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Calibration Ultrasonic Thickness Gauges and Estimation Measurement Uncertainty

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Annotation: Ultrasonic thickness gauges are also one of the non-destructive testing tools. This type of measuring device differs from other non-destructive testing devices in that it is widely used in various industries. This point increases the calibration requirements for ultrasonic thickness gauges. The article considers the calibration process and assessment for the measurement uncertainty of ultrasonic thickness gauges, which is used in the ultrasonic method of non-destructive testing.

Keywords: non-destructive testing, ultrasonic method, thickness gauges, ultrasonic standard measurement blocks, accuracy, ultrasound examination, measurement, nominal value, uncertainty.

The direction of non-destructive testing is one of the main elements of industrial safety expertise to ensure technical safety of construction and production facilities in Uzbekistan. In recent years, all areas of non-destructive testing in the world are developing. new methods and techniques, equipping laboratories with new and modern equipment, automation of processes, etc. processes are developing at a rapid pace. Calibration of nondestructive testing instruments is one of such key processes.

Non-destructive testing and measuring devices used in industrial enterprises and testing laboratories operating in Uzbekistan are subject to primary and periodic control by the National Institute of Metrology of Uzbekistan. There are examples of methods of type approval, attestation and comparison of types of control of measuring devices. But in a number of developed countries along with comparison works on measuring devices the increasingly popular method of calibration is applied. At present in Uzbekistan calibration methods are used for checking of measuring devices and assessment of their errors. As an example, we can mention laboratories that carry out control processes as a result of measuring weight, temperature, length and other direct measurements. The metrological control of ultrasonic thickness gauges is carried out by the single laboratory of non-destructive testing of Uzbek National institute of metrology in Uzbekistan.

Figure 1. Ultrasonic thickness gauge

Ultrasonic thickness gauges are also one of the non-destructive testing tools. This type of measuring device differs from other non-destructive testing measuring devices in that it is widely used in industry. This fact increases the calibration requirements for ultrasonic thickness gauges. Since thickness gauges are considered one of the modern measuring instruments and direct measurement is involved, the calibration of this type of gauges has been introduced recently, and this calibration method is one of the developing calibration methods in our industry.

In this paper, the thickness measurement error and uncertainty of ultrasonic thickness gauges are evaluated based on the experimental results. The Calibration procedure UzNIM-PC36 is used for calibration of ultrasonic thickness gauges in non-destructive testing laboratory. The calibration procedure is developed according to EN 12668-1:2010 which was released in 2010 to supersede the EN 12668-1:2000 [4]. Measurement uncertainty of thickness parameter for various ultrasonic

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ultrasonic thickness gauges is estimated with the help of this document. Reference thickness gauge set type KMT 176 M-1 made of steel according to ГОСТ 5632 is used as reference measuring instrument in this evaluation process.

Technical specification of the reference thickness gauge set type KMT 176 M-1 is given in Table 1.

Table 1.

Set number and name	**Thickness of sample S, mm**	**Tolerance of thickness deviation ΔS, mm**	**Change in thickness of the sample, mm**	**Roughness of the working surfaces of the measures Ra, mkm**	**Roughness deviations of the working surfaces of the measures. ΔRa, %**
Set № 3 ultrasonic reference thickness gauge	0,2; 0,3; 0,4; 0,5; 0,6; 0,7; 0,8; 0,9	±0,01	0,002	1,25	±20
	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 18, 20, 25, 30, 35, 40, 45, 50	±0,02	0,004		
	75, 90, 100	±0,04	0,008		
Set № 4 ultrasonic reference thickness gauge	200, 300	±0,05	0,015	1,25	±20

The permissible uncertainty of calibration of reference thickness gauge set by ultrasonic propagation time or equivalent ultrasonic thickness, %, not more:

- in the range from 0.2 to 0.9 mm at 10 MHz - 0.7;
- in the range 1 to 10 mm at 10 MHz - 0,7;
- in the range 1 to 5 mm at 5 MHz - 0,7;
- in the range 6 to 10 mm band at 5 MHz - 0,4;
- in the range 12 to 300 mm at 2,5 and 5 MHz - 0,3.

Auxiliary instruments for calibration include rags for wiping measures (samples), petrol according to ГОСТ 1012 and contact lubricating oil (spindle or transformer lubricating oil, glycerine, etc.).

