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SOME FEATURES FOR THE CALIBRATION OF THE HYDROPHONES IN THE CLOSED CHAMBER

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The results reported in this paper show the influence of the sound pressure distribution on the results of the hydrophone calibration in the closed chamber. There was derived the expression binding the error of the measurement with the size of calibrated transducers and their positions related to the geometrical center of the cavity of the chamber. The corrected results of calibration by means of piezoelectric compensation were compared to the results of the reciprocity standard method calibration.

INTRODUCTION

The main problem of the hydrophones calibration is to know the function of the statial sound pressure distribution. This problem already exists for the simplest calibration of the hydrophones in the "small" closed chambers at the upper limit of the frequency range. In case of the ordinary underwater acoustic measurements, the function of the sound pressure distribution is neglected and occurs as the part of the systematic error.

The calibration of the hydrophones is usually carried out in small closed water-filled chambers. The frequency range is from a few hertz to 1-2 kHz [1, 2]. In this case, the sound pressure is uniform in the chamber cavity, which provides the acoustic connection between the projector and the calibrated hydrophone.

Let make a note, there are always two transducers in the calibration procedure. However these transducers may have the different size or may be placed in the different points of an acoustical field, and the different sound pressures acts on these transducers. It results in the increasing of the measurement error. Therefore these calibration methods are unacceptable for the precise underwater acoustic measurements.

1. THEORY

Usually, the chambers for the hydrophone calibration are the small piece of the narrow tube of the inner radius **R**, and $\mathbf{R < 0{,}61\,\lambda}$, where λ – the wave-length. In this chamber, the sound pressure depends on one co-ordinate only and needs to solve a one-dimensional problem. The second assumption is that the active element of the hydrophone is either thin-walled cylinder or sphere.

The expression describing a pressure field **p(z)** of the standing-wave in the tube with the rigid walls of the length **L** and cross-section area **S** [3] is given as:

$$p(z) = \rho c_w \xi k / Sin(kL) \times Cos k(L-z)) = p_m k Cos k(L-z) \quad (1)$$

where ρ is the water density; c_w is the speed of sound; ξ is the displacement of the piston-like projector; $k=2\pi/\lambda$ is the wave number; z is an axis of the symmetry of the chamber; p_m is an amplitude of the sound pressure.

The diagram of the chamber for the piezoelectric compensation method is shown in fig. 1.

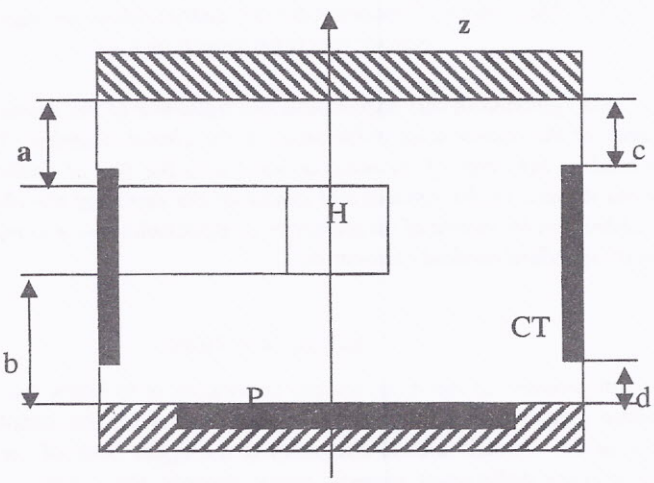

Fig.1. The diagram of the "small" closed chamber for the piezoelectric compensation method. **H** – hydrophone; **CT** – compensation transducer; **P** – piston-like source of sound

The systematic error Θ_o [4] of the hydrophone calibration in closed chamber depends on the ratio of the average sound pressure, which acts on the hydrophone active element, and the one, which acts on the zero-organ compensation transducer of the size $2h_{no}$.

In case of an ideal point-like hydrophone, this systematic error is:

$$\Theta_o = 20 lg[Sin(kl)/kl] \quad (2)$$

where $2l=L$.

