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Abstract

Theses of reports of the XXII International Scientific and Technical Seminar “Measurement Uncertainty: Scientific, Normative, Applied and Methodical Aspects” (UM-2025), which was held online on December 10-11, 2025. At the seminar, 52 reports by authors from 5 countries were presented: Bulgaria, Italy, Poland, Ukraine, USA. It includes works covering a wide range of topics: development of theoretical foundations of model and empirical approaches to measurement uncertainty evaluation; processing of results and measurement uncertainties evaluation at tests, calibrations, verifications; validation of testing and calibration methods; automation of the process of processing results and evaluation of uncertainty in measurements; improvement of the regulatory base for measurement uncertainty evaluation; organization and conduct of interlaboratory comparative tests and processing of their results; special features of training in measurement uncertainty evaluation. The materials of the seminar are a valuable resource for teachers, employees of testing and calibration laboratories, postgraduate students who seek to expand their knowledge and contribute to the development of measurement uncertainty evaluation.

The materials of the collection are published in the author's version without editing.

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INVITED REPORTS

LINKING CIPM AND RMO COMPARISONS

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We introduce an overview of three methods used to link a key comparison organized by a Regional Metrology Organization (RMO) and a key comparison organized by a Consultative Committee of the International Committee for Weights and Measures (CIPM): (i) a heuristic (or naive) approach; (ii) weighted least squares (a simplified version of Sutton, 2004); and (iii) a Bayesian common laboratory effects model (Bodnar & Elster, 2018).

These procedures are illustrated in an application to results from CCM.M-K7 (Lee et al., 2017). The expanded uncertainties that are part of the degrees of equivalence (DoEs {(D[j], U95(D[j]))}) for the linked comparisons based on (i) and (ii) were evaluated using the Monte Carlo method. Their counterparts based on (iii) were evaluated based on the output of Markov Chain Monte Carlo (MCMC) sampling of the joint Bayesian posterior distribution for the model.

The DoEs produced by the Bayesian procedure have the smallest uncertainties of the three approaches, and also have D[j] values closest to 0 mg. The Bayesian common random effects model can also easily recognize dark uncertainty in one or both comparisons being linked, and takes it into account.

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APPLYING MINIMAX APPROXIMATION TO DETERMINE A CALIBRATION LINE OF A MEASURING INSTRUMENT

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The thesis describes the essence of the MINIMAX method for determining the calibration line of the measuring instuments and also sensors, including examines the characteristics of the calibration line obtained in this way, and compares them with the parameters of the line determined by the least squares method.

The idea of using the MINIMAX method is based on the fact that in estimation theory it is known that if the random observations taken from a population with a uniform distribution are processed, then, using the most commonly used maximum likelihood method of estimation, the parameters of the population should be determined according to the criterion of minimizing the maximum deviation. In particular, the best estimator of the population location parameter (with minimum standard uncertainty) is the midrange of the random sample, and the best width parameter is the half of the range [1]. Therefore, when estimating a line describing the relationship between the input and output values of a measuring instrument, assuming a uniform distribution of possible deviations, this MINIMAX criterion should also be applied.

Beside it, in metrology practice, the MINIMAX criterion is used to describe the metrological properties of measuring instruments. Namely, manufacturers of measuring instruments usually indicate the values of the maximum permissible error (MPE). The GUM Guidelines [2] clearly state that in the absence of knowledge about the probability distribution of possible deviations of the measuring instrument readings, a uniform distribution in the range ± MPE should be used.

This article provides a description of the MINIMAX approximation procedure in detail. And also gives two examples of determining the calibration line based on the primary calibration data (obtained in licensed LABBiKAL laboratory, PRz, Poland) of a multimeter Fluke 8845A in the DC and AC voltage measurement modes, as well as the sensor. A comparison of the results obtained using MINIMAX with the results obtained using the traditional least squares method is provided.

Analysis of the results showed that, although the least squares method is the most suitable for calculating the parameters of the calibration function, it does not always provide a completely correct determination of the MPE limits of the calibrated measuring instrument. In particular, a few experimental points can often exceed the extended uncertainty limits.

In contrast, the MINIMAX in this respect much better reflects the calibration line along with the limits of possible deviations of experimental points from this line.

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ELECTRICAL POWER - THE MISSING ELEMENT IN ELECTRICAL POWER QUALITY ASSESSMENT

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The subjects of the electricity market are distinguished in the production, transmission, distribution and consumption of Electrical Energy. The electrical energy is the real commodity that is supplied by suppliers, sold by traders and paid for by consumers and, like any goods, it has quantitative and qualitative characteristics. Without limitation of the focus on the physical quantity Electrical Energy, discussing the topic of product quality, the term Electrical Power Quality (EPQ) has gained wide public popularity, including in scientific forums and a huge number of publications. Electrical Power as a physical quantity obviously does not correspond to the product (goods) - Electrical Energy, but Electrical Power is more often used in the sense of Electrical Energy, i.e. The term Electrical Power Quality should be translated and understood in its broader sense as Electrical Energy Quality.

If we consider electrical energy as a commodity: "A commodity is ... a good, a product produced to satisfy certain needs, human needs ..., and which can be sold on the market. Goods can be intended for consumption, equipment, furnishing, or exploitation." (according to wikipedia.org), the specific characteristics of this goods can be distinguished:

- Electrical energy is a commodity, a product of continuous production (and transmission);
- Electrical energy is a commodity, subject to continuous dynamic consumption, which affects its characteristics;
- Electrical energy as an exchange commodity is strictly parameterized;
- Electrical energy as a commodity requires outgoing and incoming control of compliance with certain quality parameters using quality control methods.

The quality of electricity is a compromise between the consumer and the supplier. Production, transportation and delivery are practically at the moment of consumption. The measurement and assessment of the quality of the supplied energy must be carried out at the moment of consumption. As a presumption, for proper work of the network the generation, transmission and distribution systems must always meet the requirements for sufficient energy delivery capacity. Unlike other products, the quality of electricity depends on the mutual influence of the consumers themselves. The quality of the voltage varies from point to point depending on the instant consumption. As a result, the quality of electricity can be ensured simultaneously by producers, suppliers and consumers of electricity. Maintaining satisfactory quality is a joint responsibility of the producer, supplier and consumer.

The most popular standard guiding the trade relations for electricity supply in Europe is EN 50160 "Voltage characteristics of electricity supplied by public electricity networks". EN 50160 is a CENELEC product standard that defines, describes and specifies the main characteristics of the voltages that can be expected at the supply terminals in European public low, medium or high voltage networks. It is not harmonised with the EU New Approach Directive. According to CENELEC's internal

rules, the standard must be implemented as a national standard in all CENELEC member countries. In accordance with the general status of the standard, the specifications given in the main body of EN 50160 are not mandatory in themselves, but may become mandatory if they are specified in contracts between the participants (supplier-user), in local regulations and also in EDC rules for using the network. The presumption of EN 50160 as a standard for Electrical Power Quality is that if the voltage characteristics are in norms the Quality of the supplied commodity Electrical Energy is guaranteed.

As it was said: The quality of electricity is a compromise between the consumer and the supplier. That compromise is lightly discussed in Annex A of the standard. As Norms in EN 50160 are specified only the parameters of the supplied Voltage. It is seemingly only laid down in the Standard defining Power Quality measurement methods EN 61000-4-30 with the references to the Current. It is accepted that "In a power quality context, current measurements are useful as a supplement to voltage measurements, especially when trying to determine the causes of events such as voltage magnitude change, dip, interruption or unbalance". EN 61000-4-30 limits to measurements of current magnitude, harmonics and inter-harmonics and current unbalance. The relationship with the consumed (or delivered) power is not treated – e.g. phase angle. Active, reactive and apparent power, their peak values, etc. are parameters of the contracts for connection to the electricity distribution network. In most practical cases, these limits are violated, resulting in problems with the supply voltage, but they are not included in the compliance assessment when documenting the inspection. Moreover, the popular averaging intervals in EN 50160 (based on the EN 61000-4-30) are 10 min, than the intervals of averaging the consumption for billing in LV/MV electricity meters are 15 min what reflects on the values in the respective power registers read by the supplier.

The conclusions are:

- The Electical Power Quality (EPQ) is a wide discussion area with partial one-way regulations protecting the consumer;
- The EPQ dependence on consumer loads is not reflected in standards or in regulatory sanctions;
- Typically, power limits are covered in connection contracts with certain sanctions, but they cannot cover, for example, short-term overloads, because consumption is measured at 15-minute intervals.

Therefore:

- Reporting EPQ, a compliance with the limits of contracted permissible power should be recorded on averaging intervals corresponding to the supply contract;
- Measuring consumption, a provision should be made for recording short-term overloads.

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MAPS CAN SUPPORT QUANTITATIVE EVALUATION OF EARTH'S SURFACE FEATURES AND THEIR EVOLUTION IN TIME BETTER THAN GLOBAL NUMERICAL PARAMETERS

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In recent years, the almost exclusive use of global numerical parameters is preferred to characterize trend changes in time in scientific fields like meteorology and climate science (IPCC is a reference of basic importance). The preference arises from the new possibilities allowed by the systematic use of informatics means to extract the relevant information from wider and wider databases having induced the new term 'Big Data'.

On the contrary, the present trend of informing about global changes and related parameters is the one preferred by all the International Organizations involves in climate change, namely IPCC. It consists in summarizing the changes via global numerical parameters, typically assumed to represent the evolution of the mean numerical value of big datasets correctly. However, in their synthesis, global numerical parameters may miss scientist's understanding of the existing complexity of the full set of values obtained from the measured data that they intend to qualify.

On the other hand, the traditional field of using maps for extended sets of data, namely the spatial one, was not surpassed in its unique capability to clearly convey, with its (visual) representation, details on the significance of the studied phenomena and of their variations in time, especially when the aim is to forecast future trends. In some fields, like that of analyses of the Earth's surface, maps have long since been used and recently the Food and Agriculture Organization of the United Nations has also confirmed its preference for their use. Accordingly, a revamp of the generalized advantages of visualization in science occurred, as found in the literature, especially in philosophy of science. On the other hand, within the recent developments of informatics one might also observe a possible increase of visualized-data misunderstanding.

Especially when the maps illustrate a great variety of situations, a comprehensive geometrical examination is recognized to report superior information –also quantitative since maps are graduated. This allows an overall and more reliable evaluation and its evolution, typically in time, a possibility that does not introduce any kind of conflict between mathematical and geometrical human examination but simply useful complementarities, already appreciated in the literature.

The paper first provides a comprehensive introduction to the state-of-the art of data collation in databases and manipulation. Then, illustrates data visualization by means of maps, but not from a cartographic-science viewpoint, instead from the viewpoint of measurement-science, according to the Journal readers main interest: this is a multidisciplinary frame allowing deep analyses of data of various origins according to the discipline of metrology, author's main competence. How the original numerical data can be used to plot a map is a cartography-science task. Providing evidence of the main new features introduced by Earth's mapping of climate parameters, and of the ways to

take advantage of the different types of representation in the maps, will be the only author's aim.

However, the term 'visualization' indicates a great variety of types of data graphical representation, from simple graphs, to 3D complex mapping, to its use in simulation. Therefore, the paper will restrict the subject matter exclusively to the examination of the mapping of Earth's surface—full or partial but never local, and never enter into the task of map realization from the original dataset.

It only intends to bring evidence of map superior content of information: in addition to simple visualization, this paper shows how maps allow to also retrieve underlying numerical data by means of a computer-based method recently introduced by the author. It allows the interested scientist to extend her analysis beyond the global parameters without the need to retrieve the original dataset, so paralleling the qualitative analysis obtained by visualization with the addition of quantitative analyses.

Some problems, related to the presently dominant way to get the desired local and overall information in climate science, are also shortly discussed according to the relevant literature but without the intention of making a review paper of those subject matters. The Global Mean Surface Temperature (GMST) will be used as the single example because of its special importance and normally consideration by the Intergovernmental Panel on Climate Change and others Committees, as one of the most popular parameters.

The basic features of a quantitative analysis of GMST with the method reported in this paper are fully reported and a flowchart summarizes the procedure.

Finally, qualitative examples of visualization are reported, while detailed quantitative examples and the related procedure are shortly introduced, then, due to their extension, fully discussed in an Appendix.

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A BAYESIAN MODEL FOR MEASUREMENT BY COUNTING AND ITS APPLICATION TO CONFORMITY ASSESSMENT

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Counting objects or events (hereafter simply "items") occurs very often in many scientific and technological domains, being at the base of many high-level measurements in fields such as, for example, time and frequency, optics, ionizing radiations, microbiology and chemistry. Also, in everyday life, countings play a fundamental role, as for the use of electric power meters, based on counting a number of impulsions, the assessment of pre-packaged goods, whose total price depends on the number of exchanged items, the monitoring of medication consumption, for example by monitoring of pill intake into blisters.

As for any measurement, the result of a counting process should be expressed as: a) an estimate (the number of counted items) of the measurand (the true number of items) and an associated uncertainty (or a suitable coverage interval), according to JCGM 100:2008 (the legacy GUM [1]); or b) a probability distribution (discrete, in the case of counting) describing the state of knowledge on the measurand, according to JCGM 101:2008 [2]. However, neither of the above-mentioned documents provides adequate guidance for measurements by counting. Furthermore, and despite a large number of publications available on the counting topic in so many different fields and applications, we could hardly find studies aimed at correcting counting errors possibly affecting the measurand estimate and at evaluating the associated uncertainty.

In the present work, we tackle the problem by resorting to a Bayesian model, which allows determining a posterior probability mass function for the measurand while taking into account the probability of over- and under-counting errors. The model is able to deal with any number of false positives and negatives, correcting the estimate of the measurand for the bias due to such errors and associating a proper measurement uncertainty to it. To that aim, we propose a specific likelihood function that accounts for over- and under-counting errors, and does so in terms of two parameters: the (conditional) probability that a non-existing item is mistakenly counted (probability of false positive $p_{\leftarrow}$), and the (conditional) probability that an existing item is not counted (probability of false negative $1 - p_{\rightarrow}$).

Aside from directly applying this model to counting processes, the proposed framework could well serve to classification problems in general, where $p_{\leftarrow}$ and $1 - p_{\rightarrow}$ are related to probabilities of false positives and negatives, respectively. Specifically, it can be applied to the conformity assessment of a sample of items, seen as binary classification problem. JCGM 106:2012 [3] provides a Bayesian framework for the conformity assessment of the true value of a property of interest of a single item, by combining prior knowledge on the measurand with the knowledge acquired in the measurement (affected by measurement uncertainty). Global consumer risk R_c (false positive error) and producer risk R_p (false negative error), defined therein for a single item at a time, can be generalized to the corresponding risks for the whole sample of

items. To assess the quality of the sample, indeed, the relevant question to be addressed should be: "given that a certain number of items in the sample are accepted as conforming (since they have showed a measured value of the property of interest within its acceptance interval), which is the probability to actually have the same or another number of truly conforming items (i.e., having their true value within its tolerance interval) in the whole sample"? The proposed modelling is able to answer the question, by appropriately expressing probability parameters $p_{\leftarrow}$ and $1 - p_{\rightarrow}$ in terms of R_c and R_p. This could help in the fields of quality control and inspection, acceptance sampling and conformity assessment.

In conclusion, the proposed model for measurements by counting accommodates any number of under- and over-counting's, naturally considering any prior knowledge on the measurand. It can be generalized to hierarchical models including possible prior knowledge on the statistical parameters involved and can be applied to classification and conformity assessment problems.

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WARTIME CHALLENGES AND "UNCERTAINTIES" FOR METROLOGY IN UKRAINE

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Ukraine's metrological system has faced a number of serious challenges and needs related to security risks, infrastructure destruction, economic instability, and changes in legislative regulation. At the same time, this has revealed significant opportunities for development and modernization. The challenges caused by the war have stimulated the search for new solutions, particularly in the areas of digitalization, cooperation with international partners, and strengthening the defense sector.

Main Problems and Needs:

- **Logistical Difficulties and Infrastructure Damage:** Hostilities have led to damage or destruction of metrological laboratories, National Measurement Standards, and equipment. Due to the occupation of the village of ***Lyptsi*** in the Kharkiv region, near the border with Russia, 8 standards in the field of ionizing radiation, 2 hardness standards, and a rangefinder calibration baseline were lost. This, combined with disruptions to supply chains, complicates the timely delivery of instruments for verification, calibration, and repair, especially in regions affected by fighting. It is necessary to restore and modernize these facilities to ensure the uniformity and traceability of measurements.
- **Loss of Human Resources:** Mobilization, forced displacement, and emigration have led to a decrease in the number of qualified personnel in the metrological field, creating a shortage of specialists. This necessitates the implementation of training and retraining programs.
- **Lack of Budget Funding:** The introduction of martial law led to the reallocation of state funds, which affected the financing of metrological research and equipment modernization. Metrological enterprises need financial support, including investments and grants, to update equipment and restore operations.

Opportunities for Metrology Development:

- **International Cooperation:** International and regional metrological organizations, as well as National Metrology Institutes, provide support to Ukrainian metrologists, including through knowledge exchange, equipment provision, and humanitarian aid. This creates opportunities for integration into the European metrological infrastructure. Ukrainian metrological institutions, in particular the NSC "Institute of Metrology", are actively participating in international and European scientific projects, for example, within the European Partnership on Metrology, international comparisons of national standards, and in EURAMET activities. Thanks to the support of PTB, a significant amount of reference equipment from Ukraine's National Scientific Centres has been and is planned to be calibrated directly at PTB.

- **Modernization and Innovation:** The destruction of part of the infrastructure can be an impetus for creating modern, technologically equipped laboratories. This makes it possible to implement the latest technologies and standards.
- **Attracting Investments:** The recovery of the economy and large-scale reconstruction projects will require significant funding. The metrology sector, as a critically important element of infrastructure, can attract investments from both Ukrainian and international partners.
- **Digital Transformation:** The development of digital technologies allows for the transfer of many processes to an online format, which reduces physical risks and increases efficiency. This applies to both document flow and remote monitoring.

Despite significant challenges, Ukraine's metrological sector continues to adapt to new conditions, ensuring the uniformity and traceability of measurements, which are vital processes for the economy and defense.

OBTAINING VALUES AND UNCERTAINTIES OF EQUIVALENT CIRCUIT PARAMETERS OF RESISTORS AND CAPACITORS FROM MEASUREMENTS OF THEIR IMPEDANCE FREQUENCY CHARACTERISTICS

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The paper will present the determination of the parameters *R, L, C* of the equivalent scheme of impedances of resistors and capacitors and also their uncertainties.

So, in general the impedances $\boldsymbol{Z}$ in Cartesian system of such scheme are complex:

$$\boldsymbol{Z} = \mathrm{Re}(\boldsymbol{Z}) + j\,\mathrm{Im}(\boldsymbol{Z}) \tag{1}$$

where $\mathrm{Re}(\boldsymbol{Z})$ is real and $\mathrm{Im}(\boldsymbol{Z})$ is imaginary part- reactance of impedance and *j* is imaginary unit.

The one of the most important metrological characteristics is the frequency characteristic of transmittance (Body or Nyquist) of such circuits. The examples of frequency characteristic of impedance measured with uncertainties in *n* points $\mathrm{Re}[\boldsymbol{Z}(\boldsymbol{p},\omega_i)]$, $\mathrm{Im}[\boldsymbol{Z}(\boldsymbol{p},\omega_i)]$ or $|\boldsymbol{Z}|(\boldsymbol{p},\omega_i)$, $i = 1,2,...,n$ are real or imaginary parts or module of impedance depends on all parameters $\boldsymbol{p} = [p_1, p_2, ..., p_m]$ of characterizing elements of circuits and frequency $f = \omega/2\pi$ of the sinusoidal forcing signal are given.

