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OCEANOLOGY

A Molecular-Electronic Hydrophone for Low-Frequency Research of Ambient Noise in the World Ocean

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Abstract—This work is devoted to the problems of elaboration of the instrumental basis for low-frequency sensing of ambient noise of the ocean. The experimental data of testing of the technical parameters of a molecular-electronic hydrophone are given. The amplitude-frequency and noise parameters of prototypes have been studied. The operation of a hydrophone with a frequency range of 0.02–200 Hz and sensitivity of 0.75 mV/Pa is described. Ambient noise was measured with the use of correlation analysis.

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The study of ambient noise of the World Ocean is given great attention by the modern Earth sciences. Natural noises are generated by different processes in the ocean, Earth, and atmosphere. The experimental investigations performed by G.M. Wenz are generalized in [1]. Nevertheless, the absence of the necessary elemental base of measurements makes difficult study of the low-frequency noise of the sea caused by processes such as seasonal weather changes, tectonic processes in the lithosphere, tides, and changes in undercurrents. The devices should be characterized by a sufficient sensitivity, on the one hand, and by a low level of internal noise, on the other hand. There are several technologies of sensors of variations in acoustic pressure: piezoelectric [2], optical [3], laser sensors based on optical reflection in fiber [4] and Bragg lattices [5], and the Fabry–Perot interferometer [6, 7], but they are not always available with respect to a combination of price and technical parameters for the study of weak signals in the area of ultralow frequencies.

A technology based on the principles of molecular electronic transfer (MET) of a charge, which has shown good results in seismology and geophysical surveys [8, 9], geodesy [10], and seismic safety [11], may be used in the development of pressure sensors. Devices based on MET are characterized by high sensitivity and a low level of internal noise.

In this work, we present the results of development of a wide-range (0.02–200 Hz) molecular-electronic hydrophone characterized by a low level of internal noise and high sensitivity. Similar to all devices in which MET is used, the operation of the molecular-electronic hydrophone is based on the principle of formation of a signal current, when fluid flows through a transforming electrochemical cell. A strong electrodynamic feedback was used in the hydrophone to obtain a wide amplitude range and high stability of characteristics.

The fundamental operation principles of systems based on MET are given in detail in educational [12] and popular scientific [13] works and periodicals [14]. The electrochemical cell is the key element of a device based on the MET technology (Fig. 1). It transforms the electrolyte, which flows through it, into the signal current of the sensor. The working fluid in devices on the basis of MET is traditionally represented by a strongly concentrated water solution of the electrolyte on the basis of potassium iodide (KI) or lithium iodide (LiI) with a small addition of molecular iodine I_2.

In the solution, KI is almost completely dissociated into I^- unions and positive K^+ ions, and molecular iodine reacts with I^- ions with the formation of negative ions of triiodide according to the formula $I_2 + I^- \to I_3^-$. If the electrodes placed into solution have a small potential difference (<0.9 V), the electrochemical reactions on electrodes are reversible and the electrons transported over the boundary between the metal and electrolyte solution enter into the reaction $I_3^- + 2e \to 3I^-$. The reaction is direct on cathodes and reverse on anodes. The concentration of the active component is distributed in the system. Under the conditions of the experiment, when external signals are absent, the current through the electrodes is completely determined by the diffusion component. When hydrodynamic flows are present, convection transport is added to diffusion, which results in higher or lower

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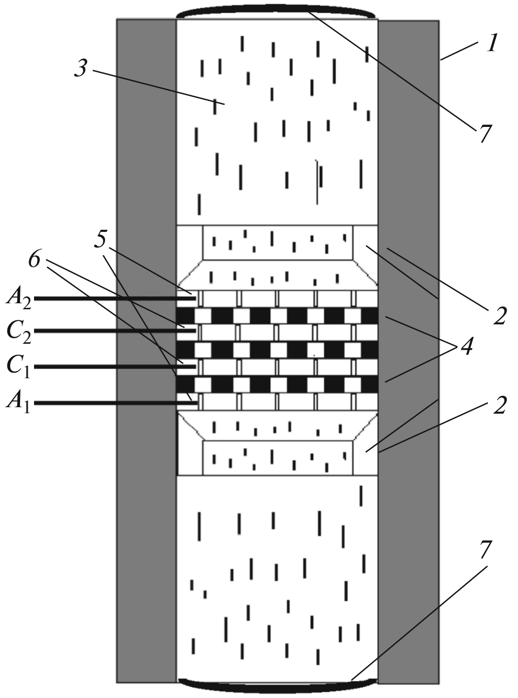

Fig. 1. Sensitive element of MET by the example of the sensor of linear transportation. (*1*) Channel walls; (*2*) rubber package; (*3*) electrolyte; (*4*) porous dielectric gaskets; (*5*) external electrodes (anodes, A_1, A_2); (*6*) internal electrodes (cathodes, C_1, C_2); (*7*) elastic membranes around the channel.

current in the system with respect to the direction of fluid flow. The variations in the electric current caused by hydrodynamic flows represent the output signal of MET. The construction of the hydrophone is similar to the sensor of linear transportations schematically described above. However, there are some important differences, which enable us to use the MET cell for measurement of variations in the external pressure. One of the membranes of the hydrophone is opened to the external medium, where the pressure varies as is shown in Fig. 1. The second membrane is hermetically covered by a solid cap, under which a small air bubble is formed. This makes it possible to measure pressure variations, because the pressure in the chamber with air is changed upon deformation of the second membrane.

