Introduction

Sensors are the key components of seismic exploration systems. Specifically, hydrophones are used as part of towed strings and ocean bottom stations. Broadband seismic data acquisiton demands for the highly sensitive hydrophones with the expanded toward low frequencies passband. Meanwhile, piezoelectric, electro strictive, magneto strictive and electrostatic sensors are not very suitable for operation at low frequencies.

The alternative way to build a low-frequency hydrophone could be based on the MET (molecular-electronic transfer) technology. The MET is a scientific and technological concept, which in the last 10 years has resulted in the appearance of a number of highly sensitive sensors. The developed devices are used in seismology (Deng et al, 2016, Levchenko et al, 2010), structural monitoring (e.g. Antonovskaya et al, 2017), navigation and motion control (Zaitsev et al, 2016).

This paper reports on the development of the MET hydrophone (METH) designed for operation in broad frequency range (0.1 – 100 Hz) and delivering very high sensitivity and low noise. Like other MET devices, the operation principles are based on deviations of the electrical current passing through the a signal coverting molecular-electronic transfer (electrochemical) cell. Besides, the force-balanced feedback design has been applied to achieve a wide dynamic range and better response stability.

The results of the work are presented in two parts. In the first part, the principles of the acoustic pressure sensor based on molecular-electron transfer technology are discussed. The second part, is devoted to experimental studiesof the MET parameters. Finally, conclusions are given.

What is MET Hydrophone?

The fundamentals of technology and the physical principles of MET sensors devices are analyzed in detailes in periodicals (Huang et al, 2013, Agafonov et al, 2013).

The main element of MET is the transforming electrode cell, placed in a concentrated electrolyte solution, (Figure 1). The composition of the solution is selected in such a way as to enable the reversible electrochemical oxidation-reduction reaction to proceed on the electrodes. For these purposes, the so-called iodine iodide electrolyte is most often used. An example of such an electrolyte is a concentrated (~ 4 M/L) KI aqueous solution with the addition of a relatively small amount of molecular iodine I_2. Almost complete dissociation of KI into negatively charged ions of I- and positive ions of K+ occurs in the solution, and molecular iodine reacts with I- ions to form a triiodide:

$$I_2 + I^- \rightarrow I_3^-$$

The triiodide ions are resposible for the electrical current passage through the surface of the electrodes. At high concentration of the KI, the flow of triiodide ions is completely determined by the diffusion. In the presence of hydrodynamic flows, convective transport is added to the diffusion flow, which leads, depending on the direction of the flow of the fluid, to an increase or decrease of the interelectrode current. Variations of the electric current due to the hydrodynamic flows are the output signals of MET transforming cell (Abramovich and Kharlamov, 2003).

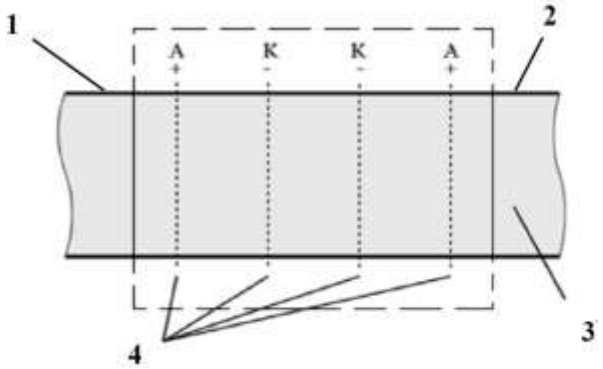

Figure 1. *Transforming electrode cell (MET). 1 – channel walls; 2 – electrical package; 3 – electrolyte; 4 – mesh electrodes (external anodes A, and internal cathodes K).*

Construction and basic principles of operation of a close-loop molecular electronic hydrophone (METH) are shown in (Figure 2). The signal transforming cell (6) is placed in to a channel, bounded by rubber membranes (4) and filled with electrolyte (7). (1) is external sensor housing. To one of the rubber membranes, a neodymium magnet (3) is glued, which can freely move inside the coil (2). The coil (2) is rigidly adhered to the upper cover (8), so that the magnet can move inside it. Such a simple scheme makes it possible to introduce closed loop feedback into the mechanical system, and allows to calibrate the hydrophone.

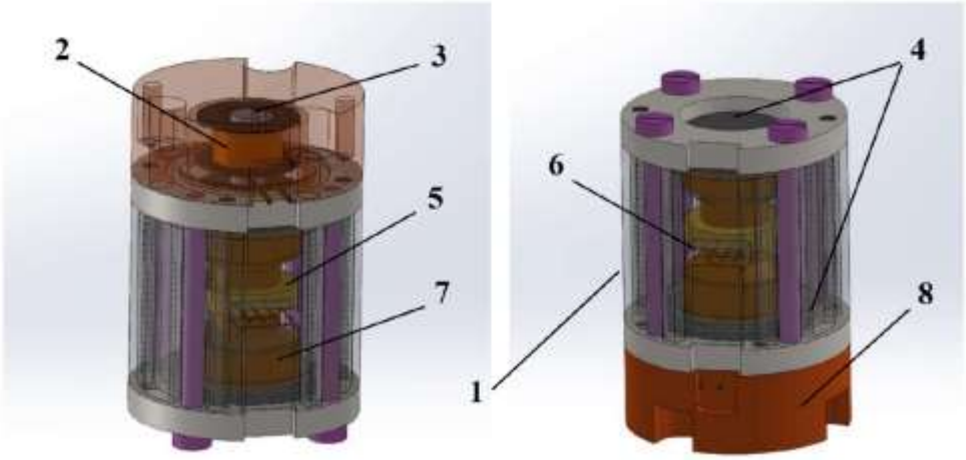

Figure 2. *Design of the MET hydrophone. 1 – external body; 2 - coil; 3 - magnet; 4 - membranes; 5 - electrical package, 6 - electrical terminals of anodes and cathodes 7 - electrolyte, 8 – cover with air bubble under it.*

