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Content

METEOROLOGICAL VISIBILITY RANGE, PROBLEMS OF MEASUREMENT ACCURACY

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The concept of visibility in meteorology is often used in two different ways. Firstly, it is one of the elements that determine the properties of air masses, reflecting the optical state of the atmosphere and widely used in synoptic meteorology and climatology. Second, it is an operational variable that meets certain criteria or a specific use case. For this purpose, it is directly expressed in terms of the distance at which certain markers or lights can be seen.

Meteorological visual range (MVR) is a conventional expression of atmospheric transparency and corresponds to the maximum distance at which black objects with sufficiently large angular dimensions (more than 15°) are projected on the northern side of the sky near the horizon. The angular size of the object must be greater than 15` to maintain a constant threshold of contrast sensitivity of the eye. Moreover, if the atmospheric haze is uniform, the visibility of an absolute black body does not change with azimuth and is the same in all directions. In this case, the MDV depends only on the opacity of the atmosphere.

To calculate the MDV it is necessary to calculate meteorological optical visibility range (MOV), defined as the path length in the atmosphere at which the luminous flux of an incandescent lamp is attenuated to 0.05 (threshold contrast sensitivity of the eye) from the original value at a daytime temperature of 2700K. Luminous flux is determined using the estimated photometric luminance function defined by the International Commission on Illumination (meter, m or kilometer, km).

Measurements are made by two methods: extinction measurement (transmissometer) and scattering measurement (nephelometer).

The main sources of error when measuring with a transmissometer are:

- mismatch between transmitter and receiver;
- insufficient rigidity and stability of the transmitter/receiver mounts (freezing and thawing of the soil, thermal shock);
- aging and inappropriate radiation sources;
- calibration errors (poor visibility or calibration in unstable conditions affecting the extinction coefficient);
- transmission of the attenuation coefficient over long distances in the form of a low-current signal, subject to interference from electromagnetic fields (especially at airports); it is preferable to convert the signals into digital form;
- obstructions caused by sunrise or sunset and poor initial setup of transmissometers;
- air pollution, which leads to contamination of optical systems;
- local atmospheric conditions (precipitation and strong winds, snow, etc.) leading to unrepresentative attenuation coefficient measurements or deviations from

Koschmider's law (snow, ice crystals, rain, sand, etc.).

The main sources of error in MOR measurements using scattering instruments are:

o Calibration errors (visibility is too poor or calibration is performed in unstable conditions affecting the extinction coefficient);

o Inability to repeat the process or lack of materials when using opaque diffusers for calibration;

o Transmits loss factor over long distances as a low current or low voltage signal susceptible to interference from electromagnetic fields;

o Interference from sunrise or sunset and poor initial alignment of the instrument;

o Air pollution leading to contamination of optical systems (the optical elements of these devices are less sensitive to contamination compared to transmissometers, but are still subject to severe contamination);

o atmospheric conditions (rain, snow, ice crystals, sand, local pollution, etc.) causing the loss coefficient to deviate from the attenuation coefficient.

The results of the first comparisons of visibility measurements carried out by WMO (WMO, 1990) show that at low MOR values, scatter meters tend to be less accurate than transmissometers and have greater variability in their readings. It has also been shown that dispersion meters as a class are more sensitive to the effects of precipitation than transmissometers.

Taking into account the above, for a sufficiently accurate measurement of MDV it is necessary to make measurements that are not will be exposed to non-meteorological conditions, on carefully prepared equipment, under constant measurement conditions, difficult to meet conditions, and leads to low accuracy of this type of measurement and inconsistency of measurement results by different instruments under the same conditions and time of measurement.

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NETWORK DIAGRAM OF COMPARISONS

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As is known, the CIPM MRA is used to establish degrees of equivalence and mutual recognition of national measurement standards and calibration and measurement certificates issued by national metrology institutes (NMIs). According to the MRA, the

technical basis for establishing equivalence is a set of results obtained from key comparisons carried out by the Advisory Committees of the CIPM, BIPM and Regional Metrology Organizations (RMOs). Results are published by BIPM upon approval and stored in the CIPM MRA Database (KCDB). Along with key comparisons, the results of successful participation of NMIs in relevant additional comparisons are also used as an objective basis for mutual recognition.

After the signing of the MRA, the number of international comparisons of different levels (CIPM and RMO) and different statuses (key, additional) increased significantly; in fact, a network of comparisons emerged, uniting the standards of different NMIs. This approach to key comparisons involving one or more downward comparisons involving many participants is very resource intensive and requires the determination of a key comparison reference value (KCRV) (weighted mean, median, etc.). The results cannot be used until all participants have completed their measurements, which often takes years.

One solution to improve efficiency and responsiveness may be a concept in which the central element is not the KCRV, but the even degrees of equivalence of all participants based on a network of two-way comparisons. In key comparisons, participant data is analyzed to produce the results required by the MRA. Current MRA practice was designed to minimize the number of comparisons by establishing a hierarchical structure in which a global comparison initiated by the CC is used to establish a reference value. RMOs will organize comparisons over time to offer reference to a reference value to those NMIs that need it. This design was originally designed to avoid the many small or two-way comparisons that, at the time the MRA was developed, placed a significant burden on several large NMIs.

There are a number of problems with the current approach. Firstly, the coordinating laboratory is subject to high demands. Second, the results cannot be used until all participants complete all measures. As the number of MRA members has increased substantially, in many CIPMs and regional comparisons with a small number of circulating standards, this process can take years, making it impossible to respond quickly to urgent requirements. The SARS-Cov-2 pandemic required initial standards for several months; a five-year term would be too late to be useful. Long lead times for the availability of primary standards delay the use of new measurement technologies, which negatively impacts commercial efficiency and compliance with regulations. Long-term comparisons are negatively affected by changes in personnel or replacement of equipment. The goal is to reduce the resources (labor, materials and equipment) required for comparisons and the time from the start of comparisons to the availability of results for CMC support—the time to market for comparison results. Effective approaches are needed with a more balanced workload between participants and results that can be quickly published.

One solution could be a network scheme of key comparisons. In contrast to multiple top-down comparisons with a large number of participants, the design will involve many two-way comparisons, each with a small number of participants. Linkages will be direct comparisons between pairs of laboratories. The network will be expanded by adding links as laboratories decide to conduct new bilateral comparisons, and once enough links have

been established, comparisons can be made between two laboratories in the network.

The proposed new key comparison scheme may have an impact in cases where it is difficult to obtain a reliable KCRV. The resources required for the key comparison will be reduced in terms of time, labor costs, materials and equipment. The workload will be evenly balanced between participants in key comparisons. Get results quickly to support the rapid development of new measurement technologies and support pressing needs.

The main result of key comparisons is the one-way degree of equivalence (DoE) of participants for KCRV, the calculations of which are not defined by the MRA. Calculation methods depend on the assumptions made and may involve increasing the uncertainties reported by participants to satisfy consistency requirements. For the same data, CCs are likely to provide different KCRVs and unilateral valuation reports. This lack of harmonization is contrary to the key objectives of the MRA – to establish criteria for mutual recognition on an objective basis.

Conversely, two-sided DoEs for a stable travel standard are expressed due to reported laboratory uncertainties regardless of the KCRV. There are good reasons to make bilateral DoEs the primary focus of the analysis of key comparative data. Network design could be an effective way to organize multiple bilateral comparisons.

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NEW ADVANCES IN REAL-TIME DIAGNOSTICS OF ASYNCHRONOUS ELECTRIC MACHINES

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A dynamic control model has been developed for remotely managing rotating electrical machines connected to open-loop drives for real-time process monitoring. Serving as a digital instructional tool, the model is intended for monitoring, optimizing, and enhancing production processes. This physical model of an industrial device is equipped with precision sensors and web-based software packages. Using this created model allows to simulate and detect faults, as well as tracking equipment condition in real-time [1].

Precision measuring instruments are connected with the developed engineering

software for early prediction of machinery component faults and their troubleshooting. Equipment condition monitoring in real-time with recording of extensive data arrays was done.

Data analysis obtained from the Power Logger Fluke 1736 and Multimeter Keysight to solve the problems arising from machine supply through electronic converters was made. By comparing input and output electrical signals of the Vacon NX frequency converter, the extent of reducing the likelihood of detecting faults in machine components due to higher harmonics present in the signals from the frequency converter can be assessed.

Monitoring was realized using the developed program, and MATLAB software for visualization of collect data was used.

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MODULAR APPROACH IN CONFORMITY ASSESSMENT GAS ENERGY MEASURING SYSTEMS

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In accordance with the adopted Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Introduction of Accounting and Calculations of Gas Volume in Energy Units on the Natural Gas Market" [1], natural gas accounting must be carried out in energy units (kW, MJ or kcal).

Automated natural gas energy control and accounting systems (gas measuring systems) for commissioning and commercial energy accounting must pass conformity assessment in accordance with the requirements of the Technical Regulation of legally regulated measuring equipment [2].

Construction of gas measuring systems is carried out in accordance with DSTU EN ISO 15112 [3]. The standard provides for the following energy determination methods:

– a natural gas energy measuring station, which uses gas volume measuring devices and flow devices for determining the heat of combustion in a complex;

– measuring stations, which provide only for the determination of the volume of gas and the selection of representative samples of natural gas with the calculation of the heat of combustion in the laboratory;

– distributed measuring stations that measure gas volume and heat of combustion by flow means, a representative value of the heat of combustion can be determined for

several gas volume measuring stations.

Metrological characteristics of automated natural gas energy control and accounting systems are standardized in DSTU OIML R 140 [4] and DSTU EN 1776 [5]. These standards are specified in the list of the evidence base of normative documents of the Technical Regulation [2].

In accordance with DSTU OIML R 140 [4], three accuracy classes of measuring systems (A, B, C) are established, the characteristics of which are shown in Table 1.

Table 1 – Maximum permissible errors (uncertainty) for measuring systems according to DSTU OIML R 140

The maximum permissible error (uncertainty) of the determination:	Class accuracy A	Class accuracy B	Class accuracy C
Gas energy	± 1,0 %	± 2,0 %	± 3,0 %
Gas volume	± 0,9 %	± 1,5 %	± 2,0 %

However, according to DSTU EN 1776 [5], the following four classes of accuracy (with the value of extended uncertainty) are standardized for natural gas energy metering systems:

1. Class A gas measuring system - uncertainty does not exceed 1,2%;
2. Class B gas measuring system – uncertainty greater than 1,2% but not exceeding 2,5%;
3. Class C gas measuring system – uncertainty greater than 2.5% but not exceeding 3.5%;
4. Class D gas measuring system – uncertainty greater than 3.5% but not exceeding 8.0%.

The conformity assessment procedure an automated system according to DSTU OIML R 140 is intended to be carried out using one of two modular approaches or a holistic approach. The first modular approach involves testing separately each measuring device connected to the measuring system according to the readings of the conversion device (energy calculator). The second modular approach involves similar tests, but the results are obtained directly from the measuring device. Accordingly, the application of a holistic approach involves testing the natural gas energy measurement system as a single whole object.

Depending on the configuration of sensors in the gas measuring system (availability visual display of readings, unified data transmission signal, availability of secondary converters, etc.), either the first modular approach, or the second modular approach, or the simultaneous application of both modular approaches can be used.

The device for determining the heat of combustion of gas (flow chromatograph) is tested using calibration gas mixtures, the list of which is regulated by DSTU OIML R 140.

The final stage testing for conformity assessment is the preliminary start-up of the automated gas energy control and accounting system as a whole with the aim of conducting tests on the correct functioning of all constituent elements and the correctness of the calculation of natural gas energy.

After analyzing the accuracy classes given in DSTU EN 1776 and DSTU OIML R 140, we can come to the conclusion that it is more appropriate to use DSTU EN 1776 (classes A, B, C, D) taking into account the volume flow range of the gas meter.

According to the results the conducted conformity assessment tests, the automated system of control and accounting of natural gas energy is assigned the value of the maximum permissible error (uncertainty), which must correspond to one of the above accuracy classes.

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STATISTICAL APPROACHES FOR THE ANALYSIS OF KEY COMPARISONS WITH TWO TRANSFER STANDARDS IN TWO PETALS

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Managing measurement quality plays an important role in measurement science. The issue of measurement quality is often addressed in key comparisons, where one of the main challenges is to identify instances of underestimation of the reported uncertainty. That is, cases where the measured values are significantly more dispersed than the associated, reported uncertainties suggest that they should be. The challenge becomes even harder when not all participants measure the same artifact, and several measurement

standards are circulated among participants in separate petals.

In this presentation we describe and compare different statistical methods to analyze data from a key comparison when two transfer standards are measured in two petals. These statistical approaches may be very helpful in linking CIPM and RMO comparisons. First, we describe an intuitive, heuristic approach, which serves as introduction and motivation for a better understanding of the approaches that employ either weighted least squares or a Bayesian random effects model that links the petals by assuming a common effect for each laboratory that measures both artifacts. The ultimate goal is to infer the degrees of equivalence that the participants would achieve if all had measured the same artifact as in a conventional key comparison without different petals. In the Bayesian framework, the degrees of equivalence comprise posterior means and credible intervals derived from the posterior distributions of the random effects.

The different methods are illustrated using measurement results from key comparison CCM.M-K7, where two different mass standards of the same 5 kg nominal mass circulated in two petals (A and B), with a single participant (KRISS) in common.

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MEASUREMENT UNCERTAINTY EVALUATION AT TEMPERATURE RISE TEST OF POWER TRANSFORMERS

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The Temperature Rise Test of power transformers is a key element of the power transformers acceptance procedure. The test methodology of the temperature rise test of liquid-immersed power transformers bases on the БДС EN 60076-2:2011 standard [1]. In practice, the specific approaches in the frame of the standardized methodology depends on the parameters of the transformers and the specifics of the production site. The paper bases on the specifics of the temperature rise test of HV liquid-immersed

transformers with rated power over 2.5 MVA. A brief description of the methodology follows:

During the temperature rise test, the transformer must be equipped with its protective devices. In case the transformer has more than one declared rated power, the test is carried out for each one of them (i.e. for each cooling mode).

Three or more sensors located around the transformer are used to determine the ambient temperature and, from there, the overheating of the transformer. Temperature sensors also are placed on the transformer itself – one on the cover of the transformer, two sensors on each cooling battery (pocket) – one measuring the temperature of the outgoing oil and one - on the incoming.

The test is carried out with the transformer connected according to the scheme for measuring losses in short-circuit mode. The total losses, consisting of no-load losses and short-circuit losses, are given for the tap with the highest measured losses.

The temperatures of the upper layer of oil and the cooling medium are observed and recorded, continuing until the so-called steady state is reached. The first part of the test may be terminated when the rate of change of temperature of the upper layer of oil falls below 1 K/h and remains so for a period of 3 h. If discrete readings are taken at regular intervals, the average of the readings during the last hour shall be taken as the test result. After the temperature rise of the upper layer of oil is detected, the test continues without interruption, with the test current reduced to the nominal one. This condition was maintained for 1 h.

A multichannel temperature measurement system controls the test. The power on the primary and secondary sides of the transformer is measured directly via the current and voltage of each winding by power analysers equipped with respective current and voltage transformers for the necessary rate transfer.

The specifics of the methodology of temperature rise test reflects on the way of the determination of uncertainties [2] related to the test method and instrumentation used. Uncertainties evaluation also has specifics presented in the paper. The estimation of the uncertainties presents in the test report according [2].

This report examines the measurement uncertainty evaluation at temperature rise test of power transformers in accordance with [3].

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CALIBRATION OF DIGITAL HYGROMETER

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The main activities of the NPP laboratory of temperature measurements are: ensuring traceability of measurements in the Kozloduy NPP by calibration to SI units and performance of metrological control of measuring instruments.

Laboratories at NPP require precise control of atmospheric conditions, relative humidity being one of the most essential to keep labs running efficiently and properly. The need to calibrate a large number of hygrometers used for environmental monitoring in an industrial plant such as Kozloduy NPP requires developing the procedure of calibration, according to ISO/IEC 17025 [1]. Calibration is essential to ensure safe and reliable operation of the plant.

This paper reports the process of Digital Hygrometers calibration. A procedure for calibrating digital hygrometers has been developed in the "Temperature measurements" laboratory. Relatively humidity is strongly proportional to temperature and highly sensitive to temperature changes. This means that if you have a stable temperature in your system, your relatively humidity will also be stable. The calibration is in the in the range of 10 %rh до 95 %rh at 25 °C. The Hygrometers has been calibrated against the Standard Digital Hygrometer, which metrological traceability to the international system of units SI. The process of obtain the reading of standard hygrometer is automated. Mathematical models for the reference and the measured relative humidity have been developed. The input quantities are defined. Paper also describes the details of estimation and expression of expanded uncertainty of measurement. The processing of measurement results and the expression of uncertainty are carried out in accordance with Guide to the expression of uncertainty in measurement (GUM) [2].

The laboratory has been participated in a proficiency testing scheme by inter-laboratory comparison BIM-T-RH-2023-01 [3]. The aim of the comparison was to evaluate the performance of laboratories and to confirm their competence in the field of relative humidity measurements.

The results are presented and analyzed. The task of this comparison was the calibration of digital hygrometer. The points of the measurements were agreed to be 30 %rh, 50 %rh and 70 %rh. Four laboratories took part in the comparison. The Bulgarian Institute of Metrology was reference laboratory and their results were used to determine participants performance. The reported results and associated uncertainties were used for the calculation of criteria E_{n}. The comparison is organized and conducted according to BDS EN ISO/IEC 17043/2023 [4].

The results were published in a final report dated 07 November 2023. The differences between the results of the participating laboratories were presented

graphically in groups in comparison to the reference laboratory X_{LAB}-X_{REF} for each measurement point together with associated expanded uncertainty.

The results are significant parameter for laboratory for assuring the quality of calibration results perform by it.

The results of NPP lab are acceptable, $|E_n| < 1{,}0$ for all points of calibration. Generally, the desire outcome is for the $|E_n|$ value to be as close to zero as possible.

The participation of NPP Temperature Measurements Laboratory in the BIM-T-RH-2023 shows that [5]:

The laboratory demonstrates that it is technically competent and can produce technically valid results in calibration it performs for its clients. The laboratory met the general requirements defined in ISO/IEC 17025 and confirmed the efficiency of the procedures, instructions and other technical documentation needed to ensure the results of the digital hygrometer calibration.

The laboratory improved its calibration and measurement capabilities (CMC) [6], which were claimed ant to reduce its CMC.

