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Main Results of GULFMET.EM-S4 Supplementary Comparison of Inductance for 10 and 100 mH at 1 kHz

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Abstract

A Supplementary Comparison of Regional Metrology Organizations (RMOs) is a comparison, usually carried out by an RMO to meet specific metrological needs not covered by Key Comparison of Consultative Committee of the International Committee for Weights and Measures (CIPM) or RMOs. The outcomes of the CIPM Mutual Recognition Arrangement (MRA) are the internationally recognized Calibration and Measurement Capabilities (CMCs) of the participants of comparisons and CMCs of National Metrology Institutes published in Key Comparison Database (KCDB) of the International Bureau for Weights and Measures (BIPM).

Main results of the participating laboratories which have been measuring the same inductance travelling standard for 10 and 100 mH at 1 kHz in a framework of GULFMET.EM-S4 Supplementary Comparison of Inductance are presented. The paper describes the evaluation of drift effect of the travelling standard and Reference Value of a Supplement Comparison. Degrees of Equivalence and Expanded Uncertainties of NMI participants are determined.

E_n number was calculated for each NMI participating in GULFMET.EM-S4 comparison with the aim of determining data consistency. Linked results of COOMET.EM-S14 and GULFMET.EM-S4 supplementary comparisons for inductance were presented. Obtained results of both comparisons have good data consistency for all NMI participants.

Keywords: drift effect; inductance; supplementary comparison; reference value; travelling standard; degree of equivalence.

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1. Introduction

Key comparisons (KC) are the special comparisons for National Metrology Institutes (NMIs) in a frame of Consultative 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 KC is the determination of the equivalence between laboratories of different NMIs. A supplementary comparison (SC) of RMO is a comparison, usually carried out by a RMO to meet specific metrological needs not covered by KC of CC or RMOs.

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 [3–5]. The degree of equivalence (DoE) of a laboratory is obtained as the deviation of its measurement result from the KC reference value (RV), together with the uncertainty associated with this deviation according to the CIPM MRA [6].

RMOs have procedures for carry out of comparisons, but only the Euro-Asian Cooperation of National Metrological Institutions (COOMET) has guidelines on KC and SC data evaluation [7, 8]. The outcomes of the CIPM MRA are the internationally recognized Calibration and Measurement Capabilities (CMCs) of the participants of comparisons and CMCs of NMIs published in Key Comparison Database (KCDB) of the International Bureau for Weights and Measures (BIPM) [9, 10].

2. Brief review of carried out comparisons of inductance

The Consultative Committee for Electricity and Magnetism (CCEM) of CIPM was a sponsor of international comparisons of the national measurement standards of electromagnetic quantities between laboratories of different NMIs in the CIPM–MRA framework. From 1989 to 1999, CCEM-K3 KC [11] for inductance of 10 mH at 1 kHz was carried out. 11 NMIs that are the members of four RMOs: EURAMET, APMP, COOMET and SIM, participated in this KC. The PTB was the pilot laboratory of this KC.

In 2006, EURAMET.EM-K3 [12] KC for inductance 10 mH at 1 kHz was carried out. 3 NMIs participated in this KC and PTB was the pilot laboratory. In 2016, SIM.EM-K3 [13] KC for inductance 10 mH at 1 kHz was carried out. 7 NMIs participated in this KC and SENAM (Mexico) was the pilot laboratory.

From 2002 to 2003, EURAMET.EM-S20 [14] SC for inductance 100 mH at 1 kHz was carried out. 3 NMIs participated in this SC and PTB was the pilot laboratory. From 2006 to 2008, EURAMET.EM-S26 [15] SC for inductance 100 mH at 1 kHz was carried out. 7 NMIs participated in this SC and SENAM (Mexico) was the pilot laboratory. SE "UKRMETRTESTSTANDART" (UMTS, Ukraine) took part as the participant in EURAMET.EM-S26 SC with the aim of publishing CMCs for inductance in the KCDB of the BIPM.

From 2013 to 2014, the COOMET.EM-S14 [16] SC for inductance 10 and 100 mH at 1 kHz was carried out in the CIPM–MRA framework. The SC was carried out between 4 NMIs which are the members of two RMOs: COOMET and GULFMET. The UMTS (Ukraine) was the pilot laboratory of this SC.

The procedure was proposed for linking results of EURAMET.EM-S20, EURAMET.EM-S26 and COOMET.EM-S14 SCs to those NMIs which have also taken part in those comparisons [17].

3. Participants of supplementary comparison of inductance

The GULFMET.EM-S4 [18] SC for inductance 10 and 100 mH at 1 kHz was carried out in the CIPM–MRA framework from June to October 2018. The SC was carried out between 3 NMIs which are the members of two RMOs: COOMET and GULFMET.

The travelling standards (TSs) were compared at UMTS (Ukraine), QCC EMI (United Arab Emirates), and SASO-NMCC (Saudi Arabia). UMTS was a pilot laboratory responsible for providing the TSs, coordinating the schedule, collecting and analysing the comparison data, preparing the draft report, etc.