During calibration, the following environmental conditions must be observed according to the UzNIM-PC36.

- room temperature (20±2)°C;
- relative humidity (50–80) %;
- air pressure (84-106) kPa.

The environmental conditions are controlled by instrument for measuring environmental parameters type OPUS 20. It displays the room temperature, relative humidity and air pressure in the laboratory at all times and helps us to ensure that measurements are made under acceptable conditions. Before calibration, all calibrated measuring instruments and ultrasonic thickness gauges must be stored in a room with temperature (20±2)°C for at least 12 hours.

Figure 2. Environmental measurement device

In the calibration process of ultrasonic thickness gauges, activities such as visual inspection, testing, and determination of the measurement error of the thickness gauge are performed. When estimating their measurement uncertainty, the following measurement model is created:

$$E = d_x - d_s + \delta d_x - \delta d_s \qquad (1)$$

where d_x - thickness gauge reading, mm;

δd_x - correction to the thickness gauge readings due to the final resolution of the thickness gauge, mm;

d_s - equivalent ultrasonic thickness of the measure (sample), mm;

δds - change of the equivalent ultrasonic thickness of the measure (sample) since the last calibration due to drift, mm.

We have direct measurements and a linear model function with coefficients equal to one. Thus, the sensitivity (influence) coefficients are also equal to one.

The sources of uncertainties are analyzed and calculated in Table 2. The input values are considered as uncorrelated values.

Table 2

Input quantity	Description
d_x thickness gauge readings, mm	Type of uncertainty: A. Distribution type: normal (Gauss). Rating value: $d_x = \frac{\sum_{i=1}^{n} d_i}{n}$, arithmetic mean of n = 10 thickness measurements. Standard uncertainty is expressed as the standard deviation of the arithmetic mean of the measurement results $u(d_x) = \sqrt{\frac{\sum_{i=1}^{10} (d_i - d_x)^2}{n(n-1)}}$ Sensitivity (influence) coefficient: 1.
δdx correction to the thickness gauge readings due to the finite resolution of the thickness gauge, mm	Type of uncertainty: B. Distribution type: rectangular. Rating value: 0 mm with borders $\pm\frac{a}{2}$, where a – the value of the least significant digit of the thickness gauge indicator. The standard uncertainty is estimated using the formula: $u(\delta d_x) = \frac{a}{2\sqrt{3}} = \frac{0,1}{2\sqrt{3}} = 0,03$ mm, or $u(\delta d_x) = \frac{a}{2\sqrt{3}} = \frac{0,01}{2\sqrt{3}} = 0,003$ mm. Sensitivity (influence) coefficient: 1.
d_s equivalent ultrasonic thickness of measure (sample), mm	Type of uncertainty: B. Distribution type: indicated in the calibration certificate of the KMT-176 M-1 kit. Rating value: equivalent ultrasonic thickness of the measure (sample) d_s. Standard uncertainty $u(d_s)$ is taken from the calibration certificate of the set of measures (samples) (by dividing the expanded uncertainty by the coverage factor).

	Sensitivity (influence) coefficient: 1.
δd_s change in the equivalent ultrasonic thickness of the measure (sample) since the last calibration due to drift, mm	Type of uncertainty: B. Distribution type: прямоугольный. Rating value: 0 mm with borders ± 0, 002 mm (the estimate is derived from the results of previous calibrations). The standard uncertainty is estimated by the formula: $u(\delta d_s) = \frac{0{,}002}{\sqrt{3}} = 0{,}00$[illegible] mm. Sensitivity (influence) coefficient: 1.

Processing of observation results at each point is carried out in the following sequence:

The average value of the thickness gauge readings is calculated at each calibration point based on the results of a series of observations using the formula:

$$d_x = \frac{\sum_{i=1}^{n} d_i}{n} \quad (2)$$

The deviation of the thickness gauge readings (measurement error) is calculated using the formula:

$$E_x = d_x - d_s \quad (3)$$

Calculate an estimate of the components of the combined standard measurement uncertainty $u(d_x)$, $u(\delta d_x)$ и $u(\delta d_s)$.

