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Alternative Method for Processing of International Comparison Results

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Abstract

The CIPM Mutual Recognition Arrangement of National Standards, Calibration and Measurement Certificates issued to National Metrology Institutes (NMIs) defines the status of key comparisons as a priority tool for implementation of quality management systems in NMIs and the determination of the competence of a particular NMI based on its calibration and measurement capabilities in accordance with the unified database of key comparisons — KCDB.

The general approach for evaluating the key comparisons results is presented in the International Committee for Weights and Measures procedures, as well as in the various articles. The question of the development and practical application of alternative methods for processing data of international comparisons is of the particular interest. It will allow to expand the methodological basis for confirming the calibration and measurement capabilities provided by the NMIs and published in KCDB.

The paper considers the alternative approach for processing the international comparisons results, which based on preference aggregation method. It allows to determine reference value for evaluation the comparison data on the basis of ranking the obtained uncertainty intervals presented by National Metrology Institutes. Processing of COOMET.EM-K6.a Key Comparison data by the preference aggregation method is presented. The results are compared with the general approach and the considered method.

Keywords: key comparison; reference value; rankings; uncertainty; national metrology institute.

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1. Introduction

International comparisons (ICs) of the national measurement standards play a specific role in metrological practice. Importance of ICs is increased with the growth of requirements to the quality level of metrological services provided by National Metrology Institutes (NMIs) and calibration laboratories. IC means organization, carrying out and evaluation comparison data of travelling standard according to predetermined conditions [1].

Key Comparisons (KCs) and Supplementary Comparisons (SCs) are distinguished depending on the objectives of IC, requirements to preparation, carrying out the procedure and presentation of the results [2]. NMIs' national measurement standards, which have the highest technical competence and experience in the appropriate type of measurements, participate in KCs and SCs of the International Committee for Weights and Measures (CIPM) and Regional Metrology Organizations (RMOs).

The CIPM Mutual Recognition Arrangement (MRA) for the mutual recognition of national measurement standards and for recognition of the validity of calibration and measurement certificates issued by the NMIs [1] defines the status of KC as a priority instrument for: implementing quality management systems in NMIs and determining the competence of a specific NMI on the basis of data on its calibration and measurement capabilities (CMCs) [3] according to a uniform Key Comparison Database – KCDB [4].

In [5] a general approach is presented for the evaluation of the KC results, and in [6] the clarifications to the general approach of determining the largest consistent subset are given. The evaluation of the RMOs' comparison results is carried out according to the established procedures, but only the Euro-Asian Cooperation of National Metrological Institutions (COOMET) has special guidelines for processing data as KC [7] and SC [8]. These guidelines can be conventionally called traditional methods of processing KC results.

Of particular interest is the development and practical application of alternative methods for processing KC data, which will expand the methodological basis for confirmation of CMCs provided by NMIs and published in the KCDB.

2. Processing the international comparisons data based on preference aggregation method

The IC procedure of the national measurement standards can be represented as five main stages, which are shown on Fig. 1.

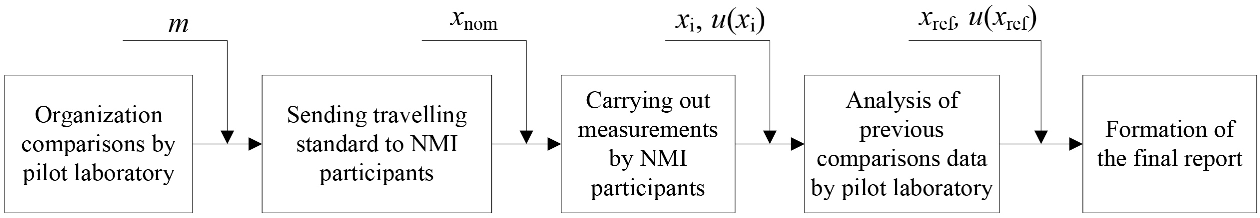

Fig. 1. The main stages of the comparisons procedure

A pilot laboratory (PL) is selected for the organization and carrying out of IC. The PL provides and researches the travelling standard and organizes its sending to all *m* NMI participants of IC in accordance with approved schedule. The NMIs participated in the KC independently from each other carry out research of the travelling standard, which is characterized by a nominal value of x_{nom}. Based on carried out measurements, the IC NMI participants provide estimation of nominal value x_i and their corresponding standard uncertainties $u(x_i)$. The measurand results are sent to the PL, which defines the reference value x_{ref} and its uncertainty $u(x_{ref})$.