4. General review of travelling standards

The UMTS as pilot laboratory has performed repeated measurements on the TSs of types P5109 10 mH and P5113 100 mH during the course of this comparison as well as COOMET.EM-S14 comparison [16]. TSs of inductance are shown on Fig. 1.

Fig. 1. TSs for inductance 10 and 100 mH

Thermostatically regulated standards of inductance of types P5109 and P5113 allow the monitoring of critical parameters: the temperature difference of values within each standard thermostat and internal supply voltage. The standards contain inbuilt precision thermostat with dual temperature sensors, which provides increased reliability and accuracy of the measurement results.

Main characteristics of the standards of inductance:

- instability: 10 ppm/year;
- temperature inside the thermostat: 29.5 °C to 30.5 °C;
- temperature instability: 0.05 °C/hour;
- time to thermostat operating mode: not more than 3 hours;
- weight: 9 kg.

5. Behaviour of the travelling standard

Connection of TSs in accordance with connection schemes for 2- and 3-terminal is shown on Fig. 2.

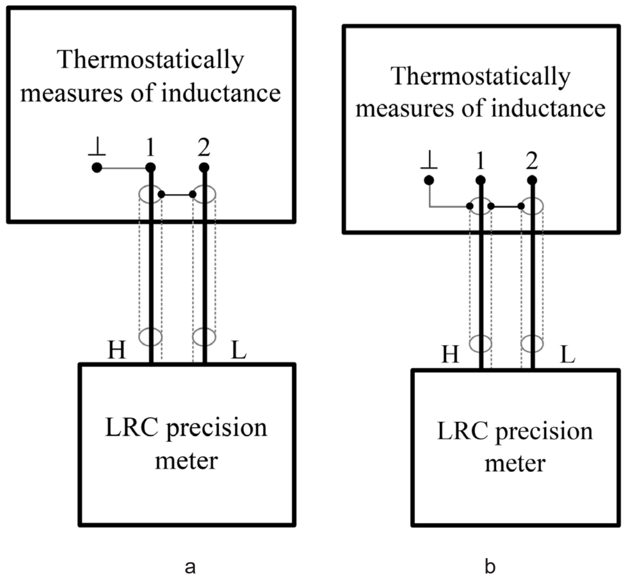

Fig. 2. Connection scheme: a) for 2-terminal; b) for 3-terminal

From these measurements, the behaviour of the TSs can be seen in Fig. 3–6.

As the values of the inductance are time-dependent they were measured before and after each visit so that a drift curve for each one could be established. The drift of the TSs by using all results weighted with the variance of the measurements was checked. The drift was neglected.

6. The reference values of comparison

The RV x_{ref} calculated as the mean of participant results with GULFMET.EM-S4 data are given by [3–5]

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

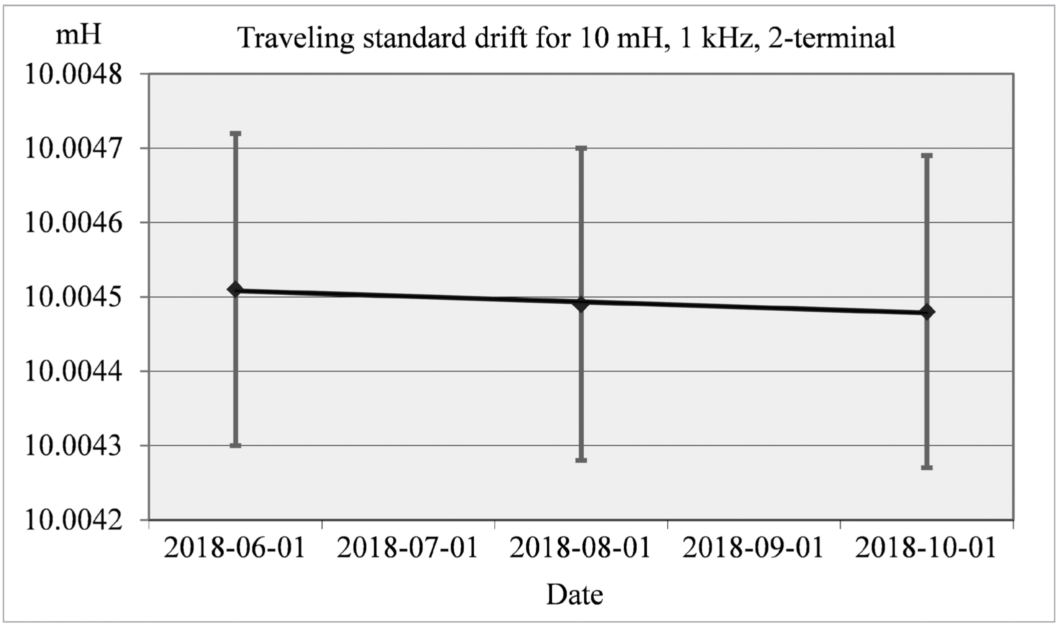

Fig. 3. Behaviour of the TS for 10 mH (2-terminal)

