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# Expression of calibration and measurement capabilities of accredited calibration laboratories in a measurement range

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**Abstract**

The expression of calibration and measurement capabilities (CMCs) of accredited calibration laboratories in a range of values is analysed, and the insurance of appropriate linear interpolation to find the measurement uncertainty at average values is considered.

To minimize the expanded measurement uncertainty, it is proposed to calculate the coverage factor using the kurtosis method so that it would correspond to the composition of the distribution laws of the input quantities.

To approximate the laboratory calibration and measurement capabilities when expressing them as an explicit function of the measurand, it is proposed to apply the least squares method. For non-polynomial dependencies, the capabilities shall be first transformed by replacing the variables into linear ones, which shall be followed by using the least squares method. To facilitate the approximation of CMCs, the use of the “trend line” function of MS Excel is proposed. Four additional nonlinear functions are considered, which are approximated by hyperbolic and homographic functions of Types 1 and 2, as well as by quadrature addition, which can also be transformed into a linear function, and the estimates of their parameters can be obtained by using the least squares method.

An example of performing the approximation by various functions of calibration and measuring capabilities of a laboratory when calibrating a digital caliper is considered.

**Keywords:** interpolation; approximation; best calibration and measurement capabilities; scope of accreditation; calibration laboratory; measurement uncertainty.

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## 1. Introduction

According to the Law of Ukraine “On Metrology and Metrological Activity” [1], “Uniformity of measurements is a state of measurements for which their results are expressed in measurement units determined in this Law, and the characteristics of the error or measurement uncertainty are known with a known probability and do not exceed the established limits”.

As it is known, measurement uncertainty is a quantitative measure of measurement accuracy. The measurement accuracy evaluation is not only one of the tasks of ensuring the uniformity of measurements, but also a necessity for building the customer confidence in the quality of metrological works.

One of the essential criteria that characterize calibration and measurement capabilities (CMCs) of a laboratory accredited by the National Accreditation Agencies of Ukraine – according to the criteria of DSTU EN ISO/IEC 17025:2019 “General Requirements for the Competence of Testing and Calibration Laboratories” [2] – is the lowest measurement uncertainty that the laboratory achieves when calibrating measuring equipment.

As it is stated in ILAC-P14:09/2020 “ILAC Policy for Measurement Uncertainty in Calibration” [3]: “A CMC is a calibration and measurement capability available to customers under normal conditions: as described in the laboratory’s scope of accreditation granted by a signatory to the ILAC Arrangement or b) as published in the BIPM key comparison database (KCDB) of the CIPM MRA”.

The measurement uncertainty covered by CMCs shall be expressed as the expanded measurement uncertainty having a coverage probability of approximately 95%.

According to [3], there shall be no ambiguity in the expression of CMCs in the scopes of accreditation of the calibration laboratory and, consequently, no ambiguity regarding the lowest measurement uncertainty that the laboratory anticipates to achieve during calibration.

In accordance with [3]: "There shall be no ambiguity in the expression of CMCs in the scopes of accreditation and, consequently, no ambiguity regarding the lowest measurement uncertainty that may be anticipated to be achieved by a laboratory during a calibration or a measurement". CMCs shall be always declared numerically and not exclusively by reference to a standard or other document that describes the performed measurements [4]. The unit of the measurement uncertainty shall be always the same as that of the measurand or expressed in terms relative to the measurand, e.g., percent, μV/V, or part per $10^6$. Because of the ambiguity of their definitions, the use of terms "PPM" and "PPB" are not acceptable [3].

Calibration laboratories in their "Scopes of Accreditation" declare the lowest measurement uncertainties so that their potential clients could assess the possibility and quality of calibration works.

Currently, there are 37 accredited calibration laboratories in Ukraine, each of which has declared its calibration and measurement capabilities in a tabular form by the range of the calibrated measuring equipment in the "Scope of Accreditation".

The declared measurement uncertainty during calibration does not characterize metrological characteristics of the measuring instrument (hereinafter referred to as MI) being calibrated, but the requirement for the quality of its calibration.

