Features of automation of gas meter verification process using bell-provers

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Abstract — **This paper presents an analysis of a bell-prover used for the metrological verification of gas flow meters and gas meters, highlighting its advantages and disadvantages. Based on the analysis of scientific sources and experimental studies of reference bell-provers, it was established that these installations are the most accurate means for testing and calibrating gas meters. However, their metrological characteristics significantly depend on the operating conditions, particularly on working pressure, sealing liquid level, and ambient temperature. Variations in pressure can cause systematic errors up to 1.5%, while fluctuations in the sealing liquid level due to temperature, evaporation, or vibration can cause errors up to 0.7%. These errors can be considerably reduced through automation of gas volume reproduction and gas meter verification. The authors have proposed to improve the systems for air pressure stabilization under the bell, control of sealing liquid level to compensate for its dynamic variation, and stabilization of air temperature during meter verification.**

Keywords — **bell-prover, gas volume reproduction, automation, measurement error, dynamic changes of gas parameters, control system.**

I. Problem Statement

Accurate measurement of natural gas flow is a critical task in the power engineering, industrial, and municipal sectors. Errors in gas flow and volume measurements may result in significant economic losses and complicate financial settlements between suppliers and consumers.

Various methods and installations are used for testing and calibrating gas meters to ensure high accuracy of gas flow and volume reproduction. Among these are bell provers, piston provers, installations based on reference meters, and critical flow nozzles [1,7]. Each method has specific advantages and limitations that must be considered in metrological assurance of gas measurement instruments.

In addition, bell-prover flow-measurement installations are widely used both in Ukraine and around the world. These devices are the basis for national and international calibration laboratories, in particular in the Netherlands [8], Germany [10], and are also used by companies in many European countries, for example in Croatia [6]. In Ukraine, the national gas flow and volume standard is also based on a bell-prover installation. At Lviv Polytechnic National University, a bell-prover flow-measurement installation is used for both educational and research purposes. Therefore, improving the accuracy and efficiency of bell-provers, particularly through automation, is an urgent task that can increase the accuracy of natural gas accounting in our country.

II. Features of Bell-Prover Automation

Bell-prover reference installations are widely used for gas meter verification due to their high precision in reproducing gas volume. Their operating principle is based on displacing gas by a bell that moves downward under its own weight, generating a steady gas flow [1].

A bell-prover installation consists of the following main components:

1) gas bell – the main chamber that is immersed in the liquid; the bell must have a hard and smooth surface to ensure uniform movement [11], the dimensions of the bell depend on the flow range that needs to be reproduced;

2) a tank with a liquid into which the bell is immersed; the tank is filled with water or oil (to protect against evaporation or changes in humidity) and ensures the tightness of the volume beneath the bell; the liquid provides hydrostatic pressure that reduces gas leakage during displacement;

3) bell position measurement system; the movement of the bell (raising or lowering) is controlled by special position sensors to determine the volume of gas; modern installations commonly use digital-output position sensors that deliver precise real-time position data.

4) measuring devices: the installation must be equipped with sensors for measuring temperature, pressure and humidity, as these parameters affect the gas volume and, accordingly, the accuracy of reproducing the gas flow rate and volume; some installations use temperature and pressure compensation algorithms to ensure high measurement accuracy [12].

A schematic diagram of a free-moving bell-prover is shown in Fig. 1 [11].

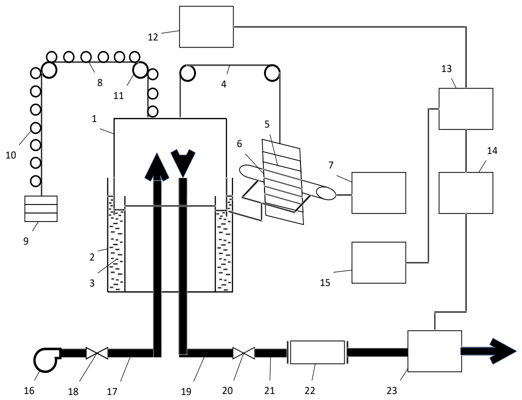

Figure 1. Schematic diagram of a free-moving bell-prover [11]: 1 – bell, 2 – liquid-filled tank, 3 – liquid, 4 – steel tape for attaching reference scale, 5 – reference scale, 6 – optoelectronic pair, 7 – microprocessor-based volume transducer, 8 – steel tape for attaching the bell, 9 – counterweight, 10 – local weights for pressure stabilization, 11 – pulley, 12 – brake clutch, 13 – torque control unit, 14 – setpoint generator for unit 13, 15 – pressure sensor beneath the bell, 16 – blower, 17 – inlet pipeline, 19 – outlet pipeline, 18, 20 – shut-off valves, 21 – test section, 22 – research flow meter, 23 – flow rate setting node

The cycle for reproducing a unit flow (volume) of gas and for verifying the gas flowmeter (meter) 22 is carried out as follows. Before testing, the required operating mode of the torque-control unit 13, which controls the brake clutch 12, is set by the setpoint generator 14. This establishes the necessary braking torque on pulley 11 of the compensation mechanism corresponding to the target gas flow and sets the required position of the throttling element in assembly 23 that defines the flow through the test section. The bell is then filled with the working gas in the following sequence:

- with valve 18 open and valve 20 closed, blower 16 feeds working gas through the inlet pipeline 17 into the space beneath the bell; this continues until bell 1 reaches its upper (raised) position;

- when the required position is reached, valve 18 is closed, the gas supply is stopped, and the bell is in a stationary, suspended state.

