of this version of the standard are checked against the limit. Therefore, the most effective will be measures aimed at reducing the influence of dominant sources, which were identified in the previous iteration. The proposed adaptive method makes it possible to find optimal solutions in such situations.

If at the second, third and subsequent iterations it is not possible to achieve the specified accuracy characteristics, that is, the current level of development of science and technology does not allow fulfilling the requirements set in the TS, or requires very large expenses, then other ways of reproducing the unit of measurement are considered, the question is raised on increasing resources for creating a standard or reducing the requirements in relation to its accuracy.

The development of a secondary standard for the unit of ultrasound power in an aqueous medium was carried out according to the proposed adaptive method.

1. First iteration.

a) analysis of a priori information and the choice of reproduction principle of the unit of measurement. On the basis of the collected information, the method of radiation pressure balance using a precision electronic weight, recommended by the international standard IEC 61161, was chosen to implement the unit of ultrasound power in water medium in the standard.

b) physical model.

The authors have considered a simplified physical model for measuring ultrasonic power in an aqueous medium by the force balance method.

At the first iteration, a simplified version of the standard structure was considered, which included only a generator, a power amplifier, an ultrasonic emitter, a container with a target, a class 3rd weight, and a water treatment system. The cost of creating such a standard is minimal.

c) mathematical model.

The formulas (1) and (4) were taken as a mathematical model of the measurement process.

d) estimation of uncertainty by the improved PUMA method.

According to the mathematical model and the pre-selected structural scheme, all possible sources of uncertainty are analysed, all available information on the accuracy characteristics of the input quantities (informative parameters and influential quantities) is collected and analysed, and a table (list) of the input quantities is drawn up. As an example, a table of input quantities for the secondary standard of the unit of ultrasound power is given (Table 1). Accuracy characteristics lead to a unified form – standard uncertainty.

TABLE I. NAME, DESIGNATION AND UNITS OF MEASUREMENT OF INPUT QUANTITIES

Input quantity	**Designation**	**Measurement units**
Frequency	f	MHz
Sound speed in wate	c	m/s
The angle between the direction of propagation of the acoustic wave and the normal of reflecting (conical convex) surface	ϑ	degree
Ultrasonic emitter radius	a	mm
Density of liquid (distilled water)	ρ	kg/m^3
Temperature	t	^{o}C
Target radius	b	mm
Non-centeredness of ultrasonic beam and target, obliqueness	Sp	%
Weight force (mass, which is equivalent to radiation force)	F_b	g
Voltage at the ultrasonic emitter	V	V

Based on the calculations in Table 1, the uncertainty budget of the first iteration was compiled in the form of a table, the end result of which is the expanded uncertainty in the measurement according to the pre-selected structural scheme of the standard and the share of the contribution of each of the sources of uncertainty to the total uncertainty of the initial value.

The distribution law of the input quantities was assumed to be uniform for all quantities, with the exception of a random error. The space has a normal distribution.

When analysing the relationships between the input quantities, no significant correlation was found, therefore, all sources of uncertainty were assumed to be uncorrelated.

Table 2 provides an example of an uncertainty budget for 0.005 W power at 5 MHz. When constructing the table, various sources of information about the accuracy characteristics of the input quantities were used (technical documentation for devices, reference books, international standards, in particular IEC 61161, reports on international reconciliation, technical literature).

The first iteration is rather rough, performed on the basis of a simplified mathematical model in order to preliminary estimate the expanded uncertainty and compare it with the technical specification requirements for creating a standard, as well as in order to identify the dominant components of uncertainty. In our case, the expanded uncertainty at the first iteration was approximately 39% and turned out to be significantly higher than that listed in the technical specification. With this physical model, the resources required to create the reference did not exceed the allocated limit

e) making a decision on the direction of further work on the creation of a standard.

The authors looked for ways to reduce the expanded uncertainty and performed a second iteration.

2. Second iteration.

a) analysis of the uncertainty budget and search for ways to reduce the uncertainty of the input quantities

Analysis of the results of the first iteration showed that the dominant components were the inaccuracy of the weights of the 3rd class, the expanded uncertainty in the measurement of which was 17% and the random component, which reached 8%. Therefore, to reduce the expanded uncertainty in the composition of the standard, a weight of increased accuracy was used. To reduce the random component of uncertainty, its possible sources were shown when choosing a structural scheme, developing the design of the standard, software and arranging the room where the standard was located, which made it possible to reduce the random component of the measurement error by half.

b) improvement of the physical model.

