SECTION 3. DEVICES

DOI: 10.46299/ISG.2024.MONO.TECH.2.3.1

3.1 Development of a methodology for calibration of pressure measuring instruments

3.1.1 Area of application

This procedure defines the procedure, content and scope of work for calibration of pressure meters, vacuum meters and barometers.

This procedure contains:

- Procedure for determining the absolute deviation of readings of pressure meters, vacuum meters, technical, electrical contact, tyre meters of accuracy class 0.25 and below.

- Procedure for determining the absolute deviation of meteorological barometers;

- The procedure for calculating the measurement uncertainty during calibration;

- Guidelines for drawing up calibration results.

This methodology establishes the procedure for calibration of manometers, vacuum meters, and barometers of the above types (hereinafter referred to as instruments) manufactured in Ukraine and imported from abroad and intended for pressure measurement.

References.

This methodology contains references to the following documents:

DSTU ENISO/IEC 17025:2019 General requirements for the competence of testing and calibration laboratories [106].

MPU 003/04-2014 Recommendations. Metrology. Manometers, vacuum meters, manovacuum meters, pressure meters, load cells and load cells indicating and self-recording. Calibration methods [107].

GOST 23696-79 Membrane meteorological barometers. Technical specifications [108].

EA-4/02 Evaluation of the uncertainty of measurement in calibration [109].

3.1.2 Calibration means

For calibration, the standards listed in Table 1 are used. It is allowed to use other reference equipment, but the method must undergo additional evaluation in accordance with the method "Evaluation of the suitability (validation) of methods".

Table 1

Standards for calibration

Name of operations	Number of the methodology item	Working standards, equipment, technical and metrological characteristics
1	2	3
Monitoring of calibration conditions	4	Aneroid barometer BAMM-1, 80-120 kPa; Digital thermo-hygrometer T-06, 0-50 °C, 20-95 %;
External inspection. Testing	7	-
Performing measurements and determining readings. Procedure for estimating measurement uncertainty.	8	Etalons: Pressure meter with conventional MB scale (range 0 - 2.5 kgf/cm2); Pressure meter with a nominal scale MB (range 0 - 60 kgf/cm2); Pressure meter with a conditional MB scale (range 0 - 16 kgf/cm2); Electronic barometer Testo 511. Auxiliary equipment: Means for creating pressure MP-60, Thermobaric chamber TVV1000-V (-70 to +120°C; 0 - 1.33 hPa); Pressure calibrator CPH7000 - 1...+25 bar, 0.025% of the range, Pressure converter CPT7000 0...100 bar, G1/2B, - 20...+80°C, 0.025 % of the range

The equipment used for calibration shall be calibrated to ensure traceability of measurements. Also, the equipment shall be checked to establish its compliance with the technical requirements set out in the relevant EP.

It is allowed to use other means of auxiliary equipment with characteristics not worse than those specified in Table 1.

3.1.3 Calibration conditions

1 Calibration is performed under the following conditions:

- The ambient air temperature in the room must be (20 ± 5) °C.
- Relative humidity of the ambient air - no more than (60 ± 20) %.
- atmospheric pressure from 84 to 106 kPa.

2. The temperature change during the calibration of the pressure meter should not exceed 5°C for every 30 minutes.

3. The rate of pressure measurement during the calibration of the pressure meter is not more than 5% of the largest measurement value in 1 s; the change in pressure during measurements should be smooth and monotonous.

4. External vibration during the calibration of the manometer should not create a range of oscillations of the device arrow more than 0.1 fraction of the smallest division of the scale.

3.1.4 Safety requirements for calibration

1. Only persons with experience in working with the devices and who have undergone occupational safety training in accordance with the established procedure are allowed to perform calibration.

2. When performing calibration, the following shall be observed:

- requirements of NPAP 40.1-1.21;
- during the work it is necessary to comply with the requirements of the sections "Safety requirements" of the technical descriptions for the equipment used.

3. During the work, it is necessary to comply with the labour protection rules established by the labour protection instructions for this type of work, as well as the rules specified in the operating documents for specific equipment.

4. The operating environment of the devices must comply with their documentation.

It is allowed to use other environments that do not cause corrosion of parts and components of the device, if they are specified in the technical documentation for the device.

5. It is forbidden to create a pressure during measurements that exceeds the upper measurement limit of the instrument.

Personnel qualification requirements

This method can be used by specialists certified and authorised to perform this type of work.