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FEATURES OF ASSESSING THE CONFORMITY OF MEASURING INSTRUMENTS BASED ON CALIBRATION RESULTS ON THE TERRITORY OF UZBEKISTAN

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Nowadays, one of the most pressing challenges facing our industry is to accelerate the production od cheap, exportable and competititve products. One of the recognized mechanisms for accelerating and achieving product recognition in the global market is

memebership in the World Trade Organization (WTO) and addressing issues related to the elimination of technical barriers therein. In this regard, in order to prevent repeated testing of products in the export process, to ensure reliable resultsin one-off testing, the activities of testing laboratories complying with the standard ISO/IEC 17025:2017 «General requirements for the competence of testing and calibration laboratories» (Uzbekistan uses its own standard O'z DSt ISO/IEC 17025:2019, which is called «IDT») will need to be established in accordance with global requirements. Today, in order to increase the number of such testing laboratories and to conduct tests in accordance with international requirements, Uzbekistan uses the mechanism of their accreditation. Signing an agreement on mutual recognition of the international organization «ILAC» («ILAC MRA») in the field of accreditation of laboratories is an urgent task facing the conformity assessment system of Uzbekistan.

In an age based on market relations and where human values and benefits are a priority, the main challenge is to ensure international metrological traceability of measurements in order to facilitate the inter-comparison and recognition of measurements made in any country.

With the adoption in Uzbekistan of the new edition of the international standard (ISO/IEC 17025:2017), which includes requirements for the competence of testing and calibration laboratories, ensuring metrological traceability of measurement results in accredited laboratories has become one of the main and mandatory requirements.

However, assessment of conformity taking into account the concepts of «uncertainty», «base value» and «correction factor» is not applied in the methods of comparison (verification), methodology (methodology) of measurements, test methods, system of ensuring the state unit of measurement and other standards in force in Uzbekistan, based on the generally accepted and now significantly outdated concepts of «error» and «error characteristic». In addition, the level of risk («risk») of suitability or non-suitability («compliance» or «non-compliance») specifically mentioned in «ISO/IEC Guide 98-4:2012» [1] and «OIML G19:2017» [2] are not considered in the decisions made in relation to compliance.

To ensure compliance with the international requirement, it is advisable to understand and apply the meaning of the terms contained therein on the basis of internationally recognized dictionaries. In this case it is necessary to refer to the international metrological dictionary «ISO/IEC Guide 99:2007 - VIM3», which is referenced in «O'z DSt ISO/IEC 17025:2019». For these terms to be understood exactly as they are, national laws and regulations must be recognized as having international meaning. In what order are the terms actually applied? How seriously is this issue being addressed? To find a solution to such questions, let us understand the differences between national legislation and regulations by briefly analyzing some important terms in the International Metrology Dictionary.

In modern metrology metrological observability cannot be imagined without measurement uncertainty. In the calibration of measuring instruments, the relationship

between the standard and the instrument being calibrated is understood by expressing the uncertainty of measurement.

So, in what order are such terms used in the system of conformity assessment of national metrology of Uzbekistan? By essence or differently? Let's try to find solutions to such questions one by one.

The laboratory does not always have the possibility to calibrate the required measurement points when calibrating «Equipment». In the orders for verification of measuring instruments, among the orders of the calibration office for a sufficient and necessary number of measuring points, it is desirable to specify the function of values of deviation of measuring points from the reference value and uncertainty of measurements for «Equipment».

It should be noted separately that it is not advisable to limit ourselves to checking whether the «Equipment» conforms to the characteristics specified in its operating documents. Considering that the main purpose of testing is to ensure the reliability of measurement results (Ensuring the validity of results), it is advisable to prioritize the fulfillment of «Equipment» accuracy requirements in the test methods to obtain reliable results.

Conclusions:

- Since clause 5.4 of the international standard «ISO/IEC 17025:2017» provides for the compatibility of laboratory activities with the current legislation of the country, harmonisation of the system for ensuring the uniformity of existing measurements with generally recognised international norms and rules;

- Development of decision rules that take into account the level of risks («risk») based on the accuracy characteristics of the results at each measurement point of measuring instruments and tests and adopt industry acceptable ones;

- Develop (developed) a simplified illustrative technique for assessing the compliance of its metrological characteristics with the established requirements, taking into account the fact that one measuring equipment is used in several laboratory works based on the requirements of the measurement method;

- By fulfilling requirement clause 6.4.11 of the standard when assessing the conformity of measuring instruments, i.e., by applying corrections (deviations) in determining the base value, the negative impact of risks («risk») associated with ensuring the metrological traceability of measurement results and ensuring the continuous reliability of measurement results is prevented or reduced.

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MEASURMENT UNCERTAINTY OF DENSITY OF ANISE EXTRACT AS ONE OF THE COMPONENTS OF A NEW TINCTURE

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At present day for Ukraine the development the new and the improvement the known technologies of the producing of liquor-vodka drinks with using plant raw materials is actual.

Evaluation the measurement uncertainty of the density of the anise water-ethanol extract at the researches in the frame of the development of the new tincture is a purpose of the work.

The questions of the measurement uncertainty evaluation of the parameters of the quality of the components of the food products were considered in [1], the questions of the measurement uncertainty evaluation of the parameters of the quality of the sunflower seeds were considered in [2, 3].

The chemical researches in this work were aimed at the development of the receipt of the new tincture with improved taste-aromatic organoleptic properties. The density of the anise extract significantly influences on these properties.

There are two methods of the determination of the density of the raw materials of the semi-products and final products: picnometrical and aerometric.

The water-ethanol solutions are usually used for obtain the plant extract for liquor-vodka industry.

It was determined, that ethanol's concentration, temperature of the process and duration of the extracting are the main factors, that influence on the density of the anise extract.

The realization of the full factorial experiment by type 2^n allowed to determine the optimal values of these factors. Therefore, the following optimal conditions of the technological process were determined: ethanol's concentration – 50 % vol, temperature of the process – $50\,^0C$, duration of the extracting – 60 min.

The measurements were performed in reference conditions. Therefore, only the intrinsic error of measurement was in measurement results (the complementary errors were absent).

The measurement of the density of the anise extract was performed three times at each line of the matrix plan by picnometer [4]. The results of the replicated measurements were used for calculation the type A standard measurement uncertainty of the density of the anise's extract.

The relative density of the extract at the temperature 20^0C is calculated by formula [5]:

$$d^{20} = \frac{m_2 - m}{m_1 - m}, \qquad (1)$$

where m – the mass of the empty picnometer, g;

m_1 – the mass of the picnometer with distilled water [6], g;

m_2 – the mass of the picnometer with researched extract, g.

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.

The input quantities in a measurement model were measured by the analytical weigh AXIS of the series ANG. Taking into account, that the given in the technical instruction of the weigh value of the absolute error of the measurement of the mass is equal $\Delta m = \pm 0{,}0001\,\text{g}$, the type B standard measurement uncertainty of the mass was calculated.

The sensitivity coefficients of the input quantities of the measurement model were defined.

The combined standard measurement uncertainty and the expanded measurement uncertainty of the density of the anise extract were calculated for each line of the matrix plan.

Therefore, the evaluation of the measurement uncertainty of the density of the anise extract at the realization of the picnometrical method of the determination of the density was done in this work.

The components of the of the input quantities' measurement uncertainty of the density of the measurement model were analyzed.

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UNCERTAINTY EVALUATION AT CALIBRATION MEASURING DEVICE OF A MAGNETIC QUANTITIES

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The purpose of the work is to improve the metrological assurance of the measurement of the magnetic quantities by developing a method of calibrating an magnitometr. Research methods – methods of statistical analysis of measurement information, methods of uncertainty theory. The object of the study is the uncertainty of magnetometer calibrations.

There is an objective need to evaluate the influence of the magnetic field of the source (electrical equipment, sea ship, space satellite) on devices, microelectronics objects, instruments. In addition, the level of the magnetic field determines the safety of human life.

To solve certain problems in magnetometry, based on the combined dipole model [1] and the principle of construction of the measuring system [2], a point measurement method was developed. To implement this method, a measuring tool - a multifunctional digital magnetometer – is proposed. The multifunctional digital magnetometer is designed to measure several magnetic quantities. These are magnetic field strength, magnetic moment, spatial configuration of the field. Fields of application of the multifunctional magnetometer: aerospace industry, shipbuilding, geophysics, space research, design and operation of electrical equipment.

Calibration of measuring equipment is carried out in order to establish the suitability of measuring equipment for use. The calibration of measuring equipment is performed by metrological services of organizations. Calibration is carried out by metrological services of legal entities using standards subcontracted to state standards of units of quantities. The results of the calibration of the measuring equipment are certified by a calibrated mark, certificate, and an entry in the operating documents. The development of the magnetometer calibration program is carried out in accordance with the regulatory document ДСТУ OIMLD 20:2008.

Recommendations [3-5] were used to develop the methodology for calculating the uncertainty during magnetometer calibration and establishing the suitability of the device.

Multiple observations of n=70 magnetic moments were made to develop a methodology for calculating the uncertainty during magnetometer calibration and establishing the suitability of the device.

The processing of the results of repeated observations was carried out. The standard uncertainty according to type A, B and the total standard uncertainty are determined. Type B uncertainty was calculated as the standard uncertainty of the influencing quantity due to systematic sources.

Analysis of measurement uncertainty (uncertainty budget) contains a list of input values, their estimates with standard measurement uncertainties, laws of their

distribution and the number of degrees of freedom. A measurement uncertainty budget was developed (Table 1).

Table 1 - The uncertainty budget of the magnetic moment M, $A \cdot m^2$ measurement.

Input value, X_i	Estimation of the input quantities	Type of uncertainty	The number of degrees of freedom	Sensitivity coefficient.	Probability distribution	Total uncertainty ,
Random component	M_1=1.221	A	n-1	1	Normal distribution	u_A = 0.263
Reference measures of the magnetic field	Δ_s=0.025	B	∞	1	Uniform distribution	$u(\Delta_s)$= 0.025
Deviation of the size of reference measures from the nominal value	Δ_n=0.4	B	∞	1	Uniform distribution	$u(\Delta_n)$= 0.289
Difference between the excess air temperature and the normal one	Δ_t=0.2	B	∞	1	Uniform distribution	$u(\Delta_t)$= 0.200
Magnetometer reading resolution	0.01	B	∞	1	Uniform distribution	$u(\Delta^*)$= 0.005
M	1.200	0.439	-	2	P=0.95	0.879

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MEASUREMENT UNCERTAINTY EVALUATION AT TESTING OF FIRE-FIGHTING LAYFLAT DELIVERY HOSES

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Testing of fire-fighting layflat delivery hoses is carried out in order the conformity assessment with the requirements of current legislative acts of Ukraine and the mandatory requirements of [1] and other regulatory documents in force in Ukraine. Passing the conformity assessment procedure is one of the mandatory conditions for the sale and use of fire hoses on the territory of Ukraine.

An estimation, or at least a full consideration, of the components contributing to the overall uncertainty of a measurement or test result provides a means of establishing that the measurements made and the results obtained are valid. It may also help to confirm that tolerances included within a performance specification have been met or that the item under test is fit for the intended purpose.

Testing of delivery fire hoses presupposes certain types of control and testing (Test program): internal diameter control; length control; tests of resistance to operating and test pressure; hot object resistance test; abrasion resistance test; cold resistance test. According to [2], uncertainty was assessed.

Within a this work a methodology for the estimation of uncertainty the main tests of fire hoses have been developed. In this case we will focus in 9069-2021. This calculation is performed as an indirect measure since it takes into account several variables that have to be measured, as reflected in the equations for the determination of this property, such as the abrasion resistance test, etc. Once the different contributions to uncertainty were analysed, finally three groups were selected:

1) uncertainties associated to testing equipment;
2) uncertainties associated with the repeatability of measurements;
3) uncertainties associated with the reproducibility of measurements.

Table 1 - Uncertainty values for tests.

Test	Assigned value	Expanded uncertainty	Relative extended uncertainty, %
Pressure test, MPa	1,5	0,045	3
Adhesion test, m/min	17	0,09	0,5
Abrasion resistance test, *n*	50	1	2
Rigidity test, H	0,58	0,01	1,7

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MEASUREMENT UNCERTAINTY EVALUAION AT CALIBRATION PULSE ULTRASONIC LEVELMETER

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Measurement equipment for measuring the level of substances are used in all sectors of industry and agriculture for measuring, monitoring and regulating the parameters of technological processes, testing machines, equipment and various equipment, for quantitative accounting.

The purpose of the work is to improve the metrological support for measuring the level of a substance by developing a method for calibrating a digital levelmeter. Research methods – methods of statistical analysis of measurement information, methods of uncertainty theory. The object of the study is the uncertainty of calibration of digital levelmeters.

For estimating uncertainty during levelmeter calibration and establishing the device's suitability, multiple observations of n=200 were made for the level range (000,000 - 600,000 sm). The processing of the results of multiple observations has been performed. Delayed ultrasound response, ms and value of the output signal are obtained, mA (Table 1).

Table 1 - Calibration results

Level		Delayed ultrasound response, ms	Estimated value of the output signal, mA		
sm	%		0-5	0-20	4-20
600	0	45,987	0	0	4
420	30	35,672	1,5	6	8,8
300	50	38,795	2,5	10	12
150	75	20,199	3,75	15	16
0	100	11,603	5	20	20

Based on the recommendations [1-3], the standard uncertainty according to type A is determined: u_A=0.735; estimated uncertainties according to type B: u_B=0.574 and total standard uncertainty u_{600}=1.57 $_{(P=0.95)}$ of calibrations.

A budget of level measurement uncertainties was drawn up based on recommendations [1-3].

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PROBLEMS OF ESTIMATING MEASUREMENT UNCERTAINTY DUE TO PERIODIC INTERFERENCE AND RANDOM NOISE

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In this report, we consider the problem of estimating measurement uncertainty by type A method when processing observation results with the simultaneous influence of random uncorrelated noise and periodic interference.

Very often, during measurements with multiple observations, in addition to random noise, there may be periodic interference, for example, from an industrial frequency power supply network. The level of such interference can be several tens of times, or even sometimes more, higher than the level of random noise. The main method to reduce the impact of random noise and periodical interference on the measurement result is to use the averaging of observations over one or more interference periods.

The result of weight averaging of the set of n observations x_k $(k = 1, 2, ..., n)$ is:

$$\overline{X} = \frac{1}{n}\sum_{k=1}^{n} w_k \cdot x_k ,$$

where w_k $(k = 1, 2, ..., n)$ are the weighting coefficients.

In the case of periodic interference and random noise, two uncertainty components must be taken into account: periodical $u_{A,period}(x)$ and random $u_{A,rnd}(x)$. In this case, regardless of whether usual or weighted averaging is used, the autocorrelation $r_k = r(k)$ of the periodic interference should be taken into account when calculating the standard uncertainty:

$$u_A(x) = \sqrt{u_{A,period}^2(x) + u_{A,rnd}^2(x)} =$$

$$= \sqrt{s_{period}^2 \cdot \sum_{k=0}^{n-1} w_k^2 + 2s_{period}^2 \sum_{k=1}^{n-1} r(k) \sum_{l=0}^{n-k-1} w_l w_{l+k} + s_{rnd}^2 \cdot \sum_{k=0}^{n-1} w_k^2} ,$$

where s_{period} and s_{rnd} are the standard deviations of the periodic and random components, respectively.

However, in practice, we cannot determine both components of standard deviation separately, but only their combined impact:

$$s_{sum} = \sqrt{\frac{1}{n-1}\sum_{k=0}^{n-1}\left(x_k - \overline{x}\right)^2} .$$

Therefore, if the standard deviation of at least one of the components is unknown, the correct determination of standard uncertainty according to the above expression becomes problematic.

In general, there can be two extreme cases in which uncertainty estimation can be performed practically correctly. In the first case, the periodic interference due to the

application of weighted averaging will be reduced to the level that its influence compared to the influence of the random component will be negligibly small. That is, uncertainty evaluation can be carried out by the classical method. In the second case, even after weighted averaging, the influence of the periodic interference will be significantly greater than the influence of the random component, i.e. which can be neglected. In this case, the uncertainty can be estimated based on the spectral characteristic of the weight function and the calculated value of the standard deviation of the periodic component.

The paper analyzes examples of type A standard uncertainty evaluation using usual and weighted averaging of periodic interference along with the influence of random noise.

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THE PROBLEM OF MEASUREMENT UNCERTAINTY CONCEPT TO CLINICAL DIAGNOSTICS LAB PRACTICE

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The measurement uncertainty concept in the practice of clinical diagnostic laboratory makes it possible to carry out a statistical test of adequacy, to substantiate the coincidence reliability (difference from the critical value) of the results obtained in several medical laboratories or in the presence of dynamics. The measurement uncertainty allows the correct interpretation of the obtained result with respect to the threshold value and indicates the potential existence of a real difference between the current result and a future measurement. For example, for tests whose results are interpreted relative to the point of making a medical decision, for concentration values close to it, the location of this limit within the uncertainty interval should be considered. In this case, it is necessary to repeat the study several times at different times before establishing a diagnosis and prescribing therapy.

As a source of uncertainty, the variability of observations made under approximately the same conditions (variability of the analytical method), is taken into account. There are other sources at all stages of the process, starting from the introduction of the sample into the measurement procedure and ending with the output of the measured value [1]. However, it is impossible to quantify many of these uncertainty sources; the laboratory is limited to calculating the measurement uncertainty of the analytical stage.

Uncertainty components at the analytical stage:

- random and systematic errors due to reagent degradation or poor instrument maintenance and analytical variability;
- environmental effects on analytical processes;
- subjective errors, including sample manipulation errors;
- instrumental error at the decision point;
- calibration process errors;
- approximations included in measurements [2].

Analyzing these components of measurement uncertainty allows one to estimate their significance and to implement possible ways to minimize the contribution of each component and, therefore, to achieve the best interpretation of the test results by the clinician. Uncertainty components that can significantly affect the result, but it cannot be quantitatively analyzed, are investigated using methods used in risk management.

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MEASUREMENT UNSERTAINTY OF THE FREQUENCY DEPENDENCE OF THE REFLECTION COEFFICIENT OF THE TRANSVERSE ULTRASONIC WAVE FROM THE INTERFACE FUSED QUARTZ – VEGETABLE OILS

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One of the main, and in many cases the only, means of studying the mechanisms of intra- and intermolecular interactions in liquids under the influence of dynamic shear disturbances is acoustic methods. They are based on measuring the complex reflection coefficient of a transverse ultrasonic wave from the interface between a solid and the liquid under study.

For this purpose, viscous liquids are of particular interest, in which relaxation of dynamic shear viscosity and elasticity is expected in the ultrasonic frequency range under study. Vegetable oils were used as such liquids in this work: cottonseed, castor, tung, soybean, etc.

The reflection coefficient r of shear ultrasonic waves from the interface between a solid and vegetable oils (hereinafter referred to as the reflection coefficient) was measured in the frequency range (10-150) MHz on a two-channel pulsed ultrasonic installation developed by the author [1].

