MASTER METER PROVER FOR VERIFYING GAS METERS IN THE GAS VOLUME FLOW RANGE UP TO 6500 M³/H

SCIENTIFIC RESEARCH GROUP:

Denys Serediuk
Cand. tech. Sciences, Head of the Center for Scientific Measurement Support
SE Ivano-Frankivsk standard metrology, Ukraine

Yuriy Pelikan
Head of the research laboratory
SE Ivano-Frankivsk standard metrology, Ukraine

Oleksandr Bas
Cand. tech. Sciences, Senior Researcher of the Research Laboratory
SE Ivano-Frankivsk standard metrology, Ukraine

Volodymyr Lemishka
Head of the testing laboratory
SE Ivano-Frankivsk standard metrology, Ukraine

Roman Manulyak
Researcher of the Research Laboratory
SE Ivano-Frankivsk standard metrology, Ukraine

Volodymyr Hulyk
Senior researcher of the Research Laboratory
SE Ivano-Frankivsk standard metrology, Ukraine

Volodymyr Shevchuk
Metrology engineer
SE Ivano-Frankivsk standard metrology, Ukraine

Summary. In the article, the need to create a master meter prover for verifying gas meters in the gas volume flow range up to 6500 m³/h in SE Ivano-Frankivsk standard metrology is presented. An analysis of the existing prover’s types was carried out, indicating the advantages and disadvantages. Reasonable selection master meters of the rotary, turbine and drum type as part of the prover. Features the master meters volume flow ranges, which overlap each other, are determined. The stages of modeling the piping of the reference prover are given. The stages the calibration methodology the reference prover are described. The initial stage involves the
calibration of pressure and temperature sensors, which are mounted as part of the prover to exclude the influence of the installation. Calibration the master meters is carried out with the help of transfer standards, which are calibrated on national standards gas volume and volume flow rate. The components of uncertainty that affect the calculation of expanded uncertainty are described in detail. The features of the developed prover software, which contains the requirements of new verification methods for gas meters of various types, are given.

Keywords: master meter, prover, calibration, verify, gas volume flow rate, uncertainty, transfer standard

SE Ivano-Frankivskstandardmetrology as a scientific metrology center that stores and applies national primary and secondary standards gas volume and volume flow rate units, expanded its own reference base. In particular, the company’s specialists, as part of the initiative research work, developed, manufactured and successfully implemented a prover for verifying gas meters in the gas volume flow range from 0.1 m³/h to 6500 m³/h with the working environment air, close to atmospheric. The prover is operated in laboratory conditions with temperature values of (20 ± 2)°C. The value of the extended uncertainty according to the calibration results does not exceed U ≤ 0.3%. The value of the extended uncertainty of the prover meets the requirements of ≤ 1/3 of the maximum permissible error of the gas meter [1], which is 1% in the gas volume flow range from Qmax to Qt for class 1.0 meters.

The purpose of the article is to justify the need and describe the stages of creating a prover for verifying gas meters in the gas volume flow range from 0.1 m³/h to 6500 m³/h. In addition, it is necessary to analyze the sources of uncertainty during the prover calibration.

The need to create such a prover is dictated by the constant increase in the number of gas meters with a dynamic range (the ratio of the value of Qmax to Qmin) over 1:160 and an internal diameter of up to 300 mm with a standard size of up to G4000. These meters have passed the assessment of compliance with the requirements of technical regulations, have been introduced to the market and are used for gas metering at gas distribution and compressor stations of LLC "GTS Operator of Ukraine" and JSC "Ukrtransgaz", accounting units of gas distribution organizations (RGK, GK «Naftogaz»), heat supplying and heat generating enterprises (TPP, CHP), mining and beneficiation and steel plants. Also, the relevance of using such a prover for verifying gas meters is connected with the introduction of new types of meters into circulation in Ukraine, which contain, among other things, gas volume conversion devices and correction parameter and gas volume reduction. Such meters are made in the form of a complex in which the meter and gas volume corrector are functionally combined.

