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Application of systems thinking to the establishment of metrological traceability chains

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Abstract

International agreements in the field of metrology and accreditation of calibration laboratories are the basis for establishing global metrological traceability. Important elements of metrological traceability are calibration of measurement standards and measuring instruments, assessment of measurement uncertainty. The International Laboratory Accreditation Cooperation has a specific policy regarding on traceability of measurement results and estimation of measurement uncertainty in calibration.

The partial concept diagram around metrological traceability in accordance with the International Vocabulary of Metrology is proposed. This diagram contains a total of nine metrological concepts, which have most of the associative relations. There are associative relations between the concept of metrological traceability chain and concepts of metrological traceability, measurement standard, calibration and calibration hierarchy, and through the concept of measurement standard with the concept of measurement uncertainty.

Systems thinking to the analysis of state of proposed terminological system around metrological traceability was applied. For construction of generalized metrological traceability chain, all the established properties of the system elements around the terminology system of metrological traceability were taken into account.

Generalized metrological traceability chain for different levels of the calibration hierarchy was proposed. The proposed chain can be used to develop appropriate chains for specific areas of measurement. To achieve this, it is necessary to determine the specific measured value, the required measurement uncertainty for different levels of the calibration hierarchy and select the necessary measurement standards. Such schemes should be used in national metrology institutes and calibration laboratories.

Keywords: metrological traceability; measurement uncertainty; measurement standard; measuring instrument; systems thinking.

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Introduction

International agreements in the field of metrology of the International Committee on Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA) [1] and the International Laboratory Accreditation Cooperation (ILAC) MRA [2] for accreditation of calibration laboratories are the basis for establishing global metrological traceability. CIPM, ILAC and other international organizations have published a joint International Vocabulary of Metrology (VIM) [3] and Guide to the expression of uncertainty in measurement (GUM) [4].

The metrological traceability is a property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty in accordance with the International Vocabulary of Metrology (VIM, 2.41) [3].

Metrological traceability requires an established calibration hierarchy, which is sequence of calibrations from a reference to the final measuring system, where the outcome of each calibration depends on the outcome of the previous calibration (VIM, 2.40) [3]. The elements of a calibration hierarchy are one or more measurement standards and measuring systems (instruments) operated according to measurement procedures. Measurement uncertainty necessarily increases along the sequence of calibrations.

To confirm metrological traceability, ILAC considers the elements of the metrological traceability chain as continuous documented traceability to an international or national standard. In doing so, it is important to specify the measurement uncertainty during calibration, measurement procedure and calibration intervals [5]. The ILAC has a specific policy re-

garding the estimation of measurement uncertainty in calibration [6].

The metrological traceability chain is sequence of measurement standards and calibrations that is used to relate a measurement result to a reference (VIM, 2.42) [3]. This chain is defined through a calibration hierarchy and used to establish metrological traceability of a measurement result.

The issues of the features of metrological traceability at different levels of metrological work are considered in [7, 8]. However, a more detailed consideration requires the development of approaches to building metrological traceability chains. To solve this issue, it is advisable to use systems thinking (approach) [9] that is a direction of research methodology, which consists in the study of a certain object as a whole set of elements in the set of relations and connections between them. In this case, this research object is considered as a specific model of the system.

The problem statement, aim and objectives of the study

The purpose of the article is to highlight the results of practical application of a systematic thinking to the establishment of metrological traceability, in particular:

- to study the basis for establishing metrological concepts and concept relations around metrological traceability;
- to apply systems thinking to establishing relations between the concept of metrological traceability and other metrological concepts;
- to establish of principal of construction of metrological traceability chains for the purpose of their practical application for various areas of measurements.

The research of relations of the metrological traceability concept

Concept diagrams for concepts from vocabularies are intended to provide a visual presentation of the different relations between the defined concepts, and a check that concepts are sufficiently systematic [3]. The used concept relations are of three types as defined by International Standards ISO 704 [10] and ISO 1087-1 [11].

The two concept relations are hierarchical (having superordinate and subordinate concepts) and one concept relation is non-hierarchical. The generic and specific concepts are linked by a hierarchical generic-specific relation. A comprehensive concept with two or more partitive concepts that come together to form an overarching concept is a partitive relation. It is also a hierarchical relationship. Two concepts that are in some kind of thematic association is a non-hierarchical associative relation.

The vocabulary [3] lacks a special concept diagram around the concept of metrological traceability. The concept of metrological traceability is present in the concept diagram of vocabulary [3] around the concept of calibration.

The concept of metrological traceability has associative relation with such basic metrological concepts as measurement result, calibration and measurement uncertainty [8]. Proposed partial concept diagram around concept of metrological traceability with using concepts of vocabulary [3] is shown in Fig. 1.

The concept diagram in Fig. 1 contains a total of nine metrological concepts, which have most of the associative relations. There are associative relations between the concept of metrological traceability chain and concepts of metrological traceability, measurement standard, calibration and calibration hierarchy, and through the concept of measurement standard with the concept of measurement uncertainty.