Among the various tasks of planning and performing comparisons, there is a task of developing common agreed approaches and algorithms for evaluating the results of this procedure. The main task for different types of comparisons is to establish a reference value x_{ref}. The reference value is the best estimation of measured value obtained from all NMI participants.

In [9] the problem of establishing reference value of IC in terms of the preference aggregation problem is considered. It involves finding the consensus ranking β for the preference profile Λ consisting of *m* rankings of *n* alternatives.

According to [9, 10], there was defined the procedure for transformation uncertainty intervals obtained by *m* NMI participants into rankings. Uncertainty intervals I_i obtained by each NMI are presented as an algebraic combination of their intervals and called as the range of actual values (RAV) U of the measured value:

$$U = \bigcup_{i=1}^{m} [-u(x_i);\, u(x_i)] = \bigcup_{i=1}^{m} I_i .$$

The RAV is divided into *n*-1 equal intervals. In this case, *n* values of the measurand $A = \{a_1, a_2, ..., a_n\}$ will be corresponded to boundaries of the division intervals. These boundaries will serve as alternatives in determining of the consensus ranking. The preference profile Λ consists of *m* rankings describing the NMI participants' uncertainty intervals.

Each *i*-th ranking has the following properties:

$$a_i \succ a_j \text{ if } a_i \in u(x_k) \wedge a_j \notin u(x_k);$$
$$a_i \sim a_j \text{ if } a_i, a_j \in u(x_k) \vee a_i, a_j \notin u(x_k);$$
$$a_i \prec a_j \text{ if } a_i \notin u(x_k) \wedge a_j \in u(x_k).$$

The measurement results provided by NMIs are represented by a ranking of the measured value. Equivalent values will be more preferable, which belong to NMI participant uncertainty interval. And other values of *A* in this ranking will be less preferable and equivalent to each

