Features of Application of a Combined Approach to the Evaluation of the Measurement Results Uncertainty

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Received 20.01.2020
Accepted for publication 28.02.2020

Abstract

The article exposes description of features of the combined approach application to the evaluation of measurement results uncertainty. The aim of this work is the justification and development of new science-driven approaches to achieve maximum efficacy of measurements on the criteria "accuracy/costs" at the stated level of confidence.

It provides theoretical base for correctness of combined approach to assess measurement results uncertainty. There is proposition to conventionally divide measurement process into fragments – combining objects, each from shall be considered as individual element for evaluation. It is well known that combining objects can be formed by grouping individual components (resources) of the measurement process either via separate stages of the measurement process.

Correctness of such approach is based on the application of "resource" and "process" approaches as regards identification of the factors that affect the measurement results uncertainty. This article provides recommendations on selection of model or empiric approach for evaluating of particular contributions from combining objects of different types into total uncertainty of the final measurement result. In order to improve the validity of empiric approach of the criteria of sufficiency of measurement method uncertainty examination was formulated. It is recommended to evaluate the total uncertainty of the final measurement result by complexation of evaluations of particular total uncertainty of the results for all fragments according to the uncertainties distribution law.

It is determined two typical cases of effective application of the combined approach to evaluation of measurement results uncertainty: method of direct measurements and method of indirect measurements. This article considers features of effective application of the combined approach for both situations providing corresponding examples. Special attention is paid to the application of the combined approach to assessing the test results uncertainty. As distinct from the measurement process realized under normal conditions, testing process includes additional external influence factors that are determined by test conditions.

Keywords: measurement results uncertainty, combined approach to assessment.

DOI: 10.21122/2220-9506-2020-11-1-60-69

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Для цитирования:
P.S. Serenkov, V.L. Hurevich, T.K. Tolochko.
Features of Application of a Combined Approach to the Evaluation of the Measurement Results Uncertainty.
Приборы и методы измерений.
2020. – Т. 11, № 1. – С. 60–69.
DOI: 10.21122/2220-9506-2020-11-1-60-69

For citation:
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DOI: 10.21122/2220-9506-2020-11-1-60-69

УДК 389.1

Особенности применения комбинированного подхода к оцениванию неопределённости результатов измерений

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Поступила 20.01.2020
Принята к печати 28.02.2020

Рассмотрены особенности эффективного применения комбинированного подхода к оцениванию неопределённости результатов измерений. Целью данной работы являлось обоснование и развитие новых наукоёмких подходов по достижению максимальной эффективности измерений по критерию «точность/трудоёмкость» при заданной степени доверия.

Теоретически обоснована корректность комбинированного подхода к оцениванию неопределённости результатов измерений. Предложено процесс измерения условно делить на фрагменты – объекты комбинирования, каждый из которых следует рассматривать как самостоятельный элемент оценивания. Установлено, что объекты комбинирования могут быть сформированы путём группирования либо отдельных компонентов (ресурсов) процесса измерений, либо отдельных этапов процесса измерений.

Корректность такого подхода обоснована применением «ресурсного» и «процессного» подходов к идентификации влияющих на неопределённость результата измерений. Приведены рекомендации по выбору модельного или эмпирического подходов для оценивания частных вкладов объектов комбинирования различного типа в суммарную неопределённость конечного результата измерений. Для повышения достоверности эмпирического подхода сформулирован критерий достаточности исследования неопределённости метода измерений. Оценивание суммарной неопределённости конечного результата измерений рекомендовано производить путём комплексирования оценок частных суммарных неопределённостей результатов всех фрагментов по закону распространения неопределённостей.

Выделены два типичных случая эффективного применения комбинированного подхода к оцениванию неопределённости результатов измерений: метод прямых измерений и метод косвенных измерений. Рассмотрены особенности эффективного применения комбинированного подхода для обеих ситуаций на конкретных примерах. Особое внимание уделено применению комбинированного подхода для оценивания неопределённости результатов испытаний. В отличие от процесса измерений, реализуемого в нормальных условиях, в процесс испытаний вовлечены дополнительные факторы внешних воздействий, определённые условиями испытаний.

Ключевые слова: неопределённость результата измерений, комбинированный подход к оцениванию.

DOI: 10.21122/2220-9506-2020-11-1-60-69

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Introduction

A widespread recognition of uncertainty concept in metrology has initiated the development of new science-driven approaches, methods and means to achieve maximum efficacy of measurements (tests), for example, as for criteria "accuracy/labor intensity" at the stated level of confidence.