In essence, a concept diagram is a terminological system that contains certain terminological elements with their relationships. A system thinking can be applied to such a system to analyze its state. The decomposition can be applied to each of the elements (concepts) of this system to establish its more detailed properties [12].

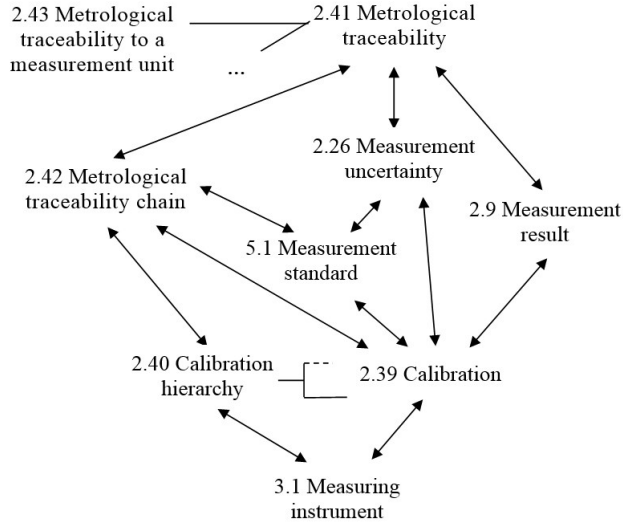

Fig. 1. Partial concept diagram around concept of metrological traceability

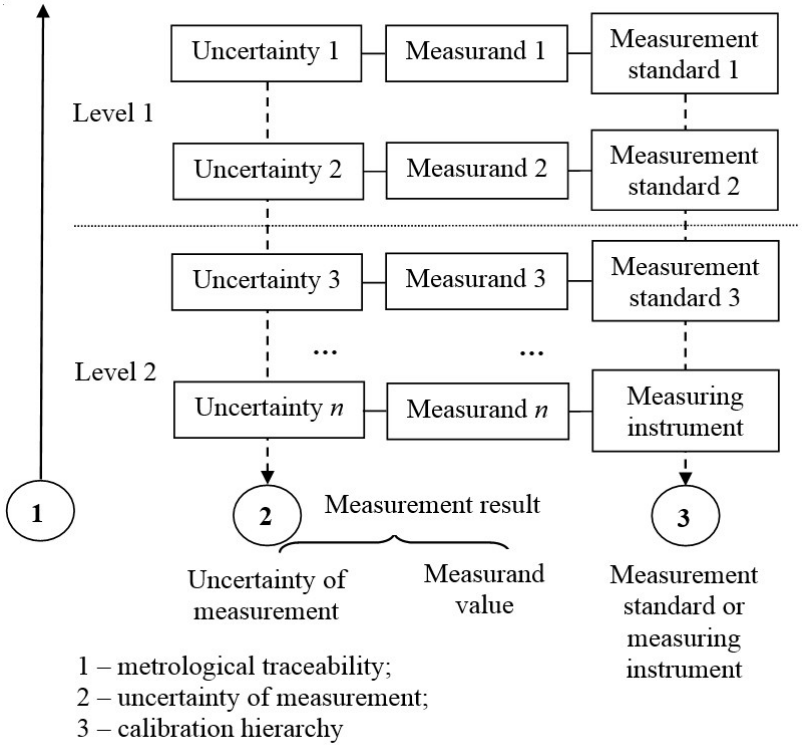

Fig. 2. Generalized metrological traceability chain for different levels of the calibration hierarchy

The properties of the terminological system around the concept of metrological traceability Q_{MT} can be represented as follows:

$$Q_{MT} = Q_{MTC} \cup Q_{MI} \cup Q_{CH} \cup Q_{UM} \cup O_{MT}, \quad (1)$$

where Q_{MTC} are properties of the element of chain of metrological traceability;

Q_{MI} are properties of the element of measuring instrument (measurement standard);

Q_{CH} are properties of the element of calibration hierarchy;

Q_{UM} are properties of the element of measurement uncertainty;

O_{MT} are properties of relations between elements of the system around metrological traceability.

Establishing the principles of construction of the metrological traceability chains

For construction (synthesis) of generalized metrological traceability chain, it is advisable to take into account all the established properties of the elements of the terminology system around the concept of metrological traceability.

The properties of the metrological traceability chain are related to the properties of the measuring instruments used for calibration (measurement standards), the properties of measurement uncertainty and the properties of calibration at different levels of the calibration hierarchy.

With this in mind, it is possible to construct a generalized metrological traceability chain for different levels of the calibration hierarchy [8], taking into account also the provisions of [13] (Fig. 2). A solid line with an arrow (1) indicates the direction of metrological traceability. Dashed lines with arrows show the direction of increasing measurement uncertainty (2) and the calibration hierarchy (3).