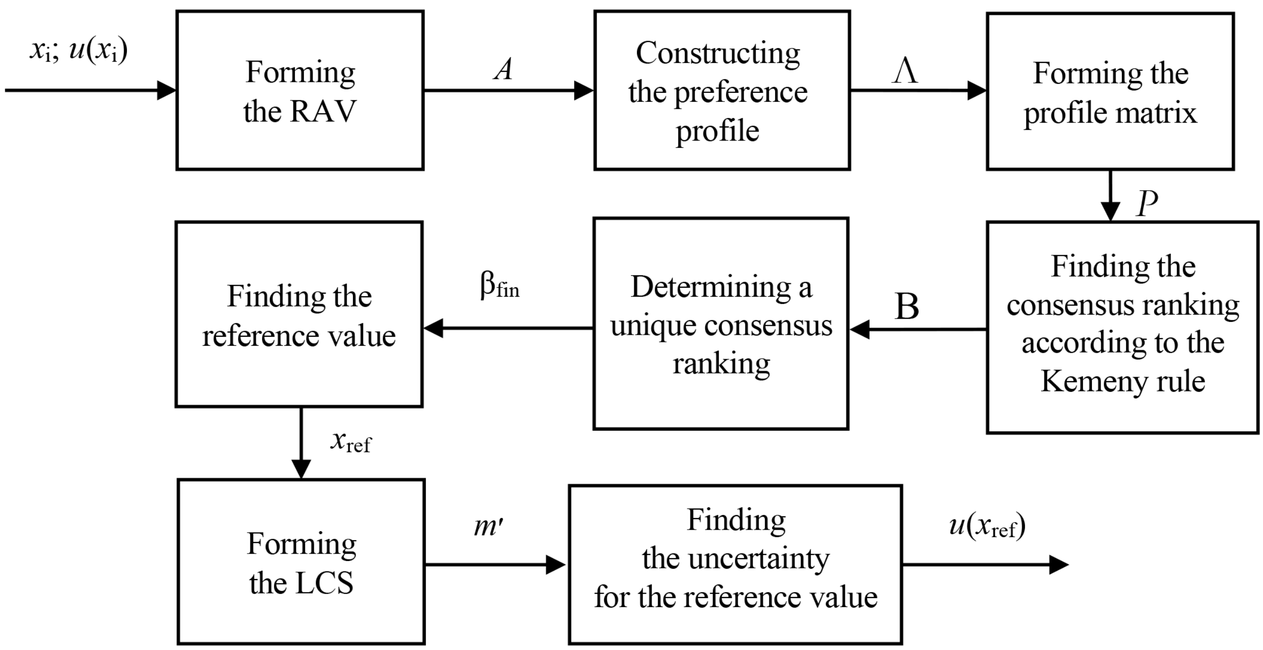

Fig. 2. The main stages of processing IC data using the PAM

other. In this case, each ranking involves a single symbol of strict order "$\succ$" and also n-1 symbols of equivalence "~" [10].

According to [10] uncertainty intervals $u(x_i)$ provided by the NMI participants are turned into rankings of measured value. Then obtained rankings and preference profile are used as initial data for finding the consensus ranking according to Kemeny rule, which allows to obtain the reference value x_{ref} of measured value [11].

Consensus ranking β defines the only unique consensus ranking β_{fin} that provides the best compromise between rankings. For example, β can be found by minimizing the Kemeny distance between the profile and finding the consensus ranking [12]. As soon as a consensus ranking β_{fin} is found, a value ranked first in it can be selected as the reference value x_{ref} of measurand.

The standard uncertainty of obtained reference value is defined as the smallest of two values: the maximum lower bound $u_l(x_i) \le x_{ref}$ and the minimum upper bound $u_u(x_i) \ge x_{ref}$ of the uncertainty intervals, which were declared by the NMI participants.

The main stages of processing IC data using the preference aggregation method (PAM) has been described in [13] and are shown on Fig. 2: forming RAV; constructing the preference profile; forming the profile matrix; finding the consensus ranking according to the Kemeny rule; determining a unique consensus ranking; finding the reference value; forming the largest consistent subset (LCS); finding the uncertainty for the reference value of IC.

Received reference value and its uncertainty using the PAM, equivalence degrees of the national measurement standards can be obtained for NMI participants of IC.

3. Processing of COOMET.EM-K6.a key comparisons results by the PAM

In [14] the COOMET KC results of AC/DC voltage standards (COOMET.EM-K6.a) were reviewed, which were carried out from 2013 to 2014. KC results were obtained by the traditional approach. These comparisons were organized by SE "Ukrmetrteststandard" — UMTS (Ukraine). The main comparisons purpose was to link the results of COOMET. EM-K6.a with the results of the KC CCEM-K6.a. The COOMET.EM-K6.a KC measured results of the NMI participants are shown in the Table 1.

Using PAM, the data in Table 1 were processed at various values n = {4, 5, 6, 7, 8, 9, 10} (at frequency of 1 kHz). The maximum capacity of the LCS has been achieved for n = 6. Thus, RAV was divided into n–1 = 5 equal divisions. The boundaries of intervals corresponded to the five values of the measured quantity a_1 = 28.4, a_2 = 18.8, a_3 = 9.2, a_4 = –0.4, a_5 = –10.0, a_6 = –19.6.

Ranking for the NMIs had a form:

$$\lambda_1: a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6;$$
$$\lambda_2: a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6;$$
$$\lambda_3: a_4 \sim a_3 \succ a_1 \sim a_2 \sim a_5 \sim a_6;$$
$$\lambda_4: a_6 \sim a_5 \sim a_4 \sim a_3 \sim a_2 \sim a_1;$$
$$\lambda_5: a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6.$$

Final consensus ranking was

$$\beta_{fin} = \{\boldsymbol{a4} \succ a_2 \sim a_3 \succ a_6 \sim a_1 \sim a_5\}.$$

The first place in it, strictly preferred by others, took the value a_4, so it was chosen as the reference value x_{ref} = –0.4 with a corresponding uncertainty $U(x_{ref})$ = 3.00 at frequency of 1 kHz.