After that, the specified gas flow is reproduced and the flowmeter (meter) 22 is checked. To do this, the shut-off valve 20 is opened and the working gas is supplied to the test section 21. Under it's own weight bell 1 begins to slowly descend, displacing the gas through the test section 21 and the research device 22. At the same time, the displaced volume of gas is measured by the microprocessor-based control volume transducer 7, which determines volume from the displacement of the reference scale 5 relative to the optoelectronic pair 6.

Pressure in the space beneath the bell is measured by pressure sensor 15. The sensor output is sent to the input of the torque-control unit 13. When pressure decreases the braking torque is reduced, and when pressure increases the braking torque is raised. In this way a constant gas flow is maintained during the entire bell descent cycle, enabling accurate reproduction and measurement of the volume or flow. At the end of the test the shut-off valve 20 is closed, which signals completion of the cycle.

For metrological verification or calibration of gas meters, the control volume measured by the microprocessor-based volume transducer 7 is determined and compared with the volume simultaneously recorded by the research meter 22. Based on the observed discrepancies, the meter's metrological characteristics are evaluated [11].

As follows from the literature review and from the above description of the free-moving bell-prover installation [11], the main advantages of bell-prover installations are:

- high measurement accuracy and stability of the reproduced gas flow;
- capability to verify devices of various types and designs;
- wide reproducible range of flow rates and gas volumes.

The disadvantages of bell-prover installations include:

- the effect of operating pressure on the accuracy of gas flow (volume) reproduction [1]; limitations on operation at high pressures [3];
- the effect of changing the level of the sealing liquid on the calibration results [2];
- relatively large overall dimensions of the installation, special requirements for the laboratory.

To increase the accuracy of bell-prover installation's operation, various error-reduction methods are proposed, in particular the introduction of digital control systems and automation taking into account mathematical models of processes occurring during the installation's operation [3, 5, 6, 7].

From the presented analysis it is evident that bell-prover installations are high-precision instruments for reproducing gas flow and volume at pressures close to atmospheric. These installations provide a high stability of the reproduced flow. However, to achieve high accuracy and productivity, it is necessary to automate the bell-prover installations taking into account following factors.

The effect of pressure changes beneath the bell on the error of gas flow and volume reproduction is one of the key factors affecting the accuracy in bell-provers.

Studies have shown that when the measuring bell is lowered, pressure fluctuations can occur that affect the accuracy of gas volume reproduction [4]. To stabilize the pressure, it is necessary to use bell weight control systems that ensure uniform immersion and reduce hydrodynamic resistance [3, 4].

The effect of changing the level of the sealing liquid. The sealing liquid level may vary under the influence of external factors such as temperature changes, liquid evaporation, or uneven immersion of the bell. A change in liquid level directly affects the displaced gas volume and can lead to an error in the measurement of the gas volume of up to 0,7% [2]. To solve this problem, an error correction model was developed in [2] that takes into account the change in the liquid level during the operation of the installation. The main idea is to dynamically balance the level of the sealing liquid and use compensation mechanisms to maintain a stable level.

The effect of gas temperature. When the temperature rises, the gas expands, which can introduce additional errors in the measured volume. When the temperature falls, the density of the sealing liquid changes, which affects the bell's immersion level. Temperature control is therefore a mandatory measure to minimize errors in bell-prover installations [1]. Even small temperature gradients in the air space around the bell can affect the stability of volume reproduction [7]; consequently, multi-point temperature sensing combined with compensation algorithms is recommended.

Thus, experimental results confirm that the implementation of automated, digital control systems is a key direction for improving the accuracy of bell-prover flow-measurement installations.

III. Conclusions

Based on the analysis of scientific sources, the review of technical characteristics of reference bell-provers, and known research results, the following conclusions were made:

- the metrological performance of bell-prover installations significantly depends on a number of factors, in particular the operating pressure, the level of the sealing liquid, and the ambient temperature; the influence of these factors can lead to significant systematic measurement errors that are unacceptable for reference standards;

- automation of the processes for reproducing gas volume and for calibrating meters (flow meters) plays a key role in reducing errors and increasing the efficiency of a bell-prover; implementation of adaptive control algorithms can substantially decrease the prover's measurement error and shorten the duration of devices calibration.

As a result of the analysis of the bell-prover installation available at Lviv Polytechnic National University as the control object, it is proposed to upgrade the subsystems for stabilization of air pressure beneath the bell, regulation of the sealing liquid level to compensate dynamic level changes and stabilization of air temperature during meter verification. Such improvements will increase the accuracy of the installation, reduce the subjective influence of the operator, and enable integration with data acquisition and analysis systems.

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