 Lag	-0.26
	0.0 Lead	0.72

The Key Comparison reference values

Measurement report containing all relevant data and uncertainty estimates was forwarded to the coordinator of KC within six weeks of completing measurement of the TS. The KC reference values (RV) x_{ref} are calculated as the mean of participant results with COOMET.EM-K5 data are given by [21, 22]:

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

with combine standard uncertainties

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

As the example RV and expanded uncertainties only for 50 Hz are given in Table 2.

Table 2

Reference values and expanded uncertainties for frequency 50 Hz

Frequency	Power factor	x_{ref}, μW/(VA)	U_{ref}, μW/(VA)
50 Hz	1.0	-0.8	6.4
	0.5 Lag	5.8	6.5
	0.5 Lead	-5.6	6.4
	0.0 Lag	4.2	5.7
	0.0 Lead	-7.1	5.7

The UMTS as pilot laboratory has provided the traceability to the SI of national national standards. All of the participating NMIs made measurements at the same measurement points for 50 Hz and 53 Hz power.

UMTS, BelGIM, GeoSTM, SMU, NIS, and LEM FEIT power measurements are traceable to the PTB. The PTB participated in CCEM-K5 KC and EURAMET.EM-K5.1 KC and also was a pilot laboratory for EUROMET.EM-K5 KC.

CSM, SASO NMCC and NIS power measurements are traceable to the UME. The UME was a pilot laboratory for EURAMET.EM-K5.1 KC and also participated in EURAMET.EM-K5 KC.

Table 3

Degrees of equivalence and the E_n numbers of the NMI participants

NMI	50 Hz					
	D_i, μW/(VA)	$U(D_i)$, μW/(VA)	E_n	D_i, μW/(VA)	$U(D_i)$, μW/(VA)	E_n
	PF = 1.0			PF = 0.5 Lag		
BelGIM	-1.1	42.5	0.02	-2.9	42.9	0.07
UME	-4.2	21.9	0.19	-6.8	22.6	0.30
GEOSTM	18.1	89.6	0.20	9.1	136.0	0.07
VNIIM	2.2	13.2	0.17	3.6	12.1	0.30
MASM	-2.2	87.3	0.02	28.2	122.2	0.23
SMU	-51.8	74.9	0.69	2.5	84.7	0.03
NIM	1.8	13.6	0.14	-1.1	13.6	0.08
QCC EMI	-5.6	22.3	0.25	-3.6	25.6	0.14
NIS	-7.0	36.4	0.19	10.0	46.7	0.22
CSM	-17.2	158.2	0.11	-15.8	158.1	0.10
SASO-NMCC	-8.2	39.5	0.21	-12.8	40.5	0.31
LEM-FEIT	46.4	115.7	0.40	0.0	115.7	0.00
UMTS	2.6	19.6	0.14	-3.3	27.2	0.12
NMI	PF = 0.5 Lead			PF = 0.0 Lag		
BelGIM	0.4	43.6	0.01	0.6	42.2	0.01
UME	0.6	22.6	0.03	-0.2	22.6	0.01
GEOSTM	4.2	136.0	0.03	1.6	203.1	0.01
VNIIM	-2.5	12.1	0.21	2.7	10.8	0.25
MASM	-24.4	106.7	0.23	18.8	84.2	0.22
SMU	-14.1	84.7	0.17	27.6	91.4	0.30
NIM	1.2	13.6	0.09	-2.1	11.5	0.18
QCC EMI	-4.8	25.0	0.19	2.5	20.8	0.12
NIS	26.8	40.9	0.66	-30.0	39.6	0.76
CSM	-16.4	158.2	0.10	-68.2	160.3	0.43
SASO-NMCC	2.6	40.5	0.06	-6.2	41.4	0.15
LEM-FEIT	86.5	115.7	0.75	38.4	115.6	0.33
UMTS	1.4	26.3	0.05	-0.5	24.6	0.02
NMI	PF = 0.0 Lead			–		
BelGIM	11.6	45.2	0.26	–	–	–
NMI	PF = 0.0 Lead			–		
UME	1.1	22.6	0.05	–	–	–
GEOSTM	-5.8	203.1	0.03	–	–	–
VNIIM	-2.0	10.8	0.18	–	–	–
MASM	34.1	84.2	0.40	–	–	–
SMU	51.8	91.4	0.57	–	–	–
NIM	0.5	11.5	0.04	–	–	–
QCC EMI	0.6	20.9	0.03	–	–	–
NIS	-18.4	37.6	0.49	–	–	–
CSM	-43.9	161.7	0.27	–	–	–
SASO-NMCC	6.1	41.4	0.15	–	–	–
LEM-FEIT	55.0	115.6	0.48	–	–	–
UMTS	3.3	25.2	0.13	–	–	–

