Ultrasonic flaw detectors. Estimation of the measurement uncertainty by calibrated attenuator\gain

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ABSTRACT

There are technical specifications such as linearity accuracy, gain and also material velocity which is estimated during the calibration of ultrasonic flaw detectors. One of these main parameters is the gain. This article considers the assessment for the measurement uncertainty by calibrated attenuator\gain of ultrasonic flaw detectors, which is used in the ultrasonic method of non-destructive testing, using ultrasonic tester

Keywords: Non-destructive testing, ultrasonic method, flaw detector, ultrasonic tester, attenuator, accuracy, ultrasound examination, measurement, nominal value, gain.

Ultrasonic flaw detectors are used to detect echo signals reflected from cracks, voids or other discontinuities in the material of which the test object is made. An ultrasonic pulse propagates in a solid homogeneous material (for example, the wall of a steel pipe) until it encounters a boundary with another material (for example, air in a crack or air adjacent to the opposite surface of the pipe wall). The flaw detector displays information about the amplitude and position of the echo signals, which can be used to classify defects. By comparing echo signals from a reference sample and from the actual test object, an experienced operator can detect hidden defects long before a real malfunction occurs.

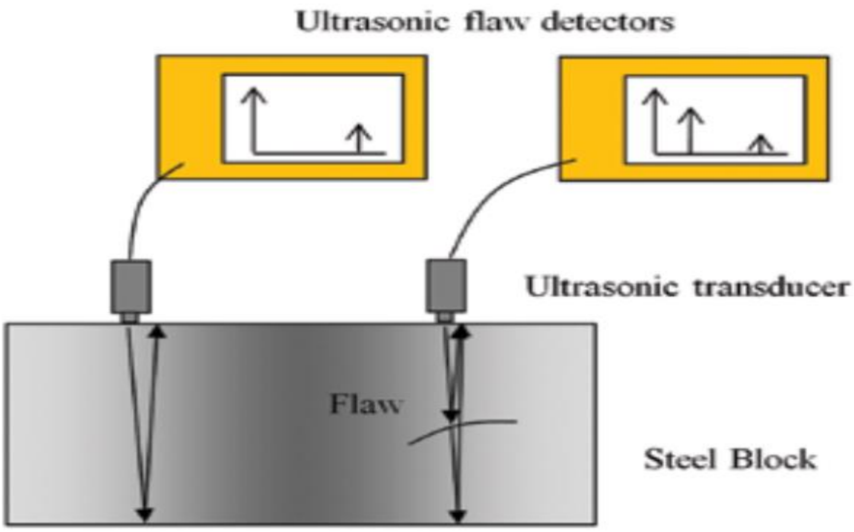

Figure 1. Working principle of of an ultrasonic flaw detector.

Ultrasonic flaw detectors are considered as one of the common measuring instruments that carry out ultrasonic testing in the field of non-destructive testing. Ultrasonic flaw detectors, considered more complex in terms of application, are related to measuring devices that have high accuracy in determining a flaw and assessing its level compared to other ultrasonic measuring instruments [1, 2]. This measuring device is widely used in the industrial sectors of Republic of Uzbekistan. In particular, it can be found various models of ultrasonic flaw detectors in the field of metallurgy, oil and gas, geology and railway transport. Metrological control of ultrasonic flaw detectors is carried out by the Uzbek National Institute of Metrology (UzNIM). Metrological certification, verification and calibration services for several types of ultrasonic flaw detectors have been created on the territory of Uzbekistan by ultrasonic non-destructive testing laboratory of UzNIM.

AUV.C1 Calibration procedure is used for calibration of ultrasonic flaw detectors. 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 2 main parameters (thickness and gain) for various ultrasonic flaw detectors is estimated with the help of this document. In this paper, the gain measurement uncertainty is evaluated based on the experimental results. Ultrasonic tester MX 02-УЗТ-1 is used as reference measuring instrument in this evaluation process. Traceability of ultrasonic tester is ensured to national measuring standard of national metrology institute of Belarus.

Technical specification of the ultrasonic tester type MX 02-УЗТ-1 is given in Table 1.

