ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 7 , July 2017

Evaluation of Ultrasound Reflection Coefficient Measurement Result and its Uncertainty by the Method of Linearization

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Annotation: It is shown that, if the ultrasound amplitudes before (A_0) and after(A) application of the test liquid (soybean oil) to the working surface of the acoustic cell are measured using only one (working) channel of the installation, the measurement results become mutually correlated. And if A0 is measured on the reference installation channel and the amplitude A is measured on the working channel of the installation, the measurement results are not mutually correlated. And thus, it becomes possible to use the method of linearization to evaluate the measurement result and its accuracy characteristics (error and / or uncertainty).

Keywords: ultrasound, liquid, soybean oil, acoustic cell, measurement, reflection coefficient, working, reference, correlation, method of linearization, error, uncertainty.

I. STATEMENT OF THE PROBLEM

The International Organization for Standardization (ISO), in collaboration with the International Committee for Weights and Measures (CIPM), the International Bureau of Weights and Measures (BIPM), the International Electro technical Commission (IEC), the International Federation of Clinical Chemistry (IFCC), the International Union for Pure and Applied Chemistry (IUPAC) (IUPAP) and the International Organization of Legal Metrology (OIML) published the international document "Guide to the Expression of Uncertainty in Measurement (GUM)" [1] in 1993. Later other versions of the document were developed and published [2,3]. The ISO / IEC Guide 98-3: 2008 (GUM) [3] sets out the basic rules for estimating and expressing the uncertainty in a measurement, which can be observed at different levels of accuracy and in various application areas. It is used to estimate measurement uncertainty using statistical methods and makes it possible to compare measurement results and evaluate their reliability.
After the publication of these international documents, the interest of world metrology to the questions of estimating the uncertainty of measurements constantly increased. As a result, in many international, regional and national organizations, such as: ISO, CIPM, BIPM, IEC, OIML, the European Association for the International Traceability of Chemical Analytical Measurements (EURACHEM), the International Laboratory Accreditation Cooperation (ILAC) The Euro-Asian Cooperation of National Metrological Institutions (COOMET), the Eurasian Organization for Standardization, Metrology and Certification »(EASC) and others began to organize scientific and technical committees and working groups on uncertainties of measurements. It has been developed and published a number of regulatory, scientific and scientific-technical and guidance documents [4-7] by above-mentioned organizations. These documents present a mandatory requirement - to provide quantitative results of measurements with uncertainty values.

II. RELEVANCE OF THE WORK

In accordance with the requirements of the international standard ISO / IEC 17025 [4, paragraph 5.4.6.1] and identical with it the state standard of Uzbekistan O'z DSt ISO / IEC 17025, calibration laboratory or testing laboratory which performs its own calibration must have and apply the Procedure for estimating uncertainty of measurements for all calibrations and types of calibrations.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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These standards [4] also require calibration and test certificates included: measurement uncertainty (Paragraph 5.10.4.1 enumeration b) and ensuring the traceability of measuring results to the International System of Units (SI) (Paragraph 5.10.4.1 enumeration c).

III. PURPOSE OF THE WORK

Despite such a wide range of developments, the estimation of measurement uncertainties of some types and subspecies of measurements were not developed. These include acoustic measurements, in particular measurements the complex reflection coefficient of ultrasonic shear waves from the line of demarcation solid body - test liquid (hereinafter - complex reflection coefficient r *).

IV. BASIC MATERIAL

In the megahertz frequency range of 10-150 MHz for measuring the complex reflection coefficient the installation [8,9] based on the impedance method is used. The acoustic cell is made in the form of two identical rectangular bars of the same size made of fused silica with the butt ends, bevelled at an angle of 82 ° 40 '.
The complex reflection coefficient module | r * | = r (hereinafter, the reflection coefficient r) is determined by the formula (1) by measuring ultrasonic amplitudes before A_0 and after A applying the liquid to the surface of an acoustic cell - fused silica

$$r = \left(\frac{A}{A_0}\right)^k, \quad k = \frac{1}{2m-1} \tag{1}$$

where m - sequential number of reflections (echoed signal).
Measurement results of the input quantities A_0 and A can be mutually related (correlated), if they are measured at the same time, with the same type of measurement, for the same echoed signal (with the same sequential number of reflections m), etc. Also the results can be not correlated. Preference is given to the case when the estimation of the input quantities are not correlated. In the absence of correlation the estimation of the result of indirect measurements and its accuracy characteristics (error and / or uncertainty) is simplified and slightly increased using the method of linearization [10].
Measurements of the reflection coefficient r can be carried out in a different sequence and order on the installation mentioned above, which has two channels - working and reference. Therefore, we conducted studies to determine the sequence and order (embodiment) of measurement in which the correlation between the estimates of the input quantities will be absent, namely:
The first embodiment (method) of the reflection coefficient r measurement is the amplitude of the ultrasound before (A_0)and after (A) application of the liquid to the surface of the acoustic cell is measured using only the working channel of the installation (Table 1);
The second embodiment (method) of the reflection coefficient r measurement is the amplitude of ultrasound A_0 is measured at the reference, and amplitude A is measured on the working channel of the installation (Table 2); To estimate the correlation between the estimates of the input quantities A_0 and A we first carried out multiple measurements of these quantities, then the correlation coefficient between the standard uncertainties of the measurements of the A_0 and A values was determined by the formula (2) and evaluated their significance by Student's test (3)

$$r(A_0, A) = \frac{1}{n(n-1)} \cdot \frac{\sum_{k=1}^{n}\left(A_{0i} - \overline{A}_0\right)\left(A_i - \overline{A}\right)}{u(\overline{A}_0) \cdot u(\overline{A})} \tag{2}$$

$$t = \left| \frac{r(A_0, A) \cdot \sqrt{n-2}}{\sqrt{1 - r^2(A_0, A)}} \right| < t_p(n-2) \tag{3}$$

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International Journal of Advanced Research in Science, Engineering and Technology
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Where tP(n-2) =3,18 is the Student's coefficient for the number of degrees of freedom (n-2) = 3 for P = 0.95. The fulfillment of condition (3) testifies to the absence of a correlation relation between the standard uncertainties of measurement of values A_0 and A. The results of studies on ultrasonic frequency 11,2 MHz first embodiment shown in Table 1. As test liquid soybean oil is used.