The calibrator must know the principle of operation, construction of manometers, vacuum meters and barometers and the rules of operation of instruments and other equipment used during calibration.

3.1.5 Preparing for calibration

1. Before performing measurements, the device must be kept in the laboratory where the calibration will be performed for

- 12 hours if the air temperature difference between the calibration room and the place from which the device is brought is more than 10 °C;

- 1 hour if the difference in air temperature between the calibration room and the place where the device was brought in is from 1 °C to 10 °C.

If the difference in temperature is less than 1 °C, no holding time is required.

2. External inspection

During the external inspection it should be established

- compliance of the device with the requirements of the ND in terms of surface quality, digitisation and scale strokes, completeness and labelling.

The device must be free from mechanical damage to the case and fitting that prevents connection and does not ensure the tightness and strength of the connection, hands, glass and dial, affecting the operational properties.

The glass and dial must be free from defects that prevent correct reading of the readings.

The connection of the pressure meter body with the holder or fitting must be strong, which excludes their mutual displacement.

Devices rejected during external inspection are not subject to further calibration.

The results of the external inspection are recorded in the protocol.

3. Testing the pressure meter and vacuum meter

The device to be calibrated is mounted on the pressure generating device in the working position, according to the marking on its body (or in the technical documentation). If the documentation is not available, the device is installed so that the axis of symmetry passing through the device connection is vertical.

The end of the calibrated device fitting should be in the same horizontal plane as the end of the reference manometer, with a permissible deviation of ± 50 mm.

The device is held under a pressure equal to the upper limit of measurement on the pressure generating unit for 5 minutes. The tightness of the seal between the fitting and the socket of the pressure generating device is checked. The seal is considered to be tight if the reading of the device does not decrease by more than 2% of the set pressure during these 5 minutes.

After the pressure test, check the position of the instrument hand relative to the zero mark of the scale:

- the arrow of the device, which has a zero corrector, if it deviates from the zero mark, is set to the zero mark. The zero corrector should ensure that the arrow moves to each side of the zero mark by at least 2 conventional units;

- for instruments without a zero corrector, the pointer should be at the zero mark with a permissible deviation not exceeding the limit of permissible basic error.

The movement of the arrow within the entire scale when increasing and decreasing pressure should be smooth.

Technical pressure meters with an electrocontact signalling device are checked for operation of the signalling device, the deviation of which is determined at least at three scale marks. The wires from the signalling device are connected to a light or sound signal source.

The test results are recorded in the protocol.

Testing the barometer.

The movement of the arrow in the working range of the scale is smooth, without snags.

The displacement of the arrow, after lightly tapping the instrument case with a finger in its working position, should not exceed half the scale division.

The barometer mechanism is securely fixed in the case and does not move when shaken.

3.1.6 Description of the calibration procedure

3.1.6.1 Description of the calibration procedure for pressure meters and vacuum meters

1. Carry out measurements and determine the instrument readings.

2. When calibrating devices, the method of comparison with the standard is used.

Calibration is carried out in the laboratory.

The source of the measurement information signal is the pressure generated by the installation and actually measured by the instrument and the reference measuring instrument (Fig.

3. The device to be calibrated is held for 5 minutes under a pressure equal to the value of the upper limit of measurement. Then determine the 0 reading of the calibrated instrument and record it in the protocol (Annex A), and perform a series of measurements:

- for pressure meters with class 0.25; 0.4; 1.5; 2.5; 4.0 at each point to be calibrated: 1 observation at pressure increase, 1 observation at pressure decrease;

The scheme of direct comparison of the calibrated device with the reference measuring instrument is shown in Fig. 1.