The desired value of the indirectly measured quantity r is found based on the results of measurements of the input quantities (arguments) A_0 and A associated with the desired quantity – the reflection coefficient r by equation (1)

$$r = \left(\frac{A}{A_0}\right)^k, k = \frac{1}{2m-1} \quad (1)$$

where A_0 and A are the amplitudes of ultrasound before and after applying liquid to the surface of the acoustic cell – fused quartz, respectively; m - number of the working echo signal ($2m<10$ depending on the viscosity of the liquid being tested).

To assess the degree of reliability and reliability of the results obtained and judgments based on them, it is undoubtedly relevant to assess their uncertainty.

The international document [2] "Guide to the Expression of Uncertainty of Measurement" as is known, mainly establishes a general rule for estimating and expressing measurement uncertainty.

It is shown that potential sources of uncertainty in the measurement of the reflection coefficient r are the uncertainties in the measurement of the input quantities - Ao and A.

Uncertainties of input quantities caused by random effects are estimated according to type A. Uncertainties caused by systematic effects - errors of the installation used for measurements [1], as well as rounding of calculation results, are estimated according to type *B*, and amount to 0.01 V.

Since the measurement is indirect, described by a nonlinear function (1), the uncertainty of the measured (output) value r is assessed taking into account the following features: correlation coefficients between the measurement uncertainties of input quantities are determined and their significance is assessed using the Student's *t*-test; negligence of the remainder term R when expanding a function in a Taylor series.

Our assessments have shown that these conditions are met. Therefore, to estimate the measured value r and its accuracy characteristics, the linearization method was used.

The results of a study of the reflection coefficient of a shear ultrasonic wave from the solid-vegetable oil interface at a temperature of 20 °C in the frequency range 10-150 MHz showed that it continues to change in the studied frequency range, i.e. the

relaxation process occurring in the liquid under study under the influence of dynamic shear stresses continues.

The total standard uncertainty $u_c(r)$ of measuring the reflection coefficient r, as follows from (1), is determined by the formula

$$u_c(r_{cp}) = \sqrt{\left(c_{A_0} \cdot u_c(A_0)\right)^2 + \left(c_A \cdot u_c(A)\right)^2} \quad (2)$$

where c_{A0} and c_A are the sensitivity coefficients $c_i = \partial f / \partial x_i$, estimates of the reflection coefficient r to changes in the signal amplitude values without liquid Ao and in its presence A, respectively; $u_c(A_0)$ and $u_c(A)$ are the total standard uncertainties in estimating signal amplitudes without liquid A_0 and in its presence A, respectively.

The total standard uncertainty $u_c(r)$ of measuring the reflection coefficient r in the studied frequency range is no more than 1.5%. Thus, the work justifies the use of the linearization method to estimate the reflection coefficient and its accuracy characteristics. The total standard uncertainty of the reflection coefficient measurement method implemented by equipment [1] is no more than 1.5%.

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MEASUREMENT UNCERTAINTY: INTRODUCING NEW TRAINING MATERIAL AND A EUROPEAN TEACHERS' COMMUNITY

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Measurement uncertainty is a key quality parameter to express the reliability of measurements. It is the basis for measurements that are trustworthy and traceable to the SI. In addition to scientific research, guidance documents and examples on how to evaluate the uncertainty for measurements, training is an important cornerstone to convey an understanding of uncertainty.

Many courses on measurement uncertainty are developed and provided by national metrology institutes, but also by universities, research institutions, national accreditation bodies, legal metrology authorities and their organizations, by service companies and many more. In 2021 a broad consortium was formed to jointly 1) develop new material for measurement uncertainty training and to 2) establish an active community for those involved in measurement uncertainty training in Europe. This project-like collaboration is called MU Training. It is an activity hosted by the European Metrology Network for Mathematics and Statistics, Mathmet (see Appendix), and aims to improve the quality, efficiency and dissemination of measurement uncertainty training.

This presentation will give an overview on how the activity MU Training advanced the teaching of measurement uncertainty in the past two years. We will describe how an active community was established that supports the teachers of measurement uncertainty. In addition, we will describe the freely available training material, that was developed for trainees and teachers, and that includes videos as well as overviews about courses, software and examples.

MU Training has increased the understanding of measurement uncertainty and will continue to do so, and by this contribute to more reliable measurements in Europe.

Appendix Mathmet

Mathmet is the European Metrology Network for Mathematics and Statistics. The network is a central reference point that addresses the need for integration between measurement science and mathematical and statistical methods and aims at fostering the field of mathematical and statistical applications for measurement science in Europe. This single focal point for best practice in mathematics and statistics in metrology will help to ensure robust and cutting-edge measurement science for the future, as well as the highest scientific excellence in European industry.

Mathmet Vision: to ensure quality and trust in algorithms, software tools and data for metrology, and in inferences made from such data, to foster the digital transformation.

Mathmet Mission: to provide a sustainable structure in Mathematics and Statistics for metrology to strengthen the European measurement infrastructure in facing the grand challenges (digital transformation, climate change mitigation, health and environment safety, energy and society sustainability).

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FEATURES OF ASSESSING THE UNCERTAINTY OF TEST RESULTS OF EQUIPMENT IMMUNITY TO ELECTROMAGNETIC INTERFERENCE

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Evaluation of the uncertainty of measurement and test results is a requirement of the ISO/IEC 17025:2017 standard, which is mandatory for testing laboratories. The test result and the uncertainty were considered as two partially independent quantities. Now, it is interpreted as follows [1]: the measurement result consists of the value of the measured quantity and the uncertainty of the measurement. In some areas of testing in which uncertainty cannot be expressed as an expanded uncertainty for the test result [2, 3], other more relevant ways of estimating the uncertainty of the results are proposed [1], such as the probability of receiving a positive test (negative) result.
For quantitative measurements, where the final results are expressed in a qualitative way (for example, pass/fail), the estimation of the uncertainty of the measurement concerns the deviation parameters of the voltage/current generators. The value of such parameters is regulated in the relevant standards. It should be noted that all existing IEC standards (61000 series, for example IEC TR 61000-1-6) and CISPR publications (CISPR 16-4-x) contain examples of assessing the measurement uncertainty of certain signal parameters.

In [4], an assessment of the uncertainty in measuring the electric field strength in a GTEM camera is considered, taking into account all parameters that have a significant impact on the measurement result. However, the degree of reliability of the test result of a particular product is not determined by this alone. The result depends on a number of factors related to the product being tested, the influence of the operator, the stability of the power supply, and the like. A significant part of such additional influencing factors is taken into account when assessing risk. The author proposes in the considered cases to combine risk assessment with measurement uncertainty and call this indicator “assessment of the reliability of the test result”.

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ABOUT SOME ASPECTS OF TRACEABILITY

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The main premise in establishing metrological traceability is a continuous chain of calibrations to a reference value(s) [1]. Traceability should be considered as a qualitative attribute of measurements. Therefore, there can be traceability to standards of different accuracy, but providing the target measurement uncertainty in calibration.

As is known, the number of quantities used in practice amounts to hundreds, and it is impractical to create standards for all of them, since most quantities are interconnected by physical laws.

It should be noted that the modern system of units SI-2019 implies the use of seven fundamental constants as the basis for determining units of quantities, which entails, in a certain sense, decentralization of the system of standards. Of course, in this case, to ensure the necessary measurement accuracy, the requirement to provide an extensive system of comparisons of standards comes to the fore.

There are a number of reasons why a continuous chain of calibrations is burdened with additional components:

1) Measurement ranges, for example, of NMI standards and working measuring systems may differ by several orders of magnitude. That is, the corresponding techniques and additional measuring systems are involved in the calibration chain;

2) There are types of measurements in which the units of measurement are the same, but the models of quantities, and therefore the models of methods and measuring instruments, differ significantly;

3) Some quantities of dimension one are defined as the ratios of two quantities of the same kind. When measuring such quantities, it is not at all necessary to use the “official” unit of measurement of the quantities of the mentioned kind;

4) The calibration chain (for the same measuring quantity and the same measuring system) can be branched and lead to several primary standards, or there can be several calibration chains leading to different sets of standards;

5) Difficulties in documenting the entire calibration chain (obtaining all calibration certificates or issuing a calibration certificate upon receipt of a reference value, for example, via the GPS network).

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USING UNCERTAINTY TO ASSESS THE AGREEMENT OF MEASUREMENT RESULTS

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Product testing is an important element of ensuring its quality. This is relevant at all stages of its life cycle. The tests require ensuring and controlling their quality (ensuring the reliability of the results). The international standard EN ISO/IEC 17025:2017 regulates this [1]. The tasks are complex and ambiguous enough.

Input information. The values measured by Method 1 and Method 2 are an array of independent and random values [2]. It is necessary to determine the probability of their simultaneous manifestation. At the same time, we take into account the value of the intervals in which the actual value of the measured value can be found. This is a criterion for assessing the comparability of measured results.

As an indicator for evaluating the coincidence of the results measured using Method 1 and Method 2, I propose to use the coincidence indicator. This indicator is the ratio of the difference between the average values of two distributions (Δy) to the common uncertainty of their measurement ($U_{y\Sigma}$), the decision rule r used (adopted) is taken into account:

$$k_c = \frac{\Delta y}{U_{y\Sigma}}, \tag{1}$$

where

$$\Delta y = \left|\overline{y}_1 - \overline{y}_2\right|; \tag{2}$$

$$U_{y\Sigma} = r\sqrt{U_{y1}^2 + U_{y2}^2}, \tag{3}$$

There are special tables on mathematical statistics in the literature. Using these tables, depending on the value of k_c, the probability with which the mathematical expectation of the value determined by one of the methods exceeds the uncertainty of measurement of the same value determined by another method is determined, while taking into account the applied decision rule. We can draw a conclusion. The kc indicator is an indicator for the quantitative expression of the total error of the measurement methods used.

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UNCERTAINTY EVALUATION OF THE TEMPERATURE TESTS RESULTS OF MEDICAL PORTABLE REFRIGERATORSE

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Medical portable refrigerators are compact refrigerators designed to store medicines, vaccines and blood at the appropriate temperature when they need to be transported or stored in places without access to standard refrigeration [1].

Donor blood transportation requires compliance with temperature and humidity conditions. Medical portable refrigerators must provide an internal temperature range of +2 to +8 °C and must operate at an ambient temperature of 10 °C to 43 °C. An internal temperature control system is required; backup power from the battery, so that the refrigerator remains operational even in the event of a power outage; preset alarms for 1,5 °C and 5,5 °C; air cooling should be provided by a fan.

The choice of measuring equipment is based on the requirements for environmental conditions, the quality of the power source when conducting tests in accordance with the requirements of standards [2,3]. ST-3 digital thermometer-hygrometer is used to monitor air temperature and humidity. Atmospheric pressure was measured using the aneroid barometer M-67. The power quality analyzer Power Master MI 2892 was used to check the established requirements. The data collection system DAS220 SEFRAM was used to determine the conditions of a stable temperature regime and the accuracy of the operating characteristics of a portable refrigerator.

After accumulating data on the air temperature in the medical refrigerator during the specified time, the temperature value was calculated. The result of the measurement is the arithmetic mean of the results of the temperature measurements T= 4,27 °C.

The sources of uncertainty specification of consists of an analysis of the technical characteristics for the control and measuring equipment, tasks and measurement conditions.

There are the following technical characteristics of measuring equipment:

– allowable relative error of humidity measurement for a thermometer-hygrometer ST-3, $\delta_h = \pm 5\%$;

– allowable relative error of temperature measurement for a thermometer-hygrometer ST-3, $\delta_t = 1$ %;

– allowable relative temperature measurement error for the data collection system DAS220, $\delta_{dc} = 0{,}2$ %;

– allowable relative error of atmospheric pressure measurement for an aneroid barometer M-67, $\delta_a = 0{,}1$ %.

– allowable the relative error of the measurement of the harmonic distortion coefficient of the power supply network for the power quality analyzer MI 2892, $\delta_{ps} = 0{,}05\%$;

– allowable relative voltage measurement error for a power quality analyzer MI 2892, $\delta_p = 0{,}1$ %.

The model metrological equation has the form

$$T=T_x+ \delta_U +\delta_H+ \delta_T+ \delta_A + \delta_C + \delta_h+ \delta_t+ \delta_{dc}+ \delta_a +\delta_{ps}+ \delta_p,$$

T_x – output value;; δ_U – voltage instability error of the power supply network; δ_H – environmental humidity instability error; δ_T – ambient temperature instability error; δ_A – atmospheric pressure instability error; δ_C – harmonic distortion coefficient error.

Calculation of the total standard temperature uncertainty

$$u_c^2(T)= u^2(\delta_U) + u^2(\delta_H) + u^2(\delta_T) + u^2(\delta_A) + u^2(\delta_C) + u^2(\delta_h) + \\ + u^2(\delta_т) + u^2(\delta_{dc}) + u^2(\delta_a) + u^2(\delta_{ps}) + u^2(\delta_p).$$

The value with expanded uncertainty [4] T = (4,27 ± 0,57) ºC, P=0,95, which meets the requirements of the standard [2], is taken as the test result. Uncertainty from the instability of test conditions does not exceed 10%, which is permissible according to the standard [2].

We believe that the test was performed under appropriate conditions, the measuring devices are calibrated, therefore, according to IEC 115 [5], their contribution to the total uncertainty is not significant. The main contribution to the total uncertainty of the refrigerator characteristics evaluation is the dispersion of the results and the temperature measurement inaccuracy.

Since the medical product belongs to the legally regulated sphere, therefore the requirements for it are stricter, when calculating the extended uncertainty, the coverage coefficient k = 3 should be chosen. Permissible errors in regulatory documents for medical devices are set in the form of an interval with a probability of P = 1. Therefore, it requires refinement expression of the total standard uncertainty of the average temperature of the refrigerator.

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MODELING AND ANALYSIS OF THE TECHNOLOGICAL ERROR OF THE LASER TRIANGULATION SENSOR FOR MEASURING THE GEOMETRIC CHARACTERISTICS BORE OF FIREARMS

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The effectiveness of the use of firearms in the performance of combat missions directly depends on the quality of periodic monitoring of its technical condition during operation. Special interest of experts is caused by the problems of controlling the technical condition of bore as an important part of any firearm, since it is the bore that is subject to wear and, thus, acts as a damaged element.

Taking into account the limited capabilities of traditional means of monitoring the technical condition of the bore, it seems promising to create an optical-mechanical measuring device (MD), the main element of which is a laser triangulation sensor (LTS), based on the triangulation method of determining distances using laser radiation to probe the surface under study.

The design of the LTS, which is adapted to measure the geometric characteristics of the bore surface, includes such basic elements as a laser radiation source, a focusing lens, a receiving lens, and a photosensitive detector (for example, a charge-coupled device). During operation, laser radiation is diffusely reflected from the object of measurement, a certain fraction of it passes through the receiving lens, is focused, and falls on the surface of the photosensitive detector. The processing of signals from the detector output, which carry information about the illumination of the photosensitive element matrix, as well as the calculation of the distance to the measurement object, is assigned to the computing component of the MD (for example, a microprocessor).

Despite the sufficient degree of study of the triangulation method of distance determination, a set of tasks aimed at analyzing the errors of the LTS as part of a specialized MD and for specific measurement conditions remains relevant.

The error of the LTS is created by a number of components, the estimation of each of which can be obtained by its mathematical modeling with subsequent quantification for characteristic combinations of device parameters. The method of combining such error components is determined by the nature and interconnection of their sources.

Based on the analysis of the optical scheme of the LTS from the composition of the MD of the geometric characteristics of the bore, the measurement method and features of its implementation were studied, the main sources of instrumental error were identified, and their influence on the total error of the LTS was studied.

The emergence of the most significant components of the error of the LTS is due to:

- technological factors, namely, deviations of the parameters of the optical circuit of the LTS from their nominal (calculated) values due to imperfections in the technology of manufacturing, assembly, and alignment processes;

- temperature influence, namely, deviations of the parameters of the LTS elements due to changes in ambient temperature.

This report discusses in detail the error component caused by technological factors.

The study of the influence of technological factors on the error of the LTS was carried out on the basis of the analysis of changes in the LTS transformation function due to deviations in the parameters of the optical circuit of the LTS. The expressions obtained as a result of applying this approach for the corresponding deviations of the input and output signals of the LTS are mathematical models of the components of its technological error.

To estimate the statistical confidence limits of the technological error of the LTS, a quasi-statistical approach was used, since the corresponding error components are systematic for one particular MD, but vary within certain limits for a set of different MD instances. At the same time, since it is possible (and seems quite reasonable) to use only one MD to determine linear values and one MD for angular values during the manufacture, assembly and alignment of the LTS, the error components in each of these two groups will be characterized by the presence of a correlation between them.

A quantitative assessment of the technological error for various characteristic combinations of the LTS parameters, which are determined by the caliber and other properties of firearms samples, has been carried out. In particular, the limits of permissible relative and absolute technological errors for four ranges of barrel calibers, which conditionally correspond to small arms, small-caliber artillery, medium-caliber artillery, and large-caliber artillery, are determined. The analysis of the results of this assessment suggests that the limit of the permissible absolute error of the LTS is ±0,001...0,005 mm. According to preliminary estimates of the authors, these results suggest that the total error of the LTS will be limited to a given level of ±0,01...0,02 mm, although to confirm this conclusion, it is necessary to complete the study of the temperature error.

In addition, we analyzed the graphs of changes in the instrumental error of the LTS in the measurement range. This analysis showed that the technological error in the initial part of the measurement range is smaller than in the final part of the range. This factor contributes to ensuring high reliability of control of the technical condition of the bore, since it is at the beginning of the measurement range that minor deviations of the geometric parameters of the bore are determined, which correspond to the first signs of the beginning of the process of its wear (degradation).

In the future, the obtained mathematical relations should be the basis for obtaining and studying the mathematical model of the total error of the measuring device. In addition, at the stage of developing recommendations for the practical implementation of the measuring device, it will be of particular interest to substantiate the scientific and methodological foundations for assessing the measurement uncertainty of the geometric characteristics of the bore, calibration of the measuring device, etc.

ASSESSMENT OF CALIBRATION AND MEASUREMENT CAPABILITIES

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We argue that the assessment of the Calibration and Measurement Capabilities, CMCs, by means of the results of a Key Comparison is a *bona fide* exercise of conformity assessment, and as such should be treated, using the appropriate tools, including risk assessment. This position contrasts with the current practice, in which acceptance or rejection of a CMC claim are based on the normalised error.

We show that, behind this seemingly unique acceptance criterion, different decision rules – guarded acceptance, simple acceptance and guarded rejection – exist in reality, depending on the characteristics of the comparison. This variety of decision rules impairs the fairness of the current equivalence arrangement.