For a real hydrophone (size $2r_h$ – along the axis z), it is:

$$\Theta_o = 20\ lg[Sin(kh_{ct})/kh_{ct} kr_h / Sin(kr_h)] \quad (3)$$

In practice of the underwater acoustic measurements, the geometrical centers of the transducers not often coincide with the geometrical center of the chamber cavity. Let us consider the case, when the center of the hydrophone is displaced at Δ_h relative to the geometrical center of the cavity chamber. The average sound pressure acting on the hydrophone is the integral of the expression (1) at the interval from **a** to **L-b**

$$p_{hsr} = 1/(L-a-b)\int_a^{L-b} p(z)dz = p_m \frac{\text{Sin } k(L-b) - \text{Sin } ka}{L-a-b} \quad (4)$$

but if

$$L\text{-}a\text{-}b = 2h_h,\quad L\text{-}b = l+h_h+\Delta_h \text{ and } a = l+\Delta_h-h_h,$$

the expression (4) reduces to

$$p_{hsr} = p_m \text{Sin}(kh_h)/kh_h \text{Cos}kl\,\text{Cos}k\Delta_h \times [1-tg(kl)\times tg(k\Delta_h)] \quad (5)$$

For the zero-organ compensation transducer

$$L\text{-}c\text{-}d = 2h_{ct},\quad L\text{-}d = l+h_{ct}+\Delta_{ct} \quad \text{and} \quad c = l+\Delta_{ct}-h_{ct}$$

the average sound pressure is

$$p_{ctsr} = p_m \text{Sin}(kh_{ct})/kh_{ct} \text{Cos}kl\,\text{Cos}k\Delta_{ct} \times (1-tg(kl)\times tg(k\Delta_{ct})] \quad (6)$$

where $2h_h$ is the size of an active element of the hydrophone along the axis **z**; and **a, b, c** and **d** - see Fig.1.

The ratio of the average sound pressure given by **(5)** and **(6)** defines the systematic error of the calibration of a real hydrophone in the closed chamber in case of some variations of the position of a hydrophone relatively to the geometrical center of the chamber cavity.

$$\Theta_o = 20lg[\text{Sin}(kh_h)/kh_h \times \text{Sin}(kh_{ct})/kh_{ct}] \times \text{Cos}k\Delta_h/\text{Cos}k\Delta_{ct} \times (1-tg\ kl\ \ tgk\Delta_h)/(1-tgkl\ \ tgk\Delta_{ct}) \quad (7)$$

The value Θ_o with opposite sign is the correction $S_m(\Delta_h)$ of the result of the real hydrophone calibration in the "small" closed chamber.

2. EXPERIMENTAL RESULTS AND DISCUSSION

In order to verify the formula (7), we carried out the series of experiments with the displacement of the hydrophone (type GI0-1-7) with an active element of diameter 7 mm. The sound pressure values measured by this hydrophone were determined in two positions: close to a cover of the chamber (for Δ_h = +19 mm - curve 1 in Fig.2.) and close to the piston-like sound source in the bottom chamber (for Δ_h = - 16 mm - curve 3 in Fig.2.), which was recounted to the geometrical center of the chamber (i.e. for Δ_h= 0 mm - curves 2 and 4 relatively).

The experimental and theoretical data of distribution the sound pressure in the chamber obtained by means of the piezoelectric compensation are shown in Tab. 1.

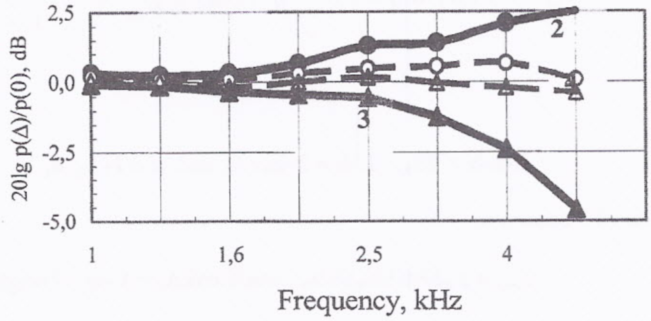

Fig. 2. The sound pressure in the point of the disposal of the hydrophone GI0-1-7 displaced by Δ_h from the center of chamber refered to the sound pressure at Δ_h= 0 vs frequency. Solid curves – experimental data, dotted curves – data calculated using the formula (7)

Table 1. Comparison of the hydrophone calibration results at different points relatively to the geometrical center of a "small" closed chamber

f, kHz	Experiment 20 lg [p(Δ_h)/p(0)], dB at Δ_h mm					Theory 20 lg [p(z)*S_m(Δ_h)/p(0)], dB at Δ_h mm				
	- 16	- 6	+ 9	+ 14	+ 19	- 16	- 6	+ 9	+ 14	+ 19
1.0	0.30	0.19	-0.00	-0.05	-0.05	0.21	0.15	0.05	0.05	0.09
1.25	0.23	0.25	-0.05	-0.31	-0.13	0.10	0.20	0.05	0.03	
1.6	0.30	0.06	-0.19	-0.35	-0.35	0.09	-0.02	-0.03	-0.16	
2.0	0.64	0.09	-0.28	-0.44	-0.44	0.31	-0.06	-0.02	0.01	0.15
2.5	1.29	0.08	-0.39	-0.52	-0.55	0.76	-0.16	0.04	0.17	
3.15	1.39	0.07	-0.78	-1.24	-1.24	0.54	-0.03	-0.06	-0.03	0.10
4.0	2.09	0.79	-1.2	-2.16	-2.38	0.64	0.15	0.01	-0.20	0.06
5.0	2.52	1.56	-2.30	-4.57	-4.57	0.08	0.44	0.04	-0.39	-1.51