The MASM power measurements are traceable to the NIM and the KRISS. The NIM participated in CCEM-K5 KC and was a pilot laboratory in APMP.EM-K5.1. QCC EMI power measurements are traceable to the NMIA. The NMIA was a pilot laboratory in APMP.EM-K5.

Degrees of equivalence of participants

The principal results of this KC are the pairwise degrees of equivalence and the DoE with respect to the KCRV of CCEM-K5 KC. Degrees of equivalence of the NMI participants are reported with respect to the measurement at 50 Hz. The DoE of *i*-th NMI and its combined standard uncertainties with respect to the KCRV (*j* is number marking for frequencies 50 Hz and PF = 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead, *j* = 10) are estimated as

$$D_i = x_i - x_{refj}, \quad (3)$$

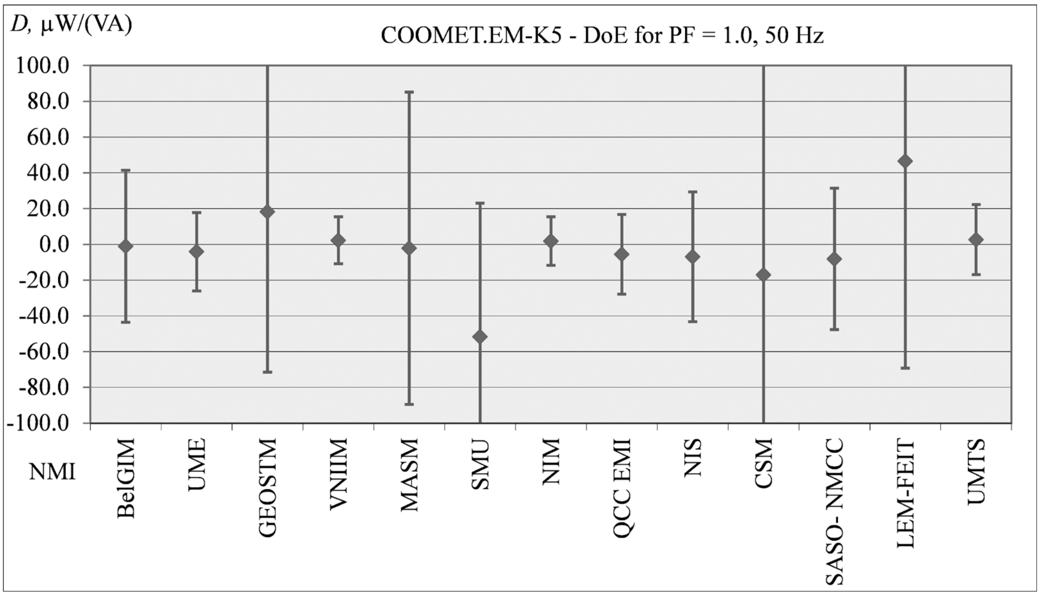

Fig. 2. Degree of equivalence for NMI participants for PF = 1.0, 50 Hz

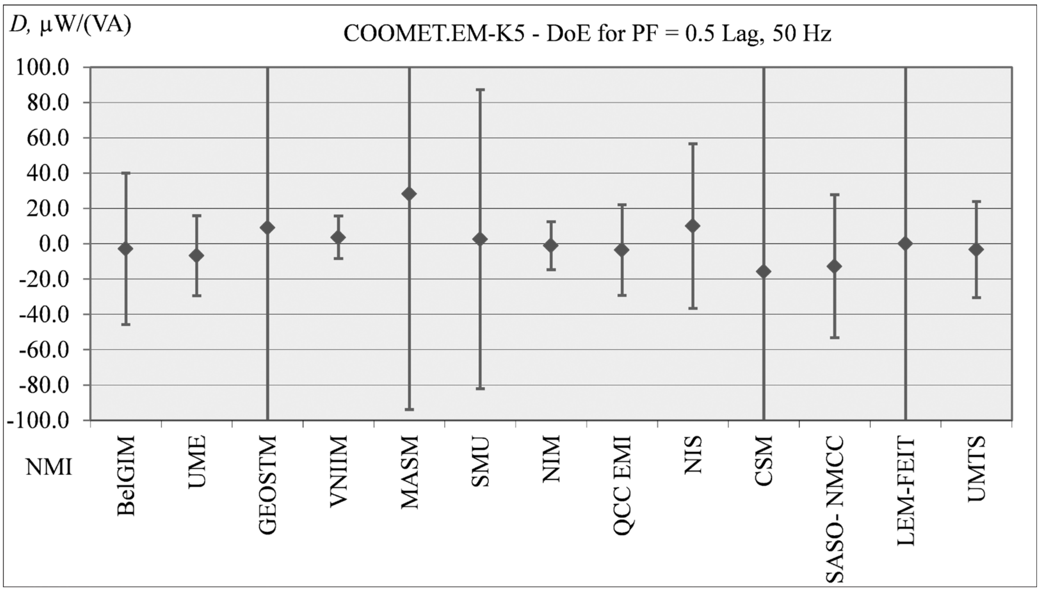

Fig. 3. Degree of equivalence for NMI participants for PF = 0.5 Lag, 50 Hz

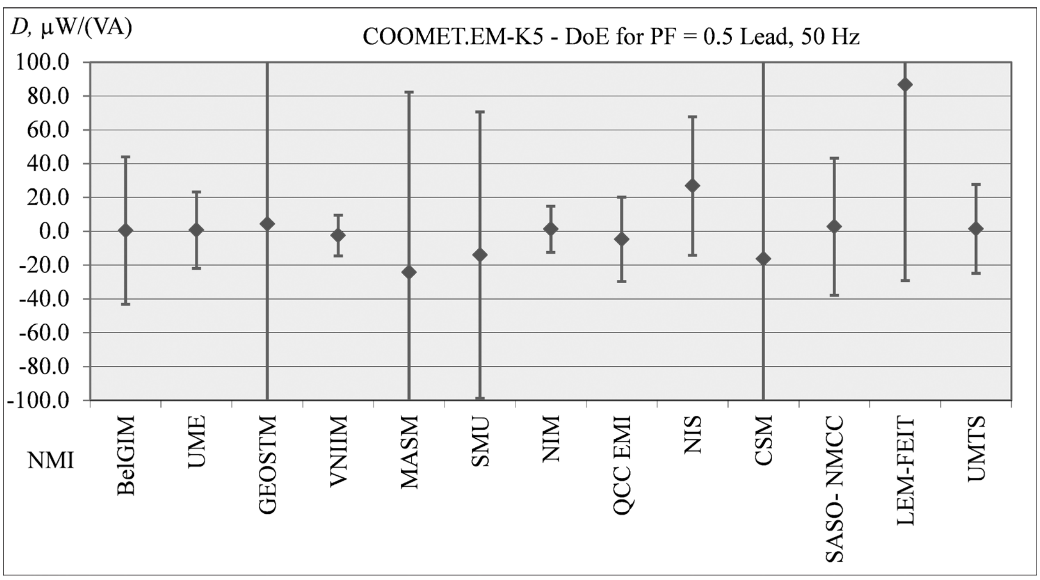

Fig. 4. Degree of equivalence for NMI participants for PF = 0.5 Lead, 50 Hz

