STANDARD FACILITY FOR FREE-FIELD CALIBRATION OF HYDROPHONES AND VECTOR RECEIVERS IN THE REVERBERANT LABORATORY WATER TANK

A. N. Matveev[a], A. E. Isaev[a]

[a]Mendeleevo, VNIIFTRI, Moscow region, Russia, 141570

A. N. Matveev. Mendeleevo, VNIIFTRI, Moscow region, Russia, 141570.
Fax: +74956602539. E-mail: matveev@vniiftri.ru

Abstract: *The data on the standard facility for calibration of underwater sound receivers in the reverberant laboratory water tank are presented. The standard facility implements the measuring procedure of the reciprocity method in the free field of a spherical traveling sound wave using three transducers. A feature of the standard facility is the measuring by the absolute method the free-field sensitivity of hydrophones and receivers of vector quantity of underwater sound field. During measurements, the free-field conditions are provided by using the method of time gating of tone-bursts and the technique of complex moving weighted averaging. The results and uncertainty estimation of calibrations performed using the standard facility are shown.*

Keywords: *Vector receiver of underwater sound, free-field calibration, phase sensitivity, underwater acoustic standard facility*

1. INTRODUCTION

Sound field distortion caused by an underwater receiver placed in a small volume chamber increases with the frequency and at frequencies above 1 kHz leads to an unacceptably large measurement uncertainty. A similar problem exists for the hydrophone calibration. At frequencies above 1 kHz, hydrophone free-field calibrations are performed in a large test tank.

Most calibration facilities use a standardized measurement procedure of reciprocity method with three transducers, one of which is a reversible hydrophone *T*, the other is a projector *P*, and the third is a calibrated hydrophone *H*. Perform measurements of the free-field electrical transfer impedance of pairs *P-H*, *T-H*, *P-T*. The calibrated hydrophone free-field sensitivity is calculated by the formula:

$$M_H = \sqrt{\frac{2}{\rho \cdot f} \cdot \frac{Z_{PH} \cdot Z_{TH}}{Z_{PT}} \cdot \frac{r_{PH} \cdot r_{TH}}{r_{PT}}}, \qquad (1)$$

where M_H is the hydrophone free-field receive sensitivity [V·Pa^{-1}], f is the frequency [Hz], ρ is the density of water [kg·m^{-3}], Z_{XX} is the free-field electrical transfer impedance of each transducer pair [Ohm], r_{XX} is the distance between projector and receiver for each transducer pair [m].

To eliminate the influence of sound reflections in the test tank and to measure the free-field transfer impedance in the presence of reverberation interference, various methods are used. The most accurate of these are the method of time gating of tone bursts and the technique of complex moving weighted averaging. When using time gating, the free-field hydrophone calibration can be performed at frequencies above 1 kHz. The reason for the limitation is insufficient resolution in the frequency of measurements by the tone-bursts method. When the technique of complex moving weighted averaging is used, the lower frequency of the calibration determines by the signal-to-noise ratio, which allows to extend the free-field hydrophone calibration range to 100 Hz [1].

For underwater acoustic measurements in addition to hydrophones – receivers of sound pressure (the scalar quantity), receivers of vector quantities of the sound field (vibrational velocity of water particles, sound pressure gradient) are getting more and more widespread. The first vector receivers (VR) were low frequency and their calibration was performed in the field of a standing sound wave of a small-volume chamber. The frequency range of modern VR is tens of kilohertz, which required to calibrate receivers at high frequencies. However, it is not possible to extend the frequency range of VR calibration in a small-volume chamber to frequencies above 1 kHz [2].

2. METHOD IMPLEMENTATION

Directly apply the reciprocity method for the VR calibration is not possible, because there is no reversible VR. Nevertheless, the formula of the reciprocity method can be used for the sensitivity of the VR determining. Note that the formula contains distance, receiver sensitivity, frequency. If we know the sound pressure at the point of VR location, the distance from the projector and frequency, we can calculate the value of vector quantities of the underwater sound field (vibrational velocity or sound pressure gradient). Thus, it becomes possible for the absolute calibration of the VR in the free field using the reciprocity method procedure.