The AD-DC voltage transfer differences (δ) and theirs expanded uncertainties U reported by the NMI participants at frequencies of 20 Hz, 1 kHz, 20 kHz, 100 kHz, and 1 MHz are shown in Table 2.

The difference of the estimation reference values x_{ref}, which were obtained using the traditional approach and the PAM, are shown in Fig. 3. As it can be seen in Fig. 3, a high level of coincidence results of evaluation reference values x_{ref} has been achieved.

Table 1

The COOMET.EM-K6.a KC measured results for NMI participants

NMI	20 Hz		1 kHz		20 kHz		100 kHz		1 MHz	
	x_i	$U(x_i)$	x_i	$U(x_i)$	x_i	$U(x_i)$	x_i	$U(x_i)$	x_i	$U(x_i)$
VNIIM (Russia)	3.7	8.3	-0.8	2.5	-1.5	2.8	-5.0	4.0	-57	28.2
UMTS (Ukraine)	-8.0	10.4	0.3	4.4	-1.6	4.4	-10.0	8.4	-71	40
SMS (Azerbaijan)	22.0	18.0	7.4	14.2	12.0	22.0	-25.0	25.6	–	–
BelGIM (Belarus)	–	–	4.4	24.0	10.0	29.0	19.0	139.0	–	–
INM (Romania)	3.8	3.0	1.5	3.0	-3.1	3.0	-12.8	12.0	-21	22

Table 2

The COOMET.EM-K6.a KC results of the NMI participants using the traditional approach and the PAM

Processing methods	20 Hz		1 kHz		20 kHz		100 kHz		1 MHz	
	x_{ref}	U_{ref}	x_{ref}	U_{ref}	x_{ref}	U_{ref}	x_{ref}	U_{ref}	x_{ref}	U_{ref}
Traditional approach	3.22	5.38	0.30	3.48	-1.98	3.69	-6.81	6.14	-40.38	31.83
PAM	3.50	6.40	0.40	3.00	-1.60	3.00	-8.80	4.40	-41.00	29.42
Difference of results	0.28	1.02	0.10	0.48	0.38	3.69	-1.99	1.74	0.62	2.41