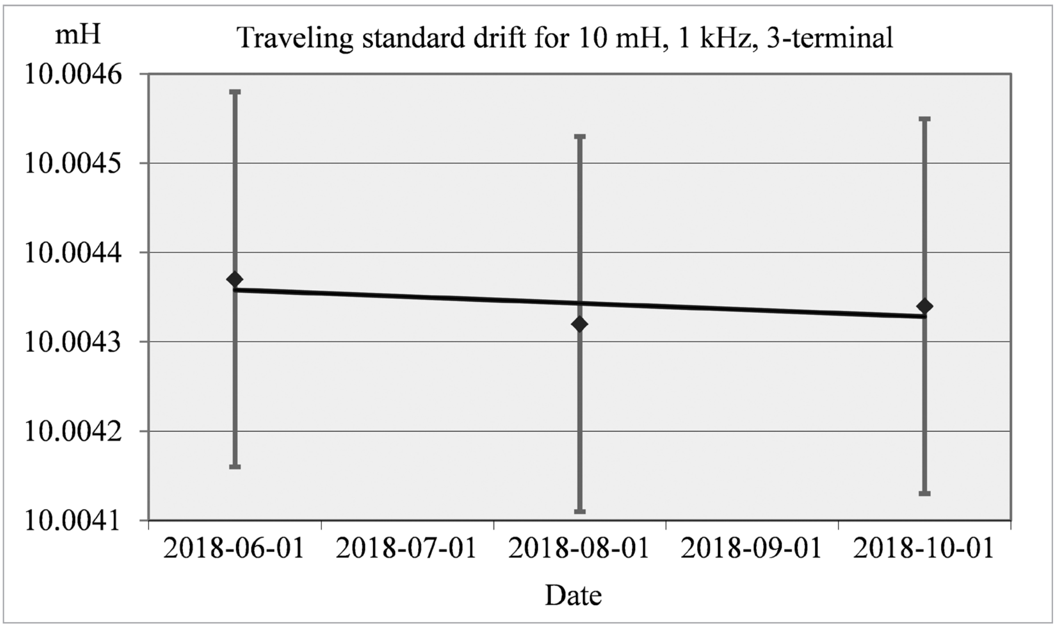

Fig. 4. Behaviour of the TS for 10 mH (3-terminal)

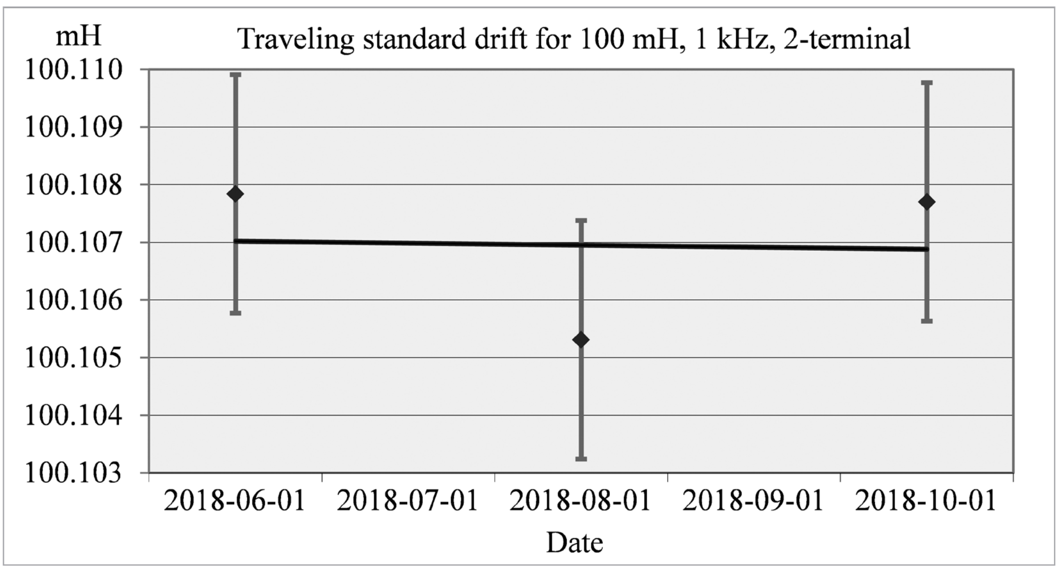

Fig. 5. Behaviour of the TS for 100 mH (2-terminal)