When analyzing the possible types for creating the prover, the following options were considered as priority: bell-type prover, prover with reference (master) meters and prover with critical nozzles. Each type of provers has a number of advantages and disadvantages. However, bell-type prover are created a priori as standards to ensure the reproduction gas volume and volume flow rate units. Using a prover of this type for verifying gas meters is not cost-effective and time-consuming, since each bell lift requires time and temperature stabilization. In
addition, in order to place a bell prover with a volume flow range of up to 6500 m³/h, a sufficiently high room with preservation of temperature conditions is required, according to the verification methods. Prover with a set of critical nozzles definitely have advantages in terms of the possibility of simultaneously using a set of parallel installed critical nozzles. However, in order to create a volume gas flow rate of 6500 m³/h in an prover with critical nozzles, a very large electrical power of the vacuum unit is needed to ensure the necessary critical pressure drop, i.e., to maintain the vacuum value. In addition, in a set of critical nozzles, a large number of them is needed to ensure all the values of the volume flow of gas, which are specified in the gas meters verification methods. Thus, the prover with reference (master) meters is optimal in terms of costs in relation to the performance of verifying gas meters.

The principle of the prover is based on the comparison of the gas volume reduced to standard conditions, which was calculated by the reference (master) meter, with the volume measured by the experimental meter, which is being verified. A set of turbine, two rotary and drum meters is used as reference(master) meters in the prover. As for rotary meters, the prover includes Delta S–Flow (Itron) and IRM DUO (Elster) meters. The Delta S–Flow meter is a rotary meter with two three-bladed rotors, each blade of which is placed at an angle of 120 degrees relative to the other and offset by 60 degrees in length. This design allows you to completely avoid the resonance phenomena characteristic of rotary meters with ordinary octagonal rotors. Similarly, the specificity of the IRM DUO meter is based on the application of the principle of damping the amplitude of pressure fluctuations from the operation of the rotors, provided that the condition of anti-phase compensation is created. Its essence lies in the following. The internal measuring chamber of the meter is divided into two identical parts, which ensure an even division of the gas flow, in each of which there is a pair of identical ordinary octagonal rotors. Both pairs of rotors are fixed on the same axis, but with a radial angular displacement of 45º, thanks to which the pressure pulsations from the rotors "meet" at the output of the measuring chamber of the meter in antiphase and are thus mutually compensated. In addition, a drum-type meter is used to ensure the minimum volume flow rate in the prover. Accordingly, the provision of the maximum volume flow rate is implemented by the turbine type meter. It should be noted that similar reference meters have a long-term practice of using SE "Ivano-Frankivskstandardmetrolo" as comparison standards when transferring gas volume and volume flow rate units and calibrating verifying provers within Ukraine. Also, the metrological stability of these meters is confirmed by the results of international comparisons gas flow rate national standards by metrological institutes [2].

The meters are selected and, accordingly, calibrated on state primary and secondary standards gas volume and volume flow rate units so that their dynamic ranges overlap. This provides significant advantages over typical verifying provers with reference meters, in which the ranges of the reference meters intersect only at one common point. That is, with the prover software use, it is possible to make diagnostic measurements in order to constantly control the stability of the metrological characteristics and uncertainty of the prover.

Several stages of 3D modeling were carried out for the piping of the prover. At the same time, various construction options were considered with the complete
configuration of pipelines. In fig. 1 shows a fragment of the modeling of the piping of the prover.

Fig. 1. **Modeling stage of the piping of the master meter prover**

Structurally, the installation uses the principle of "least resistance" within the measuring pipeline. That is, the prover does not provide for the use of bulky dampers, collectors or other "extra" elements that can create additional hydraulic resistances or increase pressure losses. In addition, the design provides two parallel straight sections (DN 300 mm and DN 200 mm) for the installation of meters to be verified, as well as a set of vertical connections for rotary type meters of various diameters and sizes (which are installed only vertically). This, in turn, makes it possible to cut off the additional connected volume of the straight section of DN 300 mm diameter during the verification of meters with internal nominal diameters up to DN 200 mm diameter or rotary type meters with vertical connection. In addition, an additional pipeline allows parallel installation of meters for verification, which increases the performance of verification. Also, the section of the reference meters is designed by connecting pipelines without "right angles" and local resistances of the type "sharp narrowing" or "sharp expansion" to reduce additional pressure losses and form the appropriate gas flow profile. To create and ensure a stable air flow, two frequency-regulated centrifugal fans with different maximum volume flow rates are used, which work in the flow rarefaction air flow. The general view of the verifying prover is shown in fig. 2.

The reference prover is located in a specially equipped distributed room, which includes a climate control system and circulation mixing of air flows to ensure a minimum temperature gradient along the height of the prover.