Calculate the value of the combined standard uncertainty of the deviation of the thickness gauge readings using the formula:

$$u(E) = \sqrt{u^2(d_x) + u^2(\delta d_x) + u^2(d_s) + u^2(\delta d_s)} \quad (4)$$

The resulting number of degrees of freedom ν_{eff} is determined by the formula:

$$\nu_{eff} = \frac{u_r^4(N_c)}{\sum_i \frac{(c_i u_{ri})^4}{\nu_i}} \quad (5)$$

where, ν_i is the number of degrees of freedom for the i-th uncertainty component u_{ri}.

Summation is carried out over all components of the total uncertainty, taken into account in the expressions for the readings of the reference and calibrated instruments, and given in the corresponding tables.

Calculate the value of expanded uncertainty using the formula:

$$U = k \cdot u(E) \quad (6)$$

Where k = 2 – coverage coefficient corresponding to a 95% coverage probability assuming a normal distribution of the measured value.

The measurements was carried out in non-destructive testing laboratory of Uzbek national institute of metrology. Ultrasonic thickness gauge A1209 was used in measurement process as a calibration object. Therefore, all measurement results are related to this measuring device. An uncertainty calculation example of the measured value for ultrasonic thickness gauge A1209 is given in this paper for understanding the topic more clearly. The value of the measured thickness must be taken from the ultrasonic thickness gauge indicator after achieving stable readings. Monitor the correct setting of the "zero" of the thickness gauge after taking measurements of each measure (sample). If the thickness gauge needs further correction of the "zero", carry out all measurements with the transducer from the beginning10 mm is taken as a measurement point. Ten measurement results and calculation of measurement uncertainty are given in Table 3 for measurement point 10 mm.

Table 3

№	d_S, mm	d_x, mm
1	10	10,05
2		10,05
3		10,05
4		10,05
5		10,05
6		10,05
7		10,07
8		10,07
9		10,07
10		10,07

Input quantity	Formula	Calculation	Results
Arithmetic mean value	$K_{изм} = \frac{\sum_{i=1}^{n} \cdot K_{измi}}{n}$	(10,05+10,05+10,05+10,05+10,05+10,05+10,07+10,07+10,07+10,07+10,07)/10	10,058
Standard uncertainty UTG	$\delta K_{изм} = \sqrt{\frac{\sum_{i=1}^{n}(K_{измi} - K_{изм})^2}{n \cdot (n-1)}}$	$[((10{,}058\text{-}10{,}05)^2+(10{,}058\text{-}10{,}05)^2+(10{,}058\text{-}10{,}05)^2+(10{,}058\text{-}10{,}05)^2+(10{,}058\text{-}10{,}05)^2+(10{,}058\text{-}10{,}05)^2+(10{,}058\text{-}10{,}07)^2+(10{,}058\text{-}10{,}07^2+(10{,}058\text{-}10{,}07)^2+(10{,}058\text{-}10{,}07)^2)/10(10\text{-}1)]^{1/2}$	0,0032
Expanded uncertainty specified in the calibration certificate of the measure	$\delta K_{серт} = \frac{U_{серт}}{2}$	0,01/2	0,005
Uncertainty due to ultrasonic thickness gauge reading resolution	$K_X = \frac{a}{2\sqrt{3}}$	0,01/2*1,73	0,003
Uncertainty due to sample drift	$K_\partial = \frac{\partial}{\sqrt{3}}$	(9,98-10)/1,73	-0,012
Combined standard measurement uncertainty	$u(K_x) = \sqrt{K_{изм}^{\ 2} + \delta K}$	$(0{,}0032^2+0{,}005^2+0{,}003^2+(-0{,}012)^2)^{1/2}$	0,013
Expanded measurement uncertainty	$U(K_x) = k \cdot u(K_x)$	2*0,013	0,026

This type of measurement uncertainty evaluation helps to estimate the measurement range of ultrasonic thickness gauges and to express the uncertainties more accurately. Because in this calibration method, not only one but several influential parameters affecting the measurement process are studied and their uncertainties are determined.

In conclusion, calibration methods, which are considered to be among the effective methods for measurement uncertainty evaluation, are used in the state control and inspection of a number of measuring devices used in our industry today. The implementation of these calibration methods in non-destructive testing instruments is one of the urgent tasks. And this paper presents the results of the study of calibration methods of ultrasonic thickness gauges, which are included in the category of non-destructive testing.

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