According to the refined physical model, a new structural and functional diagram was developed. Class 1 weight, a system of protection against acoustic interference and vibrations, a voltmeter to control the voltage stability at the input of the ultrasonic emitter, and a thermometer to control the change in water temperature were introduced into the structural and functional diagram of the standard. Formulas (1) and (3) are approximate, they are used only for working measurements, therefore, (2) – (6) was taken as a refined mathematical model of the measurement process (2)-(6).

c) the procedure for assessing uncertainty using the improved PUMA method.

To calculate the contribution of the radius of the ultrasonic emitter $u_4(y)$ to the total standard uncertainty, the method of numerical differentiation was used by the formula (4).

TABLE II. FIRST ITERATION UNCERTAINTY BUDGET (FREQUENCY 5 MHZ, POWER 0.005 W)

Input quantities					**Output quantities**	
Quantity designations	**Nominal sensitivity coefficients**	**Accuracy characteristics (deviations), %**	**Sensitivity coefficients**	**Standard uncertainty, $u(x_k)$, %**	**Contribution, $u_k(y)$, %**	**Contribution share, %**
f^1	5.00	$0.20 \cdot 10^{-5}$	1.00	0.00	0.00	0.00
c^1	1491.5	0.000070	1.00	0.00	0.00	0.00
ϑ^1	45.00	3.50	1.49	2.02	3.01	2.36
a^2	13.50	3.70	0.00	2.14	0.00	0.00
ρ^2	$997.54 \cdot 10^{-1}$	$0.\ 10 \cdot 10^{-4}$	1.00	0.00	0.00	0.00
t^2	23.00	0.20	1.00	0.12	0.12	0.00
b^2	41.00	2.00	1.00	1.15	1.15	0.34
S_p2	3.00	3.00	1.00	1.73	1.73	0.78
F_b1	$34.13 \cdot 10^{-5}$	29.30	1.00	16.92	16.92	74.32
V^2	var	4.00	2.00	2.31	4.62	5.54
Average		8.00	1.00	8.00	8.00	16.61
Combined standard uncertainty u_c, %					19.62	
Extended uncertainty U, % (k=2)					39.25	

Table 3 provides an example of an uncertainty budget for 0.005 W power at 5 MHz. In addition, for clarity, they are presented in the form of a histogram of the sources of uncertainty contribution.

According to the results of the second iteration, the obtained expanded uncertainty only in some measurement subranges slightly exceeded that specified in the specification.

The resources required to create the benchmark have not exceeded the allocated limit.

d) making a decision on the direction of further work on the creation of the standard.

The authors made a decision to improve the accuracy so as to meet the requirements of the technical specification in the entire frequency and power range and performed the next iteration.

3. Third iteration.

a) analysis of the uncertainty budget and finding ways to reduce the uncertainty of input quantities.

The dominant components were spaces of random error and uncertainty in measuring input voltage. To further reduce the random component of the error, the measuring part of the standard was equipped with a protective casing; the rooms where the standard was located were additionally protected from the influence of such influential factors as noise and vibration, air movement, changes in environmental parameters; the measuring channels of the standard were protected from electromagnetic interference and interference, etc. The algorithm for controlling the measurement process and processing the measurement information was built in a way to minimise the random component of the error, for example, by using an adaptive method for collecting the number of observations during measurement, and more. To reduce the contribution of the voltage measurement error, a voltmeter with higher accuracy characteristics was chosen.

b) improvement of the physical model.

At the third iteration, the structural diagram of the standard provided for the improvement of the software and a more effective system of protection against external influences, which reduced the random component of the error to 2%. In addition, a voltmeter with a maximum permissible error of no more than 2% was used, as well as an oscilloscope and frequency meter to determine and control the signal parameters at the input of the ultrasonic emitter and a barometer, thermometer, and hygrometer to measure environmental parameters. The target was chosen as an absorbent type.