In previous papers, the adjustment of system parameters using Monte Carlo without evaluation of uncertainty of parameters was demonstrated. The simpler method based on WTLS method for fitting straight line with exchanging coordinates is applying to all parameters with uncertainties and determinates the coverage corridor of module of impedance in such frequency characteristic.

In the case of the latter, the uncertainties of these parameters will also be estimated using the least squares method for matching the frequency characteristics of the impedance of the tested element. This task is mathematically complicated because models of the considered passive elements lead to nonlinear equations that do not have analytical solutions in general. The method of fitting with the change of variables leading to linear characteristics will be used. It facilitates the solution of the problem. The proposed method has already been presented on Inter-university Conference of Metrologists MKM2025 in Poznan Pl and on MathMet in Göteborg as poster and has been appreciated by metrologists on these both their meetings.

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MEASUREMENT OF STATIC AND DYNAMIC YOUNG'S MODULUS OF THIN FIBERS

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PART I. Measurement of Static Young's Modulus of Thin Fibers

The study of the static Young's modulus of thin fibers by diffraction will be described [1]. The vertical movement in the measuring device is made possible by the air bearing of its own design. Fiber is loaded with a mass m and an elongation occurs, which causes a change in the width of the gap. The distribution of the diffraction bands is recorded by a CCD camera.

The function of the distribution of light intensity after passing through a gap is described by the formula:

$$I = I_0 \left[\frac{\sin(k \sin \alpha)}{k \sin \alpha} \right]^2 + I_c \,. \tag{1}$$

The value of Young's modulus tested for fibers is calculated on the basis of the formula:

$$E = \left(\frac{F}{S} \right) \Big/ \left(\frac{\Delta l}{l} \right), \tag{2}$$

where F – the loading force of the fiber, S – the cross-sectional area of the fiber, Δl – the elongation of the fiber, equal to the change in the width of the gap (ΔD), l – the length of the fiber.

The width of the gap is

$$D = D_0 + \Delta D \,, \tag{3}$$

where: D_0 – Pre-gap width.

After transforming the formula (2) valid for a fiber with a diameter of $2r$, the following is obtained:

$$E = \frac{F\, l}{\Delta D\, S} = \frac{mgl}{\Delta D\, \pi r^2} = \frac{mgl}{\pi r^2 \left(\frac{k\lambda}{\pi} - D_0 \right)}, \tag{4}$$

hence:

$$k = \frac{gl}{E \lambda r^2} m + \frac{\pi D_0}{\lambda} \,. \tag{5}$$

Using the results of the fit straight-line $k = am + b$ (where a – the slope parameter of this line), we get the expression for Young's modulus E:

$$E = \frac{gl}{a \lambda r^2} \,, \tag{6}$$

in which g – acceleration of the earth.

Example 1. Measurement result for the basalt fiber with a length of 93 mm and a diameter of 17,1 μm. The value of Young's modulus E=(27,3±2,1) GPa was determined with an uncertainty of 8,6%.

PART II. Measurements of the Dynamic Young's Modulus of Thin Fibers

The implementation of the measurement of the dynamic modulus of elasticity using laser techniques is presented. A pulsed mechanical spectrometer IMS was developed and built for this purpose. It is measured by Young's modulus under dynamic conditions. Its structure is described in the full version of the thesis. The diffraction optical method used here is highly sensitive, inertial, and non-contact.

The initial values of the parameters were analyzed using a graphical method, plotting several dozen periods of mechanical loss spectra and the matching function on one graph. You can then change the parameters (A, β, n, ω, φ) overlapping two graphs. After entering the obtained initial values of the parameter into the program, an exact match was obtained. The quality of this fit was graphically analyzed by comparing the mechanical loss spectra on a single graph. The method of least squares was also used. If the matched value of the parameter n = 1 and the amplitude decay is exponential, then the matching function is described by the formula

$$g(t) = Ae^{-\beta t}\sin(\omega t + \varphi).$$

The obtained parameters β, ω allow the calculation of Young's modulus E and dimensionless logarithmic damping decrement. The calculation omits the mass of the fibers, as it is negligible in relation to the weight of the load.

The formulas describing the above measurements contain the following parameters:

$$\sigma = \frac{F}{S},\ \varepsilon = \frac{\Delta L}{L},\ k = \frac{F}{\Delta L},\ \omega^2 = \frac{k}{m},\ \omega^2 = \omega_0^2 - \beta^2,$$

where: σ – stress, Pa; F – force, N; S – fiber cross-sectional area, $S=\pi D^2/4$, m^2; m – load, kg; ε – relative elongation; L – fiber length, m; k – elasticity coefficient, 1/m.

The dynamic Young's modulus and the logarithmic damping decrement δ were calculated from the following dependencies:

$$E_{IMS} = \frac{\sigma}{\varepsilon} = \frac{F\,L}{S\Delta L} = k\frac{L}{S} = m\frac{4L}{\pi D^2}(\omega^2 + \beta^2).$$

Example 2. Measurements were made for a polyamide fiber with a length of 30 mm and a diameter of 119 μm. The value of Young's modulus E=(5,84±0,28) GPa was determined with an uncertainty of 4,8%.

The full version of the work also includes:

- introduction to diffraction methods;
- summary and conclusions of the content;
- a list of 20 items of literature in English and Polish cited in the content.

ANALYSIS OF APPROACHES TO EFFECTIVE DEGREES OF FREEDOM ESTIMATION IN THE PRESENCE OF OBSERVED CORRELATION BETWEEN THE RESULTS OF MEASUREMENT OF INPUT QUANTITIES

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One of the main principles of evaluating expanded uncertainty in the Guide to the Expression of Uncertainty in Measurement (GUM) [1] in the presence of significant contributions of type A uncertainty is to assign to the measurand the t-distribution with degrees of freedom ν_{eff} determined by the Welch-Satterthwaite equation.

In works [2,3] it is shown that for correlated data, this formula under certain, quite real conditions, leads to a value of the ν_{eff} equal to zero, which corresponds to an impossible value of expanded uncertainty equal to infinity.

The expressions for calculating ν_{eff} in the presence of an observed correlation between the results of measurements of input quantities, published in works [4,5], are analyzed.

For the analysis, a simple mathematical model is used in the form

$$Y = f(X_1, X_2) \tag{1}$$

of a linearizable function of two input quantities X_1, X_2 measured simultaneously n times, the measurement results of which are correlated with the correlation coefficient $r_{1,2}$ and contain only type A uncertainties with the same degrees of freedom $\nu = n - 1$.

In the article by R. Willink [5] Result 1 is given for this case: "If any group of input quantities is estimated from a set of n repeated observations then this group of quantities should be combined to obtain a single component of uncertainty with $n-1$ degrees of freedom". This Result 1 is confirmed by implementing the reduction method described in [4].

The article [4] gives a general formula (26) for the effective degrees of freedom for a model with N pairwise correlated input quantities with correlation coefficients r_{ij} and numbers of degrees of freedom ν_{ij}:

$$\nu_{eff} = \frac{u_y^4}{\sum_{i=1}^{N}\left(\sum_{j=1}^{N} c_i c_j r_{ij} u_i u_j\right)^2 \Big/ \nu_i}, \tag{2}$$

in which u_i, u_j and c_i, c_j are their standard uncertainties and the corresponding sensitivity coefficients.

Applying expression (2) to equation (1) yields the following result:

$$\nu_{eff} = \frac{(n-1)(c_1^2 u_{A1}^2 + 2 r_{12} c_1 c_2 u_{A1} u_{A2} + c_2^2 u_{A2}^2)^2}{(c_1^2 u_{A1}^2 + r_{12} c_1 c_2 u_{A1} u_{A2})^2 + (r_{12} c_1 c_2 u_{A1} u_{A2} + c_2^2 u_{A2}^2)^2}, \tag{3}$$

which is inconsistent with Result 1 of article [4].

In article [5] a general formula (46) for ν_{eff} is also given, similar to (2), in the form:

$$\nu_{eff} \cong \frac{u_y^4}{\sum_{i=1}^{N} \frac{c_i^4 u_i^4}{\nu_i} + \sum_{i=1}^{N-1} \sum_{j>i}^{N} r_{ij}^2 c_i^2 c_j^2 \left(\frac{u_i^2}{\nu_i}\right)\left(\frac{u_j^2}{\nu_j}\right)\left(\nu_i + \nu_j + \frac{1}{2}\right) + 2\sum_{i=1}^{N-1} \sum_{j>i}^{N} r_{ij} c_i c_j u_i u_j \left(\frac{c_i^2 u_i^2}{\nu_i} + \frac{c_j^2 u_j^2}{\nu_j}\right)}. \quad (4)$$

Applying expression (4) to equation (1) yields the following result:

$$\nu_{eff} \cong \frac{(n-1)(c_1^2 u_{A1}^2 + 2r_{12} c_1 c_2 u_{A1} u_{A2} + c_2^2 u_{A2}^2)^2}{c_1^4 u_1^4 + c_2^4 u_2^4 + r_{1,2}^2 c_1^2 c_2^2 u_1^2 u_2^2 \frac{2n-1,5}{(n-1)} + 2r_{1,2} c_1 c_2 u_1 u_2 (c_1^2 u_1^2 + c_2^2 u_2^2)}, \quad (5)$$

which is inconsistent with Result 1 of article [4].

The report discusses an extension of the Welch-Satterthwaite equation to correlated measurements, which allows avoiding the above effects. The equation proposed in [6] is an implementation of this extension:

$$\nu_{eff} = (n-1) \frac{u^4(y)}{\left[\sum_{i=1}^{N} u_{Ai}^2(y) + 2\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} r_{i,j} u_{Aj}(y) u_{Aj}(y)\right]^2}. \quad (6)$$

Applying expression (6) to equation (1) yields the following result:

$$\nu_{eff} = \frac{(n-1)(c_1^2 u_{A1}^2 + 2r_{12} c_1 c_2 u_{A1} u_{A2} + c_2^2 u_{A2}^2)^2}{(c_1^2 u_{A1}^2 + 2r_{12} c_1 c_2 u_{A1} u_{A2} + c_2^2 u_{A2}^2)^2} = n-1, \quad (7)$$

which is consistent with Result 1 of article [4].

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SESSIONAL REPORTS

EDUCING THE UNCERTAINTY OF GAS VOLUME MEASUREMENT RESULTS OF ULTRASONIC GAS METERS BY MEANS OF GRADUATION

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The process of reducing measurement uncertainty is a set of actions and methods aimed at improving measurement accuracy by decreasing the dispersion of values that could be attributed to the measured quantity. Ultrasonic gas meters have become particularly widespread. This is driven by their combination of high measurement accuracy, reliability, stability of performance parameters, and the absence of mechanical moving parts, which minimizes wear and ensures a long service life. Owing to these characteristics, ultrasonic meters are widely used both on trunk gas pipelines and within distribution networks, as well as at commercial metering stations and industrial facilities.

One of the key processes that ensures the reliability of ultrasonic gas meter readings is the graduation procedure. Unlike verification, which only confirms the instrument's compliance with established requirements, graduation involves determining and adjusting its metrological characteristics under real operating conditions. This procedure enables the elimination of systematic deviations, refinement of the meter's conversion coefficient, and improvement of the overall reliability of measurement results.

The graduation procedure is carried out in accordance with the requirements of the DSTU ISO 17089-1 standard [1] and the operational documentation. The procedure includes: verification of the meter's metrological characteristics [2], identification and analysis of errors, as well as their subsequent correction. To ensure the reliability of the results, it is necessary to comply with the regulated conditions of temperature, pressure, and humidity during verification. In addition, an important aspect is the use of a reference prover that ensures measurements are performed with a minimal uncertainty. Since conducting graduation on a setup that has not undergone calibration, has not been traceable, and has not received its measurement unit size from the state primary and secondary standards, or whose evaluated uncertainty values during calibration constitute a significant portion of the meter's maximum permissible error (MPE) limits, it will significantly degrade the reliability of gas meter measurements during graduation, rather than improve it.

The use of various correction methods (constant coefficient method, polynomial approximation, piecewise-linear interpolation) enables individual consideration of the characteristics of each device, minimizing measurement errors. In particular, the following outlines the specific features of each correction method:

- Constant coefficient: applied when the error is stable across the entire range.
- Polynomial: used in cases of smooth nonlinear deviation; allows constructing a correction polynomial (e.g., of II nd, III rd, or IV th order).
- Piecewise-linear approximation: effective when there are segments with different error behavior, where accuracy is better ensured by dividing the range into intervals with separate coefficients.

At SE "Ivano-Frankivskstandartmetrology", as a scientific metrological center, a complex of reference standards and reference setups has been established, providing

the widest dynamic range of gas volumetric flow in Ukraine and ensuring measurement results with the lowest uncertainty. In particular, the measurement and calibration capabilities of the national primary and secondary standards gas volume and volume flow rate units are included in the Database of Comparisons of National Standards of the International Bureau of Weights and Measures (KCDB BIPM) under the identifiers CMS – lines coded UA1–UA4, covering a gas volumetric flow range from 0,016 m^3/h to 7800 m^3/h [3].

Depending on the required gas volumetric flow range, SE "Ivano-Frankivskstandartmetrologiya" can perform the graduation of ultrasonic gas meters using one of the following reference standards:

- National State Primary Standard Gas Volume and Volume Flow Rate Units DETU 03-01-15 (UA1): gas volume flow rate measurement range from 1 m^3/h to 250 m^3/h, expanded uncertainty 0,07 %;
- Secondary Standards Gas Volume and Volume Flow Rate Units VETU 03-01-03-11 and VETU 03-01-04-12 (UA4): measurement range 1 m^3/h to 1250 m^3/h, expanded uncertainty 0,11 %; measurement range 50 m^3/h to 6500 m^3/h, expanded uncertainty 0,12 %; measurement range 6500 m^3/h to 7800 m^3/h, expanded uncertainty 0,14%;
- Master Meter Prover Gas Volume and Volume Flow Rate Units Stand-25000: gas volumetric flow range from 1 m^3/h to 25000 m^3/h, expanded uncertainty 0,167 % [4].

After performing metrological procedures (verifying or calibration), it is necessary to analyze the obtained results, because if the change in the characteristic is within 1% in relative terms, i.e., within the limits of the maximum permissible error, then graduation of the calibration characteristic is necessary. However, if the change exceeds this value, the graduation procedure is not recommended, since such a sharp change may be caused by, for example, contamination, mechanical defects, or internal electronic malfunctions. Moreover, such a change a priori indicates that the meter will not be able to pass the verification procedure.

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METHODOLOGICAL ASPECTS OF APPLYING MACHINE LEARNING METHODS IN MEASUREMENT: ISSUES OF REPRODUCIBILITY, TRACEABILITY, AND UNCERTAINTY

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In recent years, machine learning methods have been increasingly integrated into engineering and scientific research, including the field of measurement and metrological data processing. Their application makes it possible to automate the analysis of large datasets, identify patterns and anomalies, and enhance the efficiency of measurement procedures. However, when machine learning algorithms directly influence the formation of measurement results, they effectively become part of the measurement process itself. In such cases, they must comply with the requirements established by metrological normative documents, such as ISO 5725 [1], ISO/IEC 17025 [2], and the «Guide to the Expression of Uncertainty in Measurement» (JCGM 100:2008) [3]. According to these standards, the reliability of any measurement result is ensured by three fundamental criteria – reproducibility, traceability, and evaluated uncertainty. These criteria become central when discussing the admissibility of using machine learning methods in metrology.

The first and most apparent challenge concerns reproducibility. In metrology, this term refers to the ability to obtain consistent measurement results when the procedure is repeated under different conditions, by different operators, or using different instruments. In the case of machine learning algorithms, reproducibility is often compromised even with identical input data because the result depends on random initializations, variations in optimization procedures, random sampling of training subsets, and other stochastic factors. Consequently, two runs of the same model may produce different outcomes. To restore the metrological meaning of reproducibility, it is necessary to establish a strict fixation of all training parameters and computational conditions – including random seeds, model architecture, software versions, and hardware environment. Only with complete documentation of these parameters can one ensure that identical results can be obtained repeatedly, thus confirming reproducibility within the context of stochastic computational methods.

The second key criterion is traceability, which in metrological practice denotes the existence of an unbroken chain of comparisons linking each measurement result to national or international standards. In traditional measurements, such a chain is realized through calibration and reference standards. In the case of machine learning, this link is absent because the algorithm derives results from statistical patterns in the data and lacks a direct connection to physical measurement units. A potential solution is the introduction of the concept of «computational traceability», where every stage of the model's operation – from data selection and preprocessing to the final result – is rigorously documented. Each step must include the preservation of metadata, training parameters, and preprocessing procedures, allowing any qualified expert to reproduce the computational pathway and verify the model's correctness. Thus, in the

context of machine learning, traceability should be understood as the ability to reconstruct the entire process of result formation and validate it through documented and transparent procedures.

The third fundamental criterion is uncertainty, which reflects the degree of confidence in a measurement result. According to JCGM 100:2008 [3], uncertainty must account for both random and systematic components influencing the outcome. For machine learning algorithms, uncertainty has a mixed nature: it is partly due to data variability and partly due to the intrinsic stochasticity of the model itself. Traditional methods for estimating uncertainty do not account for these aspects, so in this context, it is appropriate to introduce the notion of «algorithmic uncertainty». This can be assessed through multiple runs of the model using the same input data and fixed parameters, followed by statistical analysis of result dispersion. Such an expanded interpretation of uncertainty allows quantifying the influence of random internal processes within the model, bringing the results of machine learning closer to metrologically justified representation.

Therefore, the use of machine learning methods in applications where they affect the measurement result requires a profound adaptation of these methods to metrological principles. Until criteria ensuring reproducibility, traceability, and quantitative evaluation of uncertainty for computational models are developed and formalized, their use as an integral part of the measurement process remains methodologically unjustified. The creation of new standards and procedures harmonizing the stochastic nature of machine learning with the fundamental requirements of metrological reliability is essential. Only after such harmonization can these algorithms be recognized as legitimate tools within metrological practice.

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SONOLUMINESCENT SPECTROSCOPY FOR THE DETERMINATION OF THE MAIN COMPONENT IN HIGH-CONCENTRATION SOLUTIONS USING ULTRAHIGH-FREQUENCY ULTRASOUND

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The use of ultrahigh-frequency ultrasound for initiating sonoluminescence in the analytical method of sonoluminescent spectroscopy was investigated. Ultrahigh-frequency ultrasound (10–25 MHz) was employed to initiate sonoluminescence during the determination of the main component in natural brines and technological high-concentration solutions (Table 1).

Analytical procedures were developed for determining the content of cesium, lithium, and sodium in high-concentration technological solutions and natural brines. It was demonstrated that the relative standard deviation of the results for cesium, lithium, and sodium decreases with increasing the ultrasound frequency initiating sonoluminescence, reaching a minimum at 20–22 MHz and an intensity of 20 W/cm^2.

The accuracy of the procedures was verified using the method of standard additions as well as by analyzing the same samples using alternative methods (Table 1).