In the field of a spherical sound wave, the vibrational velocity of water particles V and the gradient of sound pressure $grad(p)$ are related to the sound pressure p_{sph} by the following relations:

$$V = \frac{p_{sph}(r)}{\rho \cdot c} \cdot \frac{\sqrt{1+k^2 \cdot r^2}}{k \cdot r}, \tag{2}$$

$$grad(p) = p_{sph}(r) \cdot \frac{\sqrt{1+k^2 \cdot r^2}}{r}, \tag{3}$$

where $k = 2 \cdot \pi \cdot f \cdot c^{-1}$ is the wavenumber [rad·m^{-1}], c is the sound speed in water [m·s^{-1}].

The free-field sensitivity of VR to the desired vector quantity of the sound field can be determined using the formula:

$$M_{VR} = \sqrt{\frac{2}{\rho \cdot f} \cdot \frac{Z_{PR} \cdot Z_{TR}}{Z_{PT}} \cdot \frac{r_{PR} \cdot r_{TR}}{r_{PT}}} \cdot \sqrt{\frac{1}{\Theta(r_{PR}) \cdot \Theta(r_{TR})}}, \tag{4}$$

For the calibration of receiver of the vibrational velocity of water particles $\Theta(r)$ is:

$$\Theta(r) = \frac{1}{\rho \cdot c} \cdot \frac{\sqrt{1+k^2 \cdot r^2}}{k \cdot r}, \tag{5}$$

and for the sound pressure gradient receiver calibration $\Theta(r)$ is:

$$\Theta(r) = \frac{\sqrt{1+k^2 \cdot r^2}}{r}. \tag{6}$$

The difference between formula (4) for the sensitivity of the VR and formula (1) for the hydrophone sensitivity is the presence of a multiplier $\Theta(r)$ characterizing the relationship between the scalar and vector quantities of the sound field of a spherical wave.

The considered method makes it possible to perform an absolute calibration of the VR, using the reciprocity method. The peculiarity of the method consists in the fact that during vector receiver calibration a hydrophone (a scalar receiver) is used as a reversible transducer.

To reduce the dispersion of the measurement result due to the influence of noise interference, averaging is usually used. For example, averaging of the FFT estimations of received tone-burst signals reduces the dispersion, but gives a biased estimation and does not allow one to observe the envelope shape of the received signal. The feature of described facility that implements the proposed method is the synchronization of the radiating and receiving paths using one master signal generator. This ensures the invariance of the initial phase of the received signals and the possibility of synchronous accumulation of a series of signals. Synchronous accumulation allows to improve the signal-to-noise ratio while maintaining the received signal envelope, also it is used with radiation of tone-burst or chirp signals and allowed to apply the measurement algorithm, adaptive to the noise conditions.

The sensitivity of the underwater sound receiver is a complex value (the formulas (1) and (4) include complex values). Using a master generator enables measurement of the phase sensitivity characteristics. Phase responses more fully describe the properties of an underwater sound receiver, which is very important for many problems solved using digital signal processing. Phase calibration is becoming more common and is already present in the IEC standard for hydrophone calibration [3].

For measurement of phase sensitivity, the transducers are arranged according to the Luker – van Buren scheme. To determine the correction for the shift of the acoustic center of the calibrated receiver, use the technique published by us earlier in [4]. To simplify the procedure for measuring the phase characteristics of the transfer impedance of a projector – receiver pair radiate supplemented quadrature signals [5]. The radiation of such signals allows to determine the instantaneous values of the phase and amplitude – the dependence of the phase and amplitude on time (on frequency during the radiation of chirp signals). This makes it possible to objectively estimate the distortion of a tone signal by transients and to obtain detailed amplitude and phase frequency dependencies when radiate chirp signals.

3. RESULTS

The correctness of the calibration results of the VR was checked by comparing the results obtained by various independent methods: calibration in the field of a standing wave of a small-volume chamber and free-field calibrations using the tone-burst method and CMWA technique. In fig. 1 shows the frequency dependence of the sensitivity of VR type of VHS56 to sound pressure in the frequency range from 500 Hz to 12.5 kHz.