Table 1 The results of studies on ultrasonic frequency 11,2 MHz obtained by the first embodiment

i	1	2	3	4	5	$\bar{A}_0, \bar{A}$	$u(\bar{A}_0), u(\bar{A})$	$r(A_0,A)$	**t**
A_{0i}, V	3,98	4,00	4,05	4,03	3,95	4,00	0,018	0,891	3,392
A_i, V	2,67	2,31	3,20	3,01	2,13	2,66	0,018		

It follows from Table. 1 that (3) is not satisfied (3,392> 3,18), hence, the correlation coefficient r (A0, A) = 0,891 is significant. So it can be concluded that for evaluation of measurement results and accuracy characteristics (error and / or uncertainty) obtained by the first method, using the method of linearization is unacceptable.
The research results obtained by the second method (embodiment) shown in Table. 2 indicate the fulfillment of condition (3), 0.788 <3.18. Hence, the correlation coefficient r (A0, A) = 0.414 is insignificant. We have obtained identical results for other ultrasound frequencies in the range 30-150 MHz [11].

i	1	2	3	4	5	$\bar{A}_0, \bar{A}$	$u(\bar{A}_0), u(\bar{A})$	$r(A_0,A)$	**t**	$\mathbf{\Delta A_0, \Delta A}$
A_{0i}, V	4,77	4,03	4,94	5,10	5,35	4,84	0,22	0,414	0,788	0,510
A_i, V	3,03	2,76	3,67	3,62	2,87	3,19	0,19			0,478

Therefore, we can use the method of linearization if we can neglect the remainder term R at the expansion of a function (1) in a Taylor series, which is estimated by the equation (4)

$$R = \frac{1}{2}\sum_{j}^{N}\frac{\partial^2 r}{\partial A \partial A_0}(\Delta A_0)(\Delta A) \tag{4}$$

Where ΔA0 and ΔA are the maximum deviations of the i-th observation result from the average values of arguments A_0 and A respectively (see Table 2).
Applying (3) to the measurement model (1), we obtain

$$R = \frac{k \cdot r}{2}\left[(k+1)\cdot\frac{1}{A_0^2}\cdot(\Delta A_0)^2 + (k-1)\cdot\frac{1}{A^2}\cdot(\Delta A)^2 + 2k\cdot\frac{1}{A \cdot A_0}(\Delta A)(\Delta A_0)\right] \tag{5}$$

The remainder term R is neglected if the inequality

$$R<0{,}8\cdot u_c(r) \tag{6}$$

Where $u_c(r)$ –combined standard uncertainty of measuring of radiant reflectance r.
Our evaluations showed: R= -0,0010; $u_c(r)$=0,014; 0,8·$u_c(r)$=0,011.

Consequently, the condition (5) is fulfilled. It means that the remainder term R can be neglected when the function (1) is expanded in a Taylor series. It means for estimating the indirectly measurable quantity r and its accuracy characteristics, obtained by the second method (embodiment), the method of linearization can be used.
The results are shown in Table.3

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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Table 3. Estimation results of the indirectly measurable quantity r and its accuracy characteristics, obtained by the second method (embodiment)

r	c_{A0}= -k·r/ A_0	c_A= k·r/ A	u_{cA}(r)	u_{cB}(r)	u_c(r)	ν_{eff}	k	U
0,920	-0,038	0,058	0,014	0,000	0,014	4	2,746	0,038

Where $c_{A0}=\partial r/\partial A_0$, $c_A=\partial r/\partial A$ – sensitivity coefficients of the combined standard uncertainty (CH) of type A u_{cA}(r), type B u_{cB}(r) CH u_c(r) to the CH of estimates of the quantities A0 and A, respectively;

ν_{eff} – the effective degree of freedom;

k – coverage factor;

U – expanded uncertainty.

V. CONCLUSION

In conclusion, we note that as a result of the study it was revealed that the scientific works of several dozen international, regional, national, scientific, scientific-methodical and other organizations devoted to the issue of estimation of uncertainty of measurement results.

The evaluation of uncertainty of measurement results of complex reflection coefficient of ultrasonic shear wave from the line of demarcation solid body - test liquid is insufficiently studied.

If the ultrasound amplitudes before A_0 and after A applying the liquid to the surface of the acoustic cell are measured using only one (working) installation channel, the measurement results become mutually correlated.

If the ultrasound amplitude A_0 is measured using the reference installation channel, and the amplitude A is measured on the working channel of the installation, , the measurement results become mutually uncorrelated. And thus, it becomes possible to use the method of linearization to evaluate the measurement result and its accuracy characteristics (error and / or uncertainty).

Measurement results of the complex reflection coefficient of ultrasonic shear waves from the line of demarcation fused silica - soy oil and its uncertainties are estimated using a method of linearization.

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ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 7 , July 2017

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