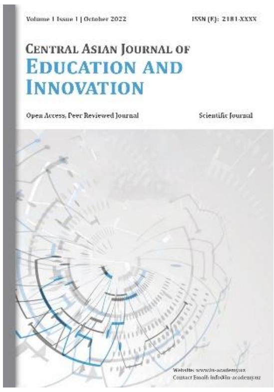


# TECHNICAL BASIS FOR METROLOGICAL VERIFICATION OF FLOW METERS FOR LIQUIDS AND GASES AND METHODS FOR CALCULATING THEIR UNCERTAINTY

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**ABSTRACT**

*This article is devoted to the theoretical and practical foundations of metrological verification of flow meters for liquids and gases, and discusses methods for assessing the accuracy, reliability and stability of flow meters. It is argued that flow meters are directly used in many areas, such as industry, energy, chemistry, oil and gas systems, ecology, water supply, heat and energy calculations, and their correct operation is a decisive factor in ensuring economic efficiency, rational use of resources and safety.*



## Introduction

General information on the types of flow meters, their design and measurement principles, in particular volumetric and mass flow meters, turbine, electromagnetic, ultrasonic, differential pressure, rotametric and Coriolis type devices are described as the most basic devices encountered in the process of metrological inspection. Along with their method of operation, scope and advantages, there are also factors that can cause measurement errors.

The content, technical requirements and stages of metrological verification are such processes as extensive calibration, comparison with reference instruments, standardization of conditions, testing using stand equipment and isolating errors of the measurement system. The parameters measured during the verification include physical quantities such as flow rate, pressure, density, temperature, pipe diameter and flow profile, which have a significant impact on the measurement result, so the stability of the test environment must be ensured. The role of mathematical modeling in uncertainty assessment is also important. Today, numerical methods such as Monte Carlo simulation, error propagation theory, regression analysis are used in metrology. We will consider the concept of measurement uncertainty as a basic scientific category.

The role of uncertainty in metallurgy and standardization is explained as the difference between the measurement result and the true value and the confidence interval for the results. Two main approaches to uncertainty assessment - statistical assessment of type A and expert assessment based on certificate data of type B - are considered important, which are widely used in practical metrology. Type A uncertainty represents random errors determined by the analysis of repeated measurements, while type B uncertainty represents components estimated based on the manufacturer's error limits, the accuracy of reference instruments, environmental changes and an experimental approach. The overall uncertainty estimate is determined by combining types A and B, and the expanded uncertainty is determined by the confidence coefficient (usually k = 2) and is recommended as the main indicator of how reliable the measurement result is for the consumer. At the same time, the annotation scientifically analyzes the sources of error encountered in the verification of flow meters - flow irregularities, sensor wear, changes in fluid viscosity, differences in gas density with pressure, and errors due to installation conditions.

The practical significance of the work is that the correct application of metrological verification methods of consumption measuring instruments allows for accurate accounting of resources, reduction of losses, strengthening of technical safety and increasing the efficiency of the work process. In addition, calibration stands and automated test systems ensure the objectivity of metrological control. Based on this, an in-depth study of metrological verification of liquid and gas consumption measuring instruments and assessment of uncertainty using scientifically based methods is an urgent issue for industry, scientific research and management systems:

- accuracy class given by the manufacturer;
- certificates of reference instruments;
- influence of environmental parameters.

This uncertainty is often given in the form of an interval.

To determine the combined uncertainty, types A and B are combined:

$$uc = \sqrt{u_A^2 + u_B^2} \quad (1)$$

This value gives the overall level of confidence of the measurement result.

Expanded uncertainty In practice, as a conclusion for the consumer: $U = k \cdot u_c$ (2)

where k is the confidence coefficient (usually k = 2).

The most common sources of error in metrological verification are the following:

- flow profile irregularities;
- sensor age and wear;
- fluid temperature or viscosity changes;
- gas density changes due to pressure;
- incorrect installation conditions All measurements should be performed in a standardized environment.

Test and verification stands Metrological centers have stands for checking flow rates, which are:

- by size ranges;

- by type of liquid or gas;
- by calibration accuracy. The stands are equipped with automated control, digital recording, and statistical analysis systems.

Documentation of results At the end of the inspection, the following documents are issued:

- metrological certificate;
- verification protocol;
- uncertainty assessment reports. They serve as the basis for packaging, commercial calculations, or state control.

The fact that liquid and gas flows can be turbulent or laminar, characterized by the Reynolds number, is noted as the main parameters that directly affect the measurement results. Therefore, the metrological verification process is based on the correct modeling of physical processes, rather than simple mechanical comparisons.

In flow meters operating on the basis of differential pressure, the flow rate is expressed in a quadratic relationship. This creates a nonlinearity of the measuring system and introduces additional errors into the uncertainty. In ultrasonic meters, the flow is determined by the time difference method or the Doppler effect, in which signal delay, echo in the pipe and turbulization can significantly affect the flow profile. In mass flow meters of the Coriolis type, the pipe vibration frequency and mass-dependent inertia changes are measured, which causes errors associated with thermodynamic effects, stiffness gradients and mechanical resonance. Therefore, metrological verification methods for different types of meters also differ.

**Conclusion:** The process of determining the consumption of liquids and gases is technically complex, and the accurate operation of measuring instruments is of great importance. Metrological verifications are carried out on the basis of reference devices, standardized stands and control conditions. The assessment of measurement uncertainty is based on statistical and analytical approaches. The correct calculation of uncertainty ensures that the measurement results are reliable, legally justified and technically convenient.

The correct organization of metrological verification of measuring instruments for liquids and gases is of decisive importance for the stability of industrial processes, the accuracy of resource accounting and an increase in the level of safety. The reliability of measurement results is ensured by minimizing measurement errors during the verification process, scientifically calculating uncertainty, improving calibration and validation systems. In the future, modern digital technologies, artificial intelligence and automated metrological systems are expected to increase the accuracy of measurements and real-time monitoring, which will bring a new level of quality to control processes.

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