Until recently the main method for evaluation of measurement results uncertainty was considered as model approach, stated in GUM[1]. Herewith this approach validity in fact is not guaranteed due to several reasons [1].

Technical reports of EUROLAB and other metrological organizations in last several years emphasize the use of empiric approach to evaluate the measurement results uncertainty as an alternative against the strict mathematic modeling [2–7]. The main argument for empiric approaches – considerable improvement of the efficacy of examination of the measurement process accuracy. Empiric approach is based on a quite trivial idea: full uncertainty evaluation can be reached in parallel with carrying out procedures that are mandatory for accredited laboratories, for example, for measurement method validation by intra- and interlaboratory examinations of method accuracy characteristics and quality control through laboratory participation in qualification check programs. As for empiric approach disadvantages we shall mention impossibility of the analysis of influence factors contributions into overall uncertainty of the measurement result, that does not allow to correct and improve the method.

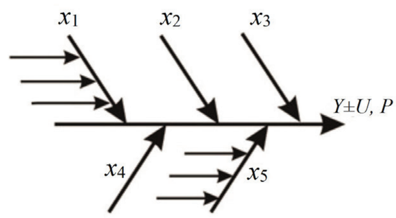
The methodological base for empiric approach are standards[2,3]. From legitimacy point of view, this approach has the same high status as the model one.

From efficacy point of view, the most rational is combined approach to estimating the measurement results uncertainty that envisages the participation of elementary as well as complex factors (grouped data) in the final integrated model [2–7]. Measuring laboratories on the base of their experience prefer combined approach [2]. However, despite of obvious advantages, combined approach is rarely used in the measuring laboratories practice. The aim of this article is to provide scientific and methodical justification for combined approach correctness and analysis of its application possibilities in metrological practice.

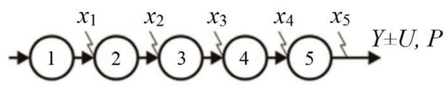
Theoretical base for combined approach

Taking into account obvious equivalency of the empiric and model approaches it is logic to suppose their possible combination within a single measurement method.

The key aspect of the combined approach to estimating overall measurement result uncertainty is grouping of individual components of the measurement process (Figure 1*a*) or measurement process individual stages (Figure 1*b*).



a



b

Figure 1 – Process of measurement of physical quantity Y as the total of "fragments": *a* – of involved quantities $x_1, \ldots, x_5$; *b* – operations $x_1, \ldots, x_5$

Identification and grouping of individual measurement process components as a variety of input quantities x_i, realize so-called "resource" approach to the evaluation of the overall uncertainty $u_c(Y)$ (Figure 1*a*).

Metrological practice knows a whole set of methods and ways that simplify the search and identification of included quantities x_i (Figure 1*a*):

– components of the overall measurement uncertainty in classic error theory: 1) instrumental, 2) methodical, 3) subjective, 4) measurement conditions;[4]

[1]ISO/IEC Guide 98-3:2008, Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995).

[2]ISO 5725-1:1994/Cor 1:1998, Accuracy (trueness and precision) of measurement methods and results – Part 1: General principles and definitions.

[3]ISO/TS 21748:2010, Guidance for the use of repeatability, reproducibility and trueness estimates in measurement uncertainty estimation.

[4]ГОСТ 8.010-2013, National system of measurement units ensurance (GSI). Measurement methods. General.

– main significant factors that determine the precision of the measurement method according to ISO 5725-3: 1) operator, 2) used equipment, 3) equipment calibration, 4) environment conditions, 5) time between measurements;[5]

– best metrological practices realized as cause-and-effect diagrams where sources of measurement result uncertainties are attributed to different parts of the measurement system, for example, S.W.I.P.E. (standard, workpiece, instrument, personnel-procedure, environment), P.I.S.M.O.E.A. (part, instrument, standard, method, operator, environment, assumptions) [8].

Identification and grouping of the measurement process individual stages as a variety of input quantities x_i realize so-called "process" approach to the evaluation of the total uncertainty $u_c(Y)$ (Figure 1*b*). The "process" approach for revealing factors as sources of uncertainty in the model of measurement task can be rationally applied in cases of complex measurement methods from the point of view of the quantity and expressiveness of process stages.