Table 1.

№	Technical parameter	Value
1	Frequency range	from 0,2 to 15,0 MHz
2	Attenuator attenuation range	from 0 to 101 dB
3	Measurement error attenuator attenuation	± (0,1 + 0,0075 N) dB
4	Attenuator input and output impedance	50 Ώ

Ultrasonic flaw detector type EPOCH LT is used as a device under test in the measurements. Before starting the calibration process, the ultrasonic flaw detector must be in the laboratory for at least 12 h to establish temperature equilibrium with the environment and carefully study the operating manual and technical description of ultrasonic flaw detectors, as well as familiarize with the location and purpose of control and monitoring elements. Determination of uncertainty when measuring the gain of ultrasonic flaw detectors is carried out according to the method in accordance with clause 9.5.4 EN 12668-1. The measurement connection diagram is shown in Figure 2, respectively.

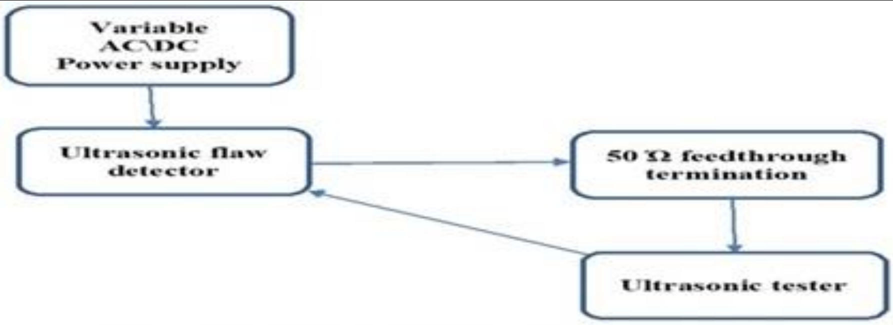

Figure 1. Block diagram for measurement set up.

МХ 02-УЗТ-1 tester is set to the mode of generating a continuous sinusoidal signal with a frequency that corresponds to the operating frequencies of the ultrasonic flaw detector, and coordinate the tester attenuator with the ultrasonic flaw detector amplifier according to the operating manual for the tester (match at the attenuation value tester attenuator – 6 dB). The gain is set in the ultrasonic flaw detector to a level that corresponds to the beginning of the gain range with the measurement error (uncertainty) normalized by the manufacturer.

The ultrasonic tester is used to controls to set the signal amplitude on the flaw detector screen to the level of 80% of the screen (unless the flaw detector manufacturer has indicated otherwise). The signal amplitude is controlled using the ultrasonic flaw detector's strobe.

The accuracy of the ultrasonic flaw detector's attenuator is checked by increasing the gain by a given degree, followed by pulling the signal amplitude to the previous level using a ultrasonic tester (an external calibrated attenuator). The check is carried out in three stages. The first step is to check the exact gain within 1 dB with the smallest resolution of which the device is capable. At the second stage, the gain is checked in the entire range normalized by the manufacturer with steps of at least 1 dB. At the third stage, the rough gain is checked in the entire range normalized by the manufacturer with specified degrees.

The deviation of the flaw detector readings (the main error of the flaw detector) when measuring the ratio of signal amplitudes is determined according to the following measurement model:

$$\Delta N = (N_x + \delta N_x) - (N_s + \delta N_s)$$

where

N_x – is the change in the set readings of the ultrasonic flaw detector, dB;

δN_x – correction to the ultrasonic flaw detector readings due to the finite resolution of ultrasonic flaw detector, dB;

N_s – average change in attenuation, ultrasonic tester, dB;

δN_s – correction to ultrasonic tester readings, dB

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

The analysis of the sources of uncertainty and their calculation is given in Table 2. The input quantities are considered as non-correlated.