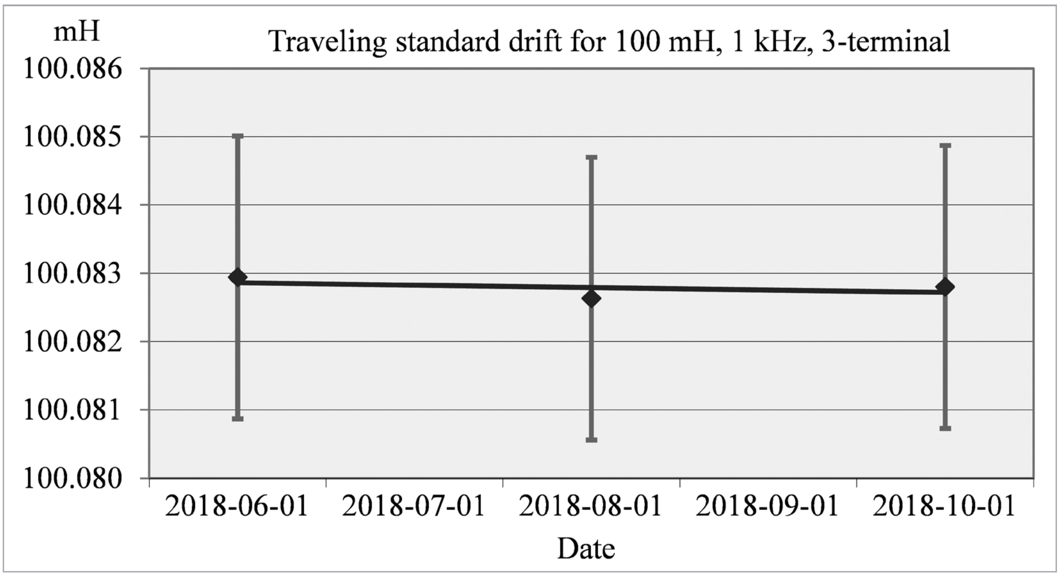

Fig. 6. Behaviour of the TS for 10 mH (3-terminal)

with associated standard uncertainty

$$u^2(x_{\text{ref}}) = 1 \Big/ \sum_{i=1}^{N} \frac{1}{u^2(x_{\text{i}})}. \qquad (2)$$

In cases the calculated simple weighted mean of all results was x_{ref} = 0.448 mH/H for 10 mH (2-terminal) and x_{ref} = 0.435 mH/H for 10 mH (3-terminal) with expanded uncertainty (k = 2) U_{ref} = 0.020 mH/H; x_{ref} = 0.977 mH/H for 100 mH (2-terminal) and x_{ref} = 0.833 mH/H for 100 mH (3-terminal) with expanded uncertainty (k = 2) U_{ref} = 0.020 mH/H.

The UMTS as pilot laboratory has provided the traceability to the SI of the national measurement standards. All of the participating NMIs made measurements at the same measurement points for 10 and 100 mH at 1 kHz.

UMTS inductance measurements are traceable to the PTB (Germany). QCC EMI and SASO-NMCC inductance measurements are traceable to the UME (Turkey). The PTB and UME participated in CCEM-K3 [11] KC, and EURAMET.EM-S20 [14] and EURAMET.EM-S26 [15] SC. The PTB participated also in EURAMET.EM-K3 [12] KC.

7. Degrees of equivalence of participants

Only one value is reported for each of NMI participants. Degrees of equivalence of the NMI participants are reported with respect to the measurement for 10 and 100 mH at 1 kHz for 2- and 3-terminals.

The degrees of equivalence of the i-th NMI and its expanded uncertainties with respect to the comparison reference value are estimated as [8]

$$D_{\text{i}} = x_{\text{i}} - x_{\text{ref}}, \qquad (3)$$

$$U^2(D_{\text{i}}) = U^2(x_{\text{i}}) + U^2(x_{\text{ref}}). \qquad (4)$$

The declared uncertainties are judged as confirmed if the following equation is satisfied

$$|D_{\text{i}}| < 2u(D_{\text{i}}). \qquad (5)$$

The Degrees of Equivalence (DoE) of the NMI participants and their expanded uncertainties (k = 2) with respect to the KCRV for 10 and 100 mH at 1 kHz for 2- and 3-terminal are also presented in Table 1 and the graphs in Fig. 7–10.

8. Results of participants of comparison

The maximum E_{n} number and declared uncertainties for degrees of equivalence of all NMIs for 10 and 100 mH (Table 2) are judged as confirmed by equations:

$$\max E_{\text{n}} = \frac{|x_{\text{i}} - x_{\text{ref}}|}{2\sqrt{u^2(x_{\text{i}}) - u^2(x_{\text{ref}})}} \le 1.0. \qquad (6)$$

Table 1

DoE of the NMI participants, mH/H

NMI	10 mH				100 mH			
	2-terminal		3-terminal		2-terminal		3-terminal	
	D_{i}	$U(D_{\text{i}})$	D_{i}	$U(D_{\text{i}})$	D_{i}	$U(D_{\text{i}})$	D_{i}	$U(D_{\text{i}})$
QCC EMI	0.010	0.074	0.007	0.073	0.073	0.122	0.084	0.089
SASO-NMCC	-0.020	0.082	–	–	0.041	0.083	–	–
UMTS	0.001	0.029	-0.001	0.029	-0.006	0.029	-0.005	0.029