The calculation of the extended uncertainty of the reference prover was made during its calibration. The calibration procedure is carried out according to the methodology [3]. The methodology at the initial stage involves the step-by-step calibration of pressure and temperature measurement channels (on reference meter lines and on the experimental line) and time channel. The calibration of the specified channels is carried out as part of the prover to exclude the influence of the installation, ensure tightness and check the operation of the software. For calibration, a pressure calibrator, a thermostat with a reference thermometer, and a
frequency meter are used. For each channel, the component of total uncertainty according to type A and type B is determined (taking into account the uncertainty of the reference device used for calibration).

The calibration of the gas volume measurement channel, i.e. the reference (master) meter, takes place using transfer standards (meter). For transfer standards periodic calibration is carried out on national state primary and secondary gas volume and volume flow rate standards.

In addition, the uncertainty component is calculated, which is caused by the effect of volume accumulation due to the change in temperature during the verification. To reduce the influence of this effect, the prover is designed using two parallel lines (DN 300 mm and DN 200 mm) for the installation of meters, with the possibility of cutting off the additional connected volume. At the same time, calculations are carried out for each reference meter in the prover. The calculation of this uncertainty component is carried out according to the following formula:

$$\Delta V_{\text{en}} = V_T \left( \frac{T_{\text{enMM}} - T_{\text{stMM}}}{T_{\text{stMM}} + 273,15} + \frac{T_{\text{enTM}} - T_{\text{stTM}}}{T_{\text{stTM}} + 273,15} \right),$$

where:
- $V_T$ – total volume of the internal space of the prover between the transfer standard and the reference meter, $m^3$;
- $T_{\text{enMM}}, T_{\text{stMM}}, T_{\text{enTM}}, T_{\text{stTM}}$ – temperature at the end ($\text{en}$) and at the beginning ($\text{st}$) the transducers measurement on the reference (master) meter ($\text{MM}$) and on the transfer standard ($\text{TM}$), respectively, °C.

The measurement uncertainty is due to the volume accumulation effect:

$$u_{\Delta V_{\text{en}}}=100 \cdot \frac{\Delta V_{\text{en}}}{\sqrt{3} \cdot V_K}, \%$$

where:
- $V_K$ – the control volume that passes through the reference meter during one measurement, $m^3$. 

Fig. 2. General view of the gas meters verifying prover in the gas volume flow range from 0.1 m$^3$/h to 6500 m$^3$/h
The next stage is the calibration of reference (master) meters. It is recommended to calibrate reference meters in descending order of maximum flow. Calibration of each reference meter is carried out at no less than 9 volume flow points, distributed throughout the volume flow range in descending order. Research at additional cost points is allowed if the form of the characteristic of the reference meter requires more detailed research of part of the range. The calibration of the reference meter of the prover consists in determining the conversion factor $K$ corresponding to 1 m³. Its calculation is carried out according to the following formula:

$$K_i = \frac{N_i}{V_i},$$

(3)

$N_i$ – the number of pulses of the reference meter corresponding to the volume $V_i$.

It should be noted that when calculating impulses, uncertainty arises, which is associated with not taking into account impulses at the $i$-th value of the volume flow rate, which is defined as:

$$u_{B,N_i} = 100 \cdot \frac{1}{\sqrt{6}} \cdot \frac{2}{N_i},$$

(4)

According to the results of all measurements, using the least squares method, the coefficients of the approximation polynomial are determined for each reference meter of the following type:

$$K(q) = A_2q^{-2} + A_4q^{-1} + A_6 + A_8q + A_2q^2$$

(5)

$A_i$ – coefficients of the approximation polynomial, which are determined based on the calibration results;
$q$ – volume flow rate, m³/h.

To determine the type B uncertainty component for each reference meter, perform at least 3 measurements using the transfer standard and calculate the uncertainty using the formula:

$$u_{B,MM} = \sqrt{\delta_{PR_i}^2 - \delta_{TM_i}^2}. \sqrt{3}.$$ 

(6)

$\delta_{PR_i}$ – the average the error value obtained for the transfer standard at the prover for the $i$-th value of the volume flow rate, %;
$\delta_{TM_i}$ – the transfer standard error value, obtained during its calibration on the national primary or secondary standards for the $i$-th value of the volume flow rate, %.