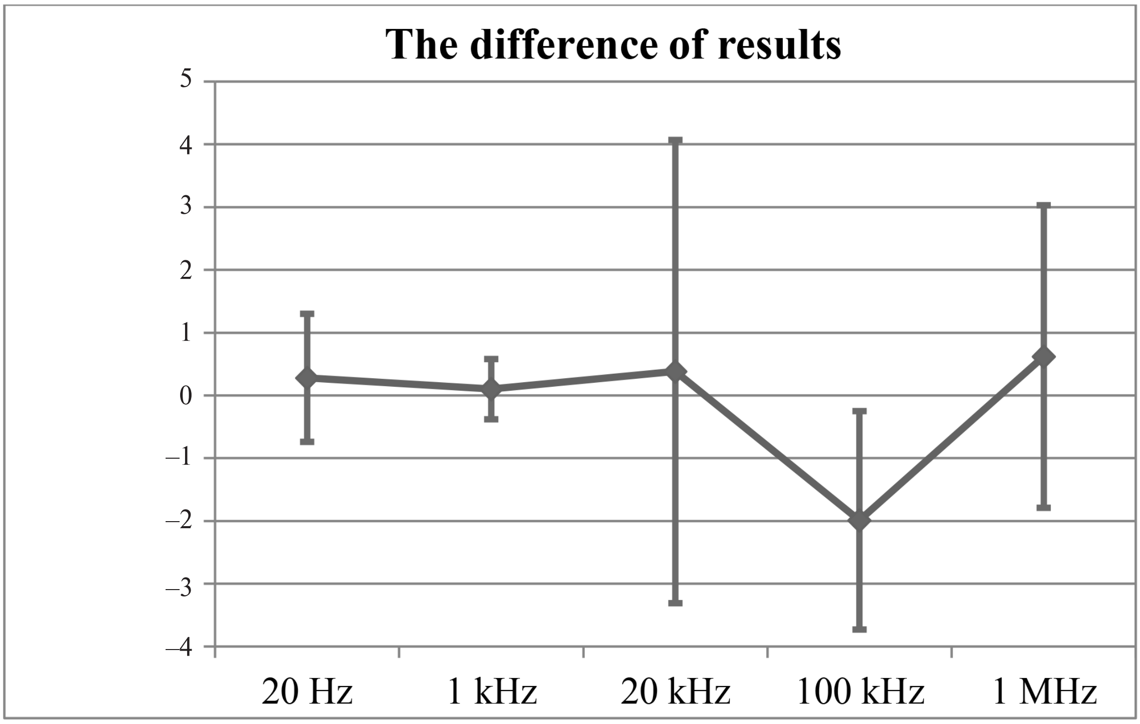

Fig. 3. The difference of results for evaluation reference values obtained by the traditional approach and the PAM

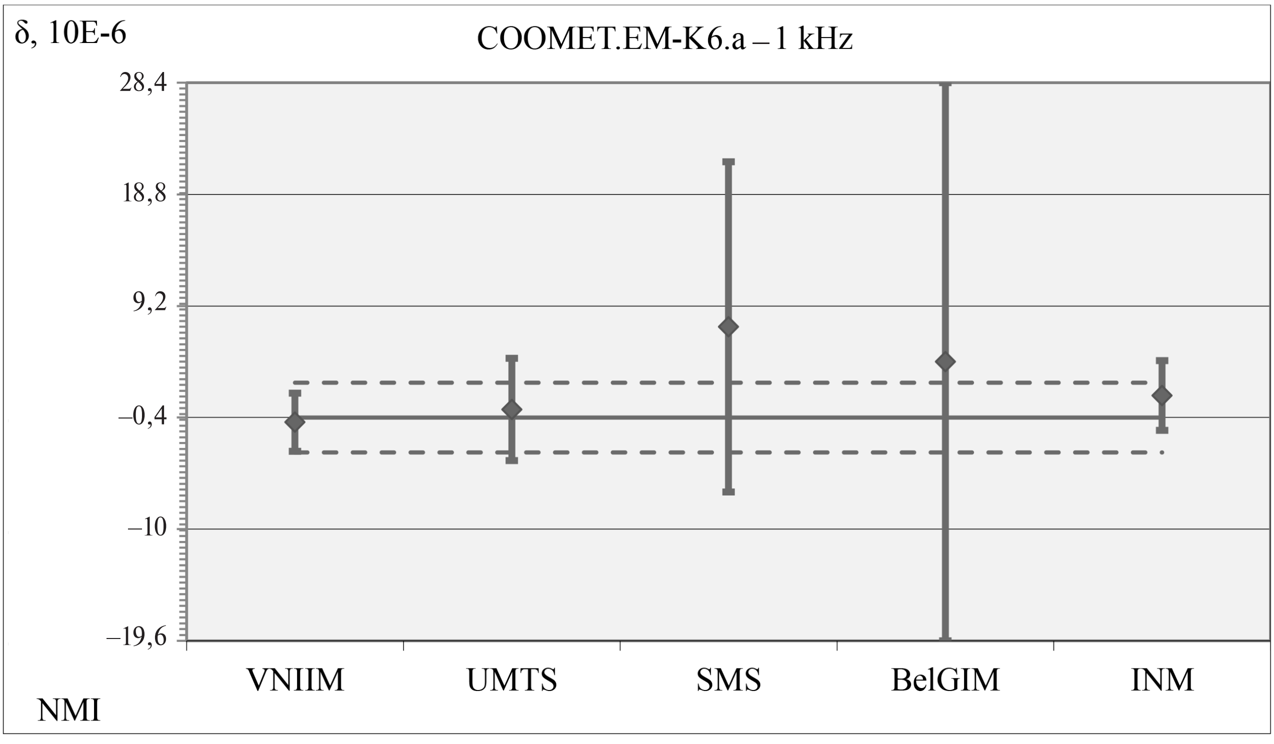

Fig. 4. Results of processing COOMET.EM-K6.a KC data using the PAM at frequency of 1 kHz