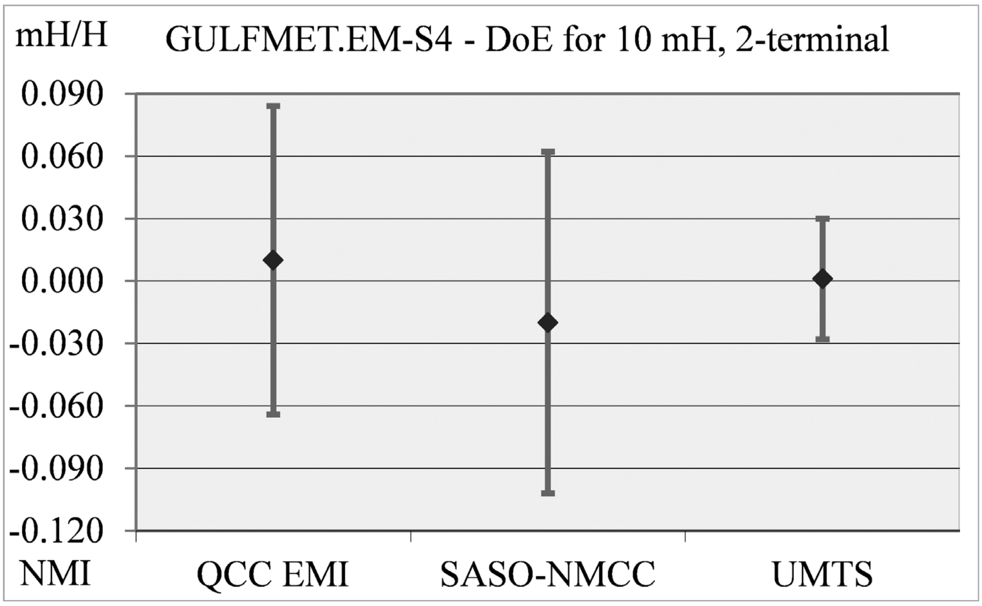

Fig. 7. Degree of equivalence of the NMI participants for 10 mH (2-terminal)

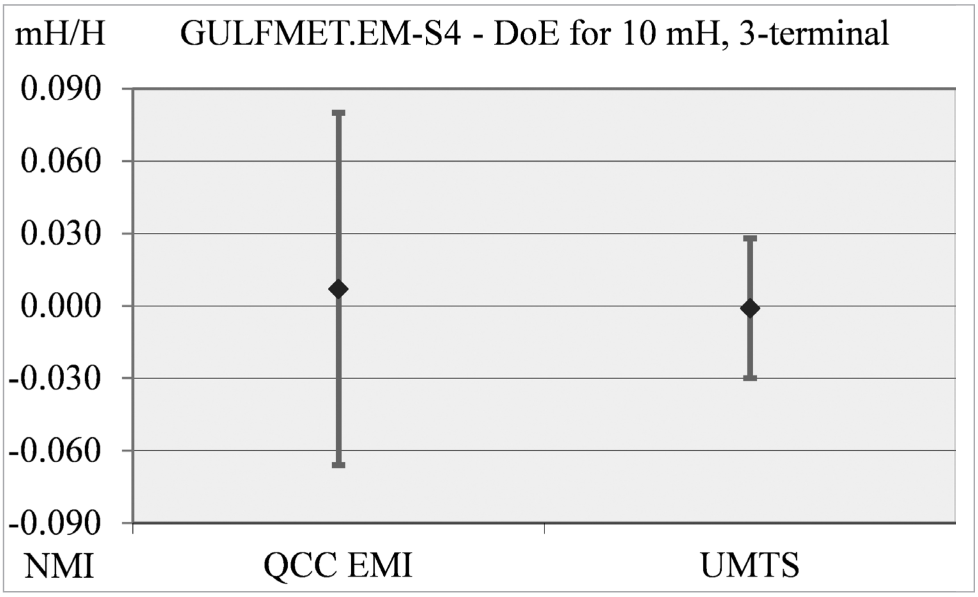

Fig. 8. Degree of equivalence of the NMI participants for 10 mH (3-terminal)