The chain of metrological traceability consists of three additional chains: a chain of measurement standards (measuring instruments); chain of measured values; chain of measurement uncertainties. As is well known, the measured value together with its measurement uncertainty constitute the measurement result of the calibration. Level 1 shows the highest level of metrological traceability, and level 2 – the lowest level of metrological traceability.

Level 1 uses the most precure accurate measurement standards to calibrate less precure standards (working standards). The most accurate standards have the lowest measurement uncertainty, which increases with increasing calibration hierarchy. At the lowest level of the calibration hierarchy, metrological traceability to the unit of measurement to SI is provided. From the bottom of Fig. 2 at level 2, there are the measuring instruments for which the greatest measurement uncertainty is used during calibration.

As the calibration hierarchy increases, the intercalibration interval decreases. This is due to the fact that working standards or measuring instruments at the highest level of the calibration hierarchy are used in metrological practice most intensively.

The proposed generalized metrological traceability chain can be used to develop appropriate chains for specific areas of measurement. To achieve this, it is necessary to determine the specific measured value, the required measurement uncertainty for different levels

of the calibration hierarchy and select the necessary measurement standards. Such schemes should be used in national metrology institutes and calibration laboratories.

The number of levels of the calibration hierarchy is determined by the measurement uncertainty required for the laboratory. The uncertainty of the measurements for different calibration levels should be assessed using international guidelines and regional recommendations [4, 14].

Summary

A generalized chain of metrological traceability for different levels of the calibration hierarchy is proposed. This chain is obtained on the basis of the analysis of conceptual diagrams of the International Vocabulary of Metrology using systems thinking. The proposed generalized chain can be used to develop appropriate chains for specific measurement areas. Such chains should be used in national metrology institutes and calibration laboratories.

Застосування системного підходу до встановлення ланцюгів метрологічної простежуваності

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Анотація

Міжнародні угоди в галузі метрології та акредитації калібрувальних лабораторій є основою для встановлення глобальної метрологічної простежуваності. Важливими елементами метрологічної простежуваності є калібрування еталонів та засобів вимірювання, оцінка невизначеності вимірювань. Міжнародне співробітництво з акредитації лабораторій має конкретну політику щодо простежуваності результатів вимірювань та оцінки невизначеності вимірювання при калібруванні.

Запропоновано часткову концепційну діаграму навколо метрологічного простежування відповідно до Міжнародного словника з метрології. Ця діаграма містить загалом дев'ять метрологічних понять, які мають більшість асоціативних зв'язків. Існують асоціативні зв'язки між поняттям "ланцюг метрологічної простежуваності" та поняттями "метрологічна простежуваність", "еталон", "калібрування", "ієрархія калібрування", "невизначеність вимірювань".

Застосовано системний підхід для аналізу стану запропонованої термінологічної системи навколо метрологічної простежуваності. Для побудови узагальненого ланцюга метрологічної простежуваності були враховані всі встановлені властивості елементів системи навколо термінологічної системи метрологічної простежуваності.

Запропоновано узагальнений ланцюг метрологічної простежуваності для різних рівнів калібрувальної ієрархії. Цей ланцюг може бути використано для розробки відповідних ланцюгів для конкретних галузей вимірювань. Для цього необхідно визначити конкретну величину вимірювань, необхідну невизначеність вимірювання для різних рівнів ієрархії калібрування та вибрати необхідні еталони. Такі схеми слід використовувати в національних інститутах метрології та калібрувальних лабораторіях.

Ключові слова: метрологічна простежуваність; невизначеність вимірювання; стандарт вимірювання; засіб вимірювання; системний підхід.

Применение системного подхода для установления цепочек метрологической прослеживаемости

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Аннотация

Международные соглашения в области метрологии и аккредитации калибровочных лабораторий являются основой для установления глобальной метрологической прослеживаемости. Важными элементами метрологической прослеживаемости являются калибровка эталонов и средств измерений, оценка неопределенности измерений.

Предложена частичная концептуальная диаграмма метрологической прослеживаемости в соответствии с Международным словарем по метрологии. Эта диаграмма содержит всего девять метрологических понятий, которые имеют, в основном, ассоциативные связи. Существуют ассоциативные связи между понятием “цепочка метрологической прослеживаемости” и понятиями “метрологическая прослеживаемость”, “эталон”, “калибровка”, “иерархия калибровки”, “неопределенность измерений”.

Применен системный подход для анализа состояния предложенной терминологической системы в части метрологической прослеживаемости. Предложена обобщенная цепочка метрологической прослеживаемости для разных уровней иерархии калибровок. Эту цепочку можно использовать для разработки соответствующих цепочек для конкретных областей измерения. Такие схемы следует использовать в национальных метрологических институтах и калибровочных лабораториях.

Ключевые слова: метрологическая прослеживаемость; неопределенность измерения; эталон; средство измерения; системный подход.

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