Table 1 – Results of the Determination of the Main Component in Brines and High-Concentration Technological Solutions (n = 6; p = 0,95)

Sample	Added, g/l	Found, g/l							
		Sonoluminescent method						Gravimetric method	
		US 22,0 kHz		US 12,0 MHz		US 22,0 MHz			
		$\overline{C}$	S_r	$\overline{C}$	S_r	$\overline{C}$	S_r	$\overline{C}$	S_r
Heat-transfer fluid “LiCl”, 400 g/l	–	381	0,042	392	0,032	398	0,011	397	0,011
	50	412	0,044	428	0,031	441	0,012	442	0,012
Heat-transfer fluid “CsCl-1”, 400 g/l	–	381	0,042	391	0,026	392	0,011	394	0,011
	50	402	0,041	421	0,027	443	0,013	448	0,010
Heat-transfer fluid “CsCl-2”, 600 g/l		571	0,042	572	0,037	591	0,012	594	0,011
	100	646	0,047	687	0,038	692	0,013	673	0,011
Sodium-chloride brine from the Sloviansk deposit, 406 g/l	–	381	0,045	388	0,032	404	0,016	402	0,012
	50	412	0,044	423	0,033	448	0,017	446	0,012
Synthetic brine, 600 g/l	–	558	0,051	572	0,037	589	0,016	591	0,011
	100	617	0,053	678	0,037	681	0,015	649	0,011

As shown in Table 1, increasing of the ultrasound frequency that initiates sonoluminescence improves the precision and accuracy of the determination of the added analyte. However, increasing the ultrasound frequency used to initiate sonoluminescence leads to a decrease in analytical sensitivity. It shifts the linearity range of the dependence between analyte concentration and sonoluminescence intensity toward higher concentrations.

UKRAINIAN LIQUIDS KINEMATIC VISCOSITY NATIONAL STANDARD: MEASUREMENT UNCERTAINTY EVALUATION

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This work presents the research results and estimation for the measurement uncertainty of the national primary standard used to ensure uniformity and traceability of kinematic viscosity measurements in Ukraine. The standard is a complex comprising a set of reference glass capillary viscometers, a high-stability thermostatic system, a system for measuring liquid efflux time, and high-precision temperature monitoring instruments. The reproduction of the unit is based on comparing the viscosity of the test liquid with the kinematic viscosity values of standard water under specified conditions.

The uncertainty evaluation was carried out in accordance with the GUM [1] and EURACHEM [2] guidelines requirements, using a mathematical model of the measurement standard that incorporates contributions from key sources of uncertainty: temperature instability, temperature field nonuniformity, accuracy of efflux-time measurement, characteristics of reference viscometers, and properties of reference materials. The components of standard uncertainty of types A and B were estimated, as well as their contribution to the combined standard and expanded uncertaintyes.

The results show that the relative standard uncertainty does not exceed $2 \cdot 10^{-4}$ for type A and $8 \cdot 10^{-4}$ for type B. The combined standard uncertainty is below $8{,}5 \cdot 10^{-4}$, while the relative expanded uncertainty with a coverage factor $k = 2$ does not exceed $1{,}7 \cdot 10^{-3}$. The research confirms that the measurement standard provides stable reproduction and reliable dissemination of the kinematic viscosity unit across the range from $4{,}0 \cdot 10^{-7}$ m²/s to $1 \cdot 10^{-1}$ m²/s, fully meeting the requirements for national measurement standards.

Thus, the research demonstrates that the national measurement standard ensures the required accuracy, stability, and traceability for kinematic-viscosity measurements in order to disseminate the measurement unit to working reference standards, certified reference materials, and measuring instruments. These results are important for industry, scientific applications, and legal metrology, and form a solid basis for further harmonization of Ukraine's metrological system with international measurement infrastructure..

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EVALUATION OF MEASUREMENT UNCERTAINTY IN THE EXPERIMENTAL DETERMINATION OF MAGNETIC FIELD PARAMETERS

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Measurement uncertainty evaluation in the experimental determination of low-frequency magnetic field parameters is an important task of metrology, since it directly affects the reliability of the results and requires further study and improvement of methods for its determination [1]. This research presents the results of statistical processing and uncertainty estimation for measurements of low-frequency magnetic field parameters obtained during experimental tests.

The developed measurement method is based on a distributed array of induction-type sensors located on a cylindrical surface, forming three measurement channels (X, Y, Z). The system configuration minimizes the influence of higher-order spatial harmonics and external interference. To quantify uncertainty, both methodological and random components were analysed.

The combined standard uncertainty u_c was determined as

$$u_c = \sqrt{u_A^2 + u_{B_1}^2 + u_{B_2}^2},$$

where u_A is the statistical component (Type A), u_{B_1} is the calibration component (Type B), and u_{B_2} is the uncertainty associated with the non-excluded remainder of spatial harmonics.

The Type *A* uncertainty was derived from a series of n=10 repeated measurements using the standard deviation S=0,12 mT, giving $u_A = S/\sqrt{n} = 0{,}038$ mT. The calibration uncertainty was $u_B = 0{,}05$ mT and u_m was evaluated using the model of an eccentric magnetic dipole, $u_m = 0{,}03$ mT. Thus, $u_c = 0{,}07$ mT, and the expanded uncertainty (k=2) is $u = 0{,}14$ mT, corresponding to a relative uncertainty of about 2,3 %. Statistical analysis confirmed the homogeneity of variances between the three measuring channels (G=0,41). Dispersion analysis showed that the methodological error of the device does not exceed 5 %, which is 1,5-6 times lower than the error of the standard type instrument.

The results demonstrate that appropriate statistical processing combined with metrological modelling of the measuring field significantly increases the reliability of magnetic parameter determination. The developed method and device can be effectively used in calibration and verification of magnetic field sensors, ensuring traceability and reduction of measurement uncertainty in industrial and laboratory conditions.

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STATISTICAL ANALYSIS OF COLORIMETRIC MEASUREMENT RESULTS AND EVALUATION OF THEIR UNCERTAINTY

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The clinical significance of control in the colorimetric assessment of biomedical samples (enzymes) is very high, since even minor deviations in color intensity can indicate essential changes in enzymatic activity or pathological conditions. Accurate control ensures that results are reproducible, comparable, and traceable to reference standards. Variations in temperature, reagent concentration, or optical path length can introduce measurement uncertainty; therefore, calibration and statistical validation are crucial. Proper colorimetric control allows clinicians to detect early metabolic disorders and evaluate treatment effectiveness, ensuring reliability of biochemical diagnostics [1].

The research presents statistical processing of experimental results obtained during testing of a digital electronic colorimeter designed for medical diagnostics. The purpose of the research is to evaluate the measurement uncertainty of optical signal parameters recorded from biological samples. Experimental data were collected for three photodiode channels: red (*R*), green (*G*), and blue (*B*). Each channel measured the output voltage $V_i(\text{mV})$ corresponding to the light intensity in the respective spectral range.

For each measurement channel [2], a series of n=10 repeated measurements were performed (Table 1). The mean value $\bar{V}$ and the experimental variance S^2 were calculated using:

$$\bar{V} = \frac{1}{n}\sum_{i=1}^{n} V_i; \qquad S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(V_i - \bar{V})^2.$$

Table 1 – The obtained data for the control sample

Channel	$U_i(\text{mV})$	$S^2(\text{mV}^2)$
R	122,4	3,5
G	118,9	2,7
B	130,1	4,1

The homogeneity of variances across channels was verified using the Cochran criterion: $G = \max(S_i^2) \Big/ \sum_{i=1}^{n} S_i^2 = 0{,}38$. At the confidence level p=0,95 and k=3, n=10, the critical value $G_{crit} = 0{,}68$. Since $G < G_{crit}$, the variances are considered homogeneous.

The combined standard uncertainty u_c for each channel is determined as:

$$u_c = \sqrt{u_A^2 + u_B^2},$$

where $u_A = S/\sqrt{n}$ is the *Type A* uncertainty, and u_B is the *Type B* component (estimated from calibration certificate, $u_B = 0{,}5\,mV$).

For the red channel: $u_A = 0{,}59\,mV$, $u_c = 0{,}77\,mV$. The expanded uncertainty at k=2 is $U = k \cdot u_c = 1{,}54\,\text{mV}$. This corresponds to a relative uncertainty of approximately 1.26 %, which is acceptable for biomedical optical diagnostics.

The performed analysis demonstrates that the developed digital colorimeter provides stable and statistically reliable results. The application of dispersion analysis and the Cochran test allows detecting unstable channels and optimizing calibration.

The achieved relative uncertainty of 1-2 % confirms that the system ensures high accuracy suitable for detecting minor color changes in biological samples, e.g., hemoglobin or bilirubin concentration variations.

The proposed approach can be generalized for calibration of optical sensors in medical and industrial colorimetric systems.

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UNCERTAINTY ANALYSIS OF TEMPERATURE MEASUREMENTS IN THE DAIRY INDUSTRY

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In the dairy industry, temperature measurements account for approximately 40 % of all measurements, so the analysis of the uncertainty of measurement results obtained using measuring channels of information and measuring systems is a relevant task. One of the most common technological processes (TP) in the dairy industry is the production of hard cheese. Such production consists of several stages at which it is necessary to control the temperature, namely:

1. The stage «Milk storage and maturation» requires temperature measurement in the range $t_1 = (+5 \ldots +12)\ ^0C$;

2. «Milk pasteurization and cooling» requires temperature measurement in the range $t_2 = (+71 \ldots +72)\ ^0C$;

3. «Milk curdling» requires temperature measurement in the range (+32 …+36) ^0C, and when reheating milk, this is the range $t_3 = (+40 \ldots +42)\ ^0C$;

4. «Cheese formation» performs temperature measurement in the range $t_4 = (+35 \ldots +40)\ ^0C$

5. «Cheese pressing» requires temperature measurement in the range $t_5 = (+35 \ldots +40)\ ^0C$;

6. «Cheese pressing» requires temperature measurement in the range $t_6 = (+8 \ldots +12)\ ^0C$.

At all these stages of production, multi-zone temperature sensors 1-3FT are used, which include the DS18B20 sensor. Since temperature measurement is carried out in different conditions, but with sensors of the same type, the task of checking their metrological reliability arises by comparing the accuracy of temperature sensors 1-3FT. Such a task is expedient to solve using the method of variance analysis, which makes it possible to compare dispersions with the subsequent selection of a larger dispersion from many. At this TP there is no correlation between the quantities [1], therefore the total standard uncertainty, which takes into account the presence of uncertainty in types A and B of the initial quantity, is determined according to the GUM algorithm by the formula [2]:

$$u_c(t) = \sqrt{\sum_{i=1}^{n} u_i^2(t)} = \sqrt{u_A^2(t) + u_B^2(t)}.$$

The standard uncertainty of measurement results for type A input quantity t_i is calculated by the formula [3]

$$u_A(\bar{t}_i) = \sqrt{\frac{\sum_{q=1}^{n_i} (t_{iq} - \bar{t}_i)^2}{n_i(n_i - 1)}},$$

where n_i – number of observations made during measurement t_i.

The standard uncertainty of type B of the input quantity depends on a priori information about the variability of the input quantity and is determined by the formula [3]:

$$u_B(t) = \frac{b-a}{\alpha_i},$$

where α_i – coefficient corresponding to the accepted distribution law within the limits of the non-excluded systematic error $\pm(b-a)$.

The uncertainty budget of temperature measurement results at the stages of the technological process of hard cheese production is presented in Table 1.

Table 1 – Uncertainty budget for temperature measurements

The measured quantity, ^{0}C	Measured value, ^{0}C	Type A uncertainty, ^{0}C	Type B uncertainty, ^{0}C	Total standard uncertainty, ^{0}C	Expanded uncertainty, ^{0}C
t_1	9,97	$u_A(t_1) = 0{,}053$	$u_B(t) = 0{,}25$ ^{0}C	$u_c(t_1) = 0{,}255$	$U(t_1) = 0{,}51$
t_2	71,50	$u_A(t_2) = 0{,}063$		$u_c(t_2) = 0{,}260$	$U(t_2) = 0{,}52$
t_3	34,22	$u_A(t_3) = 0{,}089$		$u_c(t_3) = 0{,}265$	$U(t_3) = 0{,}53$
t_4	38,55	$u_A(t_4) = 0{,}099$		$u_c(t_4) = 0{,}268$	$U(t_4) = 0{,}536$
t_5	39,27	$u_A(t_5) = 0{,}098$		$u_c(t_5) = 0{,}268$	$U(t_5) = 0{,}536$
t_6	9,50	$u_A(t_6) = 0{,}1$		$u_c(t_6) = 0{,}269$	$U(t_6) = 0{,}538$
Effective number of degrees of freedom		$\nu_{eff} \to \infty$			
Coverage ratio		$k = 2$			

Studies have established that temperature sensors at all stages of the technological process of making hard cheese are metrologically reliable, i.e. random measurement errors do not exceed the set value with a probability of $P = 0{,}9973$.

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CALIBRATION OF STEAM STERILIZERS AND AUTOCLAVES. MEASUREMENT UNCERTAINTY EVALUATION

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Autoclaves and steam sterilizers are critical equipment in the medical, pharmaceutical, food industries, as well as in laboratory and cosmetic practice. To ensure the effectiveness, safety, and reliability of the sterilization cycle, regular determination of the metrological characteristics of sterilizers, particularly their calibration, is essential.

During the calibration of sterilizers, the following metrological characteristics are determined: sterilization temperature and the working steam pressure in the sterilizer, which are standardized in accordance with EN 14180 [2]. A budget of uncertainty is also developed, and the measurement results' uncertainty is evaluated.

The combined standard uncertainty of temperature reproduction at each calibration point is calculated using the following formula 1:

$$u(T) = \sqrt{u^2(\overline{T}_{st}) + u^2(\delta T_{st.T}) + u^2(\delta T_{un}) + u^2(\delta T_{in})}\,, \qquad (1)$$

where $u(T)$ is the total standard uncertainty of the temperature measurement result, °C; $u(\overline{T}_{st})$ is the standard uncertainty of the temperature measurement result by the standard due to the scattering of the results, °C; $u(\delta T_{st.T})$ is the standard uncertainty of the standard at a given temperature, °C; $u(\delta T_{un})$ is the standard uncertainty due to temperature unevenness in the usable chamber space, °C; $u(\delta T_{in})$ standard uncertainty due to temperature instability at the control point, °C.

The combined standard measurement uncertainty of the pressure result at each calibration point is determined using the following formula (2):

$$u(P) = \sqrt{u^2(\overline{P}_{st}) + u^2(\delta P_{st.P})}\,, \qquad (2)$$

where $u(P)$ is the combined standard uncertainty of the pressure measurement result, MPa; $u(\overline{P}_{st})$ is the standard uncertainty of the pressure measurement result by the standard due to the scattering of the results, MPa; $u(\delta P_{st.P})$ is the standard uncertainty of the standard at a given pressure, MPa.

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EVALUATION OF MEASUREMENT UNCERTAINTY IN THE IDENTIFICATION OF PARAMETERS OF PYROELECTRIC MEASURING MODULES

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This work presents an analysis of measurement uncertainty arising during the experimental identification of parameters of pyroelectric measuring modules. The main attention is paid to the estimation of uncertainty components related to the determination of the thermal (τ_T) and electrical (τ_E) time constants of pyroelectric detectors based on transient and frequency responses.

Experimental data were obtained using a digital acquisition system with sampling frequency fs=10 Hz. The thermal response of the pyroelectric element was recorded during step temperature excitation, followed by numerical differentiation and exponential curve fitting. The resulting time constants ranged within τ_T=30–420 s and τ_E=0,4–2,5 s, depending on detector design and electrode configuration.

Uncertainty evaluation was performed according to the ISO/IEC Guide 98-3 (GUM). The combined standard uncertainty u_c for each parameter was calculated as:

$$u_c = \sqrt{u_A^2 + u_B^2},$$

where u_A represents the Type *A* uncertainty (statistical dispersion of repeated measurements) and u_B accounts for instrumental and modeling contributions.

For a typical pyroelectric detector, the Type A uncertainty was $u_A = 0,7$ s for τ_T and 0,05 s for τ_E. Type *B* uncertainty, determined from calibration data and curve-fitting residuals, was $u_B = 0,5$ s and 0,03 s, respectively. Thus, $u_c(\tau_T) = 0,86$ s, $u_c(\tau_E) = 0,86$ s corresponding to relative uncertainties of 2,1 % and 3,5 %.

The propagation of uncertainty in model identification was analyzed using the sensitivity coefficients of the fitting model. The expanded uncertainty with coverage factor *k*=2 provides confidence level *p*=95 %. The results show that systematic deviations caused by signal filtering and sampling discretization contribute less than 1 % to the total uncertainty budget.

The obtained uncertainty estimates confirm that the applied identification method ensures reliable determination of pyroelectric module parameters and can be effectively used in calibration and verification procedures of thermal-radiation sensors. Further improvement of measurement accuracy can be achieved through optimized sampling frequency and thermal stabilization of the setup.

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ADDITIONAL INTERPRETATION OF THE RELIABILITY OF THE RESULTS OF TESTS OF EQUIPMENT IMMUNITY TO EM PHENOMENA

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In [1], the author posed the question of the need for additional interpretation of the reliability of test results, the outcome of which is a qualitative (nominal) property [2, p. 1.30]), such as “pass/fail”. It was established that measurement is not applicable to qualitative properties [2, p. 2.1 note 1]). Therefore, for these types of tests, which include all types of equipment immunity tests to the effects of external electromagnetic phenomena, the concept of uncertainty is of limited applicability.

The management system of our institute's EMC testing laboratory (accreditation certificate 20484) uses the following components to ensure the reliability and reproducibility of test results:

- uncertainty of the measuring instruments used, specified in the calibration certificates;
- uncertainty of the verification of the test equipment (TE), specified in the relevant certificates;
- conditions for a positive test result, which are specified in the equipment test results assessment methodology, which is typically developed by the equipment manufacturer;
- a documented decision rule based on the assessment of the reliability of test results, taking into account the level of risk;
- the use of a nominal test results scale that takes into account the level of destabilizing effect of the EUT, determined by the value of the derivative of the electromagnetic signal at the front end.

Let's consider the verification of the EUT, which provides objective evidence that the EUT sample complies with the parameters established in the relevant standard. To ensure consistency in approach and facilitate comparison during interlaboratory comparison tests, new editions of the IEC 61000-4 series of standards typically include a special appendix that provides an example of calculating the uncertainty of the EUT verification results.

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APPLICATION OF ARTIFICIAL INTELLIGENCE IN AUTOMATING QUALITY METRICS ANALYSIS OF WEBSITES DURING TESTING

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Artificial intelligence can be effectively applied to automate the processing and interpretation of website quality measurement results, enabling faster feedback cycles, more reliable decisions, and higher consistency in web testing processes. By combining machine learning with existing web quality metrics, QA teams can move from manual, descriptive reporting to predictive and prescriptive analytics that directly support release readiness decisions.

During website testing, large volumes of heterogeneous metrics are collected, including performance indicators such as page load time and Core Web Vitals, SEO-related metrics, accessibility checks, security signals, and user-experience measures like bounce rate and session duration. Manual aggregation and analysis of these measurements is error-prone and slow, especially for continuous delivery environments where sites change frequently. AI-based models can ingest these multi-dimensional datasets, learn relationships between metrics and perceived quality, and output synthetic quality scores or risk levels that are easier for testers and managers to interpret.

Machine learning methods such as regression, classification, and anomaly detection are particularly suitable for this task because they can learn from historical data where websites are labeled by overall quality or business outcomes. For instance, regression models can generate weights for individual web metrics and compute composite scores that correlate with expert quality assessments, while classification models can categorize builds into acceptable, borderline, or release-blocking groups. Anomaly detection helps identify unusual metric patterns that may indicate latent defects, configuration problems, or regressions that are not captured by simple thresholds.