After that, the calculation of the measurement uncertainty according to type A is carried out during the master meter prover calibration, taking into account the following components:

$$u_A = \sqrt{u_{AMM_i}^2 + u_{AP}^2 + u_{AT}^2}.$$ 

(7)

$u_{AMM_i}$ – type A uncertainty the reference (master) meter $(MM)$;
$u_{AP}$ – type A uncertainty the pressure measurement;
$u_{AT}$ – type A uncertainty the temperature measurement.
Accordingly, the uncertainty according to the type of master meter prover will be similarly determined taking into account the following components:

\[
U_{B_i} = \sqrt{U_{TM}^2 + U_{BMM}^2 + U_{BP}^2 + U_{BT}^2 + U_{BN_i}^2 + U_{BV_{E1}}^2},
\]

(8)

- \( U_{TM} \) – uncertainty the transfer standard;
- \( U_{BMM} \) – type B uncertainty the reference (master) meter;
- \( U_{BP} \) – type B uncertainty the pressure measurement;
- \( U_{BT} \) – type B uncertainty the pressure measurement;
- \( U_{BN_i} \) – the uncertainty of not taking into account impulses;
- \( U_{BV_{E1}} \) – the uncertainty of the impact of the accumulation effect.

The extended standard uncertainty of volume measurement \( U_i \) is calculated individually for each \( i \)-th reference (master) meter, taking into account components of type A (7) and components of type B (8), according to the following formula:

\[
U_i = 2 \cdot \sqrt{U_{AI}^2 + U_{Bi}^2},
\]

(9)

Based on the results of the calculations, the largest value of the expanded uncertainty is selected.

The software of the reference installation contains the mandatory requirements of new verification methods for gas meters of turbine, rotary, ultrasonic types and meters with built-in conversion devices, which are contained in the national standards DSTU 9033 [4], DSTU 9034 [5], DSTU 9036 [6] and DSTU 9037 [7]. In particular, the formation of an electronic verification protocol for the preservation of the necessary primary data is provided. Also provided is the calculation of the checksum of the program setting parameters, which has an impact on the metrological characteristics, in particular: the conversion coefficients of the reference meters and the calibration parameters of the measuring transducers included in the prover. According to the points of verification methods, two measurements should be performed for each value of the gas volume flow rate. It should be noted that, to assess suitability, the larger of the two values of the obtained basic relative error of the meter is chosen, and not the arithmetic mean value of two consecutive measurements.

The prover, depending on the parameters of the meter to be verified, implements the following verification methods: "start from the move" and "fixed start", i.e. the prover provides the beginning and end of counting the control volume according to the signal (pulse) from the meter or volume, passed through the meter is fixed according to the readings of its meter and entered into the window of the prover software. The use of two verification methods is associated with different types and purposes of meters, for which the verification method provides a verification procedure.

In addition, the list of verification operations, which is carried out after the repair of the gas meter, includes requirements for the mandatory determination of the weighted average error (WME), which is determined by the following formula:
\[ WME = \frac{\sum_{i=1}^{n} k_i \cdot \delta_i}{\sum_{i=1}^{n} k_i} \]  

\( \delta \) – the main relative error the meter to be verified (in percent);  
\( q_i \) – the gas volume flow rate value which the verification is performed;  
\( k_i = \frac{q_i}{q_{\text{max}}} \) at \( q_i \leq 0,7 \cdot q_{\text{max}} \);  
\( k_i = 1.4 - \frac{q_i}{q_{\text{max}}} \) at \( 0,7 \cdot q_{\text{max}} < q_i \leq q_{\text{max}} \).

The developed installation is expected to be prospectively used for conducting a series of various tests of gas meters within the framework of assessing compliance with the requirements of the Technical Regulation of Measuring Instruments. In particular, according to regulatory documents [8, 9], which are the evidence base, a list of tests for flow disturbances is specified. The prover design provides for the technical possibility of installing obstacles to low-level flow disturbances and high-level flow disturbances, including the installation of various types of local resistance and pipelines with a 90° turn in one and two planes at the same time.

Conclusions. In order to carry out verification the legally regulated gas meters, a prover with master meters in the range of volume flow of gas from 0.1 m³/h to 6500 m³/h was developed, manufactured and implemented in the production practice of SE Ivano-Frankivskstandardmetrology with the possibility of verifying the gas meter with a diameter of up to 300 mm. Features the calibration of the reference prover using transfer standards and calculation the value of the extended uncertainty are described.

References: