CALIBRATION OF PRESSURE GAUGES BY MEANS OF A DIGITAL PRESSURE GAUGE

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Abstract: The report examines the requirements, methods and equipment to calibrate the pressure gauges, combined pressure gauges and vacuum gauges with scales in the measuring unit of the measured quantity or with scales with conventional intervals. (hereinafter referred to as pressure gauges or calibrated devices).

The purpose is to find out the difference (deviation from) between the pressure measured by the calibrated pressure gauge and reference pressure according to [1]. In the process of calibration, the real values of the pressure are identified in the measuring unit of the calibrated pressure gauge both in pascal, [Pa], or its multiple from the SI international system.

The methodology is designed for the calibration of pressure gauges with a measuring range of minus 90 kPa to 60 MPa with accuracy class higher or equal to 0,15.

Key words: digital pressure gauges, difference (deviation from) between the measured pressure and reference pressure, traceability.

1. Introduction

The calibration is performed according to the method of direct comparison between the pressure measured by the reference pressure gauge and the calibrated pressure gauge.

The pressure created in the measuring system is measured by both the reference pressure gauge and the calibrated one.

The purpose is to find out the difference (deviation from) between the pressure measured by the calibrated pressure gauge and the reference pressure according to [1]. In the process of calibration, the real values of the pressure are identified in the measuring unit of the calibrated pressure gauge both in pascal, [Pa], or its multiple from the SI international system.

Pressure gauges with a measuring range from minus 90 kPa to 60 MPa with accuracy class higher or equal to 0,15 are subject to calibration.

2. Calibration conditions:

– Ambient temperature – 23 °C ± 5 °C, indicated in [1];

– Atmospheric pressure – from 950 hPa to 1050 hPa;

– The calibration is carried out in the absence of vibrations;

– The variation of the temperature during calibration shall be less than 1°C.

3. Applied reference equipment

Digital pressure gauges and vacuum gauges with uncertainty (from the latest calibration certificate) less than or equal to 1/4 of the permissible error of the calibrated pressure gauge for the relevant set value

The measuring range of the reference pressure gauge should correspond to the range of the calibrated pressure gauge.

The reference pressure gauge should be traceable to national measurement standard.

4. Sequence of the operations during calibration

The pressure gauge is reset if the design of the pressure gauge allows it. The set up of zero is not allowed between the separated measurement series.

The pressure is changed gradually from the lower to the upper measuring range limit.

The indications for the different values (points) of the set pressure, if possible, evenly distributed along the measuring range are recorded. The upper and lower limit values should be included.

The operations will be repeated also when the pressure is decreased, from the upper to the lower measuring range limit.

The measuring series are performed according to Table 1 depending on the accuracy class of the calibrated pressure gauge according to [1].

Table 1

Calibration sequence		Type A Figure No. 2	Type B Figure No. 3
Accuracy class of the calibrated pressure gauge		< 0,1	0,1... 0.6
Number of measuring points with zero		9	5
Preliminary pressure increase to the maximum value, (pieces)		2	1
Pressure change + time to establish the condition (seconds)		> 30	> 30
Delay time to reach the final value of measuring series (minutes)		2	2
Number of measuring series	ascending order	2	1
	descending order	1	1

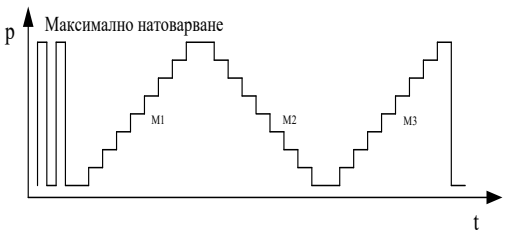

Figure No. 1

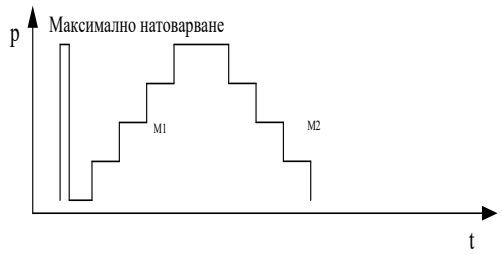

Figure No. 2

5. Processing of calibration results

5.1. Mathematical model

The mathematical model specified in [1] of the dependence between the pressure measured by the calibrated pressure gauge, the pressure measured by the reference pressure gauge and the input quantities is:

$$\Delta P = \overline{P}_{изм.} - P_{ет.} + \delta P_{хист.} + \delta P_{повт.} + \delta P_{нула} \qquad (1)$$

whereas:

ΔP - deviation of the pressure measured by the calibrated pressure gauge from the actual pressure (measured by the reference pressure gauge);

$\overline{P}_{изм}$ – mean value measured for every *j*-th point of the calibrated pressure gauge;

$P_{ет}$ – reference pressure from the calibration certificate for the *j*-th point;

$\delta P_{хист}$ – evaluation of the correction of the hysteresis of the indications of the calibrated pressure gauge for the *j*-th point;

$\delta P_{повт}$ - evaluation of the correction for repeatability of the indications of the calibrated pressure gauge;

$\delta P_{нула}$ - evaluation of the correction of the deviation from the zero point.

5.2. Evaluation of the input quantities, X_i

Evaluation of the quantity recorded by the calibrated pressure gauge is defined as arithmetic mean value $\overline{P}_{изм}$

$$\overline{P}_{изм,j} = \frac{1}{n}\sum_{i=1}^{n} x_{i,j} \qquad (2)$$

whereas:

$x_{1,j}$ – indications of the calibrated pressure gauge for the first series of measurement for the *j*-th point;

$x_{2,j}$ – indications of the calibrated pressure gauge for the second series of measurement for the *j*-th point;

$x_{3,j}$ – indications of the calibrated pressure gauge for the third series of measurement for the *j*-th point;

n – number of series.