TABLE III. SECOND ITERATION UNCERTAINTY BUDGET (FREQUENCY 5 MHZ, POWER 0.005 W)

Input quantities					Output quantities	
Quantity designations	Nominal sensitivity coefficients	Accuracy characteristics (deviations), %	Sensitivity coefficients	Standard uncertainty, $u(x_k)$, %	Contribution, $u_k(y)$, %	Contribution share, %
f^1	5.00	$0.20 \cdot 10^{-5}$	1.00	0.00	0.00	0.00
c^1	1491.5	0.000070	1.00	0.00	0.00	0.00
ϑ^1	45.00	3.50	0.79	2.02	1.59	5.35
a^2	13.50	3.70	0.01	2.14	0.00	0.00
ρ^2	$997.54 \cdot 10^{-3}$	$0.\ 10 \cdot 10^{-4}$	1.00	0.00	0.00	0.00
t^2	23.00	0.20	1.00	0.12	0.12	0.03
b^2	41.00	2.00	1.00	1.15	1.15	2.81
S_p2	3.00	3.00	1.00	1.73	1.73	6.36
F_b1	$34.13 \cdot 10^{-5}$	29.30	1.00	16.92	1.69	6.07
V^2	var	4.00	2.00	2.31	4.62	45.37
Average		8.00	1.00	8.00	4.00	34.01
Combined standard uncertainty u_c, %					7.33	
Extended uncertainty U, % (k=2)					13.72	

c) refinement of the mathematical model.

Formulas (1) – (6) were taken as a mathematical model.

In addition, key comparisons of national standards of the unit of ultrasonic power, which were carried out under the control of the International Committee of Measures and Weights, showed that for the standards of the highest rank it is more important to reproduce not the unit of power, but the electroacoustic conductivity:

$$G = \frac{W_{out}}{C_{in}^2} \tag{11}$$

where W_{out} – ultrasonic output power; V_{in} – effective value of the input voltage.

d) the procedure for estimating uncertainty by the improved PUMA& method.

The procedure for estimating uncertainty is similar to that given in the second iteration.

At the third iteration, the expanded uncertainty did not exceed 10%, which satisfied the TS requirements. The total cost of creating a benchmark was within the foreseen limit.

It should be noted that with a decrease in the dominant sources of uncertainty, more weight, a larger share of the contribution acquired and became dominant, and other sources of uncertainty, for example, the non-centeredness of the ultrasonic field and the target, obliqueness. These new dominant sources also controlled. Therefore, the design of the standard power meter provided the required positioning accuracy of the ultrasonic emitter and the target dimensions.

e) decision making.

In accordance with the above, a secondary standard for the unit of ultrasound power in an aqueous medium was created.

When developing the design of the standard, software and equipment of the room where the standard was located, the measures listed above were implemented.

The structural and functional diagram of the secondary standard of the unit of ultrasound power in the aquatic environment, developed by the adaptive method, was presented in the form of a linear model. From the generator through the power amplifier, an electrical harmonic signal of a given level is fed to the ultrasonic emitter at its resonance frequency. An ultrasonic emitter immersed in distilled and degassed water in a measuring vessel creates an ultrasonic beam that interacts with the target. The value of the radiation force that arises in this case is determined by an electronic balance, the measurement result is transmitted to a personal computer, where the power is determined according to the mathematical model described above. The parameters of the electrical signal coming from the generator through the power amplifier are monitored using an oscilloscope, the voltage across the ultrasonic emitter is measured with a voltmeter.

A set of ultrasonic emitters is used to ensure the specified operating frequency range and reproducible power range.

Control of the process of measurement and processing of measurement information in real time and the procedure for assessing the accuracy characteristics are performed on a computer with appropriate software. The temperature of the water and the content of dissolved oxygen in it during the measurement are monitored with a water thermometer and an oximeter, respectively. A barometer, thermometer and hygrometer are provided to monitor environmental conditions. A system of protection against vibrations, noise and air flows has been developed.

IV. CONCLUSION

As a result of a study on the standard formation and its modelling in a sound environment based on a neural network, the authors have improved the method for minimising uncertainty (PUMA method) by using methods of numerical differentiation and simulation modelling instead of an analytical method for assessing uncertainty. In the system, which made it possible to obtain the standard, an improved method for minimising uncertainty (PUMA method) was applied for the standard of the ultrasound power unit at the initial stage of its development. A new adaptive method and information technology for creating standards of units of measured quantities with specified high accuracy characteristics, subject to limited resources, has been developed in the structural equipment and application in the industrial sphere. As a method of measurement uniquelisation, the developed adaptive method was applied to create a standard for the unit of ultrasound power in an aqueous medium and a structural and functional diagram of a standard for a unit of ultrasound power in an aqueous medium is presented. The necessary accuracy characteristics, specified by the technical specifications and determined the resources allocated for the creation of the standard were developed.

The results of the article can be used for establishment of distributed networks for sound quality measurement, mainly within the structures of the study of sound transmission between high-tech devices. The future research will be focused on other methods for improving the efficiency of diagnostic systems in the neural network-based sound analysis.

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