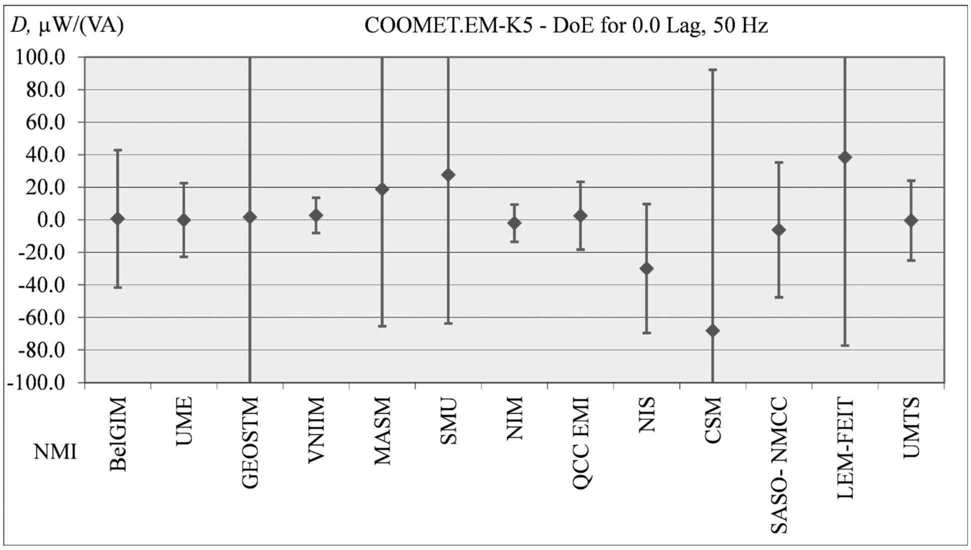

Fig. 5. Degree of equivalence for NMI participants for PF = 0.0 Lag, 50 Hz

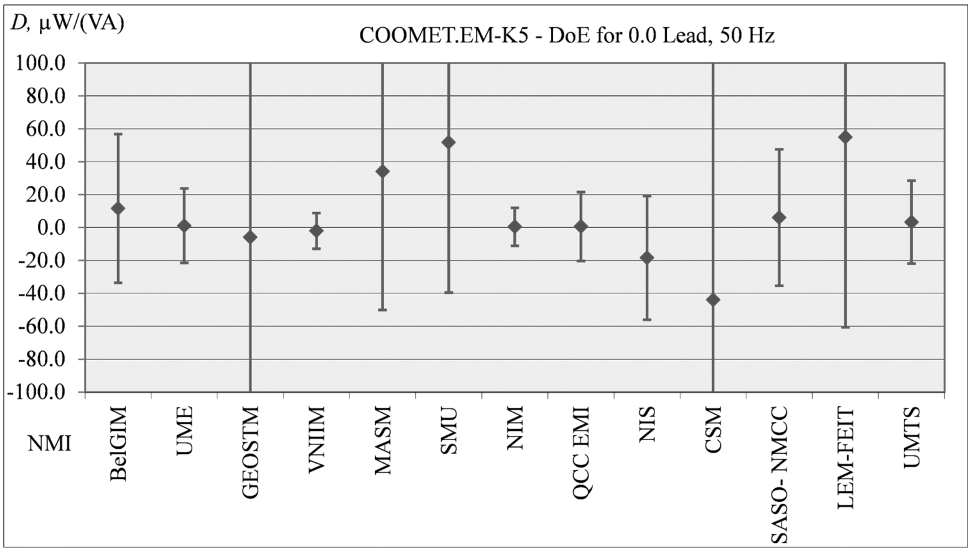

Fig. 6. Degree of equivalence for NMI participants for PF = 0.0 Lead, 50 Hz

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

Additionally, the performance E_n number was calculated as follow:

$$E_n = \frac{|D_i|}{2u_c(D_i)}. \quad (5)$$

All DoE and the E_n numbers are given in Table 3, and the graphs in Fig. 2–6. The E_n numbers for all NMI participants satisfy the condition of performance ($E_n \leqslant 1.0$).