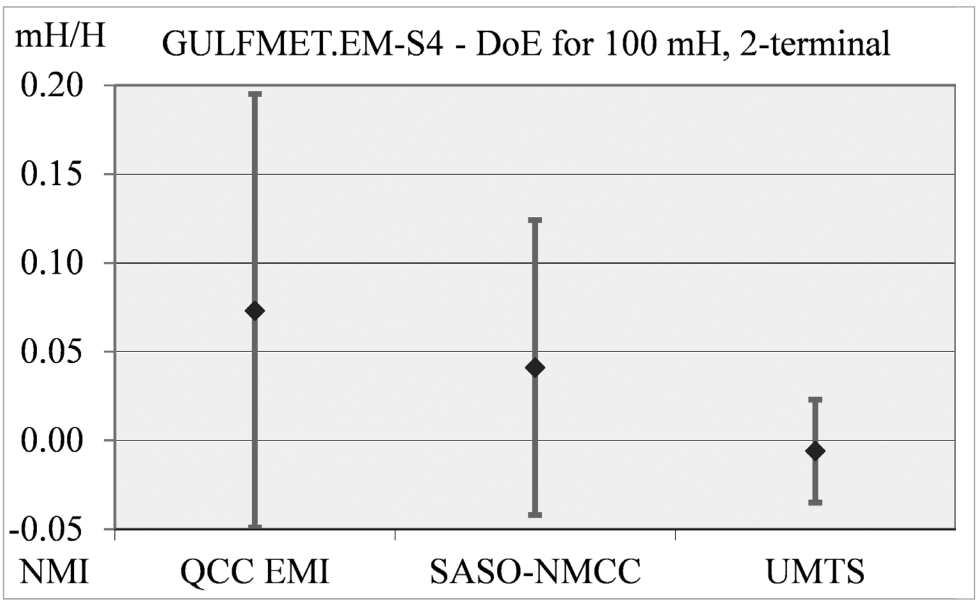

Fig. 9. Degree of equivalence of the NMI participants for 100 mH (2-terminal)

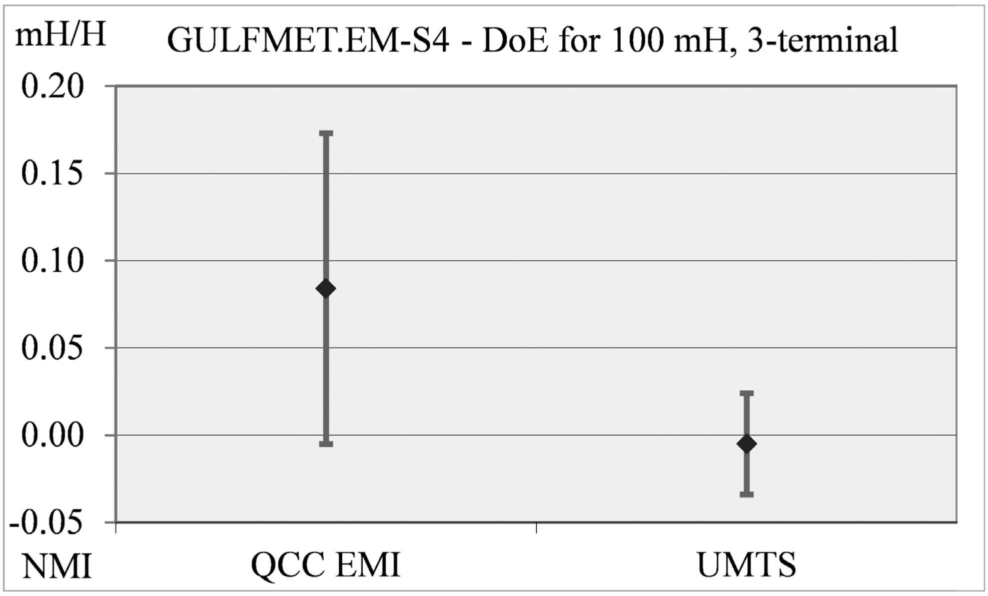

Fig. 10. Degree of equivalence of the NMI participants for 100 mH (3-terminal)

Table 2

Values for E_n number

NMI	10 mH		100 mH	
	2-terminal	3-terminal	2-terminal	3-terminal
QCC EMI	0.14	0.11	0.62	0.99
SASO-NMCC	0.26	–	0.54	–
UMTS	0.07	0.09	0.66	0.63

9. Linking results of COOMET and GULFMET supplementary comparisons for inductance

Results of GULFMET.EM-S4 (3 participants) [18] SC can be linked in terms of RV_{S14} (100 mH, 1 kHz). Results of those comparisons are expressed to COOMET.EM-S14 (4 participants) SC [16]. UMTS (Ukraine) participated in COOMET.EM-S14 and GULFMET.EM-S4 SCs, therefore, the UMTS results can be used to determine the link.

DoE of GULFMET.EM-S4 SC needs to be corrected by a value d [17], which is determined from the results of the participant linking NMI:

$$d = D_{\text{UMTS-S14}} - D_{\text{UMTS-S4}}, \quad (7)$$

where: $D_{\text{UMTS-S14}}$ is the DoE of linking NMI (UMTS) in COOMET.EM-S14 SC; $D_{\text{UMTS-S4}}$ is the DoE of linking NMI in GULFMET.EM-S4 SC and standard uncertainty of corrected factor:

$$u^2(d) = u^2(D_{\text{UMTS-S14}}) + u^2(D_{\text{UMTS-S4}}), \quad (8)$$

where: $u(D_{\text{UMTS-S14}})$ is standard uncertainty of linking NMI in COOMET.EM-S14 SC; $u(D_{\text{UMTS-S4}})$ is standard uncertainty of linking NMI in GULFMET.EM-S4 SC.