The results of processing NMI data for the project COOMET.EM-K6.a using of PAM at frequency 1 kHz are shown in Fig. 4. The solid line is indicated the reference value x_{ref} obtained by PAM, and the dashed lines are its uncertainty boundary $u(x_{ref})$.

4. Conclusion

The preference aggregation method can be applied for processing IC data of the national measurement standards in addition to the traditional method. The preference aggregation method implements the transformation of the uncertainty intervals provided by NMI participants into rankings of measured values.

The COOMET.EM-K6.a Key Comparisons data were processed using the preference aggregation method. The use of this method showed that the reference values determined by the PAM and the associated uncertainties are very close to the values obtained by traditional method.

Альтернативний метод оцінювання даних міжнародних звірень

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Анотація

Угода CIPM про взаємне визнання національних еталонів, сертифікатів калібрування і вимірювань (Mutual Recognition Arrangement, MRA), які видаються національним метрологічним інститутам (НМІ), визначає статус ключових звірень як пріоритетний інструмент для впровадження систем управління якістю в НМІ та визначення компетентності певного НМІ на підставі даних про його калібрувальні та вимірювальні можливості відповідно до єдиної бази даних ключових звірень — KCDB.

У процедурах Міжнародного комітету з мір та ваг, а також у статтях різних авторів подано загальний підхід до оцінювання результатів ключових звірень. Певну цікавість викликає питання розроблення і практичного застосування альтернативних методів оброблення даних міжнародних звірень, що дозволить розширити методичну базу для підтвердження наданих НМІ і опублікованих у KCDB їх калібрувальних та вимірювальних можливостей.

У статті розглянуто альтернативний метод оброблення даних міжнародних звірень національних еталонів на основі методу агрегування переваг. Метод дозволяє визначити опорне значення звірень на підставі ранжування отриманих інтервалів невизначеності, наданих учасниками звірень. Надано результати обробки даних ключових звірень COOMET.EM-K6.a. Здійснено порівняння отриманих результатів за загальним підходом і розглянутим методом. Використання методу агрегування переваг показало, що визначені ним опорні значення і пов'язані з ним невизначеності дуже близькі до значень, отриманих координаторами звірень при використанні традиційного методу.

Ключові слова: ключові звірення; опорне значення; ранжування; невизначеність; національний метрологічний інститут.

Альтернативный метод оценивания данных международных сличений

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Аннотация

Соглашение CIPM о взаимном признании национальных эталонов, сертификатов калибровки и измерений (Mutual Recognition Arrangement, MRA), которые выдаются национальным метрологическим институтам (НМИ), определяет статус ключевых сличений как приоритетный инструмент для внедрения систем управления качеством в НМИ и определения компетентности определенного НМИ на основании данных о его калибровочных и измерительных возможностях в соответствии с единой базой данных ключевых сличений — KCDB.

В процедурах Международного комитета по мерам и весам, а также в статьях различных авторов представлен общий подход к оценке результатов ключевых сличений. Определенный интерес представляет вопрос разработки и практического применения альтернативных методов обработки данных международных сличений, что позволит расширить методическую базу для подтверждения предоставленных НМИ и опубликованных в KCDB их калибровочных и измерительных возможностей.

Рассмотрен альтернативный метод обработки данных международных сличений национальных эталонов на основе метода агрегирования предпочтений. Метод позволяет определить опорное значение сличений на основании ранжирования полученных интервалов неопределенности, представленных участниками сличений. Представлены результаты обработки данных ключевых сличений по проекту COOMET.EM-K6.a.

Ключевые слова: ключевые сличения; опорное значение; ранжирование; неопределенность; национальный метрологический институт.

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