We suggest that the conformance probability should be the key parameter to be considered in the assessment of a CMC claim. Using a suitable Probability Density Function, PDF, for the measurand, we calculate the conformance probability for the possible scenarios, and show that using the current acceptance criterion the conformance probability can attain unacceptably low values.

Therefore, we maintain that the current acceptance criterion is ambiguous and inadequate, and suggest to rather adopt a criterion based on the calculation of the conformance probability and the establishment of a minimum threshold for acceptance.

We demonstrate our proposal by applying it to a practical case and to a fictitious example in mass metrology.

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MEASUREMENT UNCERTAINTY EVALUATION AT CALIBRATION TACHOMETRICAL (BALL) FLOW METER

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Now, during a full-scale war in Ukraine, ensuring the unity of measurements is one of the fundamental directions of supporting the technical development of the country, which determines the security form of the state. Flow meters (devices for measuring flow) play a very important role in this matter. They can measure the flow of liquids, gases and other important substances (for example: fuel). They are used in pipelines that provide water and heat to the homes of every Ukrainian, they are widely used in vehicles, such as cars, trucks, airplanes; including in military equipment.

The work purpose – development of the metrology assurance of substance flow measurement through the improvement of flow meters verification methods, and also the improvement of calibration.

Methods of researches – the analysis of flow meters, principle of operation, advantages and disadvantages, the analysis of proving practice law regulation, the analysis of the flow facility – principle of operation, parts, metrological characteristics, purpose and features. The analysis of flow meter calibration process, the metrological characteristics calculation, the finding of the list of requirements to companies, which are applying to get verification authority.

In the course of work the review of modern state of flow measurement, was made, the analysis of some methods of verification and calibration, and also some metrological legal acts were done.

Tachometric (ball) flow meters are devices or systems of devices for measuring the amount of flow of a substance, the principle of operation of which consists in the movement of a moving element (ball) under the influence of the flow of the measuring substance. In industry, such flow meters are used to measure the flow of liquid in pipes whose diameter does not exceed 150-200 mm.

Calibration of ball flow meters is a mandatory procedure before they are placed on the market or put into operation for measurement tasks. It is this point that regulates the conformity of measuring equipment, including flow meters, to the sphere of legally regulated metrology. The regulatory document that determines the conformity of calibration of ball flow meters is DSTU 7156:2010 “Tachometric ball flow meters. Methodology of verification (calibration)”.

To assess the uncertainty during the calibration of the tachometric (ball) flow meter and establish its compliance with the technical regulations, a multiple study of n=10 was conducted, and the results obtained were processed. Based on the recommendations [1-2], an uncertainty budget was compiled when calibrating a ball flow meter (listed in Table 1).

Table 1 – Uncertainty budget for ball flow meter calibration

Input quntity	Estimation of the input quantity	Type of uncertainty	Number of degrees of freedom	Sensitivity coefficient	Probability distribution	Uncertainty contribution
A random variable, a_m	4,99	A	n-1	1	Normal law, u_A	0,005
Reference measure of the speed characteristic during calibration, Δs	0,03	B	∞	1	Uniform law, $u(\Delta_{s1})$	0,013
Deviation of the size of the reference measure of the speed characteristic from the nominal value, Δn	0,04	B	∞	1	Uniform law, $u(\Delta_n)$	0,024
The difference in ambient air temperature from normal, Δt	1,2	B	∞	1	Uniform law, $u(\Delta_t)$	0,693
The price of division or the discreteness of the flowmeter reading, Δ*	0,1	B	∞	1	Uniform law, u(Δ*)	0,029
Y	1,0-10,0	-	-	2	p=0,95	0,964

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DEVELOPMENT OF DIGITAL CALIBRATION CERTIFICATES IN THE SPHERE OF NATURAL GAS FLOW METERING

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The rapid development of information technologies has led to digital transformation not only in the field of administrative management, banking, education, medicine, etc., but also in the field of technical regulation, in particular, metrology. This is evidenced by the research of leading foreign national metrology institutes on the development and implementation of digital calibration certificates (DCC) to ensure end-to-end digital quality infrastructure within the framework of Industry 4.0 development [1].

The introduction of DCC allows to solve a number of metrological tasks, in particular, ensuring metrological traceability in digital systems [2] by means of electronic confirmation that the measuring instruments has been properly calibrated and the calibration results can be trusted. In addition, unlike analog calibration certificates, DCCs allow efficient exchange of calibration data between different systems and laboratories, improving interoperability and reducing the risk of errors. Storing calibration data in digital format allows access to critical calibration data in real-time, which is essential for effective management of measurement processes. Digital certificates provide a high level of security and authentication. They can be protected by encryption and digital signature, which reduces the risk of falsification and ensures data integrity. At the same time, the use of DCC allows to create an effective history of calibrations for each measuring instrument, which makes it possible to analyze the metrological characteristics of the measuring instrument in order to determine the term of the next calibration of measuring instrument and prevent possible problems in its application.

Currently, the SE “Ivano-Frankivskstandartmetrology” is working on digitalization, including the creation and implementation of a digital calibration certificate in the field of gas volume and volume flow measurement. Currently, a DCC template has been developed in the form of an XML file using GEMIMEG software. Work continues on software selection for automated DCC generation. In parallel, work was carried out on the approval of the calibration certificate using an electronic digital signature.

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FORMATION OF THE COMPETENCES OF ENGINEERING STUDENTS IN THE FIELD OF USING THE THEORY OF MEASUREMENT UNCERTAINTY IN CONFORMITY ASSESSMENT

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The professional standards for students of engineering specialties within the framework of distance education require continual monitoring and updating of competencies, which must correspond to modern trends in the field of science and technology. During the formation of professional students' competencies in the field of Quality Assurance specialty 175 "Information and Measurement Technologies", it is important to be able to apply the theory of measurement uncertainty during the conformity assessment of products and services in accordance with international requirements. Therefore, in addition to the documents directly devoted to the issue of expressing the measurement uncertainty, namely JCGM 100:2008, JCGM 101:2008, JCGM 102:201, JCGM 104:2009, special attention should be paid to the study of the document JCGM 106:2012 Evaluation of measurement data – The role of measurement uncertainty in conformity assessment, which was implemented into the Ukrainian regulatory framework as DSTU ISO/IEC Guide 98-4:2018 Uncertainty of measurements. Part 4: The role of measurement uncertainty in conformity assessment (ISO/IEC Guide 98-4:2012, IDT) [1].

The guidance document JCGM 106:2012 contains detailed recommendations on the procedure for assessing the compliance of the object's quality indicator with the specified requirements, constructing an acceptance interval, and making a decision regarding the recognition or non-recognition of the object as meeting the requirements. This means that the evaluated quality indicator is expressed in accordance with the principles of the measurement uncertainty theory, declared in the documents JCGM 101:2008, JCGM 102:2011, JCGM 103 and JCGM 104:2009.

General recommendations for conformity assessment are contained in the national standard DSTU ISO 10576-1:2006 (ISO 10576-1:2003 has been revised by ISO 10576:2022(en) Statistical methods — Guidelines for the evaluation of conformity with specified requirements). ISO 10576-1:2003 sets out guidelines for checking conformity with specified limits in the case where a quantity is measured and a resulting coverage interval (termed "uncertainty interval") is compared with a tolerance interval. JCGM 106:2012 extends this approach to include explicit consideration of risks, and develops general procedures for deciding conformity based on measurement results, recognizing the central role of probability distributions as expressions of uncertainty and incomplete information. JCGM 106:2012 pays special attention to the analysis of the consumer's and producer's risks of making incorrect decisions, related to the uncertainty of measurements. This allows to state that the standard's approach to conformity assessment has a clearly directed risk- and business-oriented focus.

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MEASUREMENT UNCERTAINTY EVALUATION AT DIGITAL BAROMETER CALIBRATION

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The main objective of this investigation is to examine and evaluate different factors that affect the precision of measurements, during barometer calibration. By studying methods used to assess measurement uncertainty the research aims to understand and determine how these factors impact the accuracy of measurements. The ultimate goal is to improve the dependability and precision of using barometers in fields of application.

The work purpose – development of the metrology assurance of pressure measurement through the improvement of barometers verification methods, and also the improvement of calibration.

Methods of researches – the analysis of barometer, principle of operation, advantages and disadvantages, the analysis of proving practice law regulation, the analysis of the barometer facility – principle of operation, parts, metrological characteristics, purpose and features. The analysis of barometer calibration process, the metrological characteristics calculation.

A digital barometer is a device used to measure atmospheric pressure. The main difference between a digital barometer and a conventional barometer is that it uses electronic pressure sensors and converts pressure changes into a digital signal for further output or processing. Digital barometers can be embedded in a variety of technological equipment, starting from weather stations and mobile devices to scientific instrument complexes. They are widely used for pressure monitoring in environments where accuracy and reliability are key factors, such as meteorology, aerospace and medical. Because digital barometers are based on electronic sensors, their measurements are accurate, and they can be compact and convenient to carry and use in a variety of environments, compared to traditional analog barometers.

Calibration of measuring equipment is carried out in order to establish the suitability of measuring equipment for use. The calibration of measuring equipment is performed by metrological services of organizations. Calibration is carried out by metrological services of legal entities using standards subcontracted to state standards of units of quantities. The results of the calibration of the measuring equipment are certified by a calibrated mark, a certificate, and an entry in the operating documents. The development of the barometer calibration program is carried out in accordance with the normative document DSTU OIMLD 20:2008.

To develop a methodology for calculating the uncertainty during barometer calibration and establishing the suitability of the device, repeated observations n=100

was made. The results of multiple observations have been processed. The standard uncertainty according to type *A*, *B* and the total standard uncertainty were determined.

Based on the recommendations [1-2], an uncertainty budget was compiled when calibrating a ball flow meter (listed in Table 1).

Table 1 – Uncertainty budget for digital barometer calibration

Input value,	Estimation of the input value	Type of uncertainty	The number of degrees of freedom	Sensitivity coefficient .	Probability distribution	Combined uncertainty
Random component	p_1=759.25	A	n-1	1	Normal	u_A = 0.198
Reference measures of the pressure	Δ_s=0.025	B	∞	1	Uniform	u(Δ_s)= 0.015
Deviation of the size of reference measures from the nominal value	Δ_n=0.4	B	∞	1	Uniform	u(Δ_n)= 0.230
Difference between the excess air temperature and the normal one	Δ_t=0.2	B	∞	1	Uniform	u(Δ_t)= 0.117
Barometer reading resolution	Δ_r 0.01	B	∞	1	Uniform	u(Δ_r)= 0.003
P	760.00	0.258	-	2	*p*=0.95	0.651

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PECUALIARITIES OF QUANTUM STANDARDS AND ESTIMATES OF THEIR UNCERTAINTY

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The transition to quantum methods and standards made it possible to radically raise the accuracy of reproduction of electrical quantities and the level of measurements in the industry as a whole. But the use of quantum standards has a number of peculiarities. Features of quantum methods, which allowed us to raise time-space and electrical measurements to a qualitatively new level, are:

A) Absence of methodological uncertainty – quantum methods "allow us to realize all units with an accuracy that is ultimately limited only by the quantum structure of nature and our technical capabilities" [1], only except the limitation due to the principle of "Heisenberg's uncertainty" [2].

B) The absoluteness of measurements, that is, the ability to measure absolute values of physical quantities, hence the absence of the need for calibration.

C) Small dependence of quantum effects on hardware implementation.

D) The ability to visually control the presence of a quantum effect in the measurement process (that is, the reliability of the "work" of the corresponding quantum formula), which removes the question of the stability of the standard and the corresponding uncertainty component.

F) The "calculation" nature of quantum methods (standards), which means the fact that the reproduced value of a physical quantity is not the result of measurement in the generally accepted sense of this term, but the result of calculation. A classic example of such standard should be considered the time and frequency standard at a quantum transition in a cesium atom.

Another example of the "calculated" standard is the standard of electrical resistance based on the quantum Hall effect [4]. The standard resistance R_x is calculated through two initial steels (Plank h and elementary charge e) according to the formula $R = \frac{h}{m e^2}$ (in which the presence of the effect is controlled by the quantization of characteristics "resistance R_x – magnetic induction B". It is important that this approach can be applied everywhere to other electrical quantum standards that are primed on Josephson effects $U_{Дж} = n\frac{hf_0}{2e}$, nuclear magnetic resonance (NMR) $B = \frac{2\pi f_{ЯМР}}{\gamma_p}$, single-electron tunneling $I = ef$, because the frequencies that are included the corresponding formulas are actually calculated too. All this allows us to use the names of quantum methods for the creation of electrical units by the primary reference methods, and related standards – by the primary [2,3]

Less known is the quantum method of nuclear magnetic resonance (NMR), which in its classic version is used the proton resonance (resonance of the nucleus of a water atom) and the gyromagnetic ratio of the proton steel [4,5]. At [6] it is shown that a unit of magnetic induction is created at the same time as a unit of current. In addition, the NMR method is retained by New SI as the primary reference method, otherwise it becomes necessary to accept γ_p with its own error which the CODATA estimates as $2{,}4 \cdot 10^{-8}$. So, its status is lower, than that of the other original steels h, e, k, N_A.

Thus, quantum effects and corresponding measurement technologies have a number of features that are largely an important factor in their metrological efficiency and reliability [5,6].

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MINIMAL POTENTIAL UNCERTAINTY AND SPECIAL STATUS OF THE SECOND IN THE SI-2019

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The latest redefinition (wording adjustment) of the second due to Cs-133 was implemented in SI in 2019.

The second, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1}. In order to introduce practical recommendations for the reproduction of the basic SI units, the Consultative Committee for Time and

Frequency (CCTF) has developed Mise en pratique, which embodies the best method at the moment according to the existing definition – the quantum transition in cesium-133.

In the SI system of 2019, the second is related to all other basic units except the mole - m, kg, A, cd, K. This is not done by chance, because the system of standards based on the measurement of frequency (time) differs not only the highest accuracy, but it is also much more convenient and accessible for users, first of all due the possibility of transmitting reference frequencies. The only requirement is that measurements relating any quantity (such as electrical) to frequency can be easily performed in any equipped laboratory. In electricity, this is achieved with the help of technologies (methods) built on the basis of quantum effects: the Josephson effect, the Hall effect, nuclear magnetic resonance, and the one-electron tunneling effect.

It is obvious that in the new SI system, fundamental physical constants are no longer simply coefficients of transition from macroscopic to microscopic phenomena (units) - they become a means by which the frequency standard can be directly used in the measurement of many physical quantities. It is believed that the minimum potential uncertainty of the classical cesium beam-type frequency standard is close to $1 \cdot 10^{-14}$ and it is limited by the thermal motion of cesium atoms.

With the discovery of laser methods for cooling atoms, based on the interaction of atoms with photons of light, this limitation can be eliminated and the accuracy can be increased by about one or two orders of magnitude. The combination of the ideas of the cesium standard of the frequency of the vertical structure and laser cooling led to the creation in a number of countries of the so-called "cesium fountain" and the reduction of uncertainty to $(1\text{-}5) \cdot 10^{-16}$

But better results have been achieved in optical frequency standards based on various types of transitions in extremely time-stable neutral atoms. These standards recently surpassed the Cs-133 frequency standard in accuracy by about a hundred times. In this regard, at the last meeting of the CCTF, a road map was approved for choosing the best type or set of transition types for the primary reproduction of a second. Several variants of the definition are considered.

Option 1: A new definition based on a single reference optical frequency at which the primary implementation of cesium becomes the secondary representation of the SI second.

Option 2: New definition based on the ensemble of reference optical frequencies. This option involves the use of an ensemble of selected transition frequencies processed according to a certain algorithm. This approach combines the concept of using primary and secondary implementations of a second.

Option 3: New definition based on fixing the value of another fundamental constant. This approach is directly related to general relativity and the standard model of particle physics.

Speaking about the redefinition of the second, it must be emphasized that any change in the definition of the length of the atomic second will have a significant impact on the entire system of SI units, since the frequency standard clearly defines

other units. This once again emphasizes the decisive role played by the second in modern scientific research, and the special status in the international system of units, as well as the responsibility and consideration that should be shown when redefining the second

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UNCERTAINTY IN DETERMINING THE MEAN INTEGRAL REFRACTIVE INDEX OF AIR BY ITS LOCAL VALUES MEASURED AT TWO POINTS OF THE TRACE

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For laser ranging measurements on near-earth traces, the method of determining the mean integral refractive index of air by its local values at the end points of the trace is widely used. The measurement model for this method is based on the trapezoidal quadrature formula.

The accuracy of this method can be improved if the refractive index gradients are additionally measured at the endpoints [1], i.e., using the Euler-Maclaurin quadrature instead of the trapezoidal quadrature. This complicates the experiment, since determining the gradients may require measuring the refractive index at additional points equidistant from the end points. At the same time, there is a quadrature according to which two points within the integration interval can be used instead of two endpoints to more accurately determine the mean refractive index. In computational mathematics, this quadrature is known as the Gaussian quadrature.

It should be noted that the uncertainty components of type A should be of the same order for the trapezoidal and Gaussian quadratures, since their source for these quadratures is the inaccuracy of the refractive index measurement at two points of the trace. As for the uncertainty component of type B, based on the ratios for the remainders of these quadratures, a disappointing conclusion can be drawn that in the trapezoidal quadrature, this component will reach its maximum.

The report substantiates the methods of uncertainty evaluation for determining the mean integral refractive index of air by its two local values using the Gaussian quadrature. Based on the results of the analysis, the conditions under which this quadrature can provide higher accuracy than the trapezoidal quadrature are determined.

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ANALYSIS OF THE RESULTS OF PROFICIENCY TESTING SCHEME OF "KOZLODUY NPP" METROLOGICAL LABORATORIES BY INTERLABORATORY COMPARISONS

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Thousands of measurements are performed every second at the Kozloduy NPP. Tens of thousands of measuring devices and systems are used for this purpose. The total number of measuring devices and signals from information and control measurement systems at Kozloduy NPP EAD is about 60000, of which:

- need to be calibrated ~ 20 %,
- need to be verified ~ 80 %, of which:
  - internal metrological verification ~ 75 %
  - legally regulatory control ~ 25 %.

Metrological Assurance Department (MA) carries out activities to ensure the uniformity necessary accuracy and traceability of measurements at Kozloduy NPP EAD.

MA Department – is a separate part of the Safety and Quality Directorate. There are five laboratories in the structure of the department in different field of measurements and performed activities.

The number of personnel is 45 specialists, whose average age is 40 years and 90% of them with higher education.

MA Department have a metrological traceability of measurements to the national standards of Bulgaria, UK, Germany, Russia, The Netherland, The Czech Republic and Denmark for 13 physical quantities and ensures traceability of measurements in NPP.