One or more of the following methods shall be used to express the measurement uncertainty [3]:

a) a single value, which is valid over the entire measurement range;

b) a measurement range – in this case, a calibration laboratory shall ensure that the linear interpolation is appropriate to find the measurement uncertainty at intermediate values;

c) an explicit function of the measurand and/or a parameter;

d) a matrix, where the values of the measurement uncertainty depend on the values of the measurand and additional parameters;

e) a graphical form, providing there is a sufficient resolution on each axis to obtain at least two significant digits for the measurement uncertainty.

The paper considers methods b) and c), which cause the greatest difficulties for domestic metrologists when presenting the measurement uncertainty in CMCs.

## Presentation of the main material

### *1. The measurement range, defined by the limits of the measurand and the corresponding expanded measurement uncertainty limits*

This expression of CMCs is most common in domestic accredited calibration laboratories, when the range of expanded measurement uncertainties $U_{min}...U_{max}$ for the range of input quantities $X_{min}...X_{max}$ is indicated without providing a way to perform the interpolation. Usually, the value $U_{min}$ corresponds to $X_{min}$, and the value $U_{max}$ corresponds to $X_{max}$.

However, according to paragraph 4.2 b [3], "in this case, a calibration laboratory shall ensure that the linear interpolation is appropriate to find the measurement uncertainty at average values".

To find the value of the lowest achievable measurement uncertainty $U$ at any point $X$ in the specified range of the measurand $X_{min}...X_{max}$ using the linear interpolation, one needs to use the formula [5]:

$$U = U_{min} + (X - X_{min})\frac{U_{max} - U_{min}}{X_{max} - X_{min}}. \quad (1)$$

If it is impossible to ensure the required accuracy of such interpolation in the entire range $X_{min}...X_{max}$, it is necessary to divide it into subranges: $X_{1min}...X_{1max}$, $X_{2min}...X_{2max}$, ..., $X_{Nmin}...X_{Nmax}$ ($X_{1min}=X_{min}$; $X_{imax}=X_{(i+1)min}$), in which the required accuracy of the linear interpolation will be ensured. In this case, the measurement uncertainty shall coincide at the breakpoints, i.e. $U_{imax}=U_{(i+1)min}$.

It is according to the above rules that the method of expressing the CMCs in the form of a measurement range, given by the limits of the measurand and the corresponding limits of the expanded measurement uncertainty, is implemented in reputable foreign accredited laboratories.

### *2. Explicit function of the measurand and/or parameter*

When finding the appropriate approximating function, first, it is necessary to calculate the value of the measurand $X_i$ and the corresponding value of the lowest measurement uncertainty $U_i$ at $n$ points of the range ($X_{min}...X_{max}$).

To minimize the expanded measurement uncertainty, it is advisable to choose the coverage factor so that it would correspond to the composition of the distribution laws of the input quantities. This can be achieved by using the kurtosis method [6].

It is advisable to find the approximating function $U_{ap}=f(X)$ for these points using the least squares method (LSM).

If the approximating function is the $m$-th order polynomial:

$$U_{ap} = A_0 + A_1 X + A_2 X^2 ... + A_m X^m, \quad (2)$$

then its coefficients $A_0$, $A_1$, ..., $A_m$ are found by Cramer's rule [7] according to the formulas:

$$A_0 = \frac{D_0}{D}, \quad A_1 = \frac{D_1}{D}, \quad ..., \quad A_m = \frac{D_m}{D}, \quad (3)$$

where $D$ is the principal determinant, $D_0$, $D_1$, ..., $D_m$ are determinants that are derived from the principal one and correspond to the coefficients $A_0$, $A_1$, ..., $A_m$. The order of determinants to obtain the coefficients of the $m$-th order polynomial is $m$+1. For polynomials of the order from 1 to 4, these determinants are given below.