Modern AI-powered testing tools already illustrate how automation can extend from execution to result analysis. In functional and regression testing, AI systems learn from past runs which test cases and metrics are most predictive of failures, prioritize high-risk scenarios, and skip redundant tests, thereby focusing measurement and analysis efforts where they matter most. Similar ideas can be transferred to website quality metrics: historical data about performance, SEO, and UX measurements, combined with defect logs or incident reports, can be used to train models that predict the likelihood of post-release problems given the current measurement profile. This turns routine metric dashboards into proactive risk indicators that support data-driven go/no-go decisions [1].

Another important contribution of AI is in interpreting complex metric sets and providing actionable recommendations rather than raw numbers. Website rating engines powered by machine learning already assign overall performance scores and highlight the most influential issues, such as slow scripts, mobile usability defects,

accessibility violations, or misconfigured security features. These systems rank findings by expected impact on user experience and search visibility, and propose concrete optimization steps like compressing images, adjusting layout, or improving metadata, thereby closing the loop between measurement and remediation. Generative and large-language-model components can further transform metric outputs into human-readable explanations and tailored improvement plans for different stakeholders, from developers to product owners [2].

Integrating AI-driven metric processing into continuous integration and delivery pipelines enables near real-time quality monitoring. Automated crawlers and probes can continuously measure website attributes across devices and locations, feed results into trained models, and trigger alerts when quality scores degrade beyond acceptable bounds or when unusual patterns are detected. This continuous, AI-enhanced monitoring supports self-healing approaches in test automation, where scripts and test configurations adapt to interface or performance changes without manual intervention, reducing maintenance overhead and keeping the measurement system aligned with evolving websites [3]. Overall, the application of artificial intelligence to the automation of website quality metric processing transforms measurement from a reactive reporting activity into an intelligent, predictive, and recommendation-oriented component of modern web testing.

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ERRORS, UNCERTAINTIES, TRACEABILITY

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1. Almost half a century has passed since the first official document on the statement of measurement uncertainty (Recommendation INC-1) appeared [1].

The Uncertainty Approach has become widespread, for example, it is used in calibration (standard ISO 17025), as well as in establishing metrological traceability of measurements.

However, the current Law of Ukraine on June 5, 2014 № 1314-VII "On Metrology and Metrological Activity" states that "measurement results can be used in the field of legally regulated metrology, provided that the corresponding characteristics of errors or measurement uncertainty are known for such results" (Article 7, paragraph 2).

Let us consider the similarities and differences between the two approaches (Error Approach or True Value Approach and Uncertainty Approach [5]) in routine measurements, the purpose of which is to evaluate the measured value.

It should be noted that in both cases, when evaluating the measurement result, the average value of the measured quantity is found within a certain interval, the width of which characterizes the measurement accuracy. It is assumed that the true value of the measured quantity lies within this interval with some probability. The basis for such an assumption is the rated metrological characteristics (first and foremost, maximum permissible error (MPE)) of the measuring instrument used, the analysis and consideration of possible sources of measurement inaccuracy and the results of verification/calibration of the measuring instrument used.

It should be noted that when using the Error Approach, the interval width is determined not by the "error", as the difference between the measured value and the true (reference) value, but by the "error estimate", since the true (reference) value in routine measurements is unknown to us.

Thus, the assessment of the accuracy of routine measurements across different approaches is essentially the same: factors influencing measurement accuracy are analyzed and evaluated, and interval width is calculated based on these factors. The difference lies only in the details: with the Error Approach, interval width is determined by a complex composition of estimates of systematic and random factors, while with the Uncertainty Approach, interval width is determined by a generalized statistical approach to accounting for influencing factors.

As a result, other options for estimating interval width are also possible, such as using fuzzy set theory or interval arithmetic or possibility theory.

How does the verification result affect the relationship between the interval that determines accuracy and the set of possible true values?

The verification result is considered positive if the instrumental bias of the measuring instrument does not exceed the MPE, established by the manufacturer of the measuring instrument.

Typically, the calibration certificate does not indicate the obtained instrumental bias. Considering this, when determining the interval, it may turn out that the measuring instrument used has an instrumental bias close to the MPE. As a result,

approximately half of the determined interval will fall within the impossible range of true values.

To avoid this, it is necessary to select, based on the verification results, measuring instruments whose instrumental bias is less than half the MPE, or use calibration to introduce the appropriate correction in routine measurements.

2. Another factor that must be taken into account when using devices that have passed verification is that in Ukraine, a procedure has been adopted according to which a decision on conformity is made by setting a limit on a maximum permissible measurement uncertainty (MPU ≤ MPE/3). In this case, risk of false acceptance can reach 50% [3, 4].

WELMEC 4.2 also provides for another option: “allowing for risks due to uncertainty by ‘sharing’ risks” [2], which allows the acceptable level of risk for the customer to be set.

3. Currently in Ukraine, verification and calibration are two independent types of metrological activities.

At the same time, measurements carried out using a verified measuring instrument cannot formally have metrological traceability, since at the verification stage of such an instrument, the uncertainty of the measurements is not assessed, that is, the metrological traceability chain is interrupted [5].

At the same time, there is a type of metrological activity known as metrological confirmation [6], which is similar to verification but is based on calibration. This means that the measurement uncertainty is assessed and metrological traceability can be established. The calibration results are then used to carry out metrological verification.

A similar procedure based on the calibration of measuring instruments could be adopted in Ukraine for the verification of legally regulated measuring instruments, especially since technically both verification and calibration are based on comparing the indications of the measuring instruments being tested with the value of the quantity that the standard realizes.

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INTERLABORATORY COMPARATIVE TESTS OF HARD COAL, PROCESSING OF THEIR RESULTS

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The purpose of interlaboratory comparisons is to assess the level of performance and quality of certain laboratory tests, identify potential risks (related to the use of non-conforming testing methods and equipment, insufficient staff qualifications, etc.), confirming the ability of laboratories to conduct tests, identifying areas for improvement in laboratory activities, and ensuring customer confidence in laboratories. Interlaboratory comparisons are a mandatory element of external control of the quality system of a testing laboratory and are a necessary condition for both the accreditation of the laboratory and its operation.

Interlaboratory comparisons of hard coal [1] test results were performed, organized by an independent provider in accordance with the requirements [2]. Six laboratories participated in the proficiency testing.

To verify the qualifications, the provider prepared samples of "DG" coal (long-flame gas grade), fraction ≤ 0,2 mm, packed in zip bags and vacuum-sealed to preserve stable characteristics. Each sample was assigned a unique identification number. The homogeneity and stability of the samples were checked by two characteristic indicators: ash content in dry condition and index of free swelling. Ash content is a stable, reproducible indicator that accurately reflects the homogeneity of solid material. The index of free swelling is sensitive to changes due to improper storage, in particular oxidation, which makes it indicative of stability over time. After the samples were prepared, 10 samples were randomly selected and tested for homogeneity and 3 samples for stability. All these samples were tested twice under repeatability conditions. The tests were carried out in a single laboratory. This ensures that the samples can be used in professional-level verification programs, where a uniform chemical and physical composition of the material for all participants is key. The homogeneity results are satisfactory. The samples were stored in sealed containers in a dry, cool room, protected from moisture, condensation, direct sunlight and heat sources. To prove the stability of the samples, the test was repeated after 30 days - the deviation of the indicators was within the norm. Stability results - fluctuations in indicators values did not exceed the permissible criteria for changes in accordance with clause B.2 of ISO 13528:2022 (< 0,3σ) [3], confirming that storage time had no significant effect on sample stability. The index of free swelling remained unchanged within the margin of error of the visual method, which allowed us to conclude that the sample was suitable for determining this indicator within the duration of the round. The samples were sent to the participants with instructions and recommendations for conducting the tests and their deadlines. Participants received a sample ready for testing, which ensured uniform testing

conditions and minimized the impact of heterogeneity.

The assigned value of quantitative indicators is determined by a robust method using algorithm A in accordance with Appendix C, clause C.3 [3]. The type of value is statistical, obtained from the results of participants after excluding anomalies. This method of calculating the assigned value minimizes bias caused by methodology or established "expert" values, allowing data to be transformed in such a way that extreme deviations do not have a negative impact on the data set as a whole, but are accurately determined relative to the population. In addition, the consensus value calculated using robust methods is usually very close to the reference values and the consensus of expert laboratories, as well as to the median and modal values obtained in large populations. According to [2] and [3], the assigned value is not directly traceable to SI standards or certified reference materials, and metrological traceability cannot be guaranteed because the value is calculated from the aggregated results of participants rather than using an external standard. The level of confidence in this value depends on the quality of the data, the number of participants, the consistency of the methods, and the availability of homogeneous samples. Therefore, the assigned value is used only as a statistical reference point for evaluating the results of participants within a specific round of interlaboratory comparisons. It is not intended for the calibration or validation of methods that require metrological traceability in the classical sense [4]. The results of these interlaboratory comparisons should be interpreted as an assessment of the relative competence of the participants, rather than as a check of absolute accuracy.

The "Index of free swelling" indicator according to [5] is a qualimetric method with a visual scale (1–9 conventional units) and is not a quantitative method in the full sense (values are assessed based on visual comparison with a reference scale, without the use of a measuring device). It is expressed numerically but is not continuous in the classical statistical sense – it is ordinal data with a limited number of discrete levels. In this case, the use of algorithm A to determine the assigned value is statistically unjustified. It is proposed to use the median to determine the assigned value for the "Index of free swelling" indicator (according to [3], the median can be used as an assigned value for results obtained on an ordinal scale). In such conditions, the median is a statistically sound criterion that takes into account the specificity of the indicator as a discrete visual method, less sensitive to asymmetry or extreme values.

The group of participants was homogeneous in terms of methodology, with all applying recognized international standards, which reduces methodological dispersion. The results had a normal distribution, without significant outliers. The Grubbs and Irwin criteria were used for statistical testing of outliers. The participants' work for quantitative methods was evaluated using z-indices. All participants received z-indices within acceptable values ($|z| \leq 2$). The results of all participants confirm an adequate level of analytical competence. Based on the results of the proficiency testing round, general recommendations are given.

The results of the uniformity and stability checks are shown in Tables 1, 2, 3.

Table 1 – Homogeneity test [3]. Ash content in dry condition, %

Sample number	Result A	Result B	Average	W_t	W_t^2
1	5,301	5,300	5,301	0,001	0,000001
2	5,291	5,294	5,293	0,003	0,000009
3	5,290	5,296	5,293	0,006	0,000036
4	5,294	5,296	5,295	0,002	0,000004
5	5,300	5,299	5,300	0,001	0,000001
6	5,294	5,298	5,296	0,004	0,000016
7	5,304	5,301	5,303	0,003	0,000009
8	5,292	5,299	5,296	0,007	0,000079
9	5,303	5,297	5,300	0,006	0,000036
10	5,291	5,283	5,287	0,008	0,000064
$\bar{\bar{X}}$ - overall average			5,296		
min			5,287		
max			5,303		
$S_{\bar{X}}$ - standard deviation of the mean values			0,0046	$S_{\bar{X}}^2$	0,00002
S_{wb} - standard deviation within a parallel			0,0034	S_{wb}^2	0,00001
S_{bb} - intersample standard deviation			0,0040	$S_{\bar{X}}^2/2$	0,00001
S_s - an estimate of the standard deviation of variability between samples			0,0040	$S_{\bar{X}}^2 - S_{wb}^2/2$	0,000015
R - reproducibility			0,3		
S_R^* - standard deviation of reproducibility			0,108		
r - repeatability			0,2		
σ_r^*			0,072		
σ_R^2			0,012		
σ_r^2			0,005		
σ_{pt} (clause 8.5.1 ISO 13528)			0,096		
$0,3\sigma_{pt}$			0,029		
condition $S_s < 0,3 \cdot \sigma_{pt}$			homogen		
$u(X_{pt})$			0,006		

Table 2 – Results of stability testing of samples. Ash content in dry condition, %.

Sample	Test X_1	Test X_2	Mean X_m	Mean, calculated from homogeneity analysis	|Mean–X_m|	σ_{pt} (clause 8.5.1 ISO 13528)	Check value, $0,3\sigma_{pt}$	Conclusion
1	5,313	5,300	5,293	5,296	0,004	0,0287	0,0086	PASS
2	5,214	5,339						
3	5,297	5,292						

Table 3 – Analysis by Cochran's test [6], [3]

Sample number	Result A	Result B	Average	S^2 variance of the difference	S_t^2
1	5,301	5,300	5,30	0,0000	0,0000
2	5,291	5,294	5,29	0,0000	0,0000
3	5,290	5,296	5,29	0,0000	0,0000
4	5,294	5,296	5,30	0,0000	0,0000
5	5,300	5,299	5,30	0,0000	0,0000
6	5,294	5,298	5,30	0,0000	0,0000
7	5,304	5,301	5,30	0,0000	0,0000
8	5,292	5,299	5,30	0,0000	0,0000
9	5,303	5,297	5,30	0,0000	0,0000
10	5,291	5,283	5,29	0,0000	0,0000
Mean	5,296		S^2_{max} – worst pair	0,0000	
Max	5,304		SUM of S^2	0,0001	
Min	5,283		Cochrane's criterion	0,2844	
			C_{cr}, 5%	0,602	
			C_{cr}, 1%	0,718	
			Conclusion		
			5%	PASS	
			1%	PASS	

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EVALUATION OF MEASUREMENT UNCERTAINTY IN A DUAL-CHANNEL COLORIMETER FOR ANALYSIS OF BIOMEDICAL FLUIDS

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This work presents an approach to improving the accuracy and stability of colorimetric measurements of biomedical fluids by implementing a dual-channel architecture and applying statistical processing methods to evaluate measurement uncertainty. The device includes two parallel optical-measurement channels with RGB photodiodes (R-red, G-green, B-blue), normalization amplifiers and an ADC controlled by a microcontroller. The simultaneous registration of the reference and analytical signals allows compensating for variations in light-source intensity, temperature fluctuations, and sample turbidity factors that significantly affect the uncertainty of conventional single-channel colorimeters.

Each channel registers optical signals in three spectral ranges (R, G, B). The microcontroller performs digital normalization, averaging and compensation of inter-channel variability based on calibration coefficients. The measured signal S is represented as:

$$S = \frac{U_{sample} - U_{dark}}{U_{ref}}, \tag{1}$$

where U_{sample} - signal from the sample (measured solution), U_{dark} - dark noise signal (without radiation), U_{ref} a reference signal coming from the second measurement channel, used as a standard or control value to compensate for changes in external conditions.

The measured signal S represented as (1) has a reduced effect of time drift and ensures traceability of the results.

To evaluate the stability of the measurement process, repeated measurements were conducted, and the standard deviation s and Type A uncertainty were calculated: $u_A = S/\sqrt{n}$.

The combined standard uncertainty was determined by:

$$u_c = \sqrt{u_A^2 + u_B^2 + u_{drift}^2},$$

where u_B corresponds to calibration uncertainty, while u_{drift} represents the compensated influence of light-source instability. Comparison of channels X and Y enables real-time correction of drift, reducing its contribution to less than 1-2 %.

Experimental results show that the implementation of a comparative channel decreases overall measurement uncertainty by 25 % compared to single-channel devices described in [1] and [2]. The relative expanded uncertainty (k=2) in determining colorimetric intensity values does not exceed 3-5 %**,** which is sufficient for biomedical diagnostics and quality control tasks.

The proposed dual-channel measurement architecture significantly improves accuracy through compensation of external and internal disturbances. The combination of digital signal processing, real-time normalization and statistical evaluation of uncertainty ensures stable operation during prolonged or repeated measurements. The approach is promising for laboratory diagnostics, biotechnology and automated quality control of biological preparations.

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SOFTWARE IMPLEMENTATION OF THE KALMAN FILTER VIA OBJECTIVE METHOD

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The Kalman filter in its algorithmic implementation uses a series of measurements observed over a period of time to obtain estimates of unknown variables that tend to be more accurate than those based on a single measurement by estimating the joint probability distribution over the variables for each time step, which minimizes the root mean square error [1]. The filter has a set of inputs and outputs. The input signals are noisy, which obviously reduces their reliability. The outputs should have less noisy values and are intended to increase the accuracy of the measurement. The filter can be considered as an algorithm that can estimate observed and unobserved parameters with high accuracy in real time [2]. An implementation of the Kalman filter based on the “Singleton” object-oriented programming pattern is proposed, which is more efficient and flexible than the implementation given in [3].

To implement the filter, a library solution [4] based on Eigen 3 was used.

The rendering was implemented using the OpenGL 4 standard via shader technology based on the GLFW and GLAD libraries, the implementation of the graphical user interface was performed using MFC.

The use of a specialized library, a dedicated renderer, and an object-oriented approach to the implementation of the software tool allowed to increase the speed and autonomy of the software solution.

Usage of Kalman filtering approach for increasing the fidelity of scanline-based image parsing is proposed, based on results [5]. Kalman filtering applied to spline, received from simplified scanline dataset, can provide reduction to errors, introduced by imaging imperfections and artifacts.

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THEORETICAL MODELING AND COMPUTER SIMULATION OF A PHASE-IMPULSE FLUXGATE SENSOR

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Phase-impulse fluxgate sensors constitute an advanced class of magnetic field measurement devices in which the informative parameter is the time interval $\Delta\tau$ between two magnetization switching events in a soft-magnetic core. This operating principle, described in detail in [1, 2], allows the sensor to work entirely in the time domain, providing an inherently digital output that is robust against amplitude distortions, temperature drift, and electronic noise. In contrast to the classical harmonic fluxgate method, which requires demodulation of even-order harmonics, the phase-impulse approach extracts the magnetic field information directly from switching timing, significantly simplifying the signal-processing chain.

The sensor core is driven by a triangular excitation current that produces a magnetic field varying linearly with time. When the instantaneous field reaches the coercive threshold of the core material, the magnetization switches abruptly. In a perfectly symmetric case with zero external magnetic field, switching occurs at two equidistant points within each excitation cycle. However, when a static magnetic field is applied, it shifts the effective field toward one direction, causing the switching instants to move asymmetrically. One switching moment occurs earlier, while the other occurs later. The resulting time interval $\Delta\tau$ grows proportionally with the magnitude of the external field, forming a linear and reproducible conversion function. As demonstrated in [1, 2], the slope of this function depends primarily on the rate of change of the excitation field rather than its amplitude, which allows precise tuning of measurement range and sensitivity through excitation parameters alone.

To further investigate the performance of the sensor, detailed modeling was performed in *ANSYS Maxwell*, which provides full *3D* electromagnetic simulation capabilities. The nonlinear magnetic behavior of the core — including the real $B(H)$ characteristics, saturation effects, demagnetizing fields, and eddy-current losses — was incorporated into the simulation. Several soft-magnetic alloys, including Ni–Fe, Ni–Fe–Mo, and Ni–Fe–Si, were evaluated. These materials differ in permeability, coercivity, magnetization dynamics, and loss characteristics, all of which directly influence switching behavior and the precision of $\Delta\tau$ determination. The simulation results demonstrated that higher-permeability materials with stable coercive force produced shorter switching transition times and more consistent $\Delta\tau$, contributing to improved measurement repeatability.

An additional aspect identified through the simulations is the role of transient magnetic domain dynamics near the switching threshold. Because real magnetic cores exhibit not only idealized abrupt switching but also localized domain-wall motion, the exact switching moment can be influenced by microscopic processes not captured by simplified analytical models. Maxwell simulations revealed small deviations between ideal and simulated switching instants under certain excitation conditions, particularly at higher frequencies or when the material operates near partial saturation. These deviations do not undermine the linearity of $\Delta\tau(H)$, but they

highlight the need to account for material-specific magnetization kinetics when designing high-precision fluxgate sensors. Understanding these effects enables better selection of core materials and optimization of excitation waveforms to minimize dispersion in switching behavior.