The proficiency testing for a laboratory is important element to ensure the quality of its work and one of the requirements of EN ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories.

The proficiency testing via inter-laboratory comparison (ILC) is one of the most effective ways to ensure confidence in the laboratory results.

All metrology laboratories at Kozloduy NPP participated in a number of ILCs organized by the Bulgarian Institute of Metrology, the Federal Office for Radiation Protection of Germany (BfS) and the International Atomic Energy Agency to confirm their technical competence.

This report analyzes the results of the ILCs of metrology laboratories for the last ten years, presents the summary tables with the evaluations of the laboratories with the criteria used by the ILC providers according to BDS EN ISO/IEC 17043:2023 Conformity assessment - General requirements for the competence of proficiency testing providers.

By participating in the ILCs, the Kozloduy NPP laboratories receive an

independent assessment of their technical competence, which gives them the opportunity to monitor and improve their activity. The results that are not acceptable from ILC participation can occur in any laboratory. Unfortunately, anyone can get such a result, but it is very important to understand why the laboratory received such a result and to take adequate corrective actions.

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IMPROVEMENT OF METHODS OF CALIBRATION OF WORKING STANDARTS

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One of the conditions for ensuring the unity of measurements is the compliance of any measuring equipment with all the requirements of the relevant regulatory and technical documents.

The procedure for verification of legally regulated measuring equipment is regulated by the order of the Ministry of Economic Development of Ukraine dated 08.02.2016 N 193 "On approval of the Procedure for verification of legally regulated measuring equipment in operation and registration of its results", in which a requirement is established for the ratio of the expanded uncertainty (with a confidence probability of 95%) of the value of the value reproduced or measured by the standard to the maximum permissible error of the legally regulated measuring equipment subject to verification, which should be no more than one to three. The determination of such a ratio is an example of indirect consideration of measurement uncertainty. The reliability of the assessment of the compliance of the working standard with the metrological requirements, which are regulated in the technical specification, depends on the correctness of the procedures for assessing the measurement uncertainty during calibration.

According to the Procedure, the calibration of working standards should be carried out according to calibration methods contained in national standards or developed by executors taking into account national standards harmonized with relevant international and European standards and documents adopted by international and regional metrology organizations.

Currently, the calibration of working standards is carried out by calibration laboratories and scientific metrology centers accredited by the National Accreditation Agency of Ukraine, which have documented traceability of their standards to national standards, standards of other states or international standards of the relevant units of measurement.

Calibration of working standards takes place according to calibration methods developed by the performers themselves, who carry out the calibration and evaluate the uncertainty of measurements according to their understanding and at their discretion. To make sure of this, it is enough to familiarize yourself with the "Scopes of accreditation" of calibration laboratories, where the declared best calibration and measurement capabilities of calibration laboratories of the same type of working standard differ several times. This approach to the ensured unity of measurements leads to the chaos of metrological activity.

Therefore, the development of effective standardized methods of calibration of working standards is an urgent task and a guarantee of ensuring the unity of measurements in the legally regulated field of metrology.

STUDY OF COMPONENTS OF ERROR IN THE ESTIMATION OF DOSES BY THERMOLUMINESCENCE METHOD

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It is known that among all thermoluminescent materials used in conducting thermoluminescence (TL) audits of therapeutic photon beams, preference is given to LiF: Mg, Ti type TLD-100, thanks to its tissue equivalence, clear reproducibility of results in repeated measurements, and low fading. In practice, TLD-100 is used in the form of small cylinders (tablets), chips, as well as in powder form.

To assess the dose based on the magnitude of TL detector signals, a set of correction factors, also known as correction coefficients, are used. These factors are determined when studying systems such as TL signal – the delivered dose determined by ionization calibration; TL signal – the quality of radiation (photon beam energy); TL signal – the reading device.

As each correction factor is determined experimentally, its value comes with its associated uncertainty, making it one of the sources of the overall measurement uncertainty. Numerous studies have been conducted to investigate various factors that influence the formation of measurement errors in TL dosimetry [1-5].

The combined relative uncertainty of determining the absorbed dose in water using TL detectors includes two components:

- The uncertainty of the calibration of the TL system for absorbed dose in water measured by an ionization chamber;
- The uncertainty of the measurement procedure itself on the TL system.

In this case, the latter includes uncertainty due to the reading procedure (correction for daily fluctuations of the TL system), uncertainties in individual coefficients of different batches of TL powder [6].

The procedure of collecting TL signal readings from the reading device contributes the most to the overall uncertainty in dose calculation. The characteristic of TL detector signal reproducibility depends on the TL signal-reading device system. To achieve the required measurement uncertainty of up to 3% for TL audit centers, the dose reading error should not exceed 1.5% [7].

The calibration factor of the system is determined for each batch of TL detectors and for each type of reading device. In the study [4], it is mentioned that a parameter like the reproducibility of TL signal values depends not only on the measuring device but also on the quality of the preparation of the TL material before irradiation.

During the irradiation of TL detectors (powders, tablets) in international comparison programs such as IAEA, EURADOS, and EROPAQ, a standard holder for TL detectors was used. This holder typically consists of a PMMA tube with two openings for detectors at heights of 5 cm and 15 cm from the top of the holder. When determining the absorbed dose in water at a depth of 5 cm with a vertical geometry of the gamma radiation beam over the TL detector, a 5 cm layer of PMMA material is placed over the TL detector instead of water. The study [2] has shown that the

correction factor that accounts for the influence of the holder on the TL signal values allows compensating for its reduction due to the partial attenuation of the beam by the standard holder during irradiation. This factor should be determined as the ratio of the TL signal in the photon beam without the holder to the TL signal with the holder.

When determining the dose using TL dosimetry, significant attention is given to studying the effect of fading on the magnitude of the TL signal. It is known that the return of irradiated capsules from controlled radiation therapy departments to the TL audit center can take several months, creating challenges in dose assessment. Therefore, it is necessary to develop a procedure for accounting for the fading of the TL signal from the irradiated capsule.

In the study [3], the potential for the repeated use of TLD-100 (Rexon) powder was explored by analyzing changes in the thermoluminescence glow curve peaks. It was established that a procedure involving thermal treatment of the TL material at 400°C, followed by cooling to room temperature, allows the sensitivity of the detectors to be restored practically to their initial level.

Significant attention was also given to studying changes in the sensitivity of the phosphor with prolonged storage at room temperature. Such changes are one of the main sources of dose assessment when conducting remote TL audits, as the time interval between preparing the detectors for irradiation in a controlled facility and reading them at the TL audit center can be substantial. According to the authors, the primary focus should be on the stability of the TL signal over a significant period of time between irradiation and reading the TL detector. During this time interval, fading of the TL signal and changes in the sensitivity of the phosphor affect the final dosimetric results. To reduce the component of error that occurs due to a lack of time for signal stabilization, a method to eliminate the fading effect was proposed. This method involves using a programmed delay in measurements between cycles of detector preparation, irradiation, and TL signal measurement. Data from thousands of measurements for different detector groups, including both immediate measurements after irradiation and intentionally delayed ones, have shown that the combined uncertainty of absorbed dose measurements for ^{60}Co in the range from 0.5 to 4.0 Gy can be as low as 1%. This is significantly less than the IAEA's accepted permissible measurement error for TL Audit Centers, which is 3% [3].

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A METROLOGICAL REFLECTION ON UNCERTAINTY ABOUT THE USE OF MAPS INSTEAD OF GLOBAL PARAMETERS

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In recent years there is an abnormal use of *global parameters*, not only in the economical fields, but also in scientific fields like meteorology and climate, mainly deriving from political intention. They are supposed to convey in a clear and simple-to-understand way the most important significance in the changes of those numerical parameters. When informing about the global trends and related parameters, the trend consists in its summarisation via global parameters, typically supposed to represent the mean numerical value of a big dataset. In previous papers, the author has already discussed the issue that the evolution of some of these parameters in time is affected by an *inconsistently low evaluation of their uncertainty*, a "quality" factor that *must* be associated to every human piece of the always partial, and often insufficient, knowledge. That must be done according to the methodology established by the science of measurement, and in particular of "metrology" whose main goal is to study the ways to improve the precision of the measurements through a deeper understanding of the phenomena.

These reflections will be restricted to a comparison between the above common tool of using global parameters and the use instead of a different tool, for the same purpose of evaluation, consisting in the use of *maps* of the parameters in question over their whole (spatial) dimension, namely of the Earth surface, in respect to the effect of the *uncertainty* factor.

The international body involved in determining the meteorological parameters is the WMO, collecting hundredth of them with a frequency of their measurements that can be up to several times per hour, and storing in what today can be considered a «Big Data» database. Citing here only three popular parameters, they are: the ground mean temperature (SAMT, the Surface Average Mean Temperature), the show/ice coverage and the oceans level variation, all extremely complicated to obtain. The mean distance

between WMO Stations is large enough to require subsequent interpolation via mathematical/geometrical means necessary to compute additional points with respect to the original network in order to create a sufficiently dense one. For each of these additional points, the *uncertainty* necessarily associated to the data of each measurement Station must be integrated (typically increased) by the estimation of the *interpolation uncertainty*.

Overall, one obtain a database of values, *each value having an associated uncertainly*, that can then be numerically treated to get, e.g., a *mean value* (e.g., like the SAMT). It is affected by an *uncertainty*, e.g., as the one provided by the IPCC: however, the detailed statistical procedure for the calculation of the value is not *specifically* reported nor does include a published associated Uncertainty Budget (UB), as normally required in other fields and always in metrology. A mere fit of the database is often performed, but the *only* component of uncertainty it can output is the parameter called "standard deviation" (s.d.) of the data, or its double at 97.5%. It is only able to provide an indication about the *consistency* of the fitting trend, and to guide toward the "best fit", i.e. the one providing the minimum s.d.. However, the fit is only taking into account the *value of each data* not also its associated uncertainty. Non-parametric methods should be used for taking into account the full information, but they are rarely used. In all instances, a fit does not obtain the *total uncertainty* of any summary parameter, but only part of the random uncertainty components.

Plotting instead the data onto a map does not merely allow passing from a mathematical-type of representation to a geometrical-type of presentation, the latter being more significant for "geometrical minds" of scientists with respect to "mathematical minds". In such a representation, one superposes to the geographical basic information (the map) the measured values of the parameter(s) of interest. The most efficient way, in view of the subsequent analysis, is generally not to use a continuous shift of the map-colours to represent values, but discretising in (small) steps the colours: the result is that the colour map is formed of small quadrangles, most often squares, of uniform colour, each representing a small range of the values, *to which the "central" value of the measured value is attributed*. Except exceptional cases, the latter operation makes *practically ineffective the uncertainty* assigned to the value associated with each single element of area.

One gets a picture of the distribution in space of the dataset, instead of only the tabular representation of the measured values in all single places: it might be considered as a *form of averaging* that underpass the numerical values of the uncertainty, but is sufficient in meteorology for the purpose of most of the qualitative analyses then made from the obtained results. It is a *geometrical* examination, generally much more informative than a table of numbers, *and*, the necessary approximation produced by the discretization is generally sufficient to compensate for the lack of a numerical indication of the uncertainty of the original data.

A first new lesson that can be learned from the maps is that *a sufficiently univocal estimate* of the patterns and of their changes is *not possible*, a feature that only the use of maps and their comparison can reveal. It is *not* the aim of the paper to discuss these differences, but basically only to provide evidence of the fact that the *distribution* of

surface temperature bringing to the SAMT is a kind of evaluation that can be *impossible to reliably obtain* by means of a single global parameter. In such a situation, the *importance* of the effect of *uncertainty of each single* measured point constituting the database is strongly limited by the use of maps and normally can be disregarded, a useful issue especially *when the uncertainty evaluation is controversial*.

Conversely, *retrieving back* from the map the numerical values *is always possible* with the due precautions via informatics mean, as already done by the author in a couple of cases and found efficient. This is an additional bonus for curious scientists that like/need to retrieve from published maps the numerical values for their own mathematical analyses and evaluation. However, like in case of the SAMT, the *correct map-type* should be used, i.e. the iso-surface-types, Peters' or the recent EqualHearth one, normally not used in the scientific literature where instead the Mercator or Robinson ones are normally and only used. Back retrieval may be affected by a larger uncertainty due to the larger discretization of geographical coordinates. However, important and useful is the fact that it is possible to *retrieve back* the (relative) values *from the pixels* having the same assigned colour on the surfaces. That possibility have been tested by the author in two circumstances: the global snow/ice covering of the surface; the iso-color surfaces, using as the unit the pixel. For comparing the SAMT value so obtained with the one reported in the literature where Robinson-type maps are used, the use of values from the above iso-surface projections are required. In this case, an uncertainty of the retrieval estimated of SAMT within ≈± 5% was obtained. Value differences up to ≈20% from the published one can be obtained for different maps: this means that, with respect to the current SAMT *increase* considered as the reference by IPCC, +1.1 °C, a difference of 20% corresponds to a maximum spread of +(0.9–1.3) °C, still amply within the *real uncertainty* of the SAMT, ± (0.5<1) °C—based on WMO indications—that a metrological analysis considers *more reliable* than the IPCC indication of ± 0.12 °C.

In conclusion, the retrieval of several global parameters can be obtained by starting from the map distribution of the relevant parameter over the full spatial extension of the map, with an *uncertainty comparable* with the one attributed to the parameters from a direct analysis of their database. However, too much often the latter is affected by *under-estimation* due to the use of evaluation methods not considered acceptable by measurement science and by the metrological Community, or is *controversial*. That result is possible since *it makes the effect of uncertainty less critical*. Maps additionally also allow to get a much more extensive and complete analysis of the collected information, qualitative and quantitative, from its distribution on the whole extension of the map: e.g., it especially concerns the *extent of non-uniformity* of the values and the possible relations/reasons for it. In the case of the reported example of the SAMT, its non-uniformity is particularly evident, so that the scientific mean of the *global parameter can be considered significantly weak and rather irrelevant*, irrespective to any possible controversial evaluation of the uncertainty affecting the usual analysis based on the dataset. *This is particularly important to avoid in a situation where the analysis is directed to make forecasts and to take decisions*.

A BAYESIAN METHOD FOR LARGE-SCALE SENSOR CALIBRATION

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Low-cost sensors, such as Micro-Electro-Mechanical Systems (MEMS) devices, are typically produced in the order of millions of pieces per week by a single factory. This large-scale production is incompatible with standard calibration procedures requiring a proper experimental calibration for each device. In-the-lab calibrations would be unfeasibly costly and time-consuming for such a huge number of devices. A solution can be found in the use of statistical methods [1] to (at least partially) substitute for the typical calibration procedures.

In this work, we propose a Bayesian method to statistically calibrate large batches of sensors using probabilistic models and prior knowledge. Prior knowledge on the characteristics of the whole population of devices, whose batches will have to be calibrated, comes from a typical experimental calibration of a "benchmark" batch. This calibration is performed "once and for all" on a batch that is chosen as representative of the whole production process. Then, for each future batch of that population, only a small sample of sensors is experimentally calibrated, providing evidence of the presence, or not, of out-of-tolerance devices in the sample. A hypergeometric likelihood function, modelling the sampling without replacement of the small subset of sensors, together with a Binomial function, modelling the prior state of knowledge on the whole population, lead to a posterior mass function that counts the number of defective sensors in the whole batch. Such posterior is used both to define a metric for the batch quality assessment and to evaluate the uncertainty associated with the statistically calibrated sensors.

The Bayesian nature of the approach allows reducing the actual number of experimental calibrations by incorporating the available prior knowledge. The method was applied for the first time to a population of 100 digital MEMS accelerometers that were calibrated at the INRIM premises.

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METHOD OF ESTIMATING THE UNCERTAINTY OF MEASURING THE HAUSDORF DISTANCE BETWEEN TWO IMAGES FOR THEIR CLASSIFICATION

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Autonomous mobile robots (AMR) can be used to perform special tasks in unfamiliar terrain in the absence of GPS. They must detect and recognize ground objects that can be referred to landmarks. Several landmarks are the basis for creating a local coordinate system for AMR navigation. Detection of landmarks on arbitrary terrain is advisable to be carried out by passive on-board systems (without radiation), in particular, video cameras. To assign an object to the class of landmarks, it is necessary to compare the reference image of the landmark with the image of this object and draw a conclusion regarding their belonging to the same class. Among the many methods of object classification, one of the most simple and effective is the method that uses the Hausdorff distance between the contours of the reference and selected images as a criterion for belonging to a certain class. Therefore, an important operation of the method is the determination of the contours of the specified images.

The report analyzes the errors in determining contours of real images, which depend on the characteristics of the measuring tool (video camera), environmental conditions (time of day, presence of fog, precipitation, etc.) and the method being used. Since the values of these errors in pixels for different conditions can vary widely, the report substantiates the normal law of their distribution. The contour of the reference image is presented in the form of a column, that is, a deterministic rectangle stretched in the vertical plane. The determination of the Hausdorff distance is carried out using geometrically random contours of the real image. This makes it possible to estimate the uncertainty of measuring the Hausdorff distance between reference and real images using traditional methods. An increase in such uncertainty leads to a decrease in the probability of correct classification of a real image and, in particular, the probability of assigning this image to the class of landmarks for AMR.

The Hausdorff distance modeling for landmarks on real terrain images is carried out, which makes it possible to establish the correspondence between the set of these distances and the set of decisions regarding the assignment of images to the selected type of landmarks. A statistical method for determining the threshold value of the Hausdorff distance, which is a similarity criterion for the detected object image with the reference image of the landmark, has been developed.

SIMPLY METHOD OF ESTIMATION THE NONLINEAR FUNCTIONS FITTED TO MEASUREMENT DATA AND THEIR UNCERTAINTY BAND: THEORY BACKGROUND

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Characteristics of some measuring instruments, sensors, and electronic transducers, are described by a non-linear function [1]. In the presentation it is described how to fit a second-degree curve to coordinates of measured points on the example of the parabola part. In the calibration process both coordinates of tested points can be measured, and parameters of this curve fitted to their values should be found. Let us consider, e.g. an equation of the parabola arm

$$y = Ax^2 + Bx + C \tag{1}$$

The sets $\boldsymbol{X}$, $\boldsymbol{Y}$ of both coordinates x_i, y_i of n tested points can be represented together as common vector of $2n$ elements $\boldsymbol{Z} = [\boldsymbol{X}, \boldsymbol{Y}]^{\mathrm{T}} = [_1, \ldots x_i, \ldots x_n, y_1, \ldots y_i, \ldots y_n]^{\mathrm{T}}$. In general case both x, y variables are measured with random errors, and between their sets the autocorrelation and cross-correlation may occur [1]. Covariance matrix $\boldsymbol{U_Z}$ of $\boldsymbol{Z}$ contains $2n$ variances as squares of standard uncertainties:

$$u_{x1}, \ldots u_{xi}, \ldots u_{xn}, u_{y1}, \ldots u_{yi}, \ldots u_{yn}$$

on the main diagonal and covariances $\rho_{ij} u_i u_j$ (where $_{Uij} = u_{ji}$) in other positions, arranged symmetrically with respect to this diagonal.