The chamber was examined using the piezoelectric compensation method and including the VNIIFTRI secondary standard of the sound pressure-in-water unit within frequency range 0.01 Hz to 200 kHz.

The formula (7) leads to minimum error of the measurements (see Fig. 2 and Tab. 1). The error of the measurements of the hydrophone sensitivity was not greater than ± 0.6 dB. Only in one case - at 5 kHz and for Δ_h= +19 mm, the error was greater than 1 dB. This error may be explained by a non-ideal shape of a piston-like sound source.

However, in order to confirm correctness of this approach, we carried out the comparison of the hydrophone calibration by other independent method. The hydrophones were calibrated by two methods: piezoelectric compensation and reciprocity in the free-field [1, 2]. The correction was carried out for the piezoelectric compensation method using the formula (7). These methods are realized in the national primary standard for means measuring sound pressure in water within frequency range of $1\times10^{-2}\div1\times10^{6}$ Hz [5]. Four hydrophones of different types (GI-12 and GI-20 VNIIFTRI, 8104 Brűel and Kjær and RHS_2 HAARI, China) were used for the comparisons. The hydrophones GI-20 and RHS_2 have air-backed spherical piezoelectric ceramic active element, diameter 20 mm. The hydrophones GI-12 and 8104 have air-backed cylindrical piezoelectric ceramic active element, diameter 10 and 14 mm respectively.

The results of the calibration of four hydrophones obtained by both methods are shown graphically on the Fig. 3.

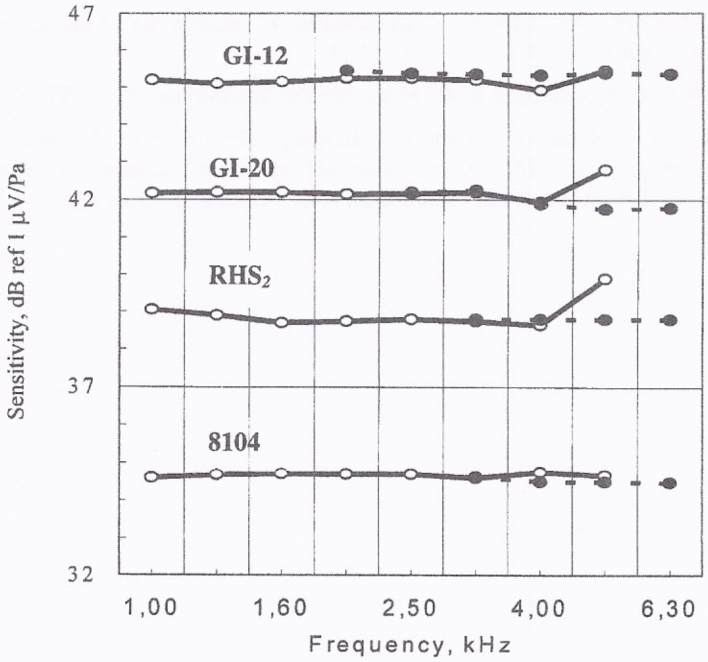

Fig.3. The results of calibration obtained for hydrophones GI-12, GI-20, RHS_2 and 8104 by means of: piezoelectric compensation (solid curves) and standard reciprocity method (dotted curves)

In order to have a good visualization in Fig. 3, the sensitivity levels of the hydrophones of types GI-20 and RHS_2 were increased by 4 and 1 dB respectively, and for GI-12, it was decreased by 28 dB.

The maximum systematic difference within the frequency range up to 4 kHz was less than 0.3 dB for all hydrophones. For the hydrophones GI-12 and 8104, which have cylindrical piezoelectric ceramic active element, the maximal difference was less than 0.3-0.4 dB at frequencies up to 5 kHz.

5. CONCLUSION

The results of experiments and comparisons showed a correctness of the expression (7), which may be taken into account in case of increasing non-uniformity of the sound field in the closed chamber.

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