Table 2

Input quantity	Description
correction to the ultrasonic flaw detector readings due to the finite resolution of the flaw detector, dB	Type of uncertainty: B. Distribution type: rectangular. Rating value: 0 dB with borders , where a – the value of the least significant digit of the ultrasonic flaw detector indicator. The standard uncertainty is estimated using the formula: $u(\delta N_x) = \frac{a}{2\sqrt{3}}$ dB. Sensitivity (influence) coefficient: 1.
N_s average change in attenuation, ultrasonic tester, dB	Type of uncertainty: A. Distribution type: normal. Rating value: $N_s = \frac{\sum_{i=1}^{n} N_i}{n}$, arithmetic mean of n = 10 signal amplitude ratio measurements. Standard uncertainty is expressed as the standard deviation of the arithmetic mean of the measurement results. $u(N_s) = \sqrt{\frac{\sum_{i=1}^{10}(N_i - N_s)^2}{n(n-1)}}$ Sensitivity (influence) coefficient: 1.
δN_s correction to ultrasonic tester readings, dB	Type of uncertainty: B. Distribution type: indicated in the calibration certificate of the ultrasonic tester. Rating value: 0 dB. The standard uncertainty $u(\delta N_s)$ is taken from the ultrasonic tester calibration certificate (by dividing the expanded uncertainty by the coverage factor). Sensitivity (influence) coefficient: 1.

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

The average value of the ultrasonic tester attenuation change at each calibration point is calculated based on the results of a series of observations using the formula:

(2)

The deviation of the flaw detector readings (the main error) is calculated using the formula:

$$\Delta N = N_x - N_s \qquad (3)$$

According to the formulas in Table 2, the estimates of the components of the total standard measurement uncertainty are calculated:

$$u(\Delta N) = \sqrt{u^2(\delta N_x) + u^2(N_s) + u^2(\delta N_s)} \qquad (4)$$

Where,

$u(N_s)$ – standard uncertainty is expressed as the standard deviation of the arithmetic mean of the measurement results, dB;

$u(\delta N_s)$ – standard uncertainty, which is taken from the ultrasonic tester calibration certificate (by dividing the expanded uncertainty by the coverage factor), dB;

$u(\delta N_x)$ – standard uncertainty due to the finite resolution of the ultrasonic flaw detector , dB

The value of expanded uncertainty is calculated using the formula:

$$U = k \cdot u(\Delta N) \qquad (5)$$

where k = 2 is the coverage coefficient, which corresponds to a coverage probability of 95% under the assumption of a normal distribution of the measured value.

The value of the expanded uncertainty is calculated to obtain the measurement result from the readings (maximum deviation taking into account the expanded uncertainty):

$$U_y = U + |\Delta N| \qquad (6)$$

The measurements was carried out in non-destructive testing laboratory of Uzbek national institute of metrology. Ultrasonic flaw detector EPOCH LT 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 flaw detector EPOCH LT is given in this paper for understanding the topic more clearly.

Changing the set readings of the device (N_x). From the minimum point of the normalized range to the maximum point of the normalized range.

The first stage begins with the minimum point of the normalized range, increase by a minimum degree (0.1 dB) within 1 dB. N_x20.1 = 20.1-20, N_x20.2 = 20.2-20.1, ...N_x21 = 21.0-20.9.

$$N_s = \frac{\sum_{i=1}^{n} N_i}{\mathrm{n}}$$

The second stage begins with the minimum point of the normalized range, increase by a degree (1 dB). N_x22 = 22-21, N_x23 = 23-22, ...N_x30 = 30-29.

The third stage begins with the minimum point of the normalized range, increase by a degree (10 dB). N_x40 = 40-30, N_x50 = 50-40, ...N_x80 = 80-70.

Correction to the instrument readings due to the finite resolution of the ultrasonic flaw detector (δN_x). The smallest digit of the ultrasonic flaw detector corresponds to a resolution of 0.1 dB. Each ultrasonic flaw detector value has a correction due to the finite resolution, which is estimated at 0 dB with limits of ± 0.1 dB. The standard uncertainty associated with this correction $u(\delta N_x)$ is 0.029 dB.

Average change in tester attenuation (N_s). The change in readings obtained by the ultrasonic tester,

$N_s = \frac{\sum_{i=1}^{n} N_i}{\mathrm{n}}$ arithmetic mean of n = 10 measurements of the ratio of changes in signal amplitudes.