The parameters A, B, C of function (1) have to be found. That can be done by the linear regression method. In the general case, with unequal uncertainties and the occurrence of correlations, this solution can be obtained only numerically [2]. In simplified cases of the matrix $\boldsymbol{U_Z}$ there are also analytical solutions. The new variable $\xi = (x + v)^2$ can be implemented, where $v = B/2A$. For variable ξ the straight-line equation is obtained, i.e.:

$$y = a\,\xi + b = A\xi + C - v^2 A, \tag{2}$$

where $a = A$; $b = C - A\,v^2$. And it is enough now numerically to find only two parameters.

The WTLS linear regression method (minimum weighted squares of distance) matching with the occurrence of cross-correlation of measured variables is used. Therefore, one can look for a minimum of the one-parameter function:

$$G(a) = a^2 \left(S_{xx} - \frac{S_x^2}{S}\right) + 2\left(\frac{S_x S_y}{S} - S_{xy}\right) a + S_{yy} - \frac{S_y^2}{S}, \tag{3}$$

where:

$$S = \mathbf{1}^{\mathbf{T}}\, \boldsymbol{U}_{\boldsymbol{eff}}^{-\mathbf{1}} \mathbf{1} = \sum_{i=1}^{n} \sum_{j=1}^{n} [\, u_{yeff}^{-1}]_{ij},$$

$$S_x = \boldsymbol{X}^{\mathrm{T}}\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}}\boldsymbol{1} = \boldsymbol{1}^{\mathrm{T}}\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}}\boldsymbol{X},$$
$$S_{xx} = \boldsymbol{X}^{\mathrm{T}}\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}}\boldsymbol{X},$$
$$S_y = \boldsymbol{Y}^{\mathrm{T}}\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}}\boldsymbol{1} = \boldsymbol{1}^{\mathrm{T}}\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}}\boldsymbol{Y},$$
$$S_{yy} = \boldsymbol{Y}^{\mathrm{T}}\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}},$$
$$S_{xy} = \boldsymbol{X}^{\mathrm{T}}\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}}\boldsymbol{Y} = \boldsymbol{Y}^{\mathrm{T}}\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}}\boldsymbol{X}.$$

Matrices:

$$\boldsymbol{U}_{\boldsymbol{Yeff}}^{-\boldsymbol{1}} = \boldsymbol{U}_{\boldsymbol{22}} - \left(\boldsymbol{U}_{\boldsymbol{12}}^{\mathrm{T}}a\boldsymbol{U}_{\boldsymbol{22}}\right)\boldsymbol{U}^{-\boldsymbol{1}}(\boldsymbol{U}_{\boldsymbol{12}} + a\boldsymbol{U}_{\boldsymbol{22}});$$
$$\boldsymbol{U} = \boldsymbol{U}_{\boldsymbol{11}} + a(\boldsymbol{U}_{\boldsymbol{12}}^{\mathrm{T}} + \boldsymbol{U}_{\boldsymbol{12}}) + a^2\boldsymbol{U}_{\boldsymbol{22}}$$

are positively defined, and then occurring matrices $\boldsymbol{U}_{\boldsymbol{11}}, \boldsymbol{U}_{\boldsymbol{12}}$, $\boldsymbol{U}_{\boldsymbol{22}}$ form the inverse matrix to $\boldsymbol{U}_{\boldsymbol{Z}}$, i.e.:

$$\boldsymbol{U}_{\boldsymbol{Z}}^{-\boldsymbol{1}} = \begin{bmatrix} \boldsymbol{U}_{\boldsymbol{11}} & \boldsymbol{U}_{\boldsymbol{12}} \\ \boldsymbol{U}_{\boldsymbol{12}}^{\boldsymbol{T}} & \boldsymbol{U}_{\boldsymbol{22}} \end{bmatrix} \tag{4}$$

describing the criterion for the offset v, that changes of vectors $\boldsymbol{X}$ and $\boldsymbol{Y}$ of measured points coordinates and their standard uncertainties. The covariance matrix of new coordinates contains standard uncertainties:

$$u(\xi_i) = |\frac{\partial x'_i}{\partial x_i}| = 2|\xi_i + v|u(x_i) \tag{5}$$

where $x'_i + v \neq 0$ for $i = 1, \ldots, n$.

All correlation coefficients in the covariance matrix of variables ξ i y are the same as in the covariance matrix for variables x and y.

The parameters are:

$$A = a_{\min};$$
$$B = 2a_{\min}\nu_{\min};$$
$$C = b_{\min} + a_{\min(}\nu_{\min)}{}^2.$$

The uncertainty band is determined from the parameters of covariance matrix U_{ab}:

$$U(x) = t_{0.95,n-2}\sqrt{(x + v_{min})^4u_a^2 + 2\rho_{ab}(x + v_{min})^2u_au_b + u_b^2}. \tag{6}$$

A few examples of using this method for thermistor circuits will be discussed in detail during the presentation.

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MEASUREMENT UNCERTAINTY EVALUATION DURING SEED CERTIFICATION TESTS

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Measurement uncertainty evaluation during seed certification tests is one of the applied aspects of uncertainty measurement. Seed certification is one of the key elements of ensuring food security in a country. Seed material is subject to mandatory certification both in Ukraine and in the EU countries. Certification schemes are not unified, but the following is common to all schemes:

- certification bodies must be accredited for compliance with EN ISO/IEC 17065:2019;
- laboratories that carry out certification tests must be accredited for compliance with EN ISO/IEC 17065:2019.

Mutual recognition of certification results is, among other things, possible due to common approaches to ensuring the validity of the certification process.

The agricultural certification process consists of a sequence of three functions that satisfy the need for conformity confirmation if the requirement is met: sampling, testing, critical review and conformity confirmation.

The validity of the certification process is determined by the validity of sampling and the validity of testing. Uncertainty estimation is the main quantitative method for assessing validity.

Measurement uncertainty arising from sampling, a guide to methods and approaches given in [1]. Two possible approaches to uncertainty evaluation of sampling are considered: modeling and empirical. The modeling approach involves identifying all sources of uncertainty, quantifying the contribution of each source of uncertainty, and combining them in the form of an uncertainty budget according to a certain model, followed by estimating the total standard uncertainty. The empirical approach to uncertainty evaluation is based on reproducibility assessments within internal or interlaboratory tests. It does not involve evaluation of all components of sampling uncertainty, and it is based on analysis of variance, which is easily automated, and is therefore widely used in testing laboratories. Paper [2] shows that evaluating the sampling uncertainty is an important stage of testing, which allows, among other things, to obtain information about the degree of homogeneity of the material under study by various factors. In cases where there is sufficient evidence that the systematic effects are insignificant, an empirical approach based on the classical analysis of variance procedure can be used. Robust analysis of variance should be used only if the initial data correspond to its purpose. Given the prerequisites for using the statistical apparatus of analysis of variance, the methodology regulated by the recommendations [1] should be supplemented in order to be able to state the statistical significance of the obtained estimates, assess their real validity and make recommendations on the required amount of data to ensure the desired validity.

The issues of ensuring validity in testing laboratories are discussed in [3]. Expanded Uncertainty is a characteristic that contains information about both the accuracy and validity of the test result. The customer of testing services draws a conclusion about the quality of testing in the laboratory based on it. Seed certification involves testing the following indicators: color, odor, purity and impurity, content of other seeds kind, germination, germinative energy of seeds, thousand seeds weight, seeds disease and pest infestation. Accuracy of measurement depends on many factors, which are ultimately defined as uncertainty components. The issue of uncertainty evaluation during sunflower seed testing based on the "moisture mass fraction" indicator was considered in [6].

The article [6] analyzed the most commonly used in the routine activities of the laboratory and regulated by the standard method of evaluating the thousand seeds weight, which is used to determine the quality indicators of agricultural seeds for certification purposes. The basic calculation formula for the test using the method of two weights of 500 seeds each is determined. The impact of repeatability and trueness of the uncertainty is evaluated. It is shown under what conditions the components of repeatability and correctness can be disregarded in the combined uncertainty.

The decision to certify/not certify a lot of seeds is made on the basis of comparison of test results with the limit values set forth in the standards. The accuracy of the extended uncertainty assessment determines the reliability of the decision. Certification of a substandard lot of entails risks to yield and disease spread. False rejection of a quality lot causes huge losses to farmers. Therefore, an accurate and reliable uncertainty evaluation during seed certification is extremely important.

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FEATURES THE “GREEN GASES” (HYDROGEN AND BIOMETHANE) USE IN THE GAS SYSTEM OF UKRAINE

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The Decree of the Cabinet of Ministers of Ukraine No. 373 dated April 21, 2023 approved the Energy Strategy of Ukraine for the period until 2050. As part of the implementation of the strategy, the Ministry of Energy of Ukraine announced that the main energy principles of Ukraine's recovery will be the transition to "green" energy, decarbonization and ensuring climate neutrality. The need to increase biomethane production, taking into account the potential of agricultural land, was also noted.

It should be noted that in order to ensure the possibility of connecting biomethane suppliers to gas networks, amendments and additions to the GTS Code [1] and the GDS Code [2] were adopted. Moreover, for gas transportation systems, an increase in the upper limit of oxygen content in gas is provided for up to 0.2%, and for gas distribution networks, the upper limit of oxygen content is up to 1.0%. As for other physicochemical parameters of biomethane (content of components, heat of combustion, content of impurities), they must meet the requirements for natural gas. Also, on November 1, 2023, the national standard DSTU EN 16723-1:2023 [3] came into force, which defines in detail the technical characteristics of biomethane for supply to the gas network. Fulfillment of the technical requirements of the EU harmonized regulatory document will make it possible to export biomethane in the future. Currently, one biomethane plant is already connected to the gas distribution network in Ukraine.

Another promising direction is the transportation and storage of hydrogen and gas-hydrogen mixtures within the framework of decarbonization and reduction of CO2 emissions. In particular, the option of using the existing gas pipeline system of LLC "Gas Transmission System Operator of Ukraine" for the export of gas-hydrogen mixture is being considered [4]. Thus, it is necessary to consider potential changes in the physic-chemical characteristics of the gas-hydrogen mixture (with volume content of hydrogen up to 20%). Pure hydrogen differs significantly in its characteristics from methane (as the main component) and other components of natural gas. Moreover, some characteristics (speed of sound in gas, speed of flame propagation, compressibility coefficient) significantly exceed the indicators of natural gas, although other indicators (density, heat of combustion, Wobbe number), on the contrary, are lower. For this purpose, a simulation of the change in the values of the gas-hydrogen mixture relative to the normalized parameters of the gas specified in [1, 2] will be carried out.

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APPLICATION OF THE CONCEPT OF UNCERTAINTY IN THE DEVELOPMENT OF A PRACTICAL ALGORITHM FOR CALCULATING THE COMPRESSIBILITY COEFFICIENT OF GAS-HYDROGEN MIXTURES

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At the moment, the question of implementing a "green" energy transition of Ukraine using hydrocarbon resources, primarily natural gas, is relevant. In this aspect, one of the directions for solving the specified task is the addition of hydrogen to natural gas, that is, the use of gas-hydrogen mixtures as an energy source. Under such conditions, natural gas can serve not only as a component of energy decarbonization, but also as a component of energy from renewable sources.

At the same time, the issue of accounting for gas-hydrogen mixtures, i.e. measuring their volume and volumetric consumption, is practically unexplored. Solving these issues requires the application of an algorithm for bringing the measured volume of gas to standard conditions [1], which is impossible without taking into account the coefficient of compressibility of the gas medium that is accounted for.

A well-known normative document of Ukraine [1] provides for the presentation of conversion coefficients between different values of standard conditions of gases, which relate to their physical properties, including the compressibility factor. However, this standard does not provide for the calculation or recalculation of the physical properties of natural gases with hydrogen content.

Another well-known normative document of Ukraine [2], which, although it provides a methodology for calculating the compressibility factor for gases with the addition of hydrogen, has a quantitative limit on the molar fraction of hydrogen in the mixture to 10%. In addition, the computer program given in this standard, which implements the algorithm for calculating the compressibility factor, is characterized by considerable complexity and is sufficiently complex for practical application.

The purpose of the study is to develop a practical algorithm for calculating the compressibility coefficient of gas-hydrogen mixtures with the presentation of the results of its metrological analysis using the theory of uncertainty.

The essence of this algorithm for determining the compressibility coefficient of the gas-hydrogen mixture involves the determination of the absolute pseudocritical temperature T_{pcr} and the absolute pseudocritical pressure p_{pcr} of the gas-hydrogen mixture according to the formulas:

$$T_{pcr} = 0{,}01\sum_i r_i T_{cri}, \quad (1)$$

$$p_{pcr} = 0{,}01\sum_i r_i p_{cri}, \quad (2)$$

where r_i – volume content in percent of the components of the gas-hydrogen mixture,

the sum of the percentages of which must be 100%; T_{cri} – absolute critical temperatures of individual components of the gas-hydrogen mixture; p_{cri} – absolute critical pressures of individual components of the gas-hydrogen mixture.

The reduced temperature T_r and the reduced pressure p_r for a gas-hydrogen mixture, as a mixture of gases, are determined by the formulas:

$$T_r = \frac{T}{T_{pcr}}, \quad (3)$$

$$p_r = \frac{p}{p_{pcr}}, \quad (4)$$

where T, p – absolute temperature and absolute pressure of the gas-hydrogen mixture.

Next, the coefficient of compressibility of the gas-hydrogen mixture is determined using the graphic dependences $K = f(T_r, p_r)$, which are known from the handbooks, using the method of linear interpolation.

An applied aspect of using the linear interpolation method and the graphical dependence $K = f(T_r, p_r)$ is presented in [3].

Estimation of the standard uncertainty when calculating the compressibility coefficient of gas-hydrogen mixtures is carried out by summing the following component uncertainties:

$$u = \sqrt{u_{tbl}^2 + u^2(T) + u^2(p) + u^2(T_{pcr}) + u^2(p_{pcr}) + u^2(T_r) + u^2(p_r) + u_{gr}^2 + u_{cgr}^2}, \quad (5)$$

where u_{tbl} – the uncertainty of obtaining reference tabular output data; $u(T)$, $u(p)$ – uncertainties of measurement of the absolute temperature and absolute pressure of the gas-hydrogen mixture, respectively; $u(T_{pcr})$, $u(p_{pcr})$ – uncertainties of calculation of the pseudocritical values of the temperature and pressure of the gas-hydrogen mixture, respectively; $u(T_r)$, $u(p_r)$ – uncertainties of calculation of the given values of temperature and pressure of the gas-hydrogen mixture, respectively; u_{gr} – the uncertainty of constructing a graph of the change in the compressibility coefficient from the given values of temperature T_r and pressure p_r; u_{cgr} – the uncertainty of calculating the compressibility factor using a graph.

Since the results of experimental studies are practically absent in the research, the uncertainties presented in (5) are considered only as type B [4]. Uncertainties $u(T_{pcr})$, $u(p_{pcr})$, $u(T_r)$, $u(p_r)$, u_{cgr} are calculated by the method of statistical summation of components according to the algorithm of their calculation.

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STATISTICAL UNCERTAINTY IN MODELING THE LIGHT COEFFICIENT IN SCINTILLATORS BASED ON YTTRIUM GARNETS DOPED WITH GALLIUM

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It is known that a change in the Ga content in YAGG:Ce yttrium garnets, its transparency to its own radiation can change significantly, which affects the transmission of light in scintillators and, accordingly, the value of the light output (LO). The effect can be both positive and negative and is associated with a change in the structure of the electronic energy levels of Ce^{3+} ions when the concentration of Ga in crystals increases [1]. Increasing the concentration of Ga in the crystals leads first to an increase and then to a decrease in LO (more than 60 % Ga).

We have simulated the light collection coefficient τ in YAGG:Ce crystals containing Ga, in at. %, equal to 0, 20, 40, 60 and 100, and also estimated the uncertainty of the obtained values. The simulation τ was carried out in the DETECT2000 program using a POLISH-type surface model for YAGG:Ce crystals with dimensions of 10×10×0.5 mm and 10×10×2 mm. The values of the optical absorption coefficients k, in cm^{-1}, calculated from the measured optical spectra were used. The diffuse reflection coefficient of the external Teflon reflector k_{ref} was assumed to be equal to 0.95. The statistical uncertainty $u_A(\tau)$ was estimated in accordance with [2]. The number of emitted photons N_{emit} was set equal to 10^5. The obtained results are shown in Table 1.

Table 1

Scintillator	Ga, at. %	k, cm^{-1}	h = 0.5 mm		h = 2 mm	
			τ	$u_A(\tau)$, %	τ	$u_A(\tau)$, %
YAG:Ce	0	0.373	0.148	0.195	0.143	0.474
YAGG:Ce	20	0.450	0.144	0.275	0.139	0.427
YAGG:Ce	40	1.136	0.117	0.359	0.109	0.350
YAGG:Ce	60	0.419	0.145	0.232	0.141	0.230
YGG:Ce	100	0.640	0.135	0.245	0.130	0.332

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SOME PRACTICAL ISSUES IN THE EVALUATION OF THE LONG-TERM DRIFT OF TRAVELLING STANDARDS FOR COMPARISONS

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The analysis of instrumental drift in measuring instruments and standards is important in metrology. Each reference instrument is periodically calibrated according to a frequency determined by the laboratory. Calibration establishes the metrological state of the instrument on a certain date of its implementation. But it is necessary to know the state of the instrument after calibration or when the calibration expires.

Reliable accounting for drift plays an important role in maintaining measurement accuracy. Unaccounted for drift can lead to significant measurement errors. Accounting for time drift is mandatory when carry out of international comparisons of national standards [1]. The drift uncertainty can be estimated from its history of successive calibrations. In the absence of such a history, an estimate of the order of magnitude of the calibration uncertainty can be made [2].

The pilot laboratory of each comparison should research metrological characteristics of travelling standards and its drift (behaviour) during the comparison. Basic requirement for a successful comparison is the stable or predictable behaviour of the travelling standards during the time of the full measurement loop. The main characteristics of the transfer standard for each comparison are indicated in the BIPM Key Comparison Database.

Evaluation and quantifying the drift of a travelling standard over certain periods is an important task. A drift (trend) is the main tendency of a certain process to change over time or a time series, which is described by various equations: linear, logarithmic, power, etc. [3].