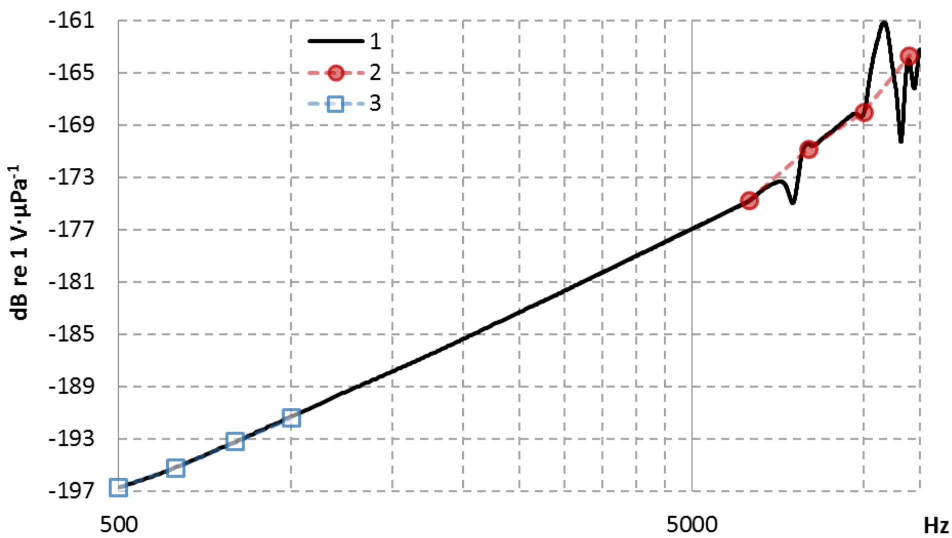

Fig. 1. Frequency dependence of receive sensitivity of VHS56 measured: in free field with tone-burst signals (1) and using CMWA technique (2), by pressure in the field of a standing wave of a small-volume chamber (3).

The presented data demonstrate a good agreement of the results obtained in various acoustic conditions. The differences do not exceed the uncertainty of calibrations estimated at 0.8 dB. Using the described method allowed us to obtain a continuous frequency dependence of sensitivity, including the range from 1 kHz to 6 kHz, not covered by other primary methods. Pay attention to the behavior of frequency dependencies at frequencies above 6 kHz. The data obtained by the tone-burst method lies close to the inclined straight line, while the continuous curve shows the presence of significant peaks and dips (oscillations), the range of which exceeds 6 dB. The reason for such typical oscillations of the frequency response is the scattering of sound on the VR mounting. This conclusion is based on the connection of the oscillation period with the distance to the source of sound scattering. The ability to establish the presence of significant sources of scattering is impossible according to the dependences measured with a rare step, for example, at frequencies of a one-third octave.

4. CONCLUSION

The metrological characteristics of the standard facility were confirmed by comparisons of the results of calibrations of hydrophones – COOMET 531/RU/11 and vector receivers – COOMET 646/RU/14. The described calibration standard facility allows to:

- perform an absolute free-field calibration of the VR in the range up to the frequencies at which calibrations are performed in a small-volume chamber,
- reduce the uncertainty of the VR calibration to values close to the uncertainties of the calibration of the hydrophone.

Hydrophones and VR are usually used as a primary transducer integrated into various underwater acoustic measurement systems. The typical example of such system is an underwater sound recorder, which consists of a hydrophone, measuring and recording devices, and a power unit placed in a sealed container.

The developed method and facility are applicable for calibrating the primary transducers, and are based on processing their output analog signal. A recorder or other similar measuring device should be able to send a signal from the primary transducer to the input of the calibration facility. The measuring device should provide this opportunity in a submerged position. In order to take into account the influence of sound scattering on the body during calibration, the device must be completely under water, and continuous or very detailed frequency dependencies should be measured. This approach is standardized for sound level meters and provides the correctness of the calibration results and accounting the effect of sound scattering on its body.

REFERENCES

[1] **A. E. Isaev, A.S. Nikolaenko**, Laboratory free-field calibration of a hydroacoustic receiver at low frequencies, *Measurement Techniques*, volume 61 (1), pp. 72-78, 2018.

[2] **V. A. Gordienko, B. I. Goncharenko, S. S. Zadorozhnyi, M. V. Starkova**, Higher-frequency extension of the gauging ranges of vector receivers in the nonuniform field of measuring chambers, *Acoustical Physics*, volume 58 (5), pp. 571-574, 2012.

[3] IEC 60565(2006). Underwater Acoustics. Hydrophones. Calibration in the frequency range from 0.01 Hz to 1 MHz.

[4] **A. E. Isaev, A. N. Matveev, A. M. Polikarpov, N. G. Shcherblyuk**, Measurement of the sensitivity phase-frequency characteristics of hydrophones by the reciprocity method, *Measurement Techniques*, volume 56 (6), pp. 706-711, 2013.

[5] **A. E. Isaev**, Reducing the influence of a transition process in field calibration of hydrophones at low frequencies with the use of quadrature-added harmonic signals, *Measurement Techniques*, volume 53 (4), pp. 379-385, 2010.