The computational study also highlighted the importance of excitation frequency and current amplitude. Lower excitation frequencies reduced dynamic switching delays and improved linearity, while reduced excitation current minimized hysteresis-induced jitter in switching moments. In addition, the geometry of the fluxgate core was shown to influence the demagnetizing factor, and therefore the effective shape of the $\Delta\tau(H)$ curve. These insights are valuable for optimizing sensor design at the prototyping stage before manufacturing physical devices.

Experimental verification was performed using the computerized measurement setup described in [3], which integrates the excitation and readout stages through a PC-based data-acquisition system. This setup allows real-time generation of triangular excitation signals and precise application of digital timing algorithms to extract $\Delta\tau$. The experiments confirmed the modeling results: $\Delta\tau$ exhibited stable linearity across the operating field range, and digital extraction significantly improved accuracy compared to analog methods of detection. Furthermore, the agreement between theoretical predictions, Maxwell simulations, and experimental data validates the phase-impulse fluxgate as a robust platform for applications requiring high temporal resolution and stability.

Overall, the combination of time-domain measurement principles, nonlinear electromagnetic modeling, and digital signal processing creates a strong foundation for the development of next-generation fluxgate sensors. These devices are particularly suitable for non-destructive testing, weak-field magnetic diagnostics, embedded navigation systems, and industrial monitoring applications, especially where low power consumption, compact dimensions, and high measurement repeatability are required. The results of this work demonstrate that phase-impulse fluxgate technology, supported by accurate modeling tools and modern digital processing methods, can offer a highly effective alternative to traditional fluxgate architectures.

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A STUDY OF THE IMPACT OF MEASUREMENT UNCERTAINTY ON DECISION CONFIDENCE

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In any decision-making process involving parameters or data obtained through measurements, uncertainty always exists – that is, the true value of the measured quantity may lie within a certain range with a certain probability. It is precisely measurement uncertainty (not knowing the true value of the measured quantity) that creates the risk of making an incorrect decision. These issues are particularly relevant for decisions regarding conditional conformity or nonconformity of product characteristics [1].

The goal of the study is to increase the reliability of decision-making by establishing the relationship between measurement uncertainty and the choice of decision criteria.

When measurement results indicate a conditional nonconformity of product characteristics, a more cautious (pessimistic) strategy is used to make the final decision, i.e., the Wald criterion. The further the measured value is from the upper limit, the more justified the Wald approach is.

In cases of conditional conformity of product characteristics, the use of the Hurwitz criterion (a compromise between optimism and pessimism) is appropriate. For a "large" value of measurement uncertainty, the optimism factor should be smaller (cautious decisions). For a "small" uncertainty, a larger value for the optimism factor can be adopted.

That is, the degree of measurement uncertainty determines the value of the optimism factor in the Hurwitz criterion.

“Large” and “small” uncertainty values are determined based on the ratio:

$$U_r = \frac{|X - TL|}{U}, \tag{1}$$

where U_r – the relative uncertainty; X – the measured value; TL – the tolerance limit (requirements); U – the measurement uncertainty.

For the upper tolerance limit, if $(X–TL) > 0$, the Wald criterion is used to make a decision.

If $(X–TL) < 0$ and $U_r < 1$, the Hurwitz criterion is applied. The optimism factor is assumed to be equal to U_r.

If $(X–TL) < 0$ and $U_r > 1$, an unambiguous decision is made on the conformity of the product characteristics.

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APPLICATION OF BLOCKCHAIN TECHNOLOGY IN MEASUREMENT UNCERTAINTY EVALUATION

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Most people have heard of blockchain in connection with cryptocurrencies, the most famous of which is probably Bitcoin. However, in reality, blockchain technology has much wider applications [1]. In recent years, publications have appeared on the use of this technology in metrology, primarily for digital traceability and the transition to digital certificates, for example, [2 – 4].

This paper proposes a three-level concept of using blockchain technology for measurement uncertainty assessment.

Blockchain technology functions as a distributed transaction log, in which each block contains a hash of the previous one, which guarantees the immutability of history. For metrology, this means that each calibration result, measurement, or uncertainty assessment record can be cryptographically signed and stored in a shared registry. The use of smart contracts allows you to automate the verification of the reliability of calibration sources, the calculation of uncertainty according to approved models and the recording of measurement results in the blockchain. Such an architecture allows you to ensure digital traceability from the standard to a specific measurement, traceability of all stages of measurement uncertainty assessment, as well as protection against interference or falsification of results. Thus, the integration of measurement uncertainty assessment into a digital metrology system is achieved.

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FEATURES OF TEACHING THE QUESTION OF ASSESSING THE UNCERTAINTY OF MEASUREMENT DURING CALIBRATION

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To ensure the competence of testing and calibration laboratories (accredited to meet the requirements of the DSTU ISO/IEC 17025:2019 standard), the main element of metrological traceability of measurements is the calibration of measuring instruments [1]. Calibration is a key process for determining and quantifying the uncertainty of measurement results.

Uncertainty assessment is an important component of qualitative measurements and data analysis, which requires the use of appropriate statistical methods and models for its calculation and interpretation.

Training in the assessment of measurement uncertainty has a number of features (theoretical complexity, practical focus, assessment methods, the formation of "metrological thinking"), due to both the very essence of the concept and the needs of practical application.

To overcome these features and form the competence of specialists, the following approaches should be used:

- active and interactive learning methods. The use of project methods and analysis of specific practical examples contributes to better assimilation of the material, contributes to improving the quality and success of the study of measurement uncertainty by specialists, their theoretical knowledge and practical skills [2];
- the use of specialized software. The use of software tools to automate complex calculations of measurement uncertainty allows you to focus on understanding the essence of the process, rather than on routine calculations;
- online training and seminars. Conducting webinars and online courses allows you to reach a wider audience of specialists and provide access to up-to-date information and expert consultations;
- teaching aids. Development and use of modern training materials containing detailed instructions and examples of calculations adapted to specific industries.

Learning to estimate measurement uncertainty is a complex process that requires a combination of a solid theoretical base, practical skills and the use of information technologies. The formation of competence in uncertainty assessment contributes to the improvement of the professionalism of specialists in the field of metrology and information and measurement technologies.

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CONTROL OF TECHNOLOGICAL REQUIREMENTS FOR ROLL-FORMED SHAPES

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The manufacturability ("technologicity") of a part is understood as a combination of the main elements of its design, which most easily ensures its manufacture and high quality of operation. Ensuring manufacturability is an integral part of the formation of both the manufacturing technology and the control technology of roll-formed shapes [1].

Processing the profile for manufacturability. When designing structures using economical roll-formed shapes, the designer strives to choose rational forms of these profiles from the point of view of the functionality of the structure, manufacturability during installation. The designer must also ensure the best operational qualities and provide for the simplest, most economical way of their manufacture.

To create a roll-formed shape manufacturing technology, the initial data are important (profile shape, cross-sectional parameters, material, profile quality requirements). The general requirements for the manufacturability of roll-formed shape production include the following: 1) the mechanical properties of the sheet material must have a temporary tensile strength of up to 390 MPa, the relative elongation must be at least 6%; 2) reducing the metal content of the part design by using stiffeners, flanges, etc.; 3) reducing the number of sheet material thicknesses (preferred thickness range: 0,6; 0,8; 1,2; 1,5; 1,8; 2,0; 2,5 mm); 4) the design of an open-type profile is better than the design of a closed and semi-closed-type profile (from the point of view of manufacturing); 5) tolerances on the cross-sectional dimensions of the profiled parts must correspond to the accuracy of the profiling process (9-14th quality); 6) it is inappropriate to set the tolerance on the length of the part to less than 2 mm; 7) the minimum permissible internal bending radii for ductile low-carbon steels are, as a rule, 0.5S, and they should be set only if structurally necessary; 8) the minimum permissible height of the flanges is, as a rule, 2s (minimum values should be assigned only if necessary for design purposes. Usually, the height of the flanges is assigned at least 4 thicknesses); 9) the strength of the coating must allow bending the workpiece to a given relative bending radius (not less than one); 10) if there is perforation in the workpieces, special conditions must be met according to the instructions [1].

The design of the part and the requirements for the implementation of its production process determine the technology and equipment used. That is why roll-formed shapes are subject to analysis for their manufacturability. When choosing the optimal option for manufacturing roll-formed shapes, the following factors should be taken into account [9]: 1) mass production; 2) the possibility of implementation on profile bending equipment; 3) profiling speed (6-20 m/min); 4) minimum economic costs for manufacturing the part: simplicity of the technological process); 5) possibility of using unskilled personnel; 6) minimum costs of material resources; 7) minimum time costs for manufacturing the tool; 8) safe human work during product manufacturing; 9) use of safe equipment.

Usually, when choosing a manufacturing method, more attention is paid to the

fourth and fifth points, which allows minimizing economic costs. The first factor is also no less important. Thus, in mass and multi-series production, it is possible to use expensive but high-speed equipment, since the economic costs for one part quickly pay off. In small-scale production, the use of such equipment is irrational, since cheaper and less high-speed equipment is used [2,3].

Choice of the scheme and modes of forming

The mode of forming is crucial for ensuring the required profile quality at minimal costs. It is characterized by the angles of bending of the profile per pass and the radii of curvature of the bending points of the workpiece. The forming mode is assigned taking into account the parameters of the stress-strain state and mechanical properties of the metal, the dimensions of the workpiece and profile elements, the roll calibration system and the technological process of profiling [2].

Methods and measures of non-destructive testing of profiling products. In modern production, non-destructive testing measures are usually integrated into the profiling line. The manufacture of metal products is accompanied by the creation of an information and measuring system or complex that performs its functions at the intermediate and final stages of forming, ensuring control of geometric (thickness, bending angles, etc.) and mechanical (hardness, plasticity, etc.) [2].

The methods of non-destructive testing used include [2,3]: 1. Acoustic (ultrasonic). Echo method, time method for thickness control. 2. Electromagnetic-acoustic method. Used for the same tasks as the standard ultrasonic method, as well as for surface inspection using longitudinal wave excitation. 3. Eddy current method. For detecting surface defects and integrity violations. 4. X-ray method. For detecting complex defects, microcracks, etc. that are not detected by other methods. 5. Penetrant testing (capillary method).

Conclusion. As a result of the development, an effective algorithm was created for selecting the most important decisions regarding the use of methods for creating profiling processes.

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UNCERTAINTY EVALUATION OF THE PREDICTED VALUE OF ELECTRIC CAPACITANCE OF THE STANDARD CAPACITOR BY THE WEIGHTED LEAST SQUARES METHOD

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Over time, the value of the quantity reproduced by the standard capacitor changes due to drift. The aim of the research is to develop a method for calculating the predicted value of reproduced quantity with uncertainty evaluation by extrapolating the results of previous calibrations.

For example, the calculation of the predicted value of the reference measure Andeen Hagerling AH11A 10 pF at frequency 1.0 kHz on 05.10.2026 is considered.

Such **methods** were used during the research:

1) **Weighted linear regression**, or **weighted least squares method**. Regression is considered where each observation has a weight $w_i = 1/u_i^2$. The smaller the uncertainty, the greater the influence of that point.

2) **Extrapolation by linear model**. This method uses the model $C(t) = a + bt$ to forecast the value C_* for a future point in time, in this case for 05.10.2026.

3) **Residue-based method** – analysis of statistical models by checking the randomness of residuals, i.e. the differences between predicted and actual values. This method is used to evaluate uncertainty from possible nonlinearity of drift.

4) **Evaluation of forecast uncertainty.** The method combines uncertainties from regression, drift nonlinearity, and previous calibrations.

For the calculation the data is used obtained from previous calibration certificates and the international comparison report COOMET.EM-S13 (Table 1):

Table 1 – Calibration and comparison results

N	Laboratory	Measurement date	t_i (years since 18.12.2008)	C_i (pF)	u_i (pF)	$\tilde{w}_i = \frac{w_i^{(0)}}{\overline{w}}$
1	GUM (PL)	18.12.2008	0.0000	10.0000082	2.5×10^{-6}	0.007592
2	GUM (PL)	25.05.2012	3.4335	10.000009	2.5×10^{-6}	0.007592
3	UMTS (UA)	14.10.2012	3.8220	10.00001053	1.1×10^{-6}	0.039212
4	BelGIM (BY)	11.12.2012	3.9810	10.00001114	1.075×10^{-5}	0.0004104
5	BIPM	28.11.2020	10.9437	10.00001158	7.2×10^{-7}	0.09152
6	PTB (DE)	04.10.2023	14.7932	10.00001279	9.0×10^{-8}	5.853674

Rows 1, 5, 6 of table 1 – calibration results, rows 2-4 – comparisons results. Number of observations $n = 6$. Number of model parameters (line) $p = 2$. Forecast target date – $t_* = 17,796685$ years (05.10.2026). Initial weights: $w_i^{(0)} = 1/u_i^2$, $W^{(0)} = \sum_{i=1}^{6} w_i^{(0)} \approx 1,2648405\times10^{14}$. Averaging: $\overline{w} = W^{(0)}/n \approx 2,1080675\times10^{13}$.

Normalization: $\tilde{w}_i = w_i^{(0)} / \overline{w},\ \sum \tilde{w}_i = 6$.

According to the formulas for weighted linear regression [1, 2]:

– model: $C(t) = a + bt$;

– weighted averages: $\overline{t}_w = \sum \tilde{w}_i t_i / \sum \tilde{w}_i,\ \overline{C}_w = \sum \tilde{w}_i C_i / \sum \tilde{w}_i$.

Weighted adjusted sum of the argument squares $S_{tt} = \sum \tilde{w}_i \left(t_i - \overline{t}_w\right)^2 = 8{,}6$ years^2, weighted corrected covariance between time and capacitance $S_{tC} = \sum \tilde{w}_i \left(t_i - \overline{t}_w\right)\left(C_i - \overline{C}_w\right) = 5{,}13 \times 10^{-6}$ pF×year.

Regression coefficients:

– weighted slope estimator (drift) $\hat{b} = S_{tC} / S_{tt} = 5{,}97 \times 10^{-7}$ pF/year;

– weighted intercept estimator $\hat{a} = \overline{C}_w - \hat{b}\overline{t}_w = 10{,}0000041$ pF.

Forecast for 05.10.2026: $C_* = a + bt_* = 10{,}00001472$ pF.

Residuals and normalized weighted sum of residuals squares: $r_i = C_i - \left(\hat{a} + \hat{b}t_i\right)$;

$RSS_{\tilde{w}} = \sum_{i=1}^{6} \tilde{w}_i r_i^2 \approx 6.58 \times 10^{-12}$ pF^2.

Unbiased estimate of model variance: $\hat{\sigma}^2 = RSS_{\tilde{w}} / \left(n - p\right) \approx 1{,}645 \times 10^{-12}$ pF^2.

Standard uncertainty component of the regression forecast:

$$u_{\text{reg}}^2\left(C_*\right) = \hat{\sigma}^2 \left(\frac{1}{\sum \tilde{w}_i} + \frac{\left(t_* - \overline{t}_w\right)^2}{S_{tt}} \right).$$

Evaluation of the predicted value uncertainty:

Forecast uncertainty components originating from uncertainties of linear regression, possible drift nonlinearity, and previous calibrations:

$u_{\text{reg}} \approx 1{,}48 \times 10^{-6}$ pF; $u_{\text{model}} = 0{,}20 \cdot u_{\text{reg}} \approx 2{,}96 \times 10^{-7}$ pF, $u_{\text{cal}} = u_{\text{PTB}} = 9{,}0 \times 10^{-8}$ pF.

Combined standard forecast uncertainty (type A + type B + type B):

$$u_{\text{total}} = \sqrt{u_{\text{reg}}^2 + u_{\text{model}}^2 + u_{\text{cal}}^2} \approx 1{,}509 \times 10^{-6} \text{ pF}.$$

Expanded uncertainty at $p = 0{,}95$ and $k = 2$:

$$U = 3{,}018 \times 10^{-6} \text{ pF}.$$

The final result of the calculations is the predicted capacitance value for the required date (05.10.2026) with an expanded uncertainty at $p = 0{,}95$ and $k = 2$:

$$C_* = 10{,}00001472 \text{ pF} \pm 3{,}02 \times 10^{-6} \text{ pF}.$$

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DEVELOPMENT OF METHODS FOR DETERMINING TARGET MEASUREMENT UNCERTAINTY IN PRACTICE

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Without knowing the target (maximum permissible) uncertainty, it is impossible to determine the largest value of measurement result uncertainty at which this result can still be considered reliable. The absence of a defined value of maximum permissible uncertainty for a specific measurement task leads to incorrect decisions during conformity assessment.

Despite the fact that the assessment of identical products is carried out in testing laboratories accredited by the same National Accreditation Body, the results differ. If a methodology for evaluating uncertainty and a target uncertainty value for testing specific products are available, the test results obtained in different laboratories can be trusted.

Ukrainian legislation defines the necessity of calibration of measuring instruments in accordance with national standards harmonized with the relevant international and European standards and documents adopted by international and regional metrology organizations. However, this requirement is not always fulfilled. Legislation also defines target uncertainty as the ratio of the expanded uncertainty (at a confidence level of 95%) of the value reproduced or measured by a reference standard to the maximum permissible error of a legally regulated measuring instrument subject to verification, and this ratio must not exceed one to three. Eurachem/CITAC in [1] provides methods for evaluating target uncertainty.

During the conformity assessment of products, target uncertainty can be determined through the accuracy characteristics of the measurement result established in the measurement procedure. For example, if the measurement procedure includes a value of measurement error at a confidence level of 95%, this value may be used as the expanded uncertainty, which is taken as the target uncertainty provided that the requirements of the procedure are met and it is verified in the laboratory. If the procedure includes values of trueness and precision (repeatability and reproducibility), the uncertainty value can be calculated based on ISO 21748 “Guidance for the use of repeatability, reproducibility and trueness estimates in measurement uncertainty estimation” and ISO/TS 21749 “Measurement uncertainty for metrological applications. Repeated measurements and nested experiments”.

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APPLICATION OF UNCERTAINTY THEORY TO ANALYZE THE RISKS OF MAKING THE INCORRECT DECISIONS IN FAVOR OF THE CONSUMER OR PRODUCER IN RISK MANAGEMENT

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International standard ISO 9001:2015 emphasizes the application of risk-based thinking in the design and implementation of a quality management system (QMS). Although ISO 9001:2015 does not require the mandatory development of a documented risk management procedure, risk analysis and risk planning are the important components of establishing an efficient and effective QMS.

Recommendations for risk management are contained in the standard DSTU EN IEC 31010:2022 Risk management – Risk assessment techniques (EN IEC 31010:2019, IDT) [1]. According to this international standard, the analysis of uncertainties associated with data, methods and models used to identify and analyze risks, plays an important role in its application. Uncertainty analysis involves determining the deviation or inaccuracy of results due to the cumulative change in the parameters and assumptions used to determine the results. That is, the concept of "uncertainty" plays a significant role in the risk management process. For example, to analyze the risks that arise during the process of incoming products control, the recommendations of DSTU 9027:2020 Quality management systems. Guidelines for incoming products inspection are used. This regulatory document states that the results of incoming control should make it possible to assess the quality of the tested products [2].