Common practice is to establish the relationship between $y(t)$ and $x(t)$, termed the calibration model, which often takes the form of a polynomial of suitable degree n (usually 1 or 2):

$$y(t) = a_0 + a_1 x(t) + a_2 x^2(t) + \ldots + a_n x^n(t). \quad (1)$$

The method ordinary least squares (OLS) can also be used to research drift, which is one of the basic methods of regression analysis for estimating unknown parameters of regression models based on sample data. It is based on the minimization of the sum of squared deviations of the selected function from the studied data. The theoretical values are determined using a mathematical function that best represents the underlying drift of the time series. This function is called an adequate function, which is calculated by the OLS method. At the same time, the sum of squared deviations between empirical $y(t)$ and theoretical $\hat{y}(t)$ values of the time series are minimized:

$$S = \sum_{i=1}^{n} \left(y_i(t) - \hat{y}_i(t) \right)^2 \to \min. \quad (2)$$

The coefficient of determination is used to assess the accuracy of such a drift model. The most reliable drift line is if its approximation probability value (R^2) is equal to or close to 1. The drift model is adequate for the process under study and reflects the

tendency of its development over time with R^2 values close to 1.

The analysis of the long-term drift of travelling standards will be limited to examples of key and supplementary comparisons of electrical standards. Quite a lot of such comparisons were carried out both by the Consultative Committee for Electricity and Magnetism (CCEM) and by most of the regional metrological organizations (RMOs). The row of international standards and guides describe various statistical methods for analysis of the measurement results [4-6].

The correct choice of travelling standard can affect the results of comparisons, so pilot laboratories pay great attention to this issueThe practice of choosing standards of the same type for comparisons by different RMOs has already developed. This contributes to the comparability of the results of such comparisons. An important issue for certain comparisons is the choice of one of several similar standards that are available from the pilot laboratory as a travelling standard. For such a choice, it is necessary to take into account not only the proximity of the real value of the standard to the nominal value, but also the real long-term instability of such a standard.

SE "Ukrmetrteststandard" (Kyiv, Ukraine) was the pilot laboratory in comparisons COOMET.EM-K4, COOMET.EM-S4, and COOMET.EM-S13 of capacitance standards. The pilot laboratory has four capacitance standards of 100 pF available, of which one standard was chosen as the travelling standard and was used in all comparisons. The drift of selected standard at frequency 1 kHz was estimated with its expanded uncertainty for 11 years and linear model. Capacitance travelling standards drifts for 10 pF between comparisons (78 months) was estimated also.

Accounting for time drift is mandatory when carry out of international comparisons of national standards. For capacitance standards, time drift is predictable and nearly linear. Linear model is used quite often in comparisons of standards, since they use a travelling standard with very good stability characteristics. Evaluation of the long-term drift of travelling standards using polynomial regression was applied. Consistent results have been obtained. Linear model was applied to estimate the drift of travelling standards in key and supplementary comparisons of COOMET of capacitance standards.

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UNCERTAINTY OF ESTIMATING THE CHARACTERISTIC PARAMETER OF THE TWO-COMPONENT MIXTURE

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The production process of many industries includes the production of multicomponent mixtures. Most often, for these mixtures, the ratio of the components is normalized by mass, namely $y=ax_1+bx_2$. A characteristic parameter of such mixtures is the relative moisture content, which must be within certain limits. Moreover, the permissible deviation of moisture in the mixture from the normalized value is significantly less than the permissible deviation of the mass of the components.

Components may come from different suppliers and consequently may have different moisture values. Therefore, before carrying out the production from the chosen components of the mixture, it is necessary to carry out the calibration of the result of the calculation of the characteristic parameter of the mixture $y(h)$, obtained by indirect measurements, with the model value $y_0(h)$. According to the results of the calibration, the ratio of a to b between the components of the mixture is adjusted. As a result, the uncertainty of the resulting mixture with the required set value of the characteristic parameter decreases.

Since the relative moisture is an informative quantity, the moisture of the chosen components is determined when its masses are the same. Then the results of direct measurements of $y_1(h)$ and $y_2(h)$ are multiplied by a and b, respectively. In production conditions, to reduce the influence of errors on measurement results, a parallel-serial structural organization of the measurement process is usually used, that is, one measurement channel is used, which has a bias in the conversion characteristic.

The input quantities are independent and the results of its direct measurement can have any possible values. However, carrying out mathematical operations on measurement results in accordance with the model equation and the presence of a common influential quantity (characteristic bias) leads to the appearance of a correlation, which we will call instrumental. This creates an additional component in the combined standard calibration uncertainty. The contribution of this component to the uncertainty of the obtained result is assessed, and the possibilities of reducing the influence of instrumental correlation are considered.

When producing a mixture, the presence of instrumental correlation during the functional transformation of the results of direct measurements can significantly increase the uncertainty of the result and thereby affect the correctness of the conformity assessment. To reduce uncertainty, it is proposed to pre-scale the components in order to increase the ratio of the value of its informative parameter to the characteristic bias. To bring the calculation equation of the indirect measurement to the original model equation, the results of the direct measurement are scaled inversely to the input scaling. The influence of instrumental correlation on the combined standard uncertainty in reproducing a characteristic parameter of a two-component mixture is researched depending on the ratio between the components.

EVALUATION OF THE UNCERTAINTY OF THE CONTROL OF POLYMER PIPES AND BLOOD VESSELS BY THE PHASE GRID METHOD

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Currently, plastic (polymer) pipes are increasingly used for water and gas supply due to their corrosion resistance and lower cost. At the same time, the ultrasound method is used to control their integrity, especially welds, both during installation and during operation. However, when using transducers with a single piezo plate, high reliability of control is not ensured, especially when there are several defects in the weld seam that follow each other. This also applies to ultrasound diagnostics of the vessels of the human body.

Therefore, it is proposed to control polymer pipes and organs of the human abdominal cavity using the technology of phased antenna arrays, which makes it possible to carry out the electronic formation of a focused ultrasound beam obtained from many elements of the array and control it. At the same time, a significant number of different beam profiles are formed by one converter [1]. When placing two phased array transducers from different sides and using a special 3D modeling program, the reliability of determining the types of defects increases, as their spatial interpretation is provided.

The components of the methodical uncertainty of the control of polymer pipes based on phased arrays are determined according to type B, taking into account the limits of the change in the speed and pressure of the flow of liquid or gas in the controlled pipeline. The law of distribution of these uncertainties is considered to be uniform, since there can be any values of speed and pressure within the specified limits of change of these values with the same probability. The flow speed varies between 1.8 – 2.2 m/s. This component of methodological uncertainty will be equal to: $u_V = 0{,}117$ m/s. The relative uncertainty is equal to: $u_V = 5{,}8\%$. It is also known, that the average pressure in the pipeline is 50 MPa and can vary between 48 and 52 MPa, hence the standard uncertainty associated with the change in pressure in the flow will be equal to: $u_p = 1{,}17$ MPa. The relative uncertainty will be equal to: $u_P = 2{,}3\%$. The total relative methodological uncertainty of the control, taking into account the uncorrelation of the components, is equal to:

$$u_{\Sigma MET} = \sqrt{u_V^2 + u_P^2} = \sqrt{5{,}8^2 + 2{,}3^2} = 6{,}2\%.$$

In a similar way, the calculated methodological uncertainty in the control of blood vessels was 5,3%. Therefore, sufficiently high methodical control accuracy is ensured.

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DISTRIBUTION OF LINEAR COMBINATIONS OF INDEPENDENT STUDENT'S T RANDOM VARIABLES AND GENERALIZATIONS: THE TSALLIS Q-GAUSSIAN PERSPECTIVE

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In this presentation, we tackle the challenge of computing the distribution of a linear combination of independent *Student's t* random variables—a well-established problem in statistics with widespread applications in measurement science and metrology. For a thorough exploration of standard approximate and exact methods to solve this problem, please refer to [1-2]. An alternative and interesting approximation to derive the required coverage factors is based on the kurtosis method, as discussed in [3]. Addressing a common issue in measurement and metrology, which necessitates the evaluation of critical points in the distribution of a linear combination of independent *t*-variates, is the common mean problem. For more details see, e.g., [4-6].

We have developed a numerical method for computing the required distribution through the numerical inversion of its characteristic function, and detailed information can be found in [7-8]. This approach can be extended to a broad class of complex probability distributions representable by the characteristic function [9]. Furthermore, we have created a MATLAB toolbox, https://github.com/witkovsky/CharFunTool, comprising algorithms for evaluating selected characteristic functions and numerically inverting combined and/or compound characteristic functions. These algorithms are utilized for evaluating the cumulative distribution function (CDF), the probability density function (PDF), and/or the quantile function (QF), as discussed, e.g., in [10].

Within this context, we provide further insights into the *Tsallis q-Gaussian* distribution—a potent generalization of the standard Gaussian distribution and the *Student's t* distribution. These distributions find application in modelling the behaviour of a diverse range of physical, social and biomedical processes, including non-extensive statistical mechanics, financial markets, and image processing [11]. Due to their versatility and practicality, *q*-Gaussians serve as a natural choice for modelling input quantities in measurement models. We present the characteristic function of a linear combination of independent *q*-Gaussian random variables and propose a numerical method for its inversion. This technique enables the determination of the exact probability distribution of the output quantity in linear measurement models, where the input quantities are modelled as independent *q*-Gaussian random variables. It offers an alternative computational approach to the Monte Carlo method for uncertainty analysis through the propagation of distributions.

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METHODS OF ACCOUNTING FOR MEASUREMENT UNCERTAINTY IN THE CLASSIFICATION OF OBJECTS ACCORDING TO QUALITY INDICATORS

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When classifying objects according to quality indicators (QIs), a combination of measurement/classification (M/C) procedures is used. If the classification is carried out according to single QIs, one property of the object is subject to measurement and the classification is performed using a categorized scale for this property. In the case of group QIs, several properties of the object are to be measured, and the results are combined using the appropriate operators for categorized data. In the case of a complex PN, ratios are used, according to which a complex PN is formed. This complex QI is subject to categorization.

Since the procedure for measuring physicochemical properties, which are used to construct most quality indicators of objects, is accompanied by significant errors (10-30%), an urgent task is to analyze the impact of measurement uncertainty on the results of further classification. Methods of taking measurement uncertainty into account when classifying objects according to different QIs can be divided into two approaches: using a fuzzy classification scale and using the fuzzy number as the measurement result.

When using single and group QIs, measurement uncertainty can be taken into account when building a classification scale, that is, when using a fuzzy scale. Then the fuzzy classification result can be obtained from the intersection of the fuzzy scale with the measurement result presented as a single-tone. For a single QI, the result can be either assignment to one quality category, or to several with the determination of the degree of belonging to this category. That is, measurement uncertainty can lead to a corresponding dispersion of the classification result. When using group QIs, the results of classification on fuzzy scales for each of several properties are combined with the use of fuzzy operators. That is, the first method of accounting for measurement uncertainty in the M/C procedure is based on the use of one or more fuzzy classification scales.

When determining the quality categories according to the complex QI, the measurement results of individual properties are combined according to the ratio established for this complex QI with the combination of the relevant uncertainties. The obtained result of the measurement of the complex QI is presented in the form of a fuzzy number with a carrier corresponding to the expanded uncertainty of the measurement of the complex QI. Since the classification scale according to this complex QI remains clear, the final classification result is determined by the intersection of a fuzzy number with the classification scale. The final result of the classification can be obtained as an assignment to one category, if the fuzzy number carrier belongs to one category, or as an assignment to several categories according to the fuzzy number carrier.

Thus, taking into account the measurement uncertainty in the M/C procedure, two methods can be used, based on the application of either a fuzzy classification scale, or on presenting the measurement result as a fuzzy number. But regardless of these methods, it is clear that measurement uncertainty in the M/C procedure leads to the dispersion of classification results into several categories with the appropriate degree of belonging.

SONOLUMINESCENT SPECTROSCOPY IN THE DETERMINATION OF THE MAIN SUBSTANCE CONTENT IN BRINES

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To control the content of the main substance - sodium chloride, in brines the most effective method is considered to be sonoluminescence spectroscopy [1, 2]. Moreover, when using low-frequency ultrasound (20-100 kHz) to initiate sonoluminescence, results with Sr 0.05-0.07 are provided, high-frequency ultrasound (1-3 MHz) is 0.03-0.04 [1].

The proposed work is devoted to the use of sonoluminescence initiated by ultrahigh-frequency ultrasound (10-25 MHz) to determine the content of the main substance in brines. The frequency of ultrasound, which was used to initiate sonoluminescence, affected the intensity of sodium chloride sonoluminescence (Table 1).

Table 1 – The intensity of sonoluminescence of sodium chloride in brines depending on the ultrasound frequency

Brine sample	Intensity of sonoluminescence of sodium chloride (units) at the frequency of ultrasound (MHz)					
	10	15	18	20	22	25
Brine of the Drohobytsky source	11,03	0,59	1,06	2,43	4,76	0,74
Brine of the Jaksy-Klych source	15,17	1,27	1,65	2,99	6,10	1,14
Synthetic brine – 400 g/l	9,54	0,47	0,97	2,34	4,22	0,61
Synthetic brine – 600 g/l	14,27	0,70	1,43	3,49	6,33	0,89

Notes. The averaged results of six experiments are presented. The intensity of ultrasound is 20 W/cm2. The temperature of the solution is 20.0±0.5 C.

The intensity of the sonoluminescence of sodium chloride during the transition of the ultrasound frequency from 10 MHz to 25 MHz undergo the following changes: during the transition from 10 to 15 MHz it decreased, then from 18 to 22 MHz it increased and then decreased again.

It should also be noted that the intensity of sonoluminescence of sodium chloride brines of different deposits differed from the intensity of sonoluminescence of synthetic brine.

This can be explained both by the different concentration of sodium chloride in

the brines of different sources (400±50 g/l), and by the presence of impurities in the brines, primarily of an organic nature, which affect the intensity of the sonoluminescence) [2].

It should also be pointed out that the intensity of sonoluminescence was proportional to the value of the ultrasound concentration for all studied frequencies (Table 1).

The intensity of sonoluminescence of sodium chloride with increasing ultrasound intensity increased to the maximum possible intensity of 20 W/cm^2, which is limited by the mechanical strength of currently existing piezoelectric emitters [2]. Thus, we have shown the possibility of using sonoluminescence spectroscopy initiated by ultrahigh-frequency ultrasound to determine the content of the main substance in brines. The method of analysis was developed. The correctness of the method was checked by analyzing the same samples by different methods (Table 2).

Table 2 – The results of determining the main substance in brines (n=6; P=0.95)

Brine sample	Injected, g/l	Found out, g/l							
		By sonoluminescent method						By gravimetric method [2]	
		US 22,0 кHz		US 12,0 MHz		US 22,0 MHz		$\overline{C}$	S_r
		$\overline{C}$	S_r	$\overline{C}$	S_r	$\overline{C}$	S_r		
Brine of the Drohobytsky source	–	365	0,054	370	0,029	372	0,016	362	0,011
	50	407	0,056	418	0,033	417	0,016	407	0,012
Brine of the Jaksy-Klych source	–	398	0,075	394	0,040	399	0,018	321	0,010
	50	440	0,072	442	0,039	347	0,019	360	0,012
Synthetic brine - 400 g/l	–	397	0,029	397	0,011	398	0,010	391	0,010
	50	439	0,030	445	0,012	448	0,011	440	0,010
Synthetic brine - 600 g/l	–	592	0,045	595	0,043	598	0,012	581	0,012
	100	680	0,047	687	0,050	689	0,013	639	0,012

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SONOLUMINESCENT SPECTROSCOPY IN THE DETERMINATION OF THE CONTENT OF MACROIMPURITIES IN BRINES

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Atomic absorption spectrometry is considered to be the most effective method for controlling the content of macro impurities in brines - calcium and magnesium salts [1]. However, the use of atomic absorption spectrometry to determine the content of calcium and magnesium salts directly in the well is technically impossible. Currently, the most technically proven method of determination of the amount of calcium and magnesium in brines directly in the well is the method of sonoluminescence spectroscopy [2]. However, when using low-frequency ultrasound (20-100 kHz) to initiate sonoluminescence, results with a sensitivity of 5-6 g/l are provided, which does not meet the requirements of industry - at least 0.01 g/l. [2]. We have previously shown that the use of simultaneous exposure to high and low-frequency ultrasound to initiate sonoluminescence, which compared to low-frequency ultrasound, allows to increase the sensitivity of determining calcium and magnesium in brines from 5.0 to 6.0 g/l to 1 ,0 - 3.0 g/l [2].

The proposed work is devoted to the use of sonoluminescence initiated by the simultaneous action of ultra-high-frequency ultrasound (10-25 MHz) and low-frequency ultrasound (20-100 kHz) to determine the content of calcium and magnesium salts in brines. When using simultaneous influence of ultra-high and low-frequency ultrasound, the lower limit of determined concentrations of magnesium and calcium chlorides in brines decreased 5 times compared to the use of high- and low-frequency ultrasound and amounted to 0.10 g/l (Table 1) [2].

Table 1 – Intensity of sonoluminescence of aqueous solutions of magnesium and calcium chlorides depends on the frequency of ultrahigh-frequency ultrasound and the concentration of the solutions

Determined component and solution concentration (g/l)		Intensity of sonoluminescence (units) at the frequency of ultrasound				
		18 MHz	19 MHz	20 MHz	22 MHz	23 MHz
$CACI_2$	0,10	-	0,04	0,23	0,22	0,09
	0,20	-	0,07	0,41	0,40	0,17
	0,40	-	0,12	0,90	0,85	0,30
	1,00	0,22	0,33	2,01	2,00	0,74
	2,00	0,43	0,64	1,92	1,93	1,45
$MGCI_2$	0,10	-	-	0,16	0,17	-
	0,20	-	0,08	0,30	0,32	0,12
	0,40	-	0,16	0,57	0,56	0,23
	1,00	0,14	0,39	1,49	1,45	0,41
	2,00	0,26	0,76	2,94	2,90	0,76

At the same time, the best results were obtained with simultaneous exposure to ultra-high-frequency ultrasound with a frequency of 20-22 MHz, intensity of 20 W/cm^2 and low-frequency ultrasound with a frequency of 19-22 kHz, intensity of 1.3-1.5 W/cm^2.