$$D=\begin{vmatrix} n & [X] & [X^2] & [X^3] & [X^4] \\ [X] & [X^2] & [X^3] & [X^4] & [X^5] \\ [X^2] & [X^3] & [X^4] & [X^5] & [X^6] \\ [X^3] & [X^4] & [X^5] & [X^6] & [X^7] \\ [X^4] & [X^5] & [X^6] & [X^7] & [X^8] \end{vmatrix} \qquad D_0=\begin{vmatrix} [U] & [X] & [X^2] & [X^3] & [X^4] \\ [UX] & [X^2] & [X^3] & [X^4] & [X^5] \\ [UX^2] & [X^3] & [X^4] & [X^5] & [X^6] \\ [UX^3] & [X^4] & [x^5] & [X^6] & [X^7] \\ [UX^4] & [X^5] & [X^6] & [X^7] & [X^8] \end{vmatrix}$$

$$D_1=\begin{vmatrix} n & [U] & [X^2] & [X^3] & [X^4] \\ [X] & [UX] & [X^3] & [X^4] & [X^5] \\ [X^2] & [UX^2] & [X^4] & [X^5] & [X^6] \\ [X^3] & [UX^3] & [X^5] & [X^6] & [X^7] \\ [X^4] & [UX^4] & [X^6] & [X^7] & [X^8] \end{vmatrix} \qquad D_2=\begin{vmatrix} n & [X] & [U] & [X^3] & [X^4] \\ [X] & [X^2] & [UX] & [X^4] & [X^5] \\ [X^2] & [X^3] & [UX^2] & [X^5] & [X^6] \\ [X^3] & [X^4] & [UX^3] & [X^6] & [X^7] \\ [X^4] & [X^5] & [UX^4] & [X^7] & [X^8] \end{vmatrix}$$

$$D_3=\begin{vmatrix} n & [X] & [X^2] & [U] & [X^4] \\ [X] & [X^2] & [X^3] & [UX] & [X^5] \\ [X^2] & [X^3] & [X^4] & [UX^2] & [X^6] \\ [X^3] & [X^4] & [X^5] & [UX^3] & [X^7] \\ [X^4] & [X^5] & [X^6] & [UX^4] & [X^8] \end{vmatrix} \qquad D_4=\begin{vmatrix} n & [X] & [X^2] & [X^3] & [U] \\ [X] & [X^2] & [X^3] & [X^4] & [UX] \\ [X^2] & [X^3] & [X^4] & [X^5] & [UX^2] \\ [X^3] & [X^4] & [X^5] & [X^6] & [UX^3] \\ [X^4] & [X^5] & [X^6] & [X^7] & [UX^4] \end{vmatrix}$$

The determinants indicate $n$, which is the number of points in the range ($X_{\min}...X_{\max}$); $[X]=\sum_{i=1}^{n}X_i$, $[X^2]=\sum_{i=1}^{n}X_i^2$, ... $[X^8]=\sum_{i=1}^{n}X_i^8$; $[U]=\sum_{i=1}^{n}U_i$; $[UX]=\sum_{i=1}^{n}U_iX_i$; $[UX^2]=\sum_{i=1}^{n}U_iX_i^2$; $[UX^3]=\sum_{i=1}^{n}U_iX_i^3$; $[UX^4]=\sum_{i=1}^{n}U_iX_i^4$.

For the compactness of the presentation of the material, the determinants of the 2, 3 and 4 orders are highlighted in the above 5-th order determinants with the corresponding dotted lines.

To find the parameters of a polynomial and a number of non-polynomial functions, one can display the calculated points $X_i$, $U_i$ on a graph in MS Excel and use the "trend line" function. This function provides the LSM-approximation of the functions listed in Table 1.

In this case, the accuracy of the approximation can be assessed both by comparing the graphs of the original and approximating functions, and by the coefficient of $R^2$ determination calculated by the program, the value of which shall be closer to 1, by means of which the more accurate approximation is performed.

The relative approximation error can be calculated for the selected approximating dependence using the formula:

$$\delta_{ap\,i}=100\cdot\frac{U_{ap\,i}-U_i}{U_i},\ \% \ . \tag{4}$$

The logarithmic, exponential, and power functions implement the LSM for a linear function, into which MS Excel transforms the original nonlinear function using the substitution of variables method.