The pair DoE of *i*-th NMI and *j*-th NMI participants D_{ij} and its expanded uncertainties $U(D_{ij})$ ($k = 2$) with respect to the KCRV, pair DoE of *i*-th NMI and *j*-th NMI participants D_{ij} with combined standard uncertainty $u_c(D_{ij})$ are estimated by

$$D_{ij} = x_i - x_j, \quad (6)$$

$$u_c^2(D_{ij}) = u_c^2(x_i) + u_c^2(x_j). \quad (7)$$

Conclusion

The paper is devoted to the discussion of issues concerning the participation and further evaluation of measurement data of COOMET.EM-K5 KC of Power.

It was determined that the TS RD-33-332 was perfectly stable during the period of long term measurement in a frame of COOMET.EM-K5. The value of drifts effect is between minus 0.14 µW/VA and 0.80 µW/VA. As the result, the calculated drifts effect was linear and small for all measurement points, so it was neglected. Also the KCRVs and their expanded uncertainties were calculated. The KCRVs lie in the range from minus 0.8 µW/VA (PF = 1.0) to minus 7.1 (PF = 0.0 Lead) with expanded uncertainties from 5.7 µW/VA to 6.4 µW/VA.

Degrees of equivalence and Expanded Uncertainties in µW/VA of NMI participants were calculated. The E_n numbers lie in the range from 0.00 to 0.76 for all NMI participants, that satisfies the condition of performance $E_n \leqslant 1.0$ and characterizes good data consistency.

Основні результати ключових звірень з потужності COOMET.EM-K5

О.М. Величко, С.Р. Карпенко

ДП "Укрметртестстандарт", вул. Метрологічна, 4, 03143, Київ, Україна
velychko@ukrcsm.kiev.ua
s.r.karpenko86@gmail.com

Анотація

Ключові звірення з потужності COOMET.EM-K5 були проведені у рамках Угоди CIPM MRA з 2016 по 2018 рік. Основними цілями цього проекту були звірення національних еталонів низькочастотної електричної потужності 50/60 Гц та прив'язка результатів до ключових звірень CCEM-K5. Зазначені звірення проводилися між 13 національними метрологічними інститутами, які є членами 5 регіональних метрологічних організацій: COOMET, EURAMET, APMP, GULFMET та AFRIMET. Обраний транспортабельний еталон низькочастотної потужності 50/60 Гц звірявся в: УМТС (Україна), BelGIM (Республіка Білорусь), ВНІІМ (Російська Федерація), GeoSTM (Грузія), CMS (Киргизстан), UME (Туреччина), SMU (Словаччина), LEM-FEIT (Республіка Македонія), NIM (Китай), MASM (Монголія), QCC EMI (ОАЕ), SASO-NMCC (Саудівська Аравія) і NIS (Єгипет). УМТС був пілотною лабораторією. NIM (Китай) і VNIIM (Російська Федерація) були запропоновані як зв'язувальні національні метрологічні інститути через їх участь у ключових звіреннях CCEM-K5 задля прив'язки результатів ключових звірень CCEM-K5 до результатів ключових звірень COOMET.EM-K5.

Статтю присвячено обговоренню питань, що стосуються участі та подальшої оцінки виміряних даних у рамках ключових звірень з потужності COOMET.EM-K5. Наведено основні результати національних метрологічних інститутів-учасників, що проводять вимірювання одного і того ж транспортабельного еталона низькочастотної потужності 50/60 Гц у рамках ключових звірень з потужності COOMET.EM-K5. Також розглянуто проблеми, пов'язані з оцінкою ефекту дрейфу транспортабельного еталона та його подальший вплив на оцінку опорного значення ключових звірень під час їх проведення. Визначено ступені еквівалентності та розширені невизначеності національних метрологічних інститутів-учасників. Також було розраховано критерій E_n для кожного національного метрологічного інституту-учасника ключових звірень COOMET.EM-K5 з метою визначення узгодженості виміряних даних.