The process of assessing the compliance of the product quality factor with the established requirements, constructing the acceptance interval and making a decision on the recognition or non-recognition of the product as compliant with the requirements is regulated by the document JCGM 106:2012 Evaluation of measurement data – The role of measurement uncertainty in conformity assessment, which is implemented in the Ukrainian regulatory framework as DSTU ISO/IEC Guide 98-4:2018 Measurement uncertainty. Part 4. The role of measurement uncertainty in conformity assessment (ISO/IEC Guide 98-4:2012, IDT) [3]. The assessing quality factor must be expressed in accordance with the provisions of the measurement uncertainty theory declared in JCGM 101:2008, JCGM 102:2011, JCGM 103 and JCGM 104:2009. The recommendations of JCGM 106:2012 regarding the risks of making the incorrect decisions in favor of the Consumer or Producer, related to measurement uncertainty, should be taken into account in the risk management process in enterprises to improve the QMS functioning efficiency.

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ANALYSIS OF THE TYPE B STANDARD UNCERTAINTY COMPONENTS AT WORKING STANDARDS CALIBRATION

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The unity of measurements is achieved by accurately reproducing and storing the established units of measurement of quantities using standards and transferring their sizes to working measuring instruments.

According to the standard [1], in order to ensure that measuring equipment complies with the requirements for its purpose, metrological confirmation of suitability is necessary, which includes calibration and verification of the equipment.

Thus, calibration is the procedure for transferring the unit of measurement of a quantity reproduced and/or stored by the standard to less accurate standards or measuring instruments. One of the conditions for ensuring the unity of measurements is the compliance of any working standard with the requirements of the relevant technical specification, which specifies its normalized metrological characteristics, of which the most important is the maximum permissible error, which determines the difference between its actual and nominal properties.

Currently, most calibration of working standards is carried out using calibration methods developed by the performers themselves, which contradicts the provisions of Article 27 of the law [2].

According to clause 7.6.1 of the standard [3], the laboratory must identify the components of measurement uncertainty. Namely, due to measurement uncertainty, there is always a risk of making a wrong decision on the compliance or non-compliance of the working standard with the established requirements, based on a certain assessment of the systematic error according to the calibration results. Therefore, the main issue during the calibration of working standards is the correct assessment of measurement uncertainty, which is possible by taking into account the contributions of all its significant components, the detection and determination of which remains in the field of empirical experience of the personnel of calibration laboratories.

The report examines the analysis of the components of type B standard uncertainty during the calibration of working standards and their impact on establishing the compliance of working standards with the requirements of the technical specification based on the calibration results.

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REGARDING THE ASSESSMENT OF THE SYSTEMATIC INFLUENCE CAUSED BY THE EARTH'S ATMOSPHERE ON THE ACCURACY OF DISTANCE MEASUREMENTS PERFORMED BY AN ELECTRONIC TOTAL STATIONS ON TRACES THAT ARE CLOSE TO HORIZONTAL

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To account for the influence of the Earth's atmosphere on the results of distance measurements using electromagnetic waves, information about the mean-integral (averaged along the measured trace) air refractive index is required. The refractive index is a function of the atmospheric meteorological parameters – air pressure P, temperature T, and humidity e. Therefore, its mean-integral value depends on the mean-integral values of the corresponding functions that link P, T, and e in the refractive-index formula.

Reference [1] examines the accuracy limitations of the widely used empirical approach for accounting for atmospheric effects in distance measurements performed by the electronic total stations (this approach uses information on meteorological parameters only at the location of the electronic total station). The relations obtained in [1] for the methodological component of the error are valid for horizontal traces along which temperature T varies, while P and e are assumed constant.

This paper provides a more general relationship for traces that are close to horizontal. A variant is considered that takes into account not only temperature changes, but also air pressure along an inclined trace. The dependence of pressure on altitude is taken into account using a barometric formula. The obtained relationships allow analyzing the influence of atmospheric conditions on the limit values of trace lengths for which an empirical approach can be used.

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MEASUREMENT UNCERTAINTY EVALUATION IN A TLD-AUDIT STUDY

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An important task for treatment efficacy and patient safety in radiotherapy is the accuracy and uncertainty in delivering the prescribed therapeutic dose to the patient. External audit programs, such as thermoluminescent dosimetry (TLD) via the "mail-based dosimetry" system, serve as a tool for the independent verification of clinical dose. A mandatory requirement for the accreditation of laboratories engaged in TLD-audit is the demonstration of metrological traceability and a correct estimation of measurement uncertainty in full compliance with international guidelines [1].

The research we conducted presents a systematic investigation of the dosimetric properties of a TLD system using TLD-100 (LiF:Mg,Ti) powder. The choice of this phosphor is due to its tissue equivalence, low fading, and high sensitivity to ionizing radiation.

The study was conducted in four stages, during which the calibration methodology was sequentially refined. It evolved from using a gamma-therapy unit with a vertical beam in conjunction with a water phantom, to a procedure utilizing the national primary standard of absorbed dose to water and absorbed dose rate for X and gamma radiation, along with a PMMA (polymethyl methacrylate) phantom. The primary objective was the experimental determination of correction factors necessary for the accurate calculation of absorbed dose to water. These included the calibration coefficient, the coefficient accounting for the nonlinearity correction of the signal with dose, the coefficient accounting for the fading correction (signal loss over time), and the coefficient accounting for the holder correction for beam attenuation. One of the results was the determination of the medium conversion factor $F_{PMMA \rightarrow water} = 1.0042$. This factor allows the use of a PMMA phantom for high-precision calibration on the primary standard enabling the simultaneous irradiation of multiple detectors and reducing positioning uncertainty while guaranteeing correct dose reporting for the water phantoms used in clinical institutions. The investigation of the nonlinearity correction factor showed that its dependence on dose becomes less pronounced upon reusing the phosphor, varying only within ±0.4% in the operational dose range at the final stage. The fading study demonstrated that the signal stabilizes approximately 30 days after irradiation. For time intervals exceeding 30 days, the fading correction factor approaches unity, which significantly simplifies the dose calculation procedure under practical audit conditions.

It was established that the main contribution to the combined uncertainty is made by the uncertainty of the calibration coefficient, which is related to the accuracy of delivering the absorbed dose to water as measured by the reference ionization chamber. To minimize this and other components, modern methods of statistical data analysis were applied to large experimental datasets.

The results demonstrate that under all investigated irradiation conditions, the combined standard uncertainty of the absorbed dose did not exceed ±3% [2]. This level of uncertainty meets the stringent requirements established by the IAEA for reference TLD-audit centers. The proposed and tested methodological approach provides a reliable and rigorous foundation for the metrological support of dosimetry in clinical practice. It guarantees the accuracy and international comparability of results, enabling its implementation in the work of national dosimetric audit services, thereby enhancing the quality and safety of radiotherapy.

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DEVELOPMENT OF A STAND FOR METROLOGICAL ANALYSIS OF A NON-CONTACT LASER TACHOMETER

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A stand was developed for metrological analysis of the operation of a laser non-contact tachometer. A series of rotational speed measurements were performed using an optical tachometer, and the influence of external factors on the accuracy of the obtained results was analyzed.

The change in shaft rotation speed is smoothly regulated by a speed controller connected in series with a DC motor, a control circuit, and a power supply. The system is powered by a 3 V battery. A special disc (eight discs are provided, white and black with different numbers of markers) with contrasting marks is installed on the shaft. This allows the device to provide informative readings even at a constant actual motor shaft speed.

The measurement process is carried out sequentially for each disc, with the laser beam of the tachometer focused directly on the rotating marker strip.

Based on the measurement results, a study and calculation of sources of uncertainty were carried out. An uncertainty budget was compiled, which includes the following sources, types of estimates, and their results:

— influence of the distance to the measurement object (white disk with a black marker), Type *A* evaluation, result is $u_A = 0{,}19$;

— influence of the distance to the measurement object (white disk with two black markers), Type *A* evaluation, result is $u_A = 0{,}06$;

— influence of the distance to the measurement object (white disk with three black markers), Type *A* evaluation, result is $u_A = 0{,}11$;

— influence of the distance to the measurement object (white disk with four black markers), Type A evaluation, result is $u_A = 0{,}05$;

— influence of the distance to the measurement object (black disk with a white marker), Type *A* evaluation, result is $u_A = 0{,}05$;

— influence of the distance to the measurement object (black disk with two white markers), Type *A* evaluation, result is $u_A = 0{,}07$;

— influence of the distance to the measurement object (black disk with three white markers), Type *A* evaluation, result is $u_A = 0{,}22$;

— influence of the distance to the measurement object (black disk with four white markers), Type *A* evaluation, result is $u_A = 0{,}08$;

— influence of the observation angle (white disk with a black marker), Type *A* evaluation, result is $u_A = 0{,}07$;

— influence of the observation angle (white disk with two black markers), Type *A* evaluation, result is $u_A = 0{,}08$;

— influence of the observation angle (white disk with three black markers),

Type *A* evaluation, result is u_A = 0,06;

— influence of the observation angle (white disk with four black markers), Type *A* evaluation, result is u_A = 0,11;

— influence of the observation angle (black disk with a white marker), Type A evaluation, result is u_A = 0,08;

— influence of the observation angle (black disk with two white markers), Type A evaluation, result is u_A = 0,06;

— influence of the observation angle (black disk with three white markers), Type A evaluation, result is u_A = 0,13;

— influence of the observation angle (black disk with four white markers), Type A evaluation, result is u_A = 0,09;

— influence of interference, Type A evaluation, result is u_A = 0,34;

— combined uncertainty, the result is (u_c) = 0,542;

— expanded uncertainty (k=2), the result is (U) = 1,084.

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MEASUREMENT UNCERTAINTY EVALUATION OF THE MOLASSES VISCOSITY BY VISCOMETER

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Viscosity is one of the rheological characteristics, determined the quality of the food materials (raw materials, semi-products and final products).

The molasses is widely used at the production of the confectionery.

The measurement of the viscosity is an important stage at the developing the new technologies of the production of the confectionery.

Evaluation the measurement uncertainty of the dynamical viscosity of the molasses at the researches the different samples of the molasses for the production marshmallow is a purpose of the work.

The questions of the measurement uncertainty evaluation of the parameters of the quality and the safety of the food products were considered in [1,2].

The rotational viscometer “Reotest” (Germany) was used for measurements the viscosity.

The viscosity is calculated by formula [1]:

$$\eta = \frac{\tau}{D}, \qquad (1)$$

where τ is the shear stress, Pa; D – the shear stress gradient, s^{-1}.

Five samples of the molasses were investigated at the temperature $50{,}5\,^{\circ}C$ at the different operating modes of the viscometer (the different speeds). The indications of the viscometer allowed to calculate the shear stress.

The three parallel measurements of the molasses’s viscosity were performed.

Taking into account the formula (1), the measurement model was formed and the analysis of the contributions of each input values to the measurement uncertainty of the measurand was done.

Using the results of the parallel measurements and the metrological characteristics of the viscometer, combined standard measurement uncertainty and the expanded measurement uncertainty of the molasses’s dynamical viscosity were calculated for each sample of the molasses.

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MODEL FOR EVALUATING THE ENERGY CHARACTERISTICS OF A VEHICLE USING THE INDICATOR OF PARTIAL ACCELERATION

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Among the main parameters of vehicles selected at the stage of preliminary design are the total mass, maximum speed, and maximum engine power. At the initial stage, it becomes necessary to determine the relationship between these parameters in order to, for example, calculate the required maximum engine power for given total mass and maximum speed, as well as to assess and compare the dynamic properties of the designed vehicles. This problem can be solved using so-called "fast" models. Based on the analysis of known studies, it has been established that the traditional indicator of specific power depends on the class and type of vehicle [1]. It has also been found that the specific power of a vehicle is not an objective indicator, as it does not allow comparison of the energy load of vehicles from different years of production, classes, and types. Moreover, specific power does not take into account the maximum design speed of the vehicle, which, according to studies [2], is constantly increasing.

As a result of the conducted research, a "fast" model has been proposed that shows the necessary relationship between the total mass, maximum speed, and required maximum engine power of a vehicle. Partial acceleration from the driving force is an indicator defined as the ratio of the maximum effective engine power to the maximum momentum of the vehicle at its total mass and maximum speed.

To evaluate the dynamic properties of passenger cars using the proposed indicator, an analysis of modern vehicle models of various classes was conducted. The study analyzed 90 modern car models classified according to the European classification system into classes A–S. It was found that the average value of partial acceleration is 1.24 m/s², while the standard deviation is 0.41 m/s², corresponding to a coefficient of variation of 33%. For specific power, the mean value is 76.74 kW/t, the standard deviation is 37.26 kW/t, and the coefficient of variation is 48.6%.

A smaller spread in the values of partial acceleration from the driving force compared to the specific power indicator allows for a more objective evaluation of the vehicles' energy characteristics. In conclusion, it has been demonstrated that the proposed indicator can be used at the preliminary design stage to determine rational ratios between mass, speed, and power, as well as to evaluate the energy load of vehicles.

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UNCERTAINTY OF BIG DATA IN THE CONTEXT OF METROLOGICAL APPROACHES

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In metrology, one of the key concepts is measurement uncertainty, which characterizes the dispersion of possible values of the measured quantity. Its evaluation is based on the analysis and combination of individual sources of error in accordance with standards such as the GUM. However, traditional metrological approaches used for big data analysis are often insufficient due to the different nature of the data, the diversity of sources, and the complexity of the processes of their formation.

Unlike classical measurements, where data come from structured and controlled sources, Big Data may be structured, unstructured, or semi-structured. Their scale and heterogeneity generate new forms of uncertainty across all stages of the data life cycle: collection, transmission, storage, processing, and analysis. Particularly challenging are real-time streaming data processing tasks that require high-performance adaptive algorithms. Insufficient adaptability of the algorithm or incorrect functioning of the system can cause the appearance of new systematic errors that are absent in classical measurements.

The main sources of uncertainty in Big Data include:

1. Errors, noise, missing and incomplete data in information from disparate sensors and digital systems.
2. Heterogeneity of data formats and structures, which complicates preprocessing and data integration.
3. Social, algorithmic, or selection bias that significantly affects the correctness of conclusions.
4. False correlations and the “curse of dimensionality”, which lead to finding statistically significant but practically meaningless relationships.

Another important challenge is traceability and reproducibility of results obtained from Big Data analytics. Unlike classical measurements, in such datasets they are complicated by their dynamic nature, the opacity of modern machine learning algorithms, and the variety of preprocessing methods. To ensure trust in the results, it is necessary to standardize data processing pipelines, create transparent models and document procedures.

Within the framework of this study, a program for estimating measurement uncertainty in the case of missing data at individual time intervals was implemented, and a model was developed and tested to analyze the impact of the “curse of dimensionality” on the accuracy of uncertainty estimation. The presented results demonstrate the operation of a neural network that is trained on non-stationary random processes and estimates measurement uncertainty on data of different dimensions. The purpose of such modeling is to quantitatively assess the impact of increasing the number of features on the uncertainty of the signal amplitude and the

stability of this uncertainty – a key parameter of metrological control.

The program generates synthetic data with added measurement errors, trains the neural network for different input dimensions (2–100 features), determines the mean square error, uncertainty, training time, and number of epochs to convergence. The simulation results clearly demonstrate the exponential deterioration of prediction quality and the increase in computational costs in high dimensions. Generalized graphs visualize the manifestations of the "curse of dimensionality" and allow comparing the behavior of the model in low-dimensional and high-dimensional cases.

Thus, uncertainty assessment in big data requires advanced approaches. For type A estimates, classical statistical models, probabilistic methods, Monte Carlo techniques, and Bayesian approaches can be used. Pre-processing of data plays an important role, determining the quality of subsequent stages of analysis.

Reducing uncertainty requires the use of parallel computing, distributed processing systems, and machine learning algorithms that can analyze data structure and ensure forecast stability. A promising direction is the creation of predictive uncertainty models and the study of the impact of high-dimensional factors on measurement accuracy.

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REGARDING THE REDUCTION OF UNCERTAINTY IN THE REALIZATION OF THE UNIT OF TEMPERATURE AT THE COPPER FIXED POINT

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Achieving high accuracy in the realization of the temperature unit at the fixed points of high-purity metal freezing, for example, at the copper point (1084,62 ºC), is a fundamental task for ensuring traceability to the International Temperature Scale, ITS-90 [1]. This is critically important not only for scientific research but also for ensuring the competitiveness and defense capability of Ukraine. The accuracy of temperature measurement is exactly what determines the quality of products in industrial sectors such as metallurgy, heavy machine building, manufacturing of high-precision equipment, etc.

In the scope of this work, the metrological characteristics of a measuring system consisting of a black body model with high-purity copper (manufactured by NSC “Institute of Metrology”, Kharkiv, Ukraine) and a linear precision pyrometer LP-4 (manufactured by KE-Technologie, Stuttgart, Germany) were analyzed. The main goal of the work is to reduce the total measurement uncertainty through targeted optimization of the budget components that contribute the most and can be influenced [2,3].

Thus, special attention was paid to the influence on the repeatability of measurements (Type A uncertainty) and instrumental components of Type B uncertainty such as drift, alignment and the influence of impurities.

The resulting uncertainty budget shows how the improvement of some system components has affected the final result.

The comparative analysis clearly indicates that the standard uncertainty of the copper freezing point realization was reduced by more than one-third compared to 2013 (from 127,1 mK to 80.7 mK). This progress is a direct result of systematic efforts aimed at optimizing key factors of the measuring system.

Improvements made to the reference cell (BB model) included the replacement of the stainless-steel holder with a graphite holder. The quality, geometric dimensions, and total mass of the crucible were also optimized. Furthermore, copper with an increased purity level, approximately 99,9999%, was used as the pure metal. These measures directly influenced the duration and stability of the copper freezing plateau.

The technical modernization of the measuring tract through the use of the precision linear pyrometer LP-4 provided significant advantages. The instrument has a more sophisticated optical system and capabilities for more precise alignment. Its photosensitive element is equipped with reliable thermal stabilization, and the signal conversion circuits ensure a low level of drift. These technical solutions positively

influenced a significant number of Type *B* uncertainty components and made a substantial contribution to reducing Type *A* uncertainty.

The key result is that the repeatability factor of the measured quantity (Type *A*) held the most significant contribution to the initial budget. Its uncertainty was reduced 7-fold (from 72 mK to 10 mK), which serves as proof of a radical increase in the stability of the measurement system. The contribution of drift and alignment was halved, and the uncertainty component attributed to impurities was reduced threefold (from 30 mK to 10 mK).

As for the components of the uncertainty budget, such as the source size effect and spectral parameters, remain limiting factors. These require further research, the search for alternative approaches to incorporating geometric corrections, and potentially the modernization of the optical system.

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EVALUATION OF MEASUREMENT UNCERTAINTY IN GAS DISTRIBUTION NETWORKS

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In natural gas distribution systems ensuring the uniformity and accuracy of measurements constitutes an essential task for the organization of commercial accounting of natural gas, as well as for the physical and commercial balancing of gas distribution networks. In this context, measurement uncertainty determines the level of reliability of the obtained data and directly affects the adoption of technological decisions during system operation. Therefore, for the purpose of monitoring the parameters of gas distribution networks a relevant scientific and technical challenge is the development and implementation of a system for controlling and evaluating measurement uncertainty through the application of modern information and measurement technologies.

Let us consider the evaluation of measurement uncertainty in the context of commercial balancing of gas distribution networks, which is described by equation (1):

$$\Delta V = V_{vh} - \sum_{i=1}^{n} V_{vuh_i}\,, \tag{1}$$

where ΔV denotes the volume of actual losses of the enterprise; V_{vh} represents the volume of gas delivered into the distribution network from the main pipeline; V_{vuh_i} corresponds to the volume of gas supplied to consumer facilities together with production expenditures.