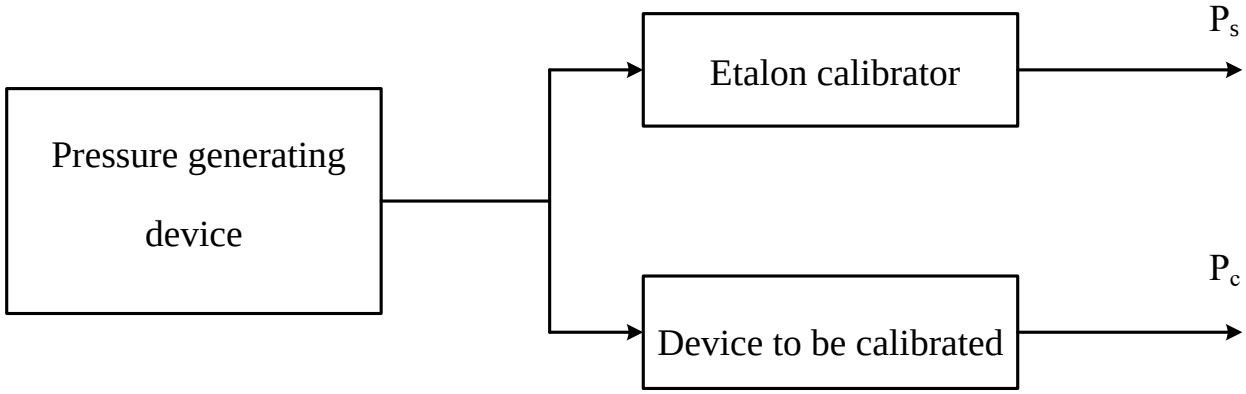

Figure 1. Scheme of direct comparison of the calibrated device with the reference measuring instrument.

By gradually increasing the pressure in the system, readings are taken at the specified calibrated scale marks. It is advisable to set the value (arrow) of the reference instrument fixedly at the calibration point, and to make all observations on the instrument to be calibrated. Readings in units of measurement are taken from the display of the instrument to be calibrated at intervals of at least 5 seconds.

At the upper limit of measurement, the devices are kept under pressure for 5 minutes. After that, the pressure is gradually reduced. The device is calibrated and readings are taken at the same pressure values as during the increase. As a standard option, each series of measurements is carried out at 5 pressure values (calibration points), the points to be calibrated must be evenly distributed over the entire scale of the instrument.

4. All the measured pressure values are used to estimate the measurement uncertainty at each calibration point and are recorded in the test report.

5. The customer, based on the production expediency, has the right to independently determine the required number and values of the calibration points of the device.

6. In the process of calibration of the device, the difference ΔP between the measurement result P_c by the device to be calibrated and the value of the reference manometer P_s is estimated

$$\overline{\Delta P} = \overline{P_c} - (P_s + \Delta P_s)$$

where $\overline{P_c}$ – is the average reading of the instrument to be calibrated (unit).

$$\overline{P_c} = \frac{1}{2}\sum_{i=1}^{2} P_{ci}$$

P_{ci} –is the reading of the calibrated instrument under loading and unloading;;

P_s – readings of the reference device;

ΔP_s – correction to the readings of the reference pressure meter.

7. Also, during the calibration process, the difference between the measurement results at increased and decreased pressure is evaluated, determining the variation of the elastic response (hysteresis).

$$\Delta P_h = |P_{c1} - P_{c2}|$$

where P_{c1} – reading of the instrument to be calibrated (pressure rise);

P_{c2} – readings of the calibrated device (pressure drop).

3.1.6.2 Estimation of measurement uncertainty during calibration of pressure meter and vacuum meter. Model equation

$$u(\Delta P) = \sqrt{u^2(\delta P_0) + u^2(\delta P_h) + u^2(\delta P_t) + u^2(\delta P_{cr}) + u^2(\delta P_{dr}) + u^2(\delta P_s)}$$

$u(\delta P_0) = \frac{\Delta P_0}{2\sqrt{3}}$ – uncertainty of zero value setting;

where ΔP_0 – deviation of the arrow from the zero value;

$u(\delta P_h) = \frac{\Delta P_h}{\sqrt{3}}$ – uncertainty taking into account hysteresis;

$u(\delta P_t)$ – correction for temperature deviation from the normalised temperature during calibration of technical, electrical contact, busbar pressure meter of accuracy class 1.5; 2.5; 4.0 is insignificant and does not significantly affect the calculation of uncertainty, therefore its values are taken equal to zero;

$(\delta P_{cr}) = \frac{q}{4\sqrt{3}}$ – standard uncertainty due to the finite resolution of the calibration instrument with an analogue counting device (q is the division price of the instrument);

$(\delta P_{cr}) = \frac{q}{2\sqrt{3}}$ – standard uncertainty due to the finite resolution of the calibration instrument with a digital counting device (q-division);

$(\delta P_{dr}) = \frac{D}{\sqrt{3}}$ – standard uncertainty due to the drift of the reference pressure gauge readings since the last calibration (D is the drift estimate since the last calibration, in the absence of a drift estimate u(δPdr) ≈ Ucal / k(p)).