Table 2 – The results of determination of macro impurities in brines

The component to be determined	Injected, g/l	Found out, g/l							
		By sonoluminescent method						Atomic absorption method [1]	
		US 22,0 кHz		US 22 кHz+4 MHz		US 22 кHz+22 MHz		$\overline{C}$	S_r
		$\overline{C}$	S_r	$\overline{C}$	S_r	$\overline{C}$	S_r		
Synthetic brine 400 г/л NaCI, 0, 40 g/l $CaCI_2$ and $MgCI_2$									
$CaCI_2$	-	-	-	-	-	0,39	0,025	0,40	0,017
	1,00	-	-	1,32	0,056	1,40	0,022	1,37	0,019
$MgCI_2$	-	-	-	-	-	0,40	0,024	0,38	0,018
	1,00	-	-	1,27	0,054	1,36	0,023	1,32	0,018
Brine of the Drohobytsky source (Ukraine)									
$CaCI_2$	-	-	-	-	-	0,22	0,026	0,21	0,019
	5,00	3,92	0,092	5,12	0,084	5,19	0,023	5,14	0,018
$MgCI_2$	-	-	-	-	-	0,32	0,024	0,34	0,017
	5,00	4,21	0,101	5,19	0,080	5,29	0,023	5,32	0,019

From the table 2, it turns out that the method of sonoluminescence spectroscopy, which uses ultrasound of ultra-high and low frequencies to initiate sonoluminescence, has better metrological characteristics than the same method, which uses simultaneous action of ultrasound of high and low frequencies. The method of atomic absorption spectrometry has better metrological characteristics when determining calcium and magnesium in brines than the sonoluminescence spectroscopy method proposed by us, but its use for the analysis of brine directly in the well is problematic when using modern technology.

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ATOMIC - ABSORPTION DETERMINATION OF CHROMIUM IN TABLE SALT USING MATRIX EXTRACTION SEPARATION AND ULTRASOUND ACTION

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When analyzing only some substances, the method of extractive separation of the base can be used to concentrate Chromium. A table salt is also related to such substances.

It is known that sodium chloride, which is the main substance of table salt, > 94%, dissolves in hydrogen peroxide at low temperatures (in the range from -5 to -10 ° C [1].

The purpose of the work is to develop a methodic of atomic absorption determination of chromium in table salt using the extraction separation of the base. Based on the study of the solubility of sodium chloride in hydrogen peroxide under the influence of low-frequency ultrasound (US), a method for Chromium determination in sodium chloride and table salt was developed.

In the Table 1 the results of determination of the chromium content in table salt using different methods of analysis are shown: 1) using mechanical stirring [1], 2) using low-frequency ultrasound, 3) using simultaneous action of high- and low-frequency ultrasound.

Table 1 – The results of Chromium determination in table salt

The method of concentrate preparation	Found out, mg/kg / S_r (n = 6, p = 0,95)			
	Table salt «Extra»		Table salt «Artemsil»	
	Injected Chromine, mg/kg			
	0	0,06	0	0,06
1)Without US	0,029±0,050 0,101	0,090±0,052 0,102	0,039±0,059 0,091	0,094±0,053 0,092
Low frequency US	0,033±0,003 0,041	0,093±0,007 0,044	0,044±0,004 0,042	0,103±0,007 0,040
Two frequency US	0,034±0,002 0,022	0,094±0,002 0,023	0,046±0,002 0,021	0,105±0,002 0,022

The use of two-frequency ultrasound compare with the use of single-frequency ultrasound allows to increase the solubility of sodium chloride in hydrogen peroxide from 42.01 to 47 g/100ml, increase the degree of extraction of the injected part of Chromium from 94-95 to 98-99%, improve the metrological characteristics of the results of the analysis of table salt (Table 1).

The comparative characteristics of known and developed methodic for determination of the Chromium content in table salt are shown in the Table 2. The

presented in the Table.2 data show that the developed methods are better known for their expressiveness and the value of the relative standard deviation of the analysis results.

Table 2 – Comparative characteristics of known and developed methodic for Chromium determination in table salt

Parameters	Methods to obtain the concentrate	
	Without US	With US of one frequency/ with two frequency US
The lower limit of Chromium determination, mg/kg	0,001	0,001/0,001
Sr analysis of table salt with content of 0.034 mg/kg	0,102	0,042/0,022
Time of analysis of 10 samples, min.	46-52 min.	55-65 /55-65
The degree of injected Chromium extraction, %	85	94 94-95/ 98-99

Methodology of analysis

A sample of sodium chloride (table salt) crushed in a mortar to a dust-like state with a mass of about 40 g is placed in a pre-dried glass crucible No. 4 and weighed to with an accuracy about 0.001 g. Crucible with the sample is placed in a glass, cooled to a temperature of -20 - 25 C and affect the system by the simultaneous action of ultrasound with a frequency of 18 - 100 kHz and an intensity of 0.25-0.50 W / cm^2 and ultrasound with a frequency of 1.0 - 2.0 MHz and an intensity of 0.25-0.50 W/cm^2 during 20 - 25 sec. Then, as hydrogen peroxide flows, the crucible with a sample is transferred to another beaker (t = -20 -25 C) and the process is repeated. The filtering crucible is placed in a percaline cup, heat it up to room temperature, add 30 ml of hydrochloric acid (1:1) heated to 60°C and heat the cup with the crucible up to boiling point. Then take out the crucible and wash it with two portions of hydrochloric acid of 5 ml each. The liquid in the cup is evaporated up to a volume of 4 ... 5 ml, replaced in a test tube with sticks and diluted with hydrochloric acid to a volume of 10 ml. In the obtained concentrate, the Chromium content is determined by the atomic absorption method.

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POLYNOMIAL APPROACH FOR ESTIMATING PARAMETERS OF A LINEAR REGRESSION MODEL WITH NEGATIVE KURTOSIS ERRORS

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One of the most significant and actual problem in descriptive statistics is to obtain the parameters of different regression models including a linear regression. Solving this issue with applying different methods can be finding in many tasks of econometric, measurement, biology, medicine etc. In some practical cases the stochastic component of linear regression is distributed according to symmetric density low and have a non-gaussian nature [1].

The approaches which can be found for estimation parameters of linear regression model most often include the Least Squares Method (LSM) and its modifications. However, the methods, which are use the higher order statistics (moments or cumulants) can be applied, when the density function is not known [2]. But there is one of new and progressive method, that operates on a set of moments or cumulants – Polynomial Maximization Method (PMM) [3] and can be applicable to finding linear regression model parameters.

It is known that if the regression residuals have a non-Gaussian symmetric distribution, PMM estimates with a polynomial of power $s = 2$ have the same accuracy as LSM estimates. Based on the above, purpose of this research can be formulated as follows: to compare accuracy of least squares method (LSM) and the polynomial maximization method (PMM) of power $s = 3$ when the linear regression residuals have the distribution with negative kurtosis. The criteria for comparing efficiency for this task can be chosen as the ratio of the variances of the estimates calculated for both methods.

As in the real-world case, this research does not have any prior information about the initial data sample, except for the negative kurtosis of random errors. And several model distributions are used only for generation the random variables with the required stochastic features: U-quadratic, U-shaped, V-shaped and Kumaraswamy [4].

The major mathematical task of this research is to obtain estimates of linear regression model parameters by using the polynomial maximization method of power $s = 3$. In general, the latter involves solving a nonlinear system of polynomial equations that has as many equations as the parameters to be estimated. This is due to the use of a linear regression model with two parameters. The coefficients near the estimated parameters can be obtained from the calculation of a posteriori estimates of higher order statistics - sample moments up to and including the order of 6 LSM regression residuals.

In the experiment performed in this research, it was used the most common method of simulation modeling - the Monte Carlo method, which is based on obtaining

a large number of random data realizations that have stochastic properties of the real data. To achieve this, the mathematical language R with additional packages was used.

The complete modeling procedure consists of the following stages: generating random data with negative kurtosis for each distribution model used in research, constructing a linear regression with two parameters, designing a system of PMM equations of power $s = 3$, finding estimates of the linear regression parameters using PMM and LSM, and comparing the variance of estimates, finding for each method. In addition, the accuracy of the parameter estimates was examined depending on the sample size, which varies from 20 to 200 values of experimental data.

Basically, the research confirms the efficiency and superiority of the polynomial maximization method over the least square's method by the criterion of the ratio of estimates variance when the stochastic component of the regression model has a negative kurtosis coefficient. However, the advantage of the PMM also depends on the level of non-Gaussian properties of the random component of the model and the size of the data sample. Analyzing the accuracy of parameter estimates, when the random data models were U-quadratic and V-shaped, the ratio of the advantage of the PMM over the LSM is more than 5 times, excluding the case of a small sample size ($n = 20$). In the last one, the advantage decreases to 2 times. In cases where the stochastic component had the properties of a U-shaped and Kumaraswamy distribution, which have the smaller negative kurtosis, the efficiency of PMM in relation to LSM was lower and was observed at the level of 2-3 times, depending on sample size.

Summarizing the results obtained in the research, it is possible to assert the effectiveness of using the polynomial maximization method to obtain estimates of linear regression parameters with a non-Gaussian random component.

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COMPARATIVE ANALYSIS OF THE ACCURACY OF QUADRATIC ESTIMATORS (SLS VS PMM2) FOR NON-LINEAR REGRESSION WITH ASYMMETRIC ERRORS

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The Least Squares Method (LSM), owing to its broad application spectrum, holds a special place among mathematical statistics methods. Although the linear variant of this method, known as Ordinary Least Squares (OLS), is commonly applied in practice, several non-linear modifications of this method are known. Notably, the quadratic variant, "Second-order" Least Squares (SLS), demonstrates its efficacy in the presence of asymmetry in the distribution of regression errors [1].

For the estimation of parameters with unequally distributed non-Gaussian statistical data, the Polynomial Maximization Method (PMM) can also be employed. It is known that when the degree of the stochastic polynomial $S=1$, it is also equivalent to the ordinary least squares method [2].

The aim of this research is a comparative analysis of the accuracy of the quadratic modification of the least squares method (SLS) and the polynomial maximization method with degree $S=2$ (PMM2), exemplified by the statistical estimation of parameters of two types of non-linear regression (exponential and logistic growth) models. The criterion for efficacy (accuracy) is the magnitude of the ratio of the variance of parameter estimates for each of the methods (SLS and PMM2) compared to the variance of the estimates from the ordinary least squares method (OLS).

The mathematical formulation of the estimation problem presupposes that the stochastic component (random errors) has a significantly different asymmetric distribution from the Gaussian, albeit a priori information about the parameters of this distribution is absent. Such a limitation is conditioned by the conditions of statistical processing of real data.

It is shown that the general task of obtaining estimate values of the sought parameters of the regression model, applying the polynomial maximization method at degree $S=2$, can be reduced to solving a system of M non-linear equations (where M is the number of informative parameters to be estimated). To ensure the functioning of the estimation algorithms, an adaptive approach is utilized [3], which involves finding posterior estimates of the 2nd order cumulant and cumulant coefficients of skewness and kurtosis of regression OLS residuals.

R programming language is used as a tool for implementing statistical modeling. This choice is due to its free distribution, as well as the availability of a large number of libraries oriented towards numerical mathematics and data analysis tasks. Specifically, the "nleqslv" package is used, containing a set of functions for solving the problem of finding roots of systems of non-linear equations, which arises when

applying the polynomial maximization method.

For the comparative analysis of the efficacy of the methods, an indirect approach is used. It involved initially calculating, through statistical modeling using the Monte Carlo method, the variance of OLS estimates and PMM2 estimates, obtained under identical initial conditions (sample sizes and probabilistic properties of the error component of regression models) with the corresponding experimental data of the study [1]. Among other things, these data contain estimate values of the variance of OLS estimates and SLS estimates, the ratio of which was used for comparison.

Based on the totality of statistical modeling results, general conclusions can be drawn that the efficacy (magnitude of the variance of estimates) of the SLS and PMM2 methods generally exceeds the accuracy of classical OLS with an asymmetric character of the distribution of the random component of regression models. Although the degree of advantage varies significantly depending on the form of the regression model, the type of their parameters, and the volume of sample values. Specifically, for the exponential growth model, the relative (to OLS) accuracy of SLS estimates is slightly higher (by 5-10%) than PMM2 estimates. However, for the logistic growth model, conversely, the PMM2 estimates are slightly more accurate (by 5-20%). An important fact is also that with the increase in sample size, the relative accuracy of PMM2 estimates tends towards the theoretically calculated magnitude.

It is evident that for a more accurate comparison of the efficacy of the SLS and PMM2 methods, it is necessary to directly compare the magnitudes of the variance of their estimates, which need to be obtained on the same statistical data. But this requires a separate algorithmic implementation of the SLS estimator. Another important research direction is analyzing the peculiarities of using various numerical methods for solving systems of non-linear equations that arise in the process of searching for parameter estimates, and tuning their hyperparameters.

Overall, the obtained results once again confirm the potential efficacy of applying the apparatus of Kunchenko's stochastic polynomials for solving practical statistical regression analysis tasks even under conditions of a priori uncertainty.

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MEASUREMENT UNCERTAINTY EVALUATION AT TESTING VEHICLES IN TERMS OF EXTERNAL AND INTERNAL NOISE LEVELS

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The levels of internal and external noise relate to the parameters of environmental safety of motor vehicles (MV), which is achieved by limiting radiation from the car, which has a negative impact on road users and the environment.

Clause 59 a of Chapter III of the International Convention on Road Traffic [1], they say that the mechanisms and equipment of vehicles do not create noise. This helps to lead to the need to regulate parameters for intensity, spectral composition, and sometimes ATS noise, as well as monitoring their compliance.

A classification of noise was carried out, and testing methods for vehicles were analyzed according to the level of external and internal noise [2].

To measure internal noise, a class 1 sound level meter [3] should be used, with frequency correction turned on, corresponding to the "*A*" scale. Measurements should be made when the vehicle is accelerating and when it is moving at a constant speed. In this case, at least 3 measurements are performed at each point and their arithmetic mean is taken as the result.

When measuring external noise, two situations are considered: noise emitted by moving and stationary MVs.

The characteristic noise level produced by a moving MV is calculated using the formula:

$$L_R = L_{acc} - K(L_{acc} - L_c)$$

where L_{acc} is the maximum sound level measured during acceleration, dBA; L_R – maximum sound level measured during constant speed tests, dBA; K – a weighting coefficient depending on the relative power and transmission system; its values for various vehicles are given in [4].

Measurements of the maximum noise level from a stationary MV are made during the period of engine operation. At each measurement point, at least three observations are made. The test result will be considered the maximum value of the three readings.

The measurement equation was written down, procedures and budgets for uncertainty evaluation were drawn up, and expressions for expanded measurement uncertainty evaluation were given [5].

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PECULIARITIES OF MEASUREMENT RESULTS PROCESSING WHEN CALIBRATING HYGROMETERS

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Various types of hygrometers are widely used to measure of the gas's humidity. Hygrometers must be calibrated to traceability ensure of humidity measurement results to SI units. At the same time, in accordance with the requirements of ISO/IEC 17025:2019 [1], the laboratory must have a procedure for measurement uncertainty evaluating.

The most common hygrometer calibration scheme involves comparing the readings of the calibrated and reference hygrometers using a comparison device – a humidity generator. Such a scheme requires taking into account the correlation between the measuring results of the calibrated and reference hygrometers while simultaneously measuring the humidity in the generator chamber [2].

The calibration scheme and a mathematical model describing it are presented. The procedure for the measurement uncertainty evaluation at hygrometer calibration by the method of comparison with a reference hygrometer is given, taking into account the possible correlation between the readings [3]. An example of measurement uncertainty evaluation at hygrometer calibration in the metrological laboratory NPP "Kozloduy" is considered.

The need to calibrate a large number of hygrometers used for environmental monitoring in a large industrial plant such as Kozloduy NPP requires an increase in calibration performance. The issues of increasing the hygrometer calibration productivity associated with the processing of measurement results are investigated. The possibility of using the characteristics of the range of a sample of observations [4] for evaluation the numerical value of the measurand and its standard uncertainty of type A is substantiated.

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APPLICATION OF THE KURTOSIS METHOD IN CONSTRUCTING UNCERTAINTY BUDGETS AT CALIBRATION OF MEASURING INSTRUMENTS

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The uncertainty of measurements conducted in calibration laboratories (CLs) is currently evaluated in accordance with the Guidelines [1] European co-operation for Accreditation (EA). However, that document essentially describes a basic algorithm for measurement uncertainty evaluating based on GUM [2] without accounting for the specifics of a calibration or examining the main step in the evaluation of uncertainty – setting up model equations whose adequacy for the method being applied determines the accuracy of the entire subsequent process of calculating the measurement uncertainty.

In this report, we formalize the procedures for measurement uncertainty evaluating at calibrations, which can be done by analyzing the measurement methods, and comparing models for, the propagation of uncertainty and uncertainty budgets in measurements employed at calibration process. This is based on the approach used in [3] to analyze the uncertainty of the main calibration methods:

• direct measurement by an indicating measuring device (IMI) of a value reproduced by a material measure (MM);

• comparison of values measured by the reference and calibrated IMIs using a transfer measurement device (TD) or values reproduced by the reference MM and MM to be calibrated using a comparator.

The result of calibration is a calibration certificate issued by the CL. One of the main parameters indicated in the certificate is expanded uncertainty (EU) which is obtained by multiplying the standard uncertainty of the measurand (combined standard uncertainty) by the coverage factor. Guidelines [1] recommend taking 2 as the coverage coefficient for a confidence level of 0.9545 or, in the presence of uncertainty contributions calculated by type A, taking as the coverage factor the Student coefficient for the effective number of degrees of freedom determined by the Welch-Satterthwaite equation. Both of these estimates are approximate, since they do not depend on the probability density function (PDF) of the input quantities.

A reliable estimate of the expanded uncertainty cannot be obtained without taking into account the PDF of input quantities, which is usually done by the Monte Carlo method (MCM) [4]. For calibration problems, a reliable estimate of the expanded uncertainty can be obtained using the kurtosis method [5]. Its use makes it possible to automate the calculation of uncertainty, and estimates of expanded uncertainty will be close to those obtained by MCM.

The construction of uncertainty budgets is considered for the above calibration methods separately for MMs IMIs. In this case, four schemes are obtained, the measurement uncertainty evaluation of which has its own features.

So, for example, when comparing a reference IMI and IMI to be calibrated, under certain conditions there may be a correlation between their readings. It is not possible

to take this correlation into account when calculating the coverage factor using the GUM recommendation [2]. In [6], the authors propose a method for calculating the coverage factor taking into account the correlation between IMIs readings both through the Welch–Satterthwaite equation and through the kurtosis method.

All considered methods for constructing uncertainty budgets based on the kurtosis method are illustrated with examples from metrological practice of calibrating various measuring instruments: direct measurement of the value reproduced by the reference gauge block by a micrometer to be calibrated [7], comparison of the reference glass thermometer and thermometer to be calibrated using a thermostat [8], calibration of the resistance box using a reference ohmmeter [9] and comparison the reference weight and weight to be calibrated using mass comparator balance [10].

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