The hydrophone operates by the following way. If a pressure is changed in the fluid contacting to the open membrane of METH, it generates the liquid flow inside the channel, thus producing the electrode current variations. The output current is conditioned by a special electronic filter. The filter is designed to shape the sensors output high in the middle of the operating frequency range and decreased 6 dB per octave on both low and higher cut-off frequencies. This frequency behavior is required to keep a feedback loop stable. The filter output is applied to the driver, providing feedback current into the coil. Finally, the feedback current applied to the coil causes the appearance of an electromagnetic field in the solenoid that interacts with the magnet (3), and through a rigid connection with the membrane creates a counterforce that balances the pressure drop caused by external acoustic field influence. At the end, the output signal is processed by an analog filter W_{filter}, providing a required operating frequency band.

METH experimental frequence response and self-noise

Amplitude and phase frequency response of the of the closed-loop METH was measured by applying a calibrating current into a feedback coil (2). The experimental amplitude vs frequency response of METH with close-loop feedback are shown in (Figure 3). The absolute value of the METH sensitivity was measured by direct comparison with a reference hydrophone, and its absolute value was 0.8 mV/Pa.

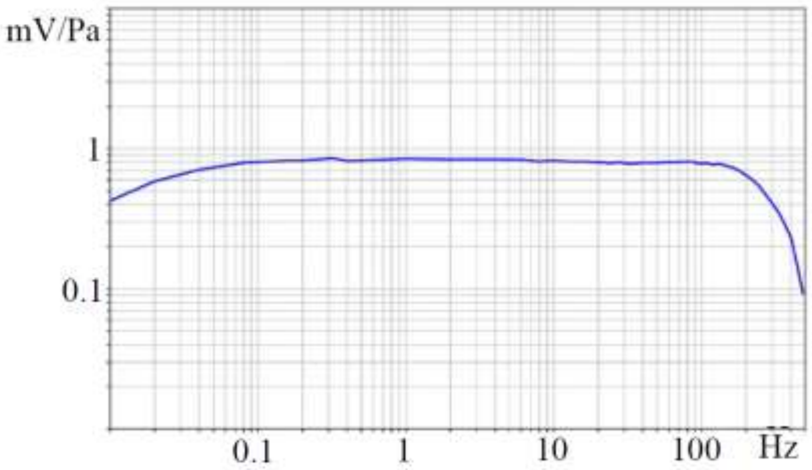

Figure 3. *METH close-loop feedback frequency response. Hz – on the X axis, mV/Pa – on the Y- axis.*

For experimental noise measurements, two identical METH were taken. METHs were placed close to each other in to a metal container with thick walls full of water, and this container was covered with foam to reduce the influence of the temperature variations. The signals were recorded for several night hours with the 24-bit data acquisition system NDAS-8226 (http://www.r-sensors.ru/11_digitizers.shtml). The METH's signals power spectral densities are shown in (Figure 4) (red and blue curves). For further analysis a quietest period of the night's recording have been used. A non-correlated part of observed METH's night period signals was calculated (violet curve) according to the method from (Holcomb, 1989, Egorov et al, 2017).

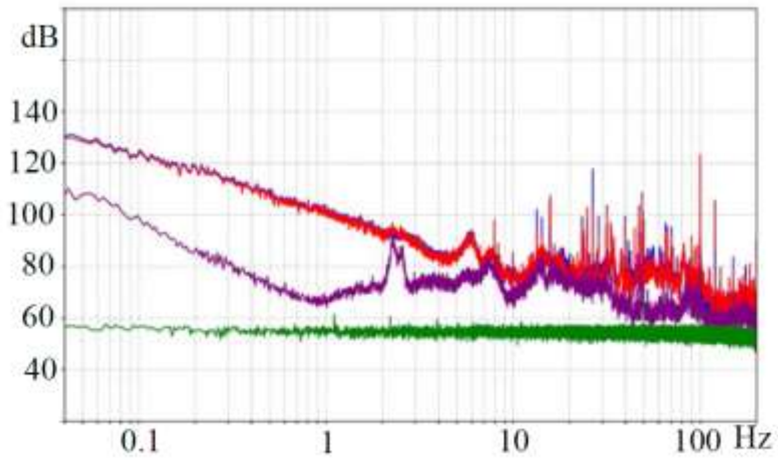

Figure 4. *METH night test. Red, Blue - PSD of close-loop METHs, Green – ADC self noise, Violet – uncorrelated part corresponding to self-METH noise. Hz – X axis, dB (re 1 µPa/√Hz) – Y axis*

For reference, the self-noise power spectral density of the data acquisition system is shown by green line.

Conclusions

The results presented in this study show the operating principle of a MET closed loop hydrophone with very wide frequency operating band. The frequency response of the sample is flat in 0.02 – 200 Hz range within 3 dB accuracy and the sensitivity is 0.8 mV/Pa. Design is simple and does not require any precision parts.

Acknowledgments

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