Complex methods are those, for example, like measurement methods in analytical chemistry, that suppose the presence of such typical, relatively individual stages as reference materials preparation, measuring equipment calibration, sample preparation and carrying out measurements [5–7].

Theoretical base for combined approach is linked to the second consequence of central limit theorem of the probability theory and mathematic statistics relating to complexation of random quantities dispersions.

The interpretation of this consequence in relation to the measurement process is provided in GUM[1]: the total uncertainty $u_c(Y)$ of the measurement result Y, obtained by complexation of constituents – standard uncertainties $u(x_i)$ of the factors x_i ($i = 1, \ldots, N$), involved in measurement process, according to the measurement model f is expressed as:

$$u_c(Y) = \sqrt{\sum_{i=1}^{N} (df / dx_i)^2 u^2(x_i)} = \sqrt{\sum_{i=1}^{N} c_i^2 u^2(x_i)}, \quad (1)$$

where $c_i = (df/dx_i)$ – sensitivity factor $u(x_i)$.

[5]ISO 5725-3:1994, Accuracy (trueness and precision) of measurement methods and results – Part 3: Intermediate measures of the precision of a standard measurement method.

Note. Quantities x_i are random, normally distributed and not inter-correlated.

Let’s suppose that measurement process for the quantity Y (see Figure 1*a*) includes five not inter-correlated influence factors x_1, x_2, x_3, x_4, x_5. According to the second consequence formula (1) is valid, where $N = 5$. It is obvious, that we can consider as mathematically correct the following expression (1):

$$u_c(Y) = \sqrt{c_{(1+2+3)}{}^2\, u_{(1+2+3)}{}^2 + c_4{}^2 u_4{}^2 + c_5{}^2 u_5{}^2}, \quad (2)$$

where $u_{(1+2+3)}$ is the intermediate total uncertainty of the measurement result Y, evaluated, for example, using empiric approach according to the results of measuring method validation via its intra-laboratory examination in accordance with the standard[5]. At that, as the result of measuring experiment we have determined standard deviation in intermediate conditions of precision $S_{R(1+2+3)}$ from three varying factors: measuring instrument – x_1, operator – x_2, time – x_3. It can be stipulated that $u_{(1+2+3)} = S_{R(1+2+3)}$.

Standard uncertainties u_4 and u_5 for condition factors (x_4) and sample (x_5) correspondingly in the Formula (2) are assessed using the model approach. At that, standard uncertainty u_4, for example, is evaluated by type *B* on the base of a priori laboratory knowledge, and standard uncertainty u_5 is assessed by type *A* by realization of one-factor experiment according to the GUM[1] approach.

The combined approach essence can be formulated as follows: during the process of evaluating the uncertainty of the result, the measurement process is conventionally divided into fragments, each of them is considered as individual object of evaluation. To determine the total uncertainty of each fragment result, model or empiric approach can be applied. Assessment of the total result uncertainty for entire measurement process $u_c(Y)$ is performed by complexation of assessments of individual total uncertainties of measurement results from all fragments according to the "law of uncertainties distribution" from the GUM approach[1].

Fields of combined approach rational application

It is obvious that the combined approach due to limits of theoretical, material, technical and economical nature, has specific rational fields of preferred application.

From our point of view, we can determine at least two typical cases of effective application of the combined approach to measurement results uncertainty evaluation: method of direct measurements and method of indirect measurements.

Case 1. Using a combined approach for the direct measurement method

Using of combined approach for the direct measurement method in most cases is not rational. As a rule, model of direct measurement according to GUM[1] is as follows:

$$Y = Y_{ind} + C_1 + C_2 + ... + C_N,$$

where Y_{ind} – measurement instrument indication; C_i – corrections for input quantities influence; $i = 1, …, N$.

Uncertainty of the results of direct measurements can be evaluated by model or by empiric approaches. Here we shall exclude situations where combined approach is the rational one:

– measurements that involve variety of consecutive operations, for example, in the field of analytic chemistry;

– measurements within the test framework.

Tests have a special place here. As distinct from measurement process realized under normal conditions, testing process includes additional external factors determined by test conditions. Accordingly, test results uncertainty will be determined taking into account two main groups of standard uncertainty sources: 1) attributed to the measurement process under normal conditions; 2) attributed to additional factors of external influences. The last are reproduced and controlled (measured) within the framework of the measurement process. Therefore, we can see obvious availability of objective conditions for the combined approach application.