Ключові слова: ефект дрейфу, ключові звірення, електрична потужність, опорне значення ключових звірень, транспортабельний еталон, ступінь еквівалентності.

Основные результаты ключевых сличений по мощности COOMET.EM-K5

О.Н. Величко, С.Р. Карпенко

ГП "Укрметртестстандарт", ул. Метрологическая, 4, 03143, Киев, Украина
velychko@ukrcsm.kiev.ua
s.r.karpenko86@gmail.com

Аннотация

Ключевые сличения по мощности COOMET.EM-K5 были проведены в рамках Соглашения CIPM MRA с 2016 по 2018 год. Основными целями данного проекта были сличения национальных эталонов низкочастотной электрической мощности 50/60 Гц и привязка результатов к ключевым сличениям CCEM-K5. Указанные сличения были проведены между 13 национальными метрологическими институтами, которые являются членами 5 региональных метрологических организаций: КООМЕТ, EURAMET, APMP, GULFMET и AFRIMET. Выбранный транспортируемый эталон низкочастотной мощности 50/60 Гц сличался в: УМТС (Украина), БелГИМ (Республика Беларусь), ВНИИМ (Российская Федерация), GeoSTM (Грузия), CMS (Кыргызстан), UME (Турция), SMU (Словакия), LEM-FEIT (Македония), NIM (Китай), MASM (Монголия), QCC EMI (ОАЭ), SASO-NMCC (Саудовская Аравия) и NIS (Египет). УМТС был пилотной лабораторией. NIM (Китай) и VNIIM (Российская Федерация) были предложены в качестве связующих национальных метрологических институтов из-за их участия в ключевых сличениях CCEM-K5 с целью привязки результатов ключевых сличений CCEM-K5 к результатам ключевых сличений COOMET.EM-K5.

Статья посвящена обсуждению вопросов, касающихся участия и дальнейшей оценки измеренных данных в рамках ключевых сличений по мощности COOMET.EM-K5. Приведены основные результаты национальных метрологических институтов-участников, которые провели измерения одного и того же транспортируемого эталона низкочастотной мощности 50/60 Гц в рамках ключевых сличений по мощности COOMET.EM-K5. Рассмотрены проблемы, связанные с оценкой эффекта дрейфа транспортируемого эталона и его дальнейшего влияния на оценку опорного значения ключевых сличений во время их проведения. Определены степени эквивалентности и расширенные неопределенности национальных метрологических институтов-участников. Также был рассчитан критерий E_n для каждого национального метрологического института-участника ключевых сличений COOMET.EM-K5 с целью определения согласованности измеренных данных.

Ключевые слова: эффект дрейфа, ключевые сличения, электрическая мощность, опорное значение ключевых сличений, транспортируемый эталон, степень эквивалентности.

References

1. Mutual Recognition of National Measurement Standards, of Calibration and Measurement Certificates issued by National Metrology Institutes (CIPM MRA 1999, revision 2003). 48 p.
2. Velichko O.N. Traceability of measurement results at different levels of metrological work. *Measurement Techniques*, 2009, vol. 52, pp. 1242–1248.
3. Wübbeler G., Bodnar O., Mickan B. and Elster C. Explanatory power of degrees of equivalence in the presence of a random instability of the common measurand. *Metrology*, 2015, vol. 52, pp. 400–405.
4. Elster C., Toman B. Analysis of key comparison data: critical assessment of elements of current practice with suggested improvements. *Metrology*, 2013, vol. 50, pp. 549–555.
5. Elster C., Toman B. Analysis of Key Comparisons: Estimating Laboratories' Biases by a Fixed Effects Model Using Bayesian Model Averaging. *Metrologia*, 2010, vol. 47, no. 3. 113 p.
6. CIPM MRA-D-05. Measurement comparisons in the context of the CIPM MRA. 2016. 29 p.
7. Oldham N., Nelson T., Zhang N.F., Liu H.-k. Final Report of CCEM-K5 Comparison of 50/60 Hz Power. *Metrologia*, 2003, vol. 40, Technical Supplement, 01003. 28 p.
8. Bergeest R. Final report on EUROMET.EM-K5: Comparison of 50/60 Hz power (EUROMET project 385). *Metrologia*, 2007, vol. 44, Technical Supplement, 01001. 64 p.
9. Çaycı H. EURAMET.EM-K5.1. Key Comparison of 50/60 Hz Power Final Report. *Metrologia*, 2011, vol. 48, Technical Supplement, 01009. 70 p.
10. Delahaye F., Witt T.J. Linking the Results of Key Comparison CCEM-K4 with the 10 pF Results of EUROMET Project 345. *Metrologia*, 2002, vol. 39, Technical Supplement, 01005. 33 p.
11. Carranza R., Campos S., Castruita A., Nelson T., Ribeiro A., So E. Final Report Key Comparison of 50/60 Hz Power. *Metrologia*, 2015, vol. 52, Technical Supplement, 01002. 52 p.
12. Velychko O., Karpenko S., Gachok V., Akhmadov A. Final Report on COOMET 344/UA/05 Supplementary Comparison of 50/53 Hz Power (COOMET. EM-S2). *Metrologia,* 2015, vol. 52, 01008. 29 p.
13. Velychko O., Karpenko S. Linking results of key and supplementary comparisons of regional metrology organization for electrical power. *International Journal of Metrology and Quality Engineering*, 2016, vol. 7, no. 3, pp. 301–308.
14. Velychko O., Karpenko S. Final report on COOMET 695/UA/16 Key Comparison of Power (COOMET.EM-K5). SE "Ukrmeterteststandard", Decemder 2018. 136 p.
15. Velychko O., Karpenko S., Karpenko I. Features of evaluation drift effect during Key Comparison COOMET.EM-K5. *22nd IMEKO TC4 International Symposium and 20th International Workshop on ADC Modelling and Testing:* Supporting world development through electrical & electronic measurements. Iasi, Romania, 2017, pp. 1–6.
16. Bergoglio M., Malengo A., Mari D. Analysis of interlaboratory comparisons affected by correlations of the reference standards and drift of the travelling standards. *Measurement*, 2011, no. 44, pp. 1461–1467.
17. Karpenko S., Velychko O. Evaluation Standard Uncertainty Depends on Travelling Standard Instability during Key Comparison: Digest of 2018 Conference on Precision Electromagnetic Measurement (CPEM 2018). Paris, France, 2018, 2 p. doi: 10.1109/CPEM.2018.8500930.
18. Stepanov A.V. General problems of metrology and measurement technique — Comparing algorithms for evaluating key comparisons with linear drift in the referencestandard. *Measurement Techniques*, 2007, vol. 50, pp. 1019–1027.
19. Zhang N.F., Liu H.-k., Sedransk N., Strawderman W.E. Statistical analysis of key comparisons with linear trends. *Metrology*, 2004, vol. 41, pp. 231–237.
20. Velychko O., Karpenko S. Investigation of Metrological Characteristics of National Standard of Electric Power and Power Factor Units. *22nd IMEKO TC4 International Symposium and 20th International Workshop on ADC Modelling and Testing:* Supporting world development through electrical & electronic measurements. Iasi, Romania, 2017, pp. 7–12.
21. Velychko O. and Gordiyenko T. The estimation of the measurement results with using statistical methods. *Journal of Physics: Conference Series*, 2015, vol. 588, 012017. doi: 10.1088/1742–6596/588/1/012017
22. Cox M.G. The evaluation of key comparison date: determining the largest consistent subset. *Metrology*, 2007, vol. 44, pp. 187–200.