The elements of force electrodynamic negative feedback were used in the experimental device for stabilization of the parameters and enlargement of the dynamic range. When the feedback is opened, regular signals may be applied to the coil and thus cause a fluid flow through the cell, imitating variations in the external pressure. At the known transmission parameter of the feedback cascade, this procedure may be used for hydrophone self-calibration under any conditions, including those concerning the terrain. The experimental data have shown that the frequency dependence of the transformation coefficient of the sensing cell of the hydrophone registered by the feedback coil under self-calibration corresponds to the standard calibration by pressure (Fig. 2). This makes significantly easier the calibration and verification of the characteristics of sensors, in terrain conditions in particular. In our research, we received examples of MET hydrophones with sensitivity no less than 0.75 mV/Pa in the frequency band from 0.02 to 200 Hz, with a deviation of the parameter of no more than 0.5 dB in the band (Fig. 3).

The internal noise was studied experimentally by correlation analysis according to the approach described in [15]. For this purpose, we used two identical closely located MET hydrophones. The spectral densities of the power of a part of night records of two molecular-electronic hydrophones (curve *1*, *2*) are given in Fig. 4. The curve *3* is the internal noise of the analog-to-digital convertor, and the curve *2* is an

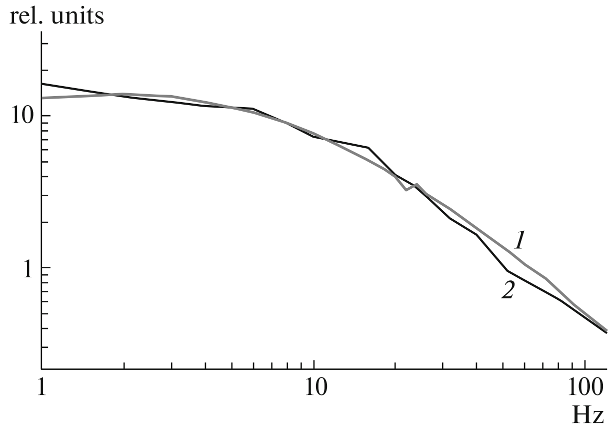

Fig. 2. Amplitude–frequency characteristic of the sensing element of the MET hydrophone under self-calibration by a coil (curve *1*) and calibration on the test system of variations in pressure (curve *2*).

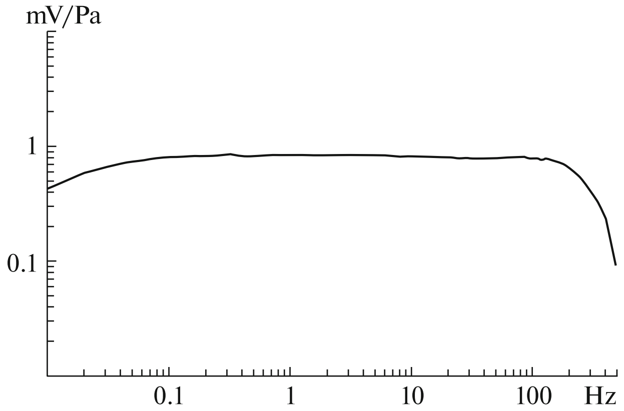

Fig. 3. Amplitude–frequency characteristic of the MET hydrophone.

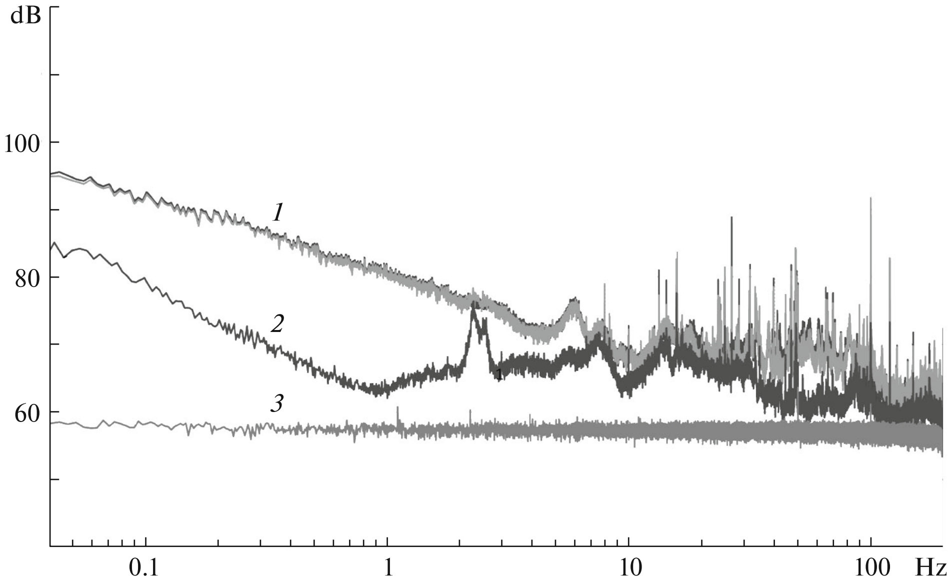

Fig. 4. Experimental internal noise of the MET hydrophone in dB relative to $\mu Pa/\sqrt{Hz}$.

uncorrelated part of the spectral density, reflecting the level of the internal hydrophone noise.

Thus, the data of our research describe the operating principle of a MET hydrophone by the example of a prototype of the broad-range device with a sensitivity of 0.75 mV/Pa in the frequency band of no less than 0.02–200 Hz.

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