The corrected DoE for i-th NMI participants [17] in GULFMET.EM-S4 SC in terms of COOMET.EM-S14 SC RV are then is given by:

$$D'_{S4i} = D_{S4i} + d \quad (9)$$

and corrected standard uncertainty of DoE:

$$u'^2(D_{S4i}) = u^2(D_{S4i}) + u^2(d), \quad (10)$$

where: D_{S4i} is the DoE of i-th NMI in GULFMET.EM-S4 SC; $u(D_{S4i})$.

The results from NMIs in COOMET.EM-S14 and GULFMET.EM-S4 SCs for 100 mH in terms of RV_{S14} are shown in Table 3 and Fig. 11. The sign "*" in Table 3 and Fig. 11 indicates those NMIs that participated in both comparisons and have two different results.

Table 3

DoE of NMIs in GULFMET.EM-S4 SC in terms of RV_{S14}, mH/H

NMI	D_{S14}	$U(D_{S14})$	D_{S4}	$U(D_{S4})$	D'_{S14}	$U(D'_{S14})$
BelGIM	-0.010	0.101			-0.010	0.101
KazInMetr	-0.014	0.027			-0.014	0.027
GUM	-0.006	0.017			-0.006	0.017
UMTS*	0.007	0.010	-0.010	0.030	0.007	0.010
QCC EMI			0.073	0.122	0.090	0.126
SASO-NMCC			0.041	0.083	0.058	0.089

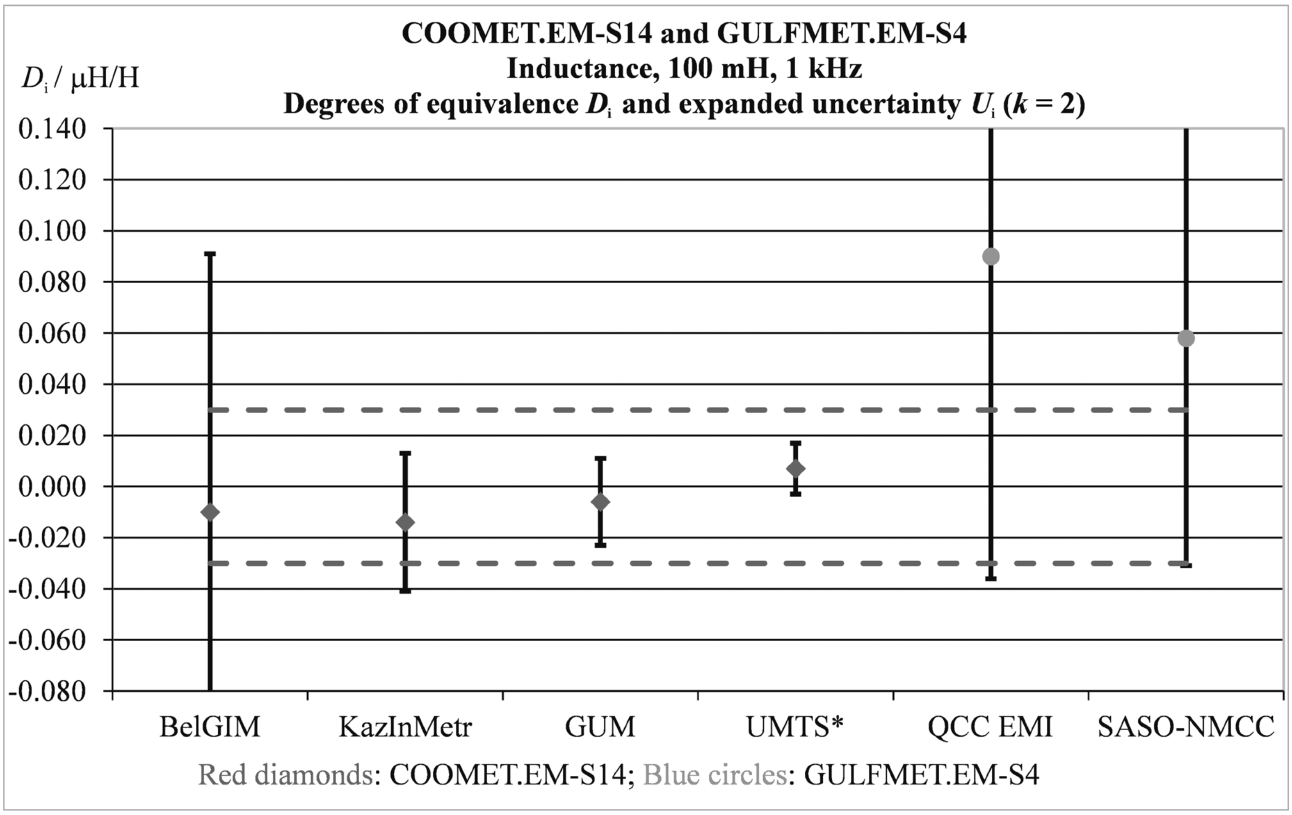

Fig. 11. DoE of NMIs in COOMET.EM-S14 and GULFMET.EM-S4 SCs in terms of RV_{S14}

In Fig. 1 red dashed lines indicate the boundaries of the minimum expanded uncertainty of the linking laboratory.