$P_{reference\ pressure}$ is the reference pressure taken from the calibration certificate for the relevant nominal value.

In the cases when the value is unknown from the certificate, it is calculated using linear interpolation (or linear extrapolation, if necessary) between two known adjacent values for the relevant measuring range of the reference pressure gauge.

The evaluation of the correction of the hysteresis of the indications $\delta P_{hysî}$ is rectangular distributed quantity with zero value and dissipation area with value calculated according to the formula:

$$h_j = |(x_{2,j} - x_{1,0}) - (x_{1,j} - x_{1,0})| \qquad (3)$$

whereas:

h_j – hysteresis of the *j*-th point;

$x_{1,0}$ – indications of the calibrated pressure gauge for pressure equal to zero for the first series of measurement;

$x_{2,,j}$ – indications of the calibrated pressure gauge for the *j*-th point for the second series of measurement;

$x_{1,,j}$ – indications of the calibrated pressure gauge for the *j*-th point for the first series of measurement.

The evaluation of the correction for repeatability of the indications of the calibrated pressure gauge $\delta P_{repeatability}$ for single installation is rectangular distributed quantity with value zero and dissipation area with value calculated according to the formula:

$$b_{повт.,j} = |(x_{3,j} - x_{3,0}) - (x_{1,j} - x_{1,0})| \qquad (4)$$

$$b = \max\{b_{повт,j}\} \qquad (5)$$

whereas:

$x_{3,0}$ – indications of the calibrated pressure gauge for pressure equal to zero for the third series of measurement;

$x_{1,0}$ – indications of the calibrated pressure gauge for pressure equal to zero for the first series of measurement;

$x_{3,,j}$ – indications of the calibrated pressure gauge for the *j*-th point for the third series of measurement;

$x_{1,,j}$ – indications of the calibrated pressure gauge for the *j*-th point for the first series of measurement.

Evaluation of the correction of the deviation from the zero point $\delta P_{zero.}$ is rectangular distributed quantity with value zero and dissipation area with value calculated according to the formula (5).

The zero point is set up prior to the first measuring cycle and should be recorded before and after the measuring cycle. The deviation from the zero point is calculated according to the formula:

$$f_o = \{x_{2,0} - x_{1,0}\} \qquad (6)$$

whereas:

$x_{1,0}$ – indications of the calibrated pressure gauge for pressure equal to zero for the first series of measurement;

$x_{2,0}$ – indications of the calibrated pressure gauge for pressure equal to zero after the second series of measurement;

5.3. Root square uncertainty of the inputs, $u(x_i)$

Root square uncertainty of the input estimates of the quantities characterized by rectangular distribution are calculated according the formulae:

The contribution to the uncertainty of $\overline{P}_{изм}$ is evaluated by the end resolution of the calibrated pressure gauge r and is rectangular distributed quantity with value zero and limits equal to 1/10 of the value of one of the relevant pressure gauge's scale intervals:

$$u(r) = \frac{r}{\sqrt{3}} \qquad (7)$$

› for the correction of the hysteresis of the indications:

$$u(\delta P_{хист}) = \frac{h}{2.\sqrt{3}} \qquad (8)$$

› for the correction of the hysteresis of the indications:

$$u(\delta P_{повт.}) = \frac{b}{2.\sqrt{3}} \qquad (9)$$

- of the correction of the deviation from the zero point of the indications:

$$u(\delta P_{нула}) = \frac{f_0}{2.\sqrt{3}} \qquad (10)$$

Root square uncertainty of the contribution to the uncertainty of the measurement imported from the reference pressure gauge is calculated according to the formula:

$$u(Pem.) = \frac{U_{em}}{k} \qquad (11)$$

whereas:

U_{ref} – expanded uncertainty of the reference pressure gauge from the calibration certificate for the relevant value;

k - coverage factor, from the calibration certificate of the reference pressure gauge;

In the cases when the value of U_{ref} is unknown

from the certificate, the highest value for the relevant range is accepted.

5.4. Sensitivity factors

At evaluation of the measured pressure values and impact of the inputs, the functional dependence $P = f(x_i)$ is linear and the sensitivity factors are $|c_i| = 1$.

5.5. Contributions to the measurement uncertainties, $u_i(p)$.

The contributions to the inputs $u(x_i)$ for the uncertainties of the measured pressure are calculated as:

$$u_i(p) = c_i . u(x_i) \qquad (12)$$

5.6. Combined root square uncertainty, $u_c(P)$

When all inputs are non-correlated or the correlation between them is negligibly low, the combined root square uncertainty of the measured pressure is calculated as a square root of the sum of the contributions of the inputs:

$$u_c(P) = \sqrt{\sum_{i=1}^{n} u_i^2(p)} \qquad (13)$$

5.7. Expanded uncertainty, U

The expanded uncertainty U of the measured pressure is calculated according to the formula:

$$U = k . u_c(P) \qquad (14)$$

whereas:

k - coverage factor. The value of k is defined according to the selected coverage factor. For coverage factor of 95 %, k is accepted to be equal to 2.

6. Conclusion

The presented methodology for calibration of pressure gauges, combined pressure gauges and vacuum gauges with a digital pressure gauge is developed in compliance with the requirements of the company and international regulations.

It is designed to comply with the requirements for providing traceability of the measurement results when calibrating the pressure gauges, combined pressure gauges and vacuum gauges.

When the pressure gauge complies with the requirements of the current methodology, a calibration certificate is issued.

It is assumed that the maximum value of all obtained values is indicated as the uncertainty of the performed calibration.

7. Reference

[1] German Calibration Service DKD. Calibration of pressure measuring devices DKD-R 6-1

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