Let's consider features of combined approach application in such cases using an example.

Laboratory participates in inter-laboratory examinations within the framework of validation of the method of measurements of the UHF-signals power for UHF-equipment testing. During examinations, the laboratory used an instrument for measuring the absorbed power E4417A with a power sensor E9300A (manufacturer – "Keysinght Technologies Microwave Products (M) Snd Bhd", Malaysia). Measurements where performed in coaxial transmission line at the frequency 50 MHz at the points 1 mW and 10 mW, as well as within frequency range from 10 MHz to 18 GHz at the point 1 mW. Reference value was realized using a reference power calibrator F1130 and a thermistor bridge 1806A (manufacturer – "Tegam", USA). Multimeter 3458A (manufacturer – "Agilent Technologies Inc.", USA) was used as measuring block.

According to the results of the measurements carried out under strictly approved conditions, the laboratory received participation certificate from provider, where method accuracy characteristics are stated. According to EUROLAB recommendations [2] the laboratory accepted the model of the total method uncertainty assessment:

$$u_c = S_{RW}, \tag{3}$$

where S_{RW} – the value of the standard deviation of inter-laboratory method reproducibility. And now this laboratory should have the full right to use this assessment in routine tests assigning this to the results of one-time measurements carried out. However, in this case, this solution is not correct, because the uncertainty of the measurement results depends on the factor "mistuning in measuring line", the value of what is determined via reflection factors of UHF-signal source and absorbed power meter.

Difference between the reflection coefficients of UHV-signal source applied during inter-laboratory examinations (power calibrator F1130 with measuring bridge 1806A) and the UHF-signal source used for routine measurements will be considered as an additional factor implying on the measurement result uncertainty [10–12].

I. e., in cases where conditions or objects under measurement in fact differ from those applied in inter-laboratory validation, additional examinations of measurement results uncertainty are required. For such cases, it is reasonable to use the standard[3], that, according to the expanded statistical model of the measurement result, recommends revealing additional influencing factors by applying expert method. These factors should be evaluated and unified with the standard deviation of the inter-laboratory reproducibility S_{RW}. For this purpose, the standard[3] recommends to use, instead of the model (3), expanded model of uncertainty assessment:

$$u_c = \sqrt{S_{RW}^2 + \sum_{i=1}^{N} c_i^2 u_i^2},$$

where $c_i u_i$ – contributions of additional influence factors, $i = 1, …, N$, that were not included in inter-laboratory comparisons process.

Examples of additional effects that were not taken into account in inter-laboratory comparisons but can significantly imply on the uncertainty of the results achieved by the laboratory using standardized method, can be like sampling and preparation conditions, measurement conditions and so on.

Assessments of standard uncertainties of the factors due to additional effects, as a rule, are determined using a model approach (by type *A* or *B*) or an empiric approach (by the method of intra-laboratory examinations [3]).

Case 2. Using a combined approach for indirect measurements

It is just the case where in order to assess the measurement results uncertainty it is reasonable to apply combined approach.

Algorithm for combined approach application is considered on the example of a method of measurement of the valid value of the direct current rate 10 A using multimeter 34401A (manufacturer – "Hewlett Packard", Germany). As the top multimeter limit for the current is 3 A, measurement method supposes using measuring shunt *B*3 (manufacturer – "Excelsiorwerk Rudolf Kiesewetter Messtechnik mbH", Germany) with nominal electrical resistance 10 mOhm. According to multimeter indications in measuring mode for direct current voltage and data on the valid value of the shunt resistance (provided in the calibration certificate for the shunt of type *B*3) by indirect method we examined the direct current rate. Measurement conditions were normal.

The model of indirect measurement of the direct current rate is as follows:

$$I = \frac{U}{R_{SH}}, \qquad (4)$$

where I – valid value for the direct current rate, A; U – valid value of the voltage measured, V; R_{SH} – valid value of the shut resistance, Ohm.

To evaluate the uncertainty of the result of the measurement of direct current rate I we propose to use two-level algorithm to resolve this task taking into account hierarchic structure of the indirect measurement model (Figure 2).

M1	$I = U/R_{SH}$
	$u_c(I) = \sqrt{\left(\frac{1}{R_{SH}} \cdot u(U)\right)^2 + \left(-\frac{U}{R_{SH}^2} \cdot u(R_{SH})\right)^2}$ (ISO/IEC Guide 98-3:2008)

M1.1	
	$U = m_U + B_U + e$ (ISO 5725-1:1994/Cor 1:1998)
	$u(U) = \sqrt{b_U^2 + S_{RW_U}^2}$ (EUROLAB Technical Report № 1/2007)

M1.2	
	$R_{SH} = R_{SH\,calib} + \Delta_{method} + \Delta_{operator} + \Delta_{condition}$ (ISO/IEC Guide 98-3:2008)
	$u(R_{SH}) = \sqrt{u(R_{SH\,calib})^2 + u(\Delta_{method})^2 + u(\Delta_{operator})^2 + u(\Delta_{condition})^2}$ (ISO/IEC Guide 98-3:2008)

Figure 2 – Two-level algorithm for evaluating the uncertainty of the result of indirect measurement for direct current I using a combined approach. First level: M1 – model of the result of indirect measurement for direct current I and its uncertainty $u_c(I)$. Second level: M1.1 – model of the result of direct measurements of the voltage U and its uncertainty $u(U)$; M1.2 – model of the valid value of the shunt R_{SH} resistance and its uncertainty $u(R_{SH})$

First level of the task of evaluating the uncertainty $u_c(I)$ for the results of indirect measurements of I supposes model approach application. This selection is due to availability of the measurement model I, which has the status of a physical law. It shall be noted, that the proposed two-level algorithm for estimating the uncertainty of indirect measurements results, allows for the first level of the task, not to include into measurement model (4) factors affecting the direct measurement results U and R_{SH}. They will be taken into account at the second level of solving the assessment task.

Model for evaluating the overall measurement result uncertainty (model M1 on the Figure 2) is formed according to the algorithm "8 steps" GUM[1].

$$u_c(I) = \sqrt{\left(\frac{1}{R_{SH}} \cdot u(U)\right)^2 + \left(-\frac{U}{R_{SH}^2} \cdot u(R_{SH})\right)^2}\ . \quad (5)$$

This formula leaves as unknown standard uncertainties $u(U)$ and $u(R_{SH})$, that are obviously represent complex assessment of the uncertainty of the results of direct measurements of the values U and R_{SH}.

Second level of the task of estimating the uncertainty of the result of indirect measurements of the valid value of the direct current rate I supposes self-sustained resolving of the tasks of estimating the uncertainties $u(U)$ and $u(R_{SH})$ of the results of direct measurements of quantities U and R_{SH}, included in the Formula (5).

Task 1 (model M1.1, Figure 2). Assessment of the uncertainty $u(U)$ of the results of measurements by direct method as for direct current voltage value U.

Laboratory has already performed validation of the direct current voltage U method of measurement. Validation method is an intra-laboratory examination of the method accuracy characteristics (bias and precision) according to the standards ISO 5725 series (Accuracy (trueness and precision) of measurement methods and results, Part 1 – Part 6). Thus, to estimate the total uncertainty $u(U)$, it is reasonable to apply an empiric approach, where the assessment model is as follows [3]:

$$u(U) = \sqrt{b_U^2 + S_{RW_U}^2}\ , \quad (6)$$

where b_U – assessment characterizing uncertainty fraction associated with the bias of the results of direct measurement of the direct current voltage [3]; S_{RW_U} – standard deviation of the results of method examination under conditions of intra-laboratory reproducibility, assessed according to the standard[5].

Evaluation of the constituent b_U (6). In this example, b_U was evaluated at the point 100 mV on the basis of experimental data obtained during intra-laboratory method examinations using, as standard, multimeter 3458A (manufacturer "Agilent Technologies Inc.", USA). Value of b_U was expressed as follows [3]:

$$b_U = \sqrt{\Delta_{st}^2 + U_{ref}^2 + \left(S_{rw}/n\right)^2}\ ,$$

where Δ_{st} – average deviation of repeated measurement results from the corresponding standard value minus correction; U_{ref} – assessment of the standard value uncertainty (obtained from the calibration certificate of the standard – multimeter 3458A); S_{rw} – standard deviation of the repeated measurement's results n, determined within the framework of the method validation according to the standard[5].

Note. Δ_{st} can be considered as an analogue of non-excluded systematic constituent of the measurement error, that is assessed as follows:

$$\Delta_{st} = \Delta - \Delta_{corr},$$

where Δ – method bias determined within the framework of validation method, Δ_{corr} – method correction significant for the stated level of confidence probability. In theory, $\Delta_{st} \approx 0$.

Evaluation of the constituent S_{RW_U} (6). Criteria for the correctness of the S_{RW_U} assessment is its representativeness, i. e. the value of S_{RW_U} must include influence effects from all significantly implying factors in laboratory that a priori are not known if full.

At the first stage, in order to examine and assess S_{RW_U}, we recommend to accept the base statistic model of the direct measurements result U (M1.1 on the Figure 2) according to the standard[5]:

$$U = m_U + B_U + e, \quad (7)$$

where m_U – overall average value of the measurement result (expectancy); B_U – aboratory bias constituent; e – bias constituent, arising at each measurement under repeatability conditions.

Summand B_U is a fixed complex of influencing factors-corrections: different operators – B_1, different measuring instruments – B_2, different measurement time – B_3, repeated calibration (validation) of measuring instruments – B_4. Variation of these factors forms conditions for intra-laboratory method repeatability. According to the results of a measurement experiment carried out within the framework of method validation in strict accordance with hierarchical plan (Figure 3), that takes into account laboratory factors ($B_1 - B_4$), method standard deviation value $S_{R(B_1-B_4)}$ under repeatability conditions was obtained.

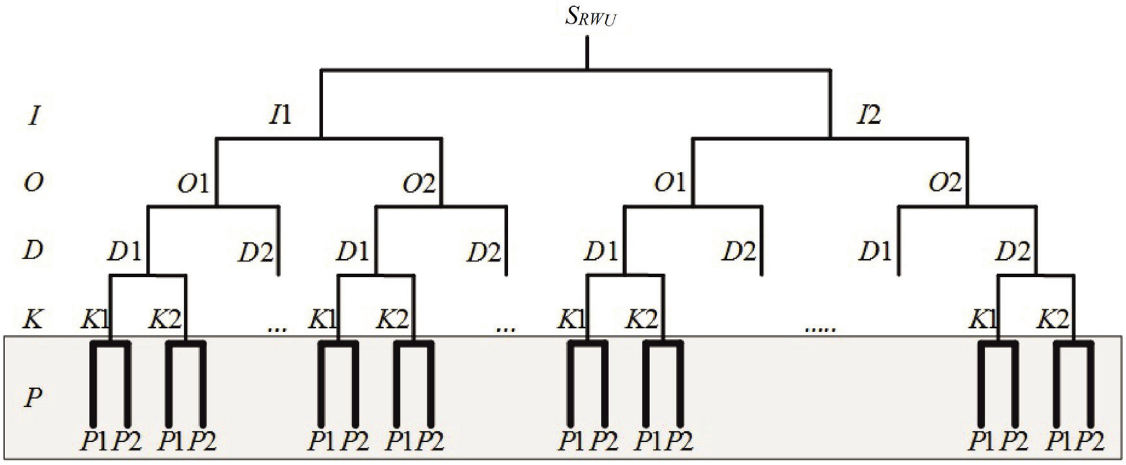


Figure 3 – Basic and corrected (expanded) plan of measuring experiment for examination the precision of the method of measuring of direct current voltage U in the laboratory (L) according to ISO 5725-3:1994. Variety factors: I – measuring instrument; O – operator; D – date of measurements; K – measuring instruments calibration; P – sample. Main plan – light background; expanded plan – light and grey background

It is reasonable to carry out the analysis of the correctness of the results of a measuring experiment using the method of dispersion analysis (software package STATISTICA can be applied) [13, 14]. During this analysis, the following can be determined:

– Required dispersion of measurement results $S_{R(B_1-B_4)}{}^2$ associated with conditions of intra-laboratory reproducibility (B_1–B_4);

– Residual dispersion S_e^2 associated with factors not taken into account in the model (7) (summand e).

Decision on the representativeness of the obtained value $S_{R(B_1-B_4)}$ is supposed to be accepted taking into account the criteria of fullness and non-redundancy:

– If $S_{R(B_1-B_4)} > S_e$ – accepted statistical measurement model (7) is adequate, assessment $S_{R(B_1-B_4)}$ is representative and can be used in model (6) for the assessment of the uncertainty $u(U)$ as summand S_{RW_U}. Further method examination is inappropriate.

– If $S_{R(B_1-B_4)} \leq S_e$ – statistical measurement model (7) is non-adequate, assessment $S_{R(B_1-B_4)}$ is not representative, i. e., it does not reflect contributions of all significant factors of the laboratory and thus can not be used in model (6) for the assessment of the uncertainty $u(U)$ as summand S_{RW_U}. Additional examinations of the direct measurement process U are required.

In the last case, statistical measurement model (7) shall be revised. For this, it is necessary to organize the second stage of examinations. It is reasonable to take as a base an expanded statistical measurement model according to the standard[3]:

$$U = m_U + B_U + \sum(c_i x_i) + e, \quad (8)$$

where, in addition to (7) the summand $\sum(c_i x_i)$ presents additional factors reveled during detailed examination of the direct measurement method U.

As the most rational ways of revealing all influencing factors x_i in (8) we can recommend methods for constructing cause-and-effect diagrams according to the methods S.W.I.P.E., P.I.S.M.O.E.A. [8]. Next, taking into account new revealed factors $c_i x_i$ we shall implement changes into the hierarchic plan of the measurement experiment and realize it at the points according to the new plan positions. Figure 3 provides an example of correction of the plan of validation experiment due to revealing of an additional influence factor $B5 - P$ (sample).

Dispersion analysis of the results of cumulative measurement experiment (factors $B1 - B5$) will allow to determine the corrected values $S_{R(B1-B5)}$ and S_e.

For the final decision on representativeness of the estimate $S_{R(B1-B5)}$ we shall apply the criteria of fullness and non-redundancy once again. If the expanded statistical measurement model (8) is still not correct, in order to reveal additional influence factors we can recommend more complex searching methods, for example, functional modeling of the measurement process according to the methodology IDEF0 [9].

Finally, verified according to representativeness condition assessment $S_{R(B1-B5)}$ can be used in Formula (6) as a summand S_{RW_U}. Assessment of the uncertainty $u(U)$ for direct current voltage measurements U, obtained from Formula (6) according to method validation results, can be considered as correct.

Task 2 (model M1.2, Figure 2). Assessment of the uncertainty $u(R_{SH})$ of the valid value of the shunt resistance R_{SH}.

To evaluate $u(R_{SH})$ it is reasonable to use model approach. To create an adequate measurement model, the laboratory realized an approach based on the application of cause-and-effect diagrams. For identification of included quantities x_i the laboratory used classification of the constituents of the total measurement uncertainty from the classical error theory[4]: 1) instrumental, 2) methodological, 3) subjective, 4) measurement conditions. Further expert analysis of these constituents allowed to state the following:

– possible methodological Δ_{method} and subjective $\Delta_{operator}$ factors, that influence the shunt accuracy, are negligible;

– among the factors of measurement conditions $\Delta_{condition}$ potentially significant factor "temperature" is identified. However, taking into account the fact, that routine measurements will be carried out under normal conditions, the factor "temperature" is recognized as only slightly influencing shunt accuracy characteristics.

As the result, the final measurement model is as follows:

$$R_{SH} = R_{SH\ calib},$$

where $R_{SH\ calib}$ – valid value of the shunt resistance R_{SH} obtained from calibration certificate. Hence, correct model of uncertainty of the resistance value reproduced by the shunt according to GUM[1] is as follows:

$$u(R_{SH}) = u(R_{SH\ calib}),$$

where the value $u(R_{SH\ calib})$ is also obtained from the calibration certificate (by type *B*).

After obtaining reliable uncertainty estimates for direct measurements results $u(U)$ and $u(R_{SH})$ it is necessary to return to the first stage of the resolution of the task of the evaluating the indirect measurements results uncertainty (model M1, Figure 2). Values $u(U)$ and $u(R_{SH})$ are substituted in the Formula (5), that then gives assessment of $u_c(I)$ looked for. Therefore, the task is solved with maximum level of rationality and correctness.

Conclusion

Thus it can be stipulated, that a correct estimation of the measurements results uncertainty by a specific method can be carried out using a combined approach, efficacy and universality of which is described in this article. Any measurement process can be conventionally divided into fragments – combination objects (resource components of the measurement process or its individual operations), each from shall be considered as individual evaluation element. In order to assess intermediate total uncertainty of each object of combining, we can equivalently select a model approach or an empiric approach. This selection is mainly based on efficacy of solving the problem. To improve empiric approach validity the sufficiency criteria of the measurement method uncertainty examination is recommended. Evaluation of the total uncertainty of the final measurement result should be done by complexation of assessments of individual total uncertainties of the results of all fragments according to the "law of errors distribution" of the GUM approach.

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