10. Conclusion

A SC of inductance for 10 and 100 mH at 1 kHz has been carried out between participating GULFMET and COOMET member laboratories. In general, there is good agreement between participating laboratories for this quantity at a nominal value of 10 mH and acceptable agreement at a nominal value of 100 mH. It is expected that this comparison will be able to provide support for participants' entries in Appendix C of the CIPM MRA.

The calculated values of drift effect for GULFMET.EM-S4 TS were linear and small for all measurement points, so it was neglected. Also the RV of SC and its expanded uncertainties were calculated. The RV of SC lies in the range from 0.448 mH/H (2-terminal) to 0.435 mH/H (3-terminal) for 10 mH with expanded uncertainty 0.020 mH/H, and from 0.977 mH/H (2-terminal) to 0.833 mH/H (3-terminal) for 100 mH with expanded uncertainty 0.020 mH/H.

DoE and its expanded uncertainties of NMI participants were calculated. The E_n numbers lies in the range from 0.07 to 0.99 for all NMI participants that satisfies the condition of performance $E_n \leqslant 1.0$ and characterizes good data consistency.

Linked results of COOMET.EM-S14 and GULFMET.EM-S4 SCs for inductance were presented. Obtained results for all NMI participants of both comparisons have good data consistency.

Основні результати додаткових звірень індуктивності GULFMET.EM-S4 для 10 та 100 mH на 1 kHz

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Анотація

Додаткове звірення регіональних метрологічних організацій (RMO) — це звірення, що зазвичай виконується RMO для задоволення конкретних метрологічних потреб, які не охоплюються ключовими звіреннями Консультативного комітету (CC) Міжнародного комітету з мір та ваг (CIPM) або RMO. Результатом Угоди про взаємне визнання CIPM (MRA) є міжнародно визнані калібрувальні та вимірювальні можливості (CMC) учасників звірень і опубліковані CMC національних метрологічних інститутів (NMI) у базі даних ключових звірень (KCDB) Міжнародного бюро мір та ваг (BIPM).

Надано коротку інформацію щодо ключових і додаткових звірень еталонів індуктивності, які проводились CC з електрики та RMO. Надано основні результати лабораторій NMI-учасників додаткових звірень індуктивності GULFMET.EM-S4, які досліджують один і той же транспортабельний еталон індуктивності для 10 та 100 mH при 1 kHz. Наведено оцінку стандартного ефекту дрейфу та опорні значення додаткового звірення для дво- і тритермінального включення транспортабельного еталона індуктивності. Встановлено ступені еквівалентності та розширені невизначеності для всіх NMI-учасників звірень. Пілотною лабораторією ДП "Укрметртестстандарт" (Україна) було встановлено простежуваність вимірювань індуктивності для кожного NMI-учасника звірень.

З метою визначення узгодженості даних були розраховані E_n числа для кожного NMI-учасника звірень GULFMET.EM-S4. Отримані результати для всіх NMI-учасників звірень мають гарну узгодженість даних. Коротко надано процедуру пов'язування результатів додаткових звірень RMO. Надано пов'язані результати додаткових звірень COOMET.EM-S14 і GULFMET.EM-S4 для еталонів індуктивності. NMI-учасники звірень можуть використати отримані результати для розроблення чи підтвердження своїх CMC.

Ключові слова: ефект дрейфу; індуктивність; додаткове звірення; опорне значення; транспортабельний еталон; ступінь еквівалентності.

Основные результаты дополнительных сличений индуктивности GULFMET.EM-S4 для 10 и 100 mH на 1 kHz

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Аннотация

Дополнительное сличение региональных метрологических организаций (RMO) — это сличение, обычно выполняемое RMO для удовлетворения конкретных метрологических потребностей, которые не охватываются ключевыми сличениями Консультативного комитета Международного комитета мер и весов (CIPM) или RMO. Результатом Соглашения о взаимном признании CIPM (MRA) являются международно признанные калибровочные и измерительные возможности (CMC) участников сличений и опубликованные CMC национальных метрологических институтов (NMI) в базе данных ключевых сличений (KCDB) Международного бюро мер и весов (BIPM).

Представлены основные результаты участвующих лабораторий, которые исследуют один и тот же транспортируемый эталон индуктивности для 10 и 100 mH при 1 kHz в рамках дополнительных сличений индуктивности GULFMET.EM-S4. Описывается оценка стандартного эффекта дрейфа и эталонное значение дополнительного сличения. Установлены степени эквивалентности и расширенные неопределенности участвующих NMI.

E_n число было рассчитано для каждого участвующего в сличениях GULFMET.EM-S4 NMI с целью определения согласованности данных. Представлены связанные результаты дополнительных сличений COOMET.EM-S14 и GULFMET.EM-S4 для индуктивности. Полученные результаты для всех участвующих NMI имеют хорошую согласованность данных.

Ключевые слова: эффект дрейфа; индуктивность; дополнительные сличения; опорное значение; транспортируемый эталон; степень эквивалентности.

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