$u(\delta P_s) = \frac{U_{cal}(P_s)}{k(p)}$ – expanded calibration uncertainty of the reference pressure gauge and the corresponding coverage factor (from the calibration certificate of the reference pressure gauge).

The expanded uncertainty of measurement deviation P- for a confidence level of p=0.95 is calculated by the formula:

$$U(\Delta P) = k \cdot u(\Delta P),$$

where k – coverage factor (k = 2 is the 95% confidence level assuming a normal distribution and k = 1.65 is the 95% confidence level assuming a uniform distribution).

The method of calculating the measurement uncertainty is automatic, using the Exel software. Evaluation of computer software is carried out by comparing the results of calculations and analysis obtained in parallel on a computer and manually. The results of the evaluation are documented in the Measurement Uncertainty Budget and recorded in the protocol.

3.1.7 Description of the procedure for calibration of barometers

1. Carrying out measurements and determining the instrument readings.

2. When calibrating devices, the method of comparison with the standard is used.

Calibration is carried out in the laboratory. The scheme of direct comparison of the calibrated instrument with the reference measuring instrument is shown in Fig. 2.

The source of the measurement information signal is the pressure generated by the thermobaric chamber, which is actually measured by the device and the reference measuring instrument.

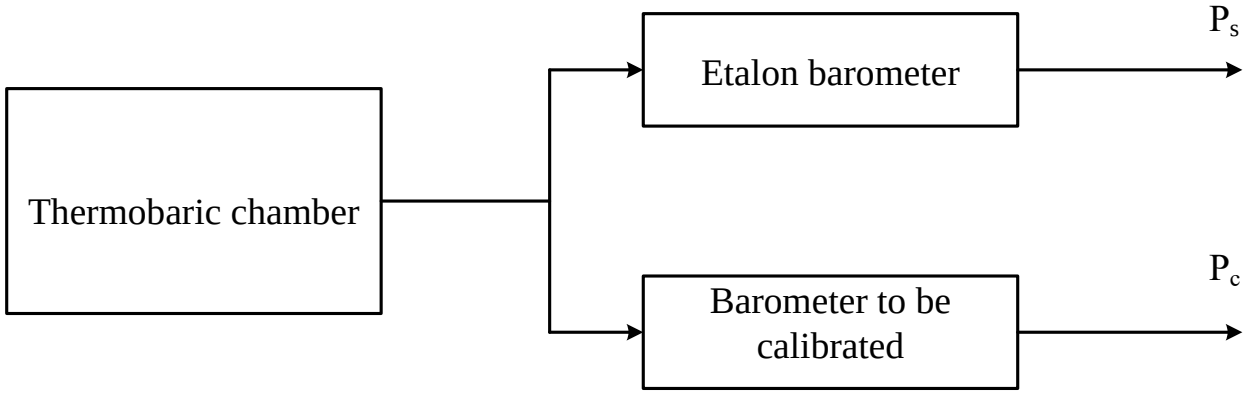

Fig. 2. Scheme of direct comparison of the calibrated device with the reference measuring instrument

3. Place the device to be calibrated in the thermobaric chamber;

4. Set the temperature value to 20 °C in the middle of the thermobaric chamber;

5. Perform a series of measurements at increasing and decreasing pressure and record the readings of the calibrated instrument in the protocol;

6. If the number of points is not specified by the customer, calibration of three points (50%, 70%, 90% of the instrument scale value) is performed. First, set the value of 50% of the scale, then 70%, and then 90%, and then reduce the pressure by setting the points of 70% and 50% of the scale. The readings of the calibrated device at each scale mark are counted down after the pressure and temperature have stabilised, at least after 2 minutes.

7. In the process of calibration of the barometer, the difference ΔP between the measurement result P_c by the barometer to be calibrated and the value of the reference barometer P_s is estimated

$$\overline{\Delta P} = \bar{P} - (\bar{P_s} + \Delta P_s)$$

where $\bar{P}$ – average of the readings of the barometer to be calibrated

$\bar{P_s}$ – average of the readings of the reference barometer;

ΔP_s – correction to the reading of the reference barometer from the calibration certificate.

8 In addition, during the calibration process, the difference between the measurement results at higher and lower pressures is evaluated, determining the variation.

$$V = |P_1 \_ P_2|$$

where P_1 – readings of the device to be calibrated (pressure increase);

P_2 – readings of the instrument to be calibrated (pressure drop).