Table 1

Approximating functions of MS Excel

| № | Function name | Mathematical expression |
|---|---|---|
| 1 | Linear ($m=1$) | $U_{ap}=A_0+A_1X$ |
| 2 | Polynomial, order $m=2...6$ | $U_{ap}=A_0+A_1X+A_2X^2...+A_mX^m$ |
| 3 | Logarithmic | $U_{ap}=A_0+A_1\ln(X)$ |
| 4 | Exponential | $U_{ap}=A_0\exp(A_1X)$ |
| 5 | Power function | $U_{ap}=A_0X^{A_1}$ |

Table 2

Other approximating functions

| № | Function name | Mathematical expression | Substitution of variables | | Linear function |
|---|---|---|---|---|---|
| | | | $U^* = \varphi(U)$ | $X^* = \psi(X)$ | |
| 6 | Hyperbolic | $U_{ap} = A_0 + \frac{A_1}{X}$ | $U^* = U$ | $X^* = \frac{1}{X}$ | $U = A_0 + A_1 X^*$ |
| 7 | Homographic functions of Form 1 | $U_{ap} = \frac{1}{A_0 + A_1 X}$ | $U^* = 1/U$ | $X^* = X$ | $U^* = A_0 + A_1 X$ |
| 8 | Homographic functions of Form 2 | $U_{ap} = \frac{X}{A_0 + A_1 X}$ | $U^* = 1/U$ | $X^* = \frac{1}{X}$ | $U^* = A_1 + A_0 X^*$ |
| 9 | Quadrature addition | $U_{ap} = \sqrt{A_0^2 + A_1^2 X^2}$ | $U^* = U^2$ | $X^* = X^2$ | $U^* = A_0^2 + A_1^2 X^*$ |

Four more nonlinear functions, which are approximated by hyperbolic and homographic functions of Form 1 and 2, as well as by quadrature addition (Table 2), can also be transformed into a linear function, and the estimates of their parameters $A_0$ and $A_1$ can be obtained using the LSM [8].

In the case of simultaneous presence in the measurement uncertainty budget of contributions that do not depend on the value of the measurand and the contributions that are proportional to the value of the measurand, in documents [4], [9], it is proposed to evaluate the expanded measurement uncertainties of these contributions separately, respectively, in absolute $U_{ABS}$ and relative $U_{REL}$ form, and to record the combined expanded measurement uncertainty in CMCs in the form of $\pm Q(U_{REL} + U_{ABS})$. To find the value of the combined measurement uncertainty in this case, the following expression is used:

$$U_{ap} = \sqrt{[U_{REL} \cdot X]^2 + U_{ABS}^2}. \quad (5)$$

It shall be noted that this formula is valid if both coverage coefficients when calculating $U_{REL}$ and $U_{ABS}$ are equal to 2 (i.e., when assigning a normal distribution to both components).

***3. Example of approximation. Approximation of CMCs of a calibration laboratory when calibrating a caliper***

The best existing caliper was selected as the digital caliper ШЦЦ-I-150-0,01 (measuring range 0-150 mm, digital readout step 0.01 mm) [10].

Calibration of the ШЦЦ-I-150-0,01 caliper is carried out by the method of direct measurement of end gauges, which were used as working measurement standards and correspond to the 1st accuracy class according to DSTU ISO 3650:2009 "Geometrical Product Specifications (GPS) – Length Measurement Standards – Gauge Blocks (ISO 3650:1998, IDT)" [11]. Calibration of the caliper ШЦЦ-I-150-0,01 took place at the following points of the measurement range of external dimensions – 0.5 mm, 21.2 mm, 51.4 mm, 71.5 mm, 101.6 mm, 126.8 mm, 150.0 mm.

The dominant components of the standard measurement uncertainty of Type $B$ are as follows:

1) Estimate of the correction for the discreteness of the digital caliper reading device.

Quantization error occurs in digital MIs and is an instrumental random additive static error.

The estimate of the standard measurement uncertainty of the quantization error is determined by the formula:

$$u_B(\delta l_{iX}) = \frac{q}{2\sqrt{3}}, \quad (6)$$

where $q$ is the resolution of the digital caliper. For $q$ = 0.01 mm, $u_B(\delta l_{iX})$ = 2.89 μm.

2) Estimate of the correction for mechanical effects.

Mechanical effects include the measuring force and the gap between the measuring surfaces of the caliper jaws.

Since the caliper is not equipped with a measuring force stabilizer, the measurement requires the application of a uniform and sufficient force. The permissible value of the force of moving the frame along the rod for a caliper with a measuring range of (0 – 150) mm is 10 N. This leads to a rotation of one extreme section of the rod relative to the other. The measurement error caused by this rotation will be determined by the formula [12]:

$$\delta l_M = \frac{P \cdot l^2 \cdot L}{E \cdot I}, \quad (7)$$

where:

$L$ is the measured length, mm;

$E$ is the modulus of elasticity of the rod material, Pa ($\hat{E}_{steel} = 2 \times 10^5$ MPa);

$l$ is the jaw extension length ($\hat{l}$ = 40 mm);

$P$ is the measuring force ($\hat{P}$ = 10 N);

$I$ is the inertia moment of the cross-section of the rod mm$^4$, $\hat{I}$ = 843.75 mm$^4$.

Table 3

Values of dominant contributions of measurement uncertainty at the calibration points of the caliper ШЦЦ-І-150-0,01

| Calibration point, mm | $u_B(\delta l_{iX})$, μm | $u_B(\delta l_M)$, μm | $u_c$, μm | η | $k(\eta)$ | Expanded measurement uncertainty $U$, μm, $p$ = 0.9545 |
|---|---|---|---|---|---|---|
| 0.5 | 2.89 | 0.027 | 2.89 | –1.200 | 1.67 | 4.83 |
| 21.2 | 2.89 | 1.16 | 3.11 | –0.913 | 1.82 | 5.65 |
| 51.4 | 2.89 | 2.81 | 4.03 | –0.600 | 1.91 | 7.72 |
| 71.5 | 2.89 | 3.91 | 4.86 | –0.652 | 1.90 | 9.25 |
| 101.6 | 2.89 | 5.56 | 6.27 | –0.799 | 1.86 | 11.65 |
| 126.8 | 2.89 | 6.94 | 7.52 | –0.898 | 1.82 | 13.71 |
| 150.0 | 2.9 | 8.21 | 8.70 | –0.965 | 1.80 | 15.63 |

The measurement uncertainty from mechanical effects, assuming a uniform distribution law, will be determined by the formula:

$$u_B(\delta l_M) = \frac{\delta l_M}{\sqrt{3}}. \quad (8)$$

The combined standard measurement uncertainty will be determined by the formula:

$$u_c = \sqrt{u_B^2(\delta l_{iX}) + u_B^2(\delta l_M)}. \quad (9)$$

The data for calculating the combined standard measurement uncertainties of Type $B$ at the specified caliper calibration points are summarized in Table 3.

Since the distribution laws of both components are uniform, the value of the expanded measurement uncertainty when calibrating a caliper is easiest to calculate using the kurtosis method [6]:

$$U = k(\eta)\cdot u_c, \quad (10)$$

where $k(\eta)$ is the coverage factor for the confidence level of 0.9545, which was calculated by the formula:

$$k(\eta) = 0.12\eta^3 + 0.1\eta + 2, \quad (11)$$

where η is the kurtosis of the measurand, which in this case is calculated by the formula:

$$\eta = -1.2\frac{u_B^4(\delta l_{iX}) + u_B^4(\delta l_M)}{u_B^4}. \quad (12)$$

The values of kurtosis and coverage factors for the above calibration points are given in Table 3.

In the example of implementing the approximation for a caliper, the values of the dependence $U=f(L)$ and the results of its approximation are presented in Table 4 and Fig. 1.

Table 4

Values of calculated CMCs and results of their approximation

| Measurable length, $L$, mm | Expanded measurement uncertainty (CMCs), $U$, μm, $p$ = 0.9545 | Linear | Quadratic | Cubic | Exponential | Quadratic addition |
|---|---|---|---|---|---|---|
| 0.5 | 4.83 | 4.29 | 4.70 | 4.82 | 4.97 | 5.70 |
| 21.2 | 5.65 | 5.82 | 5.88 | 5.79 | 5.87 | 6.10 |
| 51.4 | 7.72 | 8.05 | 7.76 | 7.71 | 7.48 | 7.67 |
| 71.5 | 9.25 | 9.54 | 9.11 | 9.22 | 8.79 | 9.14 |
| 101.6 | 11.65 | 11.77 | 11.28 | 11.68 | 11.20 | 11.64 |
| 126.8 | 13.71 | 13.63 | 13.24 | 13.78 | 13.71 | 13.89 |
| 150.0 | 15.63 | 15.35 | 15.16 | 15.63 | 16.52 | 16.03 |

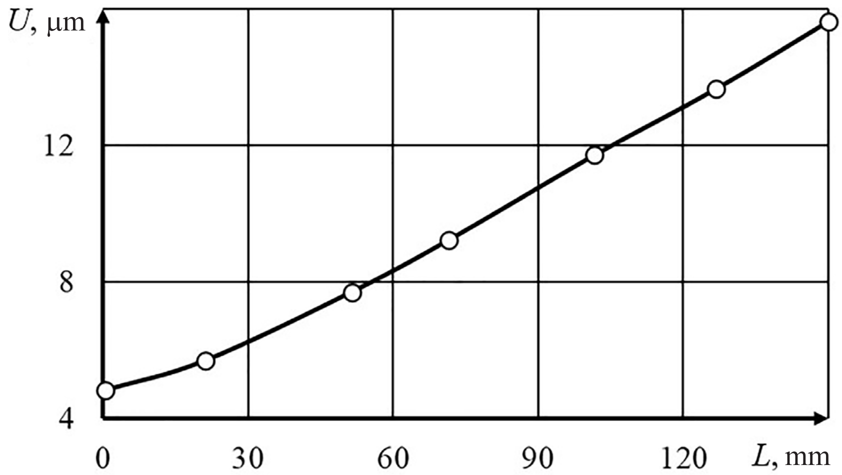


Fig. 1. Caliper dependence $U=f(L)$

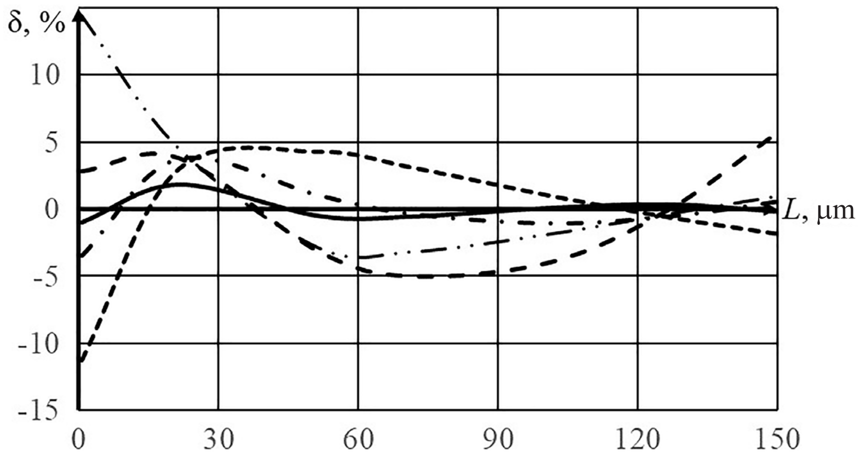


Fig. 2. Relative error of approximation of the expanded measurement uncertainty (CMCs) dependence of the caliper by different functions, %: linear (-----); quadratic (– · –); cubic (——); exponential (— —); quadratic addition (– · · –)

Table 5

The parameters of the approximating functions and values $R^2$

| № | Function name | Mathematical dependence $U_{anp}=f(L)$ | Values $R^2$ |
|---|---|---|---|
| 1 | Linear | $U_{app}=4.251+0.0740\cdot L$ | 0.9938 |
| 2 | Quadratic | $U_{app}=4.6348+0.05513\cdot L+1.25\cdot 10^{-4}\cdot L^2$ | 0.9989 |
| 3 | Cubic | $U_{app}=4.7621+0.03837\cdot L+4.27\cdot 10^{-4} L^2-1.34\cdot 10^{-6} L^3$ | 0.9998 |
| 4 | Exponential | $U_{app}=4.9467\cdot \exp(0.008\cdot L)$ | 0.9911 |
| 5 | Quadratic addition | $U_{app}=\sqrt{0.00971545\cdot L^2+30.5578}$ | 0.9964 |

The parameters of the approximating functions and their values $R^2$ are given in Table 5.

Fig. 2 shows the relative error of approximation of the expanded measurement uncertainty (CMCs) dependence of the caliper by different functions, expressed in percentage, which is calculated by formula (4).

From Fig. 2 it is seen that the best approximation is achieved using a polynomial of the third degree. In this case, the approximation error does not exceed ± 1.9%.

In this case, the CMCs table will be like Table 6.

**Conclusions**

1. One of the essential criteria characterizing the CMCs of an accredited calibration laboratory is the lowest measurement uncertainty that the laboratory achieves when calibrating measuring equipment and which is expressed in the form of an expanded measurement uncertainty having a coverage probability of approximately 95%.

2. To minimize the expanded measurement uncertainty, it is advisable to calculate the coverage factor using the kurtosis method so that it would

Table 6

Excerpt from the scope of accreditation

| № | Object of measurements | Measurement range in which the calibration is performed | Expanded measurement uncertainty $U$ | Designation of regulatory documents for calibration methods |
|---|---|---|---|---|
| 1 | Caliper ШЦЦ-І-150-0,01 | 0.5-150 mm | $U = 4.7621 + 0.03837 \cdot L + 4.27 \cdot 10^{-4} L^2 - 1.34 \cdot 10^{-6} L^3$ | МК01:2024 |

correspond to the composition of the distribution laws of the input quantities.

3. When presenting CMCs in the form of a range of values, it is necessary to perform linear interpolation in the specified range. If it is impossible to ensure the required accuracy of such interpolation in the entire range, it is necessary to divide it into subranges in which the required accuracy of linear interpolation will be ensured. In this case, the measurement uncertainty shall coincide at the breakpoints.

4. When presenting the CMCs as an explicit function of the measured quantity and/or parameter, the Least Squares Method (LSM) shall be used to approximate the calculated values of the lowest expanded measurement uncertainty. For non-polynomial dependencies, CMCs shall be first transformed into linear ones by changing the variables, followed by the LSM application.

# Подання калібрувальних та вимірювальних можливостей акредитованих калібрувальних лабораторій у діапазоні вимірювань

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**Анотація**

У статті розглянуто питання, пов’язане з формуванням “Сфери акредитації” калібрувальної лабораторії, яка акредитується відповідно до вимог ДСТУ EN ISO/IEC 17025:2019 “Загальні вимоги до компетентності випробувальних та калібрувальних лабораторій”. Найкращою мірою якості калібрувань, які проводяться калібрувальною лабораторією, є найменше значення невизначеності вимірювань, яке досягається цією лабораторією під час калібрування вимірювального обладнання відповідної категорії.

Проаналізовано форму вираження калібрувальних та вимірювальних можливостей акредитованих калібрувальних лабораторій діапазоном значень і розглянуто забезпечення належної лінійної інтерполяції для знаходження невизначеності при середніх значеннях.

Для мінімізації розширеної невизначеності пропонується розраховувати коефіцієнт покриття за допомогою методу ексцесів так, щоб він відповідав композиції законів розподілу вхідних величин.

Запропоновано застосування методу найменших квадратів (МНК) для апроксимації калібрувальних та вимірювальних можливостей лабораторії при вираженні їх у вигляді явної функції вимірюваної величини. Для неполіноміальних залежностей їх необхідно спочатку перетворити шляхом заміни змінних на лінійні з наступним використанням МНК. Для полегшення апроксимації СМС пропонується використання функції “лінія тренду” MS Excel. Розглянуто чотири додаткові нелінійні функції, які апроксимуються гіперболічною та дрібно-лінійними функціями виду 1 і 2 та квадратурним додаванням, яке також можна перетворити на лінійну функцію, і за допомогою МНК отримати оцінки їхніх параметрів.

Наведено приклад виконання апроксимації різними функціями калібрувальних та вимірювальних можливостей лабораторії при калібруванні цифрового штангенциркуля.

**Ключові слова:** інтерполяція; апроксимація; найкращі калібрувальні та вимірювальні можливості; сфера акредитації; калібрувальна лабораторія; невизначеність вимірювань.

**References**

1. The Law of Ukraine "On metrology and metrological activity" dated June 5, 2014, No. 1314–VII (in Ukrainian).
2. DSTU EN ISO/IEC 17025:2019. General requirements for the competence of testing and calibration laboratories (EN ISO/IEC 17025:2017, IDT; ISO/IEC 17025:2017, IDT) (in Ukrainian).
3. ILAC-P14:09/2020. ILAC Policy on Measurement Uncertainty in Calibration.
4. Lab 45. Schedules of accreditation for calibration laboratories. UKAS, Edition 5, June 2023. 16 p.
5. Zakharov I.P., Novoselov O.A. Opredeleniye izmeritelnykh i kalibrovochnykh vozmozhnostey kalibrovochnoy laboratorii v protsesse yeye akkreditatsii [Determination of the measuring and calibration capabilities of the calibration laboratory in the process of its accreditation]. *Ukrainian Metrological Journal*, 2017, no. 4, pp. 3–11 (in Russian). doi: https://doi.org/10.24027/2306-7039.4.2017.125040
6. Zakharov I.P., Botsyura O.A. Calculation of Expanded Uncertainty in Measurements Using the Kurtosis Method when Implementing a Bayesian Approach. *Measurement Techniques*, 2019, vol. 62(4), pp. 327–331. doi: 10.1007/s11018-019-01625-x
7. Bronshtein I.N., Semendyayev K.A. Handbook of Mathematics. Sixth Edition. Springer, 2015. 972 p.
8. Zakharov I., Neyezhmakov P., Semenikhin V., Warsza Z.L. Measurement Uncertainty Evaluation of Parameters Describing the Calibrated Curves. In: Szewczyk R., Zieliński C., Kaliczyńska M. (eds). Automation 2022: New Solutions and Technologies for Automation, Robotics and Measurement Techniques. *Advances in Intelligent Systems and Computing*, 2022, vol. 1427, pp. 391–398, Springer, Cham. doi: 10.1007/978-3-031-03502-9_38
9. M3003:2024. The expression of uncertainty and confidence in measurement. UKAS, Edition 6, March 2024. 106 p.
10. DSTU EN ISO 13385-1:2018. Geometrical product specifications (GPS) – Dimensional measuring equipment – Part 1: Design and metrological characteristics of callipers (EN ISO 13385-1:2011, IDT; ISO 13385-1:2011, IDT) (in Ukrainian).
11. DSTU ISO 3650:2009. Geometrical Product Specifications (GPS) – Length standards – Gauge blocks (ISO 3650:1998, IDT) (in Ukrainian).
12. Novoselov O.A. K voprosu otsenivaniya kalibrovochnikh i izmeritelnikh vozmozhnostei akkreditovannoi kalibrovochnoi laboratorii [To the question of estimation the calibration and measurement capabilities of the accredited calibration laboratory]. *Information processing systems*, 2018, vol. 4(155), pp. 128–133. doi: 10.30748/soi.2018.155.18