$N_{s20.1} = \frac{\sum_{i=1}^{10} N_{i20.1}}{10}$ For the first stage $N_{i20.1}$ is a series of ten differences in tester readings at the set

The value of the ultrasonic flaw detector amplitude N=20.1 and N=20. Ni20.1 = 6.8-6.7=0.1;6.8-6.7=0.1;.. ..;6.8-6.7=0.1. Ns20.1 =0.10 dB.

$\Delta N_{20,1}$=(0,1+0)-(0,1+0)=0 dB;

For the second stage, N_{i25} is a series of ten differences in tester readings at the specified amplitude value of the ultrasonic flaw detector. N=25 и N=24. N_{i25} =11,7-10,7=1,0;11,8-10,7=1,1;.. ..;11,7-10,7=1,0. N_{s25} =1,03 dB.

ΔN_{25}=(1+0)-(1,03+0)= -0,03 dB;

For the third stage N_{i40} is a series of ten differences in tester readings with the rear-marked amplitudes of the ultrasonic flaw detector. N=40 и N=30. Ni40 =26,5-16,5=10,0; 26,4-16,5=9,9;.. ..;26,5-16,5=10,0. N_{s40}=9,91 dB.

ΔN_{40}=(10+0)-(9,91+0)=0,09 dB;

Results were calculated for N=40 dB for 5MHz frequency.

The standard uncertainty u(Ns) for N = 40 dB at 5 MHz is expressed as the standard deviation of the arithmetic mean of the measurement results:

$$u(N_s) = \sqrt{\frac{\sum_{i=1}^{10} (N_i - N_s)^2}{10(10-1)}} = 0{,}028$$

dB

$$u(\Delta N) = \sqrt{u^2(\delta N_x) + u^2(N_s) + u^2(\delta N_s)} = \sqrt{0{,}029^2 + 0{,}028^2 + 0{,}11^2} = 0{,}12$$

Standard uncertainty taken from the ultrasonic tester calibration certificate= 0,1+0,01·A dB:

$$u(\delta N_s) = \frac{0{,}1 + 0{,}01 \cdot N_x}{\sqrt{3}} = 0{,}11 \quad \text{dB}$$

Standard uncertainty due to the finite resolution of the ultrasonic flaw detector:

$$u(\delta N_x) = \frac{a}{2\sqrt{3}} = \frac{0{,}1}{2\sqrt{3}} = 0{,}029 \quad \text{dB}$$

Combined standard uncertainty:

The expanded uncertainty is calculated using the formula:

where k = 2 is the coverage coefficient, which corresponds to a coverage probability of 95% under the assumption of a normal distribution of the measured value.

U = 2·0,12 = 0,24 dB

Table 3 shows us uncertainty budget for gain parameter of ultrasonic flaw detector according to measurement results.

Table 3

Input value	**Inp. value estimat.**	**Standard uncertain.**	**Number of degrees of freedom**	**Probability distribution of the input quantity**	**Sensitivity coefficient**	**Uncertainty contribution**
1	**2**	**3**	**4**	**5**	**6**	**7**
Deviation, dB	ΔN	ΔN	∞	normal	1	u(NS)
Correction to tester reading, dB	δN_s	u(δNs)	∞	normal	1	u(δNs)
Correction due to the resolution of the Device's amplifier, dB	δN_x	u(δNx)	∞	rectangular	1	u(δNx)
The combined uncertainty						*u(E)*
Expanded uncertainty			*k=2*			*U=2•u(E)*
Effect. num. of degrees of freedom			ν_{eff}			

Non-destructive testing laboratory of Uzbek national institute of metrology was accredited by SE "Center for Accreditation" for the calibration of ultrasonic flaw detectors by gain in 2024 y. The laboratory has been accredited also for the calibration of ultrasonic flaw detectors by thickness. Every year about 500 ultrasonic measuring devices like ultrasonic flaw detectors and ultrasonic thickness gauges are calibrated and estimated measurement uncertainty by a single laboratory of Uzbek national institute of metrology in Uzbekistan.

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

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