Estimation of the measurement uncertainty during the calibration of barometers. Model equation

$$\Delta P = \bar{P} + \delta P_t + \delta P_v + \delta P_{tr} + \delta P_b + \delta P_{cr} - (\overline{P_s} + \Delta P_s + \delta P_s + \delta P_{dr})$$

P_v– correction for variation;

δP_t – correction that takes into account the effect on the instrument readings when the temperature inside the thermobaric chamber deviates from the normalised temperature during calibration;

δP_{tr} – correction that takes into account the effect of uncertainty in the temperature of the thermobaric chamber (from the calibration certificate of the thermobaric chamber);

δP_b – correction for the uncertainty in the pressure of the thermobaric chamber (from the calibration certificate);

δP_{cr}– correction to the readings of the calibrated instrument due to its finite resolution;

δP_s – correction to account for the uncertainty of the reference instrument (from the calibration certificate of the reference);

δP_{dr} – correction for the drift of the reference barometer.

The total standard uncertainty of the measurement of the deviation of the pressure determination of the calibrated instrument is estimated by the formula:

$$u(\Delta P) = \sqrt{u^2(\delta P_t) + u^2(\delta P_v) + u^2(\delta P_{tr}) + u^2(\delta P_b) + u^2(\delta P_{cr}) + u^2(\delta P_{dr}) + u^2(\delta P_s)}$$

$u(\delta P_{tr}) = \frac{U_{cal}(T_b)}{k(p)}$ – uncertainty that takes into account the total uncertainty in the temperature of the thermobaric chamber from the calibration certificate, and the corresponding coverage factor

$C_B = \frac{\mathrm{a} + bt + \mathrm{ct2} + dt3 + k(\mathrm{P}k - P)}{\sqrt{3}}$, where a, b, c, d, k, Pk – are typical temperature dependence coefficients given in the barometer certificate;

$\mathrm{u}(\delta \mathrm{P_v}) = \frac{\mathrm{V}}{\sqrt{3}}$ – uncertainty that takes into account the variation

$u(\delta P_t) = \frac{\mathrm{a} + bt + \mathrm{c}t^2 + dt^3 + k(\mathrm{P}k - \bar{P})\Delta \mathrm{t}}{\sqrt{3}} 3$ – standard uncertainty that takes into account the effect on the instrument readings when the temperature inside the thermobaric chamber deviates from the normalised temperature during calibration. (Δt is a correction for a temperature of 20 ºC from the calibration certificate of the thermobaric chamber, $\bar{\mathrm{P}}$ is the average value of the readings of the instrument to be calibrated).

$(\delta P_{cr}) = \frac{q}{4\sqrt{3}}$ – standard uncertainty due to the finite resolution of the instrument being calibrated with an analogue counting device (q is the division price of the instrument);

$u(\delta P_{cr}) = \frac{q}{2\sqrt{3}}$ – standard uncertainty due to the finite resolution of the instrument being calibrated with a digital counting device (q – resolution);

$u(\delta P_{dr}) = \frac{D}{\sqrt{3}}$ – standard uncertainty due to the drift of the reference barometer since the last calibration (D – estimate of the drift since the last calibration, in the absence of an estimate of the drift $u(\delta P_{dr}) = 0$).

$u(\delta P_s) = \frac{U_{cal}(P_s)}{k(p)}$ – expanded calibration uncertainty of the reference barometer and the corresponding coverage factor (from the calibration certificate of the reference barometer).

$u(\delta P_b) = \frac{U_{cal}(P_b)}{k(p)}$ – expanded uncertainty of the thermobaric chamber calibration and the corresponding coverage factor (from the calibration certificate), in

the absence of $u(\delta P_b) = \frac{\Delta P_b}{\sqrt{3}}$, where ΔP_b – pressure fluctuation inside the thermobaric chamber (from the passport).

The expanded uncertainty of measurement deviation P – for a confidence level of p=0.95 is calculated by the formula:

$$U(\Delta P) = k \cdot u(\Delta P)$$

where k – coverage factor (k = 2 is the 95% confidence level assuming a normal distribution and k = 1.65 is the 95% confidence level assuming a uniform distribution). The method of calculating the measurement uncertainty is automatic, using the Exel software. Evaluation of computer software is carried out by comparing the results of calculations and analysis obtained in parallel on a computer and manually. The results of the evaluation are documented in the Measurement Uncertainty Budget and entered into the calibration report.

Documentation of calibration results

The calibration results shall be documented by a calibration certificate in a specified form.