Since the quantities V_{vh} and V_{vuh_i}, included in expression (1), are simultaneously influenced by multiple sources of uncertainty, the evaluation of ΔV will be carried out using the combined standard uncertainty in accordance with [1]:

$$u_c(\Delta V) = \sqrt{u_c^2(V_{vh}) - \sum_{i=1}^{n} u_c^2(V_{vuh_i})}\,. \tag{2}$$

The condition $|\Delta V| > k_p u_c(\Delta V)$ makes it possible to conclude that the gas distribution network is operating in an abnormal mode (likely failure of metering devices, pipeline damage, gas thefts, etc.). Conversely, if $|\Delta V| < k_p u_c(\Delta V)$, the difference is statistically insignificant, which indicates that the gas distribution network is functioning under normal operating conditions.

In the future, it is planned to conduct research for the case when the measurement results of the arguments in formula (2) are correlated quantities. The obtained research results may be applied to the processing of measurement data of natural gas volumes, including for the automation of the technological process of its distribution.

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UNCERTAINTY OF SPATIAL INHOMOGENEITY IN THE CALIBRATION OF CLIMATIC CHAMBERS

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The calibration of a climatic chamber serves to determine the deviation of the climatological characteristics of air temperature and relative humidity in those parts of the chamber volume which are provided for use or in individual points of the chamber volume from the values displayed by the indicators of the chamber. Besides these deviations, additional properties such as inhomogeneities, stabilities, etc. are frequently determined to characterize the chamber and potential effects on the test material placed in the chamber [1]. One of the most important characteristics of a climate chamber is spatial inhomogeneity T_{inhom}.

According to Guideline DKD-R 5-7 [1], spatial inhomogeneity is defined as the maximum deviation of the relative humidity or temperature of a corner or wall measurement point T_i from a reference measurement point T_{ref} (usually in the center of the useful volume). The uncertainty of spatial heterogeneity when calibrating climatic chambers (by temperature) is calculated by the formula (1):

$$u(T_{inhom}) = \frac{1}{\sqrt{3}} \cdot \max(T_{ref} - T_i). \quad (1)$$

This is equivalent to the half-width of the rectangular contribution in the assumption of the maximum interval of the variability limits of the input quantity and the symmetry of these interval limits with respect to zero.

We believe that this assumption is not true for all cases and therefore propose the following formula for calculating the uncertainty of spatial inhomogeneity:

$$u(T_{inhom}) = \frac{1}{2\sqrt{3}} \cdot [\max(T_i) - \min(T_i)]. \quad (2)$$

Formula (2) allows us to take into account in calculations the case where the maximum difference in temperature at the reference measurement point T_{ref} and the temperatures at other measurement locations is not maximum and is not symmetrical relative to zero, and the maximum temperature difference is the difference in temperature measurements at other measurement locations, not necessarily at the control point, which is more realistic in practice (Table 1).

Table 1 – Spatial temperature distribution during climatic chamber calibration, ºC

T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	$T_{9\,(ref)}$	max T difference by (1)	max T difference by (2)	u by (1)	u by (2)
81,2	82,0	80,3	80,9	78,7	81,9	81,2	80,9	80,5	1,76	3,30	1,02	0,95
106,8	107,7	105,5	106,3	103,2	107,5	106,6	106,3	105,7	2,41	4,50	1,39	1,30
132,0	133,1	130,3	131,4	127,5	132,8	131,6	131,4	129,9	3,15	5,56	1,82	1,61

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METROLOGICAL ASPECTS OF UNCERTAINTY ASSESSMENT OF COMPREHENSIVE POWER QUALITY INDICATOR

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The quality of electric energy is one of the important factors of reliability, efficiency, and safety of functioning of energy systems. Indicators of the quality of electric energy are regulated by international and national standards, in particular [1, 2]. These documents consider individual quality indicators, their numerical values and permissible limits of change, as well as methods and algorithms for their determination. At the same time, there is currently no methodology that would provide assessment of the quality of electric energy based on simultaneous measurement or determination of individual indicators and their formation into a complex quality indicator (QI), for example, based on the provisions of qualimetry.

The purpose of the work is to evaluate the CPQ of electric energy based on the calculation of the uncertainty of individual unit quality indicators.

To determine the CPQ of electric energy *K,* a qualimetric approach based on the weighted arithmetic average can be used [3]:

$$K = \sum_{i=1}^{n} q_i \gamma_i , \tag{1}$$

where q_i is the normalized dimensionless quality indicator of the *i*-th unit indicator, γ_i is the weight coefficient of the *i*-th quality indicator, *n* is the number of unit quality indicators.

To form the CPQ, we selected the following six single indicators of the quality of electric energy from the regulatory document [1], which relate to the characteristics of the nominal voltage V_n and the nominal frequency f_n of the distribution network, the short-term flicker indicator P_{st} [4], total harmonic distortion factor K_{THD}, voltage dips (by residual voltage and duration) V_c , network overvoltages (by maximum overvoltage and duration) V_n. We also chose the power factor P_φ as a unit indicator.

Since the CPQ is formed through the arithmetic mean, the standard uncertainty of the CPQ is calculated by the formula

$$u_c(K) = \sqrt{\sum_{i=1}^{n} u_B^2(q_i) + \sum_{i=1}^{n} u_A^2(q_i) + \sum_{i=1}^{n} u_B^2(\gamma_i)} , \tag{2}$$

The uncertainty of the measured quality indicators is carried out based on the calculation of the uncertainties u_A , u_B of measuring instruments (voltage, frequency, power factor measurement).

For example, the normalized quality indicator of the nominal voltage of the distribution network is calculated using the formula:

$$q_{V_n} = 1 - \frac{|V_m - V_n|}{V_n}, \tag{2}$$

where V_m is the actual (measured) value of the voltage in the network, V_n is the normalized (nominal) value of the voltage in the network.

Therefore, the uncertainty of the measurement of the actual voltage will be determined by the formula:

$$u_B(V_m) = \frac{\delta_{V_m}}{\sqrt{3}}, \tag{3}$$

where δ_{V_m} is the error of the voltmeter when measuring the actual voltage.

To evaluate the weighting factors of the quality of the nominal voltage, γ_{V_n} we will use a methodological approach, according to which the weighting factor will be determined based on the normatively permissible voltage change of ±10% of the nominal voltage value of 230V, which allows it to be written as:

$$\gamma_{V_n} = \frac{10\%}{100\%} = 0{,}1. \tag{4}$$

A feature of calculating the uncertainty of the characteristics P_{st}, K_{THD}, V_{with}, V_n. is the use of the calculation algorithm as the combined uncertainty u_c in indirect measurements in conjunction with their weighted coefficients according to the calculation algorithm and the uncertainties u_A of the measurement parameters that are included in the algorithms for indirect calculation of these unit quality indicators [2, 4].

The uncertainty of weighting factors is determined only by type *B*, since they are formed on the basis of their determination on the basis of normatively permissible changes in measured or calculated unit characteristics of the quality of electrical energy.

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METROLOGICAL RESEARCH OF THE INSTALLATION FOR CALIBRATION OF GAS METERS ON HYDROGEN GAS MIXTURES

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Currently, in Ukraine and globally, the feasibility of using hydrogen as an additive to natural gas is becoming increasingly relevant, which contributes to solving the issues of environmental decarbonization and saving natural gas. At the same time, the issue of accounting for gas-hydrogen mixtures is practically unexplored, since known studies were aimed at studying the state of gas networks when they are filled with hydrogen or at the performance of gas meters after their long stay in a gas environment [1].

We have developed a concept for creating a device for calibrating gas meters using gas-hydrogen mixtures, and the goal of the research is to develop its metrological model using uncertainty theory.

The principle of operation of the installation is based on the practical implementation of the PVTt method using a high-pressure vessel, in which a calibration gas mixture is created by the comparison method. Then, using known algorithms for the mixture to flow out of this vessel through a calibration meter, it becomes possible to determine its metrological characteristics depending on the volume and composition of the hydrogen gas mixture.

Since the estimation of the uncertainty of the installation during its operation in the calibration mode is known [2], it is necessary to first estimate the uncertainty of the hydrogen gas mixture created in the tank.

The tank is filled alternately with natural gas and then with hydrogen. The following algorithm is used: measuring the mass of gas in a container :

$$m_G = q_G \rho_{GS} \frac{P_G}{P_S} \frac{T_S}{T_G Z_G} \Delta t_G , \tag{1}$$

$$m_H = q_H \rho_{HS} \frac{P_H}{P_S} \frac{T_S}{T_H Z_H} \Delta t_H , \tag{2}$$

where m_G , m_H – mass of gas and hydrogen in the tank; q_G , q_H – volumetric flow rate of gas and hydrogen under operating conditions; ρ_{GS} , ρ_{HS} – density of gas and hydrogen under standard conditions; P_G, P_H – absolute pressure of gas and hydrogen at the outlet of the pressure stabilizer when the tank is filled; T_G , T_H – absolute temperature of gas and hydrogen at the outlet of the pressure stabilizer when the tank is filled; T_S, P_S – standard conditions for temperature and pressure; Δt_G, Δt_H – duration of filling the tank with gas and hydrogen, respectively; Z_G, Z_H – compressibility factor of gas and hydrogen under operating conditions.

After a given degree of filling of the container, the mass concentration of hydrogen (in relative units) in the hydrogen-gas mixture is determined by the formula:

$$C = m_H / m_G , \tag{3}$$

B uncertainty of the measurement of the mass of each component of the capacitance u_B(m) is calculated using the well-known formula of the theory of uncertainty in measurements.

$$u_B(m) = \sqrt{\sum \left[\frac{\partial m}{\partial x_i} u_B(x_i) \right]^2}, \quad (4)$$

where $u_B(x_i)$ is the uncertainty of parameter measurement x_i, which are included in formulas (1) and (2).

The uncertainty in determining the concentration of hydrogen in a hydrogen-gas mixture is calculated using the formula:

$$u_B(C) = \sqrt{u_B^2(m_H) + u_B^2(m_G)}, \quad (5)$$

where $u_B(m_G)$ $u_B(m_H)$ are the type *B* uncertainty of the measurement of the mass of gas and hydrogen in the container, respectively.

When filling, type *A* uncertainty is also calculated, which is determined from the results of several fillings of the container using known algorithms.

According to the data obtained (created) operating parameters in the tank and the known component composition of the mixture, known algorithms for calibrating gas meters on a gas-hydrogen mixture are implemented. In this case, the compressibility factor of the mixture at the beginning and end of the measuring cycle is also calculated.

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ULTRA-HIGH-FREQUENCY ULTRASOUND IN THE DETERMINATION OF LEAD AND CADMIUM CONTENT IN DAIRY PRODUCTS

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Lead and cadmium belong to toxic trace elements; their content is regulated in food products, including dairy products. The content of lead in raw milk and milk intended for the production of dairy-based products must not exceed 0,020 mg/kg. In drinking milk and fermented milk products, the lead content must not exceed 0,10 mg/kg, and the cadmium content must not exceed 0,03 mg/kg [1]. Direct determination of lead and cadmium in dairy products, even with a sensitive method such as atomic absorption spectrometry, is not feasible due to significant matrix effects [2]. Therefore, mineralization is used. Dry mineralization is time-consuming, requiring 16 to 30 hours; moreover, due to losses of volatile lead and cadmium, the relative standard deviation of the obtained analytical results is not less than 0,106 [2].

We previously developed a rapid procedure for the atomic absorption determination of lead and cadmium in dairy products using wet mineralization with a mixture of nitric (1:1) and hydrochloric (1:1) acids in a ratio of 3:1, or with nitric acid (1:1) (only for milk, fermented dairy products and cream with fat content below 8%), while intensifying the process with ultrasound at a frequency of 20–46 kHz and an intensity of no less than 7 W/cm^2 for at least 2 minutes [2]. However, the reproducibility of the obtained analytical results was insufficient, with a relative standard deviation exceeding 0,096. It is due to the instability of magnetostrictive ultrasonic transducers operating at 20–46 kHz under high-intensity ultrasound (> 7 W/cm^2). The need to use different oxidizing agents for various types of dairy products also complicated the wide application of the developed procedure in the dairy industry [2]. Piezoelectric transducers used to generate high- and ultra-high-frequency ultrasound are characterized by high operational stability and high efficiency in intensifying mass-transfer processes [2].

In the present work, we investigated the possibility of using ultra-high-frequency ultrasound with frequencies from 8 to 14 MHz and intensities of 12–18 W/cm^2 to intensify wet mineralization. Optimal ultrasound parameters were established: frequency 10–12 MHz, intensity 14–17 W/cm^2, exposure time 3–4 minutes. At ultrasound frequencies of 8–14 MHz, the predominant formation of small spherical cavitation bubbles occurs in this system; the collapse of these bubbles is responsible for the intensification of the processes. The formation of the predominant number of small spherical bubbles is confirmed by the presence of an infrasonic component of 7–15 Hz in the secondary noise, as measured with hydrophones.

It was also experimentally established that the determining factor of the intensifying effect of ultra-high-frequency ultrasound on wet mineralization is cavitation involving radicals. When the sample is saturated with gases soluble in

water, cavitation becomes impossible because the dissolved gases penetrate the cavitation bubble, prevent electrical breakdown, and suppress excited states. Thus, when the sample was saturated with CO_2, the extraction degree of lead under optimal ultrasound parameters did not exceed 12%, and that of cadmium – 18%; whereas without CO_2 saturation, the extraction degree reached 97% and 98%, respectively.

Table 1 presents a comparison of the results of determining lead and cadmium in dairy products using low-frequency and ultra-high-frequency ultrasound to enhance wet mineralization. The results in Table 1 clearly show that the use of ultra-high-frequency ultrasound improves the metrological characteristics of the analytical results.

Table 1 – Comparison of Atomic Absorption Determination Results for Lead and Cadmium in Multicomponent Samples

Product name	Added pb and cd, mg/kg		Trace elements found, mg/kg Relative standard deviation Sr (n = 6, p = 0,95)			
	Pb	Cd	Pb	S_r	Cd	S_r
Determination using ultra-high-frequency ultrasound						
Pasteurized farm milk, 3,2%	0	0	0,0041	0,064	0,0016	0,052
	0,010	0,010	0,0139	0,067	0,0114	0,058
Kefir, 1% Milk	0	0	0,0075	0,063	0,0011	0,057
	0,010	0,010	0,0163	0,061	0,0109	0,059
Determination using low-frequency ultrasound [2]						
Pasteurized farm milk, 3.2%	0	0	0,0033	0,100	0,0012	0,098
	0,010	0,010	0,0118	0,107	0,0101	0,096
Kefir, 1% Milk	0	0	0,0061	0,100	0,0008	0,100
	0,010	0,010	0,0145	0,102	0,0097	0,102

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ACID EXTRACTION OF LEAD AND CADMIUM FROM FATS AND OILS USING ULTRA-HIGH-FREQUENCY ULTRASOUND

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The content of toxic elements-lead and cadmium - in fats and oils must not exceed 0,100 and 0,050 mg/kg, respectively. Due to significant matrix effects, determining lead and cadmium in fats and oils requires either mineralization or extraction-based isolation [2]. The most widely applied method is flame atomic absorption determination of lead and cadmium after acid extraction from fats and oils by boiling for 1,5–2,0 hours [2]. Under these conditions, the extraction degree of lead does not exceed 85% and that of cadmium – 87%, which adversely affects the metrological characteristics of the analytical results: the relative standard deviation Sr is 0,104 0,110 for lead and 0,097–0,105 for cadmium [2].

The use of microwave-assisted intensification for acid extraction allows the extraction degree of lead to increase to 92–93% and of cadmium to 93–95%, while reducing the total analysis time to 30 minutes. However, this approach may lead to the formation of nitroglycerin, which poses an explosion risk [2].

We previously developed a rapid flame atomic absorption method for the determination of lead and cadmium in fats and oils, which involved dissolving the sample in carbon tetrachloride and extracting lead and cadmium with nitric acid (1:2) containing 0,2% Trilon B, under the action of ultrasound at 18–44 kHz and an intensity of 1,4–1,5 W/cm^2 for 2–3 minutes. Under these conditions, the extraction degree for lead and cadmium did not exceed 92–94%. The relative standard deviation was 0,085–0,091, which is due to the instability of magnetostrictive ultrasonic transducers operating at 18–44 kHz. Piezoelectric transducers used to generate high- and ultra-high-frequency ultrasound exhibit high operational stability and high efficiency in intensifying mass-transfer processes [2].

In the present work, we investigated the possibility of using ultra-high-frequency ultrasound at 11–16 MHz and an intensity of 4–8 W/cm^2 to intensify the acid extraction of lead and cadmium from fats and oils. Optimal ultrasound parameters were established: frequency 12–15 MHz, intensity 5,0–7,0 W/cm^2, exposure time 5–7 minutes. The determining factor in the intensifying effect of ultra-high-frequency ultrasound on the acid extraction processes is the action of acoustic streaming. When the sample is saturated with gases soluble in water, cavitation becomes impossible because dissolved gases penetrate the cavitation bubble, prevent electrical breakdown, and suppress excited states; as a result, only acoustic streaming acts on the system [2].

When the sample was saturated with CO_2, the extraction degree of lead under optimal ultrasound conditions was 95% and that of cadmium – 96%, whereas without CO_2 saturation the extraction degree reached 97% and 98%, respectively. Thus, the main intensifying factor of ultra-high-frequency ultrasound in the acid extraction of lead and cadmium from fats and oils is acoustic streaming, which ensures efficient

mixing. It should also be noted that performing acid extraction under cavitation-active conditions increases the extraction degree of lead and cadmium by about 2% compared to extraction in the absence of cavitation. This may be attributed to the additional mixing efficiency provided by cavitation.

Table 1 presents the characteristics of sample preparation methods for fats and oils for the determination of lead and cadmium. The results in Table 1 show that the use of ultra-high-frequency ultrasound reduces the relative standard deviation of analytical results and increases the extraction degree of lead and cadmium.

Table 1 – Characteristics of Sample Preparation Methods for the Atomic Absorption Determination of Lead and Cadmium in Fats and Oils

Name of the indicator	Indicator result	
	Method using 18 kHz US	Method using 12 MHz US
Ratio of the organic to the aqueous phase that ensures quantitative extraction of lead and cadmium (> 90%)	2:1	6:1
Degree of extraction of lead and cadmium	92-94%	97-98%
Relative standard deviation of lead determination results	0,089 - 0,091	0,065-0,068
Relative standard deviation of cadmium determination results	0,085-0,089	0,060-0,063
Time required for the preparation of fat and oil samples for the determination of lead and cadmium	11-14 min.	15-20 min.

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DESTRUCTION OF SOLUBLE ORGANIC COMPOUNDS IN SODIUM CHLORIDE SOLUTIONS UNDER THE ACTION OF DUAL-FREQUENCY ULTRASOUND

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We previously demonstrated [1] that the destruction of soluble organic compounds in sodium chloride solutions under ultrasonic irradiation occurs due to the formation of sonochemical reactions involving radicals. In those studies, low-frequency ultrasound (18–44 kHz) at an intensity of at least 10 W/cm^2 was used. However, the application of high-power ultrasound resulted in the generation of intense secondary sound-noise (≥ 90 dB), which adversely affected laboratory personnel [2].

To reduce ultrasound intensity, simultaneous irradiation with high-frequency (1 MHz) and low-frequency (18–47 kHz) ultrasound was employed. The optimal intensities of the high- and low-frequency ultrasound depended on their relative ratio, the type of sample, and the high-frequency ultrasound value [1]. Using 1 MHz ultrasound together with 22 kHz ultrasound, the optimal intensities were 4,0 and 2,5 W/cm^2, respectively. The exposure time of the dual-frequency ultrasound had to be at least 3 min.

The degree of destruction of dissolved organic compounds of lead, copper, and cadmium in sodium chloride solutions ranged from 90% to 93%. The degree of destruction depended on the type of sodium chloride (solar, lake, rock), correlating with the content of humic and fulvic acids, which form stable complexes with analytes. For each type of sodium chloride, the optimal ultrasound parameters had to be determined experimentally [1, 3].

It is known that two types of bubbles are formed in a cavitation field: large deformed bubbles (LDB), responsible for physicochemical effects such as surface cleaning and erosion, and small spherical bubbles (SSB), whose collapse induces sonochemical reactions and sonoluminescence [1,2]. When ultrasound of two different frequencies is applied simultaneously, the total mass of SSB exceeds that of LDB. Moreover, the greater the difference between the two frequencies, the larger the total mass of SSB becomes [1–3].

The combined use of ultrahigh-frequency ultrasound (18–23 MHz) and low-frequency ultrasound (19–25 kHz) for the destruction of soluble organic compounds of lead, copper, and cadmium in sodium chloride solutions was investigated. Optimal ultrasound parameters were established as follows: high-frequency ultrasound of 17–29 MHz; low-frequency ultrasound of 20-24 kHz; and an exposure time of ≥ 7 min. Table 1 presents the results of experiments on the effect of various combinations of low-frequency and high-frequency ultrasound intensities on the degree of destruction of dissolved organic substances in different types of sodium chloride.

Table 1 – Effect of Ultrasound Intensity on the Degree of Destruction of Dissolved Organic Substances

Int. of low-freq. ultra-sound, W/cm^2	Degree of destruction of dissolved organic substances, %, at an intensity of ultrahigh-frequency ultrasound, W/cm^2																	
	1			2			3			4			5			6		
	Pb	Cu	Cd	Pb	Cu	Cd	Pb	Cu	Cd	Pb	Cu	Cd	Pb	Cu	Cd	Pb	Cu	Cd
Sodium chloride from the Heroyske Salt Plant																		
1	46	52	44	75	85	65	88	80	78	90	94	84	93	96	90	95	99	95
2	95	96	92	98	99	98	98	98	97	99	98	99	99	98	98	99	99	99
3	96	97	93	98	98	96	99	98	98	99	99	99	99	98	99	99	99	99
4	97	98	93	99	99	97	99	98	98	99	99	99	99	99	99	99	99	99
Sodium chloride from the Drohobych Salt Plant																		
1	59	67	65	73	85	65	78	89	75	84	87	84	90	93	90	93	97	95
2	95	98	97	96	98	98	98	99	98	99	99	99	99	98	98	99	99	99
3	97	98	98	97	99	99	99	99	98	99	99	99	99	98	99	99	99	99
4	98	99	98	99	99	99	99	99	98	99	99	99	99	99	99	99	99	99

Thus, we demonstrated the feasibility of using simultaneous ultrahigh-frequency and low-frequency ultrasound irradiation to destroy soluble organic compounds of lead, copper, and cadmium. To achieve the required degree of destruction, the intensities of both ultrahigh-frequency and low-frequency ultrasound may be varied accordingly.

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ASPECTS OF ROLL FORMING TECHNOLOGY IN THE CONTEXT OF NON-DESTRUCTIVE TESTING OF PROFILING EQUIPMENT AND TOOLING

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Non-destructive testing (NDT) is an integral part of quality assurance at all stages of production. NDT methods and technologies allow checking the integrity, compliance of geometric parameters and structural condition of materials, tools and equipment without damage, which is key for quality control after turning, heat treatment, final processing operations. The introduction of NDT is necessary to prevent defects such as cracks, discontinuities, deviations in the thickness of coatings and incorrect hardness, ensuring the durability and reliability of the tool used in the subsequent process of forming bent profiles. NDT is usually implemented on the basis of distributed information and measuring systems (DIMS) or complexes (DIMC), which provide the possibility of automation and computerization of NDT [1-3].

When manufacturing roll-formed shapes, special attention is paid to the compliance of the caliber dimensions with the drawing and the quality of the surface of the rolls [2]. Most often, the surface roughness is brought to 0.4 μm by polishing. In some cases, in serial production, special anti-friction and wear-resistant coatings (titanium nitride, chromium, etc.) can be applied to the rollers. The main forming shafts are manufactured in the following sequence: 1) cutting of rolled stock or forgings into blanks (mechanical hacksaw, Heller saw); 2) turning of the cut blanks to the overall size of the roller, drilling a hole for the shaft (universal lathe type 16K20); 3) rough turning along the working contour with an allowance of 0.5 mm for linear dimensions and 1 mm for diametrical dimensions; hard-to-reach places are processed without allowances to the finishing size (universal lathe type 16K20); 4) drilling, gouging and other metalworking operations; 5) heat treatment (58..62 HRC); 6) grinding of the landing hole for the shaft and roller ends (internal grinding machine).

To conduct research and manufacture a number of profiles, a six-stand profile bending unit with a working shaft length of 350 mm is used.

The choice of a profiling and bending unit for manufacturing a profile of a given standard size is determined by: the cross-sectional size of the shape; the number of transitions; the required power for forming the profile.

To ensure the compliance of dimensions and exact shape, coordinate measuring devices, optical profilographs, eddy current, acoustic or electromagnetic-acoustic thickness gauges are used [4, 5]. Achieving roughness up to 0.4 μm is controlled by contact or non-contact profilometers. Thermal quality control is confirmed by hardness testers and magnetic powder testing to detect surface cracks, or electromagnetic-acoustic hardness testers [5]. The presence of internal defects in forgings and finished rolls is checked using ultrasonic testing. If special coatings are used, their thickness is estimated by eddy current thickness gauges.

Additional devices and equipment are used to prevent defects such as edge waviness, deviations in profile geometry; at the same time, they bend the profile elements, which allows to reduce the number of main transitions (cage). Auxiliary

equipment (straightening, cutting, cutting, as well as roll forming machines, stackers, etc.) for profiling, acceptance tests of profile bending units and adjustment of units in current production are described in detail in the work [2, 3].

Caliber refinement is carried out in case of profile defects during the development of the technology. Here we will list only those types of refinements that were most often encountered in the process of performing the work. Caliber refinements include the introduction of additional angles, the release of adjacent zones.

NDT methods as well as measuring DIMC are used to assess the condition of equipment, equipment, tools, etc. To detect internal defects of the strip metal and the finished profile, such as delamination or voids, ultrasonic inspection is used, in particular, the echo method or the penetration method, or the non-contact EMA method to reduce wear of NDT equipment (sensors, protectors, etc.). Checking the profile geometry and for shape deviations or edge waviness is carried out by optical, laser methods, as well as using the eddy current method. To control the condition of the main parts of the mill (rolls, frame, transmission elements), either visual, capillary control methods are used in idle mode, or ultrasonic control methods associated with the excitation of a near-surface wave (EMA testing based on Rayleigh waves) [1, 5].

Conclusions. As a result of the analysis, an algorithm was created for selecting the most appropriate solutions for using methods for creating profiling processes and their NC. NC is important for ensuring the quality, reliability and durability of the forming tool at all stages of production.

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UNCERTAINTIES IN CHEMICAL ANALYSIS OF FILM COMPOSITION IN A FILM TEMPERATURE SENSOR

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Many important practical decisions are based on the results of quantitative chemical analysis. In all cases where decisions are made based on analytical results, it is important to have some evidence of the quality of these results, i.e., the extent to which they can be relied upon to achieve a specific goal. It is important to distinguish between uncertainty and error.

The uncertainty estimation process requires the analyst to carefully consider all possible sources of uncertainty. A reasonably good uncertainty estimate can be obtained by focusing on the main components.

This paper examines possible sources of uncertainty in the chemical analysis of the composition of the deposited film in a film temperature sensor.

The assessment and expression of uncertainty in quantitative chemical analysis is most rationally based on the approach adopted in the literature [1].

When identifying the main components of uncertainty, it is usually necessary to compile a list of the uncertainty sources inherent in the analysis methodology. It is useful to structure this process to ensure comprehensive coverage of all uncertainty sources while avoiding redundancy.

This goal is achieved in two stages:

1) Identifying influencing factors. In practice, the necessary structural analysis is carried out using a cause-and-effect diagram (known as an Ishikawa diagram, or "Christmas tree" diagram) [2].

2) Simplifying the diagram and eliminating duplication. The initial list of sources is refined to simplify the picture and avoid unnecessary duplication.

The principles of constructing a cause-and-effect diagram are as follows:

- write down the complete equation for the measurement result; the parameters of this equation form the main branches of the diagram;
- consider each stage of the analysis methodology and add to the diagram all factors that may occur in addition to the main effects;
- add contributing factors for each branch;
- eliminate duplication and rearrange the diagram to simplify the picture and integrate related sources.

analytical methods and instruments often employ calibration obtained by recording the responses y at different analyte concentrations x.

In most cases, a linear functional relationship is adopted

$$y = b_0 + b_1 x.$$

This calibration function is then used to calculate the concentration x_{pred} of the analyte in the sample corresponding to the observed response y_{obs} using the expression

$$x_{pred} = (y_{\text{obs}} - b_0)/b_1.$$

Typically, the constants b_1 and b_0 are found using weighted or unweighted least squares based on n pairs of values (x_i, y_i).

Not all uncertainty components will make a significant contribution to the overall uncertainty. In practice, only a small number of components are significant.

There are four main sources of uncertainty that should be considered when determining the uncertainty of the concentration x_{pred}:

- random fluctuations in the measurement y, which affect both the calibration responses y_i and the measured response y_{obs};
- random effects, which result in errors in the assigned initial values x_i;
- the values of xi and y_i may be affected by a constant unknown bias, for example, when concentration values x are obtained by successive dilutions of a stock solution;
- the assumption of linearity may not correspond to reality.

Of these sources, random fluctuations of the variable are the most significant in practice. Methods for estimating uncertainty due to this source are described in detail in the literature. Let's briefly consider the remaining sources of uncertainty and their corresponding estimation methods.

The uncertainty $u(x_{pred}, y)$ of the predicted value x_{pred} due to the variability of y can be estimated in several ways:

- using the calculated variance and covariance;
- using calibration data;
- using information generated by computer programs.

In the first case, if the values b_1 and b_0, their variances var(b_1), var(b_0), and the covariance covar(b_1,b_0) are calculated using the least squares method, then the variance x, var(x), obtained by differentiating the normal equations, and the corresponding uncertainty $u(x_{pred}, y)$ are equal to $\sqrt{\text{var}(x_{pred})}$.

In the second case, the formula for var(x_{pred}) can be written for a set of n pairs of points (x_i, y_i) used to establish the calibration curve.

For the third case, many programs provide a value of S, expressed, for example, as the relative standard deviation (RSD) or residual standard deviation. Some programs also provide the standard deviation $s(y_c)$ of the value of y calculated using the calibration function for some new value of x, and this can be used to calculate var(x_{pred}).

The values of x_i may have their own uncertainties, which affect the final result. In practice, these uncertainties are usually small compared to the uncertainties of the responses y_i and can be neglected.

The uncertainty associated with possible nonlinearity in the dependence of y on x is usually small and does not require estimation.

The approaches discussed are suitable for the most common case of linear least-squares regression. However, they are not applicable to more general problems that take into account uncertainties in x values or correlations in x and/or y.

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ANALYSIS OF FACTORS INFLUENCING UNCERTAINTY IN THE CONTACT ANGLE CONTROL BY THE SESSILE DROP METHOD

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The sessile drop method is a fundamental tool in surface physics and materials science, used to quantitatively assess the interaction between a liquid and a solid surface. The sessile drop method allows the measurement of the contact angle and surface tension, which is key to understanding the properties of materials and technological processes. For a sessile drop under the action of gravity, Δp changes with height (z) relative to the reference level (e.g., a flat liquid surface) [1]:

$$\Delta p(z) = \Delta p_0 + \rho g z\,, \tag{1}$$

where Δp_0 is the pressure difference at $z = 0$.

The Young-Laplace equation [1] is fundamental in determining the equilibrium shape of a drop, linking the pressure field (which is affected by gravity) to the geometry of the interface (curvature). This equation can be rewritten as a system of ordinary first-order differential equations for $r(s)$, $z(s)$, $\varphi(s)$:

$$\frac{d\varphi}{ds} = 2b + \frac{\Delta\rho g z}{\gamma} - \frac{\sin\varphi}{x};\ \ \frac{dx}{ds} = \cos\varphi;\ \ \frac{dz}{ds} = \sin\varphi\,. \tag{2}$$

The study of surface and interphase properties consists in obtaining an experimental image of a sessile drop, further comparing the points of the experimental contour with a model. One of the main sources of uncertainty is the quadratic deviation of the points of the experimental points from the theoretical ones. The uncertainty of the obtained experimental contour is influenced by such factors as: the resolution of the digital camera, the clarity of the obtained image, the coefficient of conversion of coordinates into a dimensional format, etc. To obtain an adequate simulated contour, it is necessary to enter the exact values of the initial conditions of integration, namely (2) b is curvature at the apex, $\Delta\rho$ is difference in density between liquid and gaseous, g is acceleration due to gravity, γ is surface tension of the liquid. All initial conditions can be taken from published sources, but the curvature at the top of the drop must be determined from the obtained experimental contour, which is a difficult task. In [2], it is proposed to determine the approximate value of this parameter depending on the volume. As further research, it is proposed to record the volume of the drop (which can be determined before the experiment with an accuracy of 0,01-0,02 ml) and establish the dependence of the parameter b on the contact angle.

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ESTEMPMM PACKAGE FOR ESTIMATING PARAMETERS OF TIME SERIES AND REGRESSION MODELS WITH ASYMMETRIC NON-GAUSSIAN ERRORS

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Accurate estimation of model parameters under non-Gaussian error distributions remains a fundamental challenge in statistical analysis and the assessment of measurement uncertainty. Classical least squares and maximum likelihood methods are optimal under the Gaussian assumption but lose efficiency when error distributions exhibit skewness or heavy tails. Such conditions frequently arise in financial time series, hydrological measurements, industrial process monitoring, and many other applied domains.

The Polynomial Maximization Method (PMM) [1] explicitly leverages information contained in higher-order moments of the error distribution, in particular skewness, which classical methods inherently ignore. Even the quadratic, second-order variant attains substantially lower variance of parameter estimates than classical approaches when innovations are non-Gaussian and asymmetric. The theoretical variance-reduction factor is expressed through the square of the skewness and the kurtosis of the error distribution, demonstrating a direct link between efficiency gains and asymmetry.

Despite the theoretical advantages established in prior studies, practical adoption has been limited by the lack of accessible and reliable software implementations. This work presents a comprehensive package for the R statistical environment, providing the first implementation of the second-degree PMM for both regression models and time-series analysis. The package was released on the CRAN repository in November 2025 under the name EstemPMM [2].

The package implements a three-step adaptive procedure that removes the need for a priori knowledge of the error distribution. First, preliminary estimates are obtained using classical methods; second, empirical moments up to the fourth order are computed from residuals; third, refined estimation is performed using the inferred moments. This adaptive strategy makes the method practically applicable without distributional assumptions.

For linear regression, the package provides PMM-based estimation with an interface aligned with standard R regression functions. Tools for direct comparison with ordinary least squares are included to quantify efficiency gains.

Another application area is time-series analysis. Full support is provided for the Box–Jenkins family, including autoregressive (AR), moving-average (MA), autoregressive moving-average (ARMA), and integrated variants (ARIMA). All functions share a unified interface with a method switch that allows users to choose between PMM and the classical Conditional Sum of Squares (CSS) approach. This flexibility enables head-to-head comparisons within a single functional framework. Forecasting is available via R's standard mechanisms.

An important component of the package is inference. For linear models, bootstrap procedures are implemented to construct confidence intervals. For time series, a methodologically sound block bootstrap that preserves serial dependence is provided. This is critical because naively applying the ordinary bootstrap to time-series data breaks the autocorrelation structure. Facilities for visualizing bootstrap distributions of parameter estimates are included.

The package also includes a comprehensive suite for validation and method comparison. Functionality is provided for Monte Carlo simulations to enable thorough, simulation-based benchmarking. Comparison utilities are available for all model classes supported by the package.

The package architecture relies on base R components, ensuring stability, minimal external dependencies, and straightforward integration into existing analytical workflows.

Monte Carlo studies show substantial accuracy improvements under asymmetric innovations. For linear regression with moderately skewed data-typical of measurement errors with systematic bias – the polynomial maximization approach reduces standard errors of parameter estimates by 15–30% relative to classical methods. For time-series models, simulations for ARMA processes with sample size $n = 200$ and pronounced innovation asymmetry show mean-squared-error improvements of 25–35% for AR parameters and 12–20% for MA parameters compared with classical estimators. Information criteria consistently favor models estimated via PMM.

The proposed approach is particularly effective for asset-return series with asymmetric volatility, hydrological series exhibiting natural asymmetry, industrial process measurements with systematic asymmetric errors, and macroeconomic indicators with business-cycle asymmetry. Its key advantages include the explicit use of distributional asymmetry as an additional source of information, automatic adaptation to empirical data characteristics without specifying the distribution, robust bootstrap-based uncertainty quantification, and an open-source implementation available for R via CRAN.

The current roadmap includes a third-order variant PMM optimized for non-Gaussian symmetric distributions, the development of method-specific information criteria, and extensions to generalized linear and seasonal models.

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ATOMIC ABSORPTION DETERMINATION OF ANALYTES IN PHARMACEUTICAL SUBSTANCES

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An important analytical task is the determination of metals in environmental samples, food products, and pharmaceuticals at the level of their maximum allowable concentrations. Analytes and their compounds can both positively influence the human body and cause harm, as they possess the property of accumulating in tissues and causing a range of diseases.

The presence of excess metals in pharmaceutical drugs is not merely a pharmacological error but a major threat to human health and life. Therefore, controlling their content in accordance with National Standards of Ukraine requirements is mandatory [1]. Monitoring the content of trace amounts of analytes in pharmaceutical substances is a crucial task for ensuring the quality and safety of medicines.

This work investigates the influence of the non-ionic surfactant Triton X-100 on the analytical signal value during the atomic absorption determination of iron, lead, and magnesium in pharmaceutical substances. The sensitivity and precision of the analyte determination were increased by using Triton X-100 solutions (w = 4%), calibration solutions based on metal acetylacetonates, and ultrasound-assisted treatment of analyzed samples for 20 minutes. The sensitivity of the atomic absorption determination increased by a factor of 1,50 for iron, 1,40 for lead, and 1,70 for magnesium.

The content of analytes in multicomponent samples was determined by atomic absorption spectrometry. The accuracy of the analysis results was verified by varying the sample mass and using the recovery test ("added-found" method). It was established that the systematic error of analyte determination is insignificant.

The limit of detection (C_{min}) was determined by the atomic absorption method for iron (C_{min} = 0,010 μg/mL; C_{lit} = 0,015 μg/mL), lead (C_{min} = 0,01 μg/mL; $C_{lit.}$ = 0,05 μg/mL), magnesium (C_{min} = 0,011μg/mL; $C_{lit.}$ = 0,015 μg/mL).

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CONTENT

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