THE OCEAN-BOTTOM SEISMIC CABLE SYSTEM BASED ON LOW-NOISE HIGH-SENSITIVE MOLECULAR-ELECTRONIC TRANSFER SENSORS

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ABSTRACT

The purpose of this work is to develop new solutions in seismic acquisition technique used in marine conditions to acquire seismic data for hydrocarbon search technologies at the sea bottom and in the transit zones. The ocean-bottom seismic cable system based on molecular-electronic sensors is a cable telemetry system consisting of units connected by cables that transmit the digitized signal to the receiving point on the vessel. Each unit is an assembly of a vertical molecular-electronic geophone, a molecular-electronic hydrophone, an analog-to-digital signal converter and an Ethernet switch. The seismic and acoustic signal conversion in molecular-electronic sensors is based on the principles of ion transfer that provides high sensitivity and low-noise level as well as high dynamic range. The operation frequency band is 1–300 Hz, which is wider than that of the majority of seismic nodes based on using standard (10 Hz) geophones and hydrophones. The technique of summing vertical geophone and hydrophone data to attenuate strong spectral notches caused by receiver ghost reverberation (receiver-side multiples) is generally accepted by the industry while using seabed seismic receivers deliver the optimum measurement of subsurface reflectivity. The solution allows to combine the cost effectiveness of seismic streamers with the data quality and freedom of ocean bottom nodes. The first marine tests showed good coverage of the seismic survey data compared to the ARAM ARIES II recording system.

Keywords: seismic streamer, 2,5-D geological survey, geophone, hydrophone, transit zones

INTRODUCTION

The industry associated with the search and production of hydrocarbons is one of the frameworks of the modern economy. At the same time, under current conditions the tasks of discovering new locations, as well as updating the information about petroleum layers for already developed reserves in complex areas, are particularly important in the seismic exploration of hydrocarbon. In particular, complex objects of exploration include transit zones, where the use of a simple combination of standard for land and sea seismic equipment is not always possible.

Among other things, this implies the necessity to use seismic data recording facilities with the widest possible frequency band and dynamic range. This way, high-quality registration of the comprehensive wave field can be achieved and a higher resolution, determined by the ratio of the maximum and minimum registration frequencies, can be obtained.

The world's leading companies make significant efforts and spend a lot of money to conduct research aimed at creating primary converting cells of the seismic signal with these properties. The most known results are related to the development of MEMS technology. Compared with geophones, seismic sensors made with MEMS technology provide a wider band of the recorded signal, high linearity of measurements, insensitivity to slopes during installation and high identity. At the same time, the sensors based on the MEMS technology have not yet reached a degree of distribution comparable to electrodynamic geophones due to the high price.

For these reasons, the widespread use of motion and vibration sensors based on the principles of molecular electronic transfer (MET) is of interest. The advantages of the molecular electronic technology include high conversion coefficient of mechanical motion into electric signal, the possibility to expand significantly the frequency range in the direction of low frequencies in comparison with the electrodynamic geophone and piezoelectric hydrophone. To date, this instrument type has been used primarily for the measurements in the low-frequency area, but the progress made in recent years has allowed the production of the devices with an upper limit frequency completely covering the current and future frequency ranges for seismic surveys.

Regarding the seismic exploration in the sea and in the transit zone, one of the technology development directions is the use of two-component (vertical vibrating velocity and acoustic wave pressure) seismic recording systems. The advantage of two-component seismic systems compared to the single-component streamer based on hydrophones is the ability to separate seismic waves depending on whether they spread up or down. Such waves differ in output signal phases for the hydrophones and sensors of vertical vibrating velocity. Accordingly, by inserting signals with a certain type of the specified phase, it is possible to allocate the wave reflected from the underlying layers in a signal, and consequently, to improve resolutions of a geological cross-section, a signal-noise ratio and accuracy of seismic wave speed definition in the registered data.

TECHNICS AND APPROACHES

The purpose of this work is to design a two-component ocean-bottom seismic system based on molecular-electronic sensors which enlarges the instrument base of the hydrocarbons search technology on the sea bottom and in the sea-land transition zones. The two-component system consists of digital recording modules connected to each other using outboard connecting cables and couplings.

In the data transfer mode, digital recording modules are connected by TCP/IP with the data collection system and transmit ‘raw’ data – as binary data files of pre-known size (Figure 1).

According to Figure 1, acoustic [1] and seismic [2–4] sensors provide the conversion of signals into the electrical analog form (voltage proportional to measured signal). The received electrical signals on the analog-to-digital (ADC) board after the gain correction are converted into the digital form, and then transferred to the controller, which simultaneously receives an external synchronization signal, as well as data from the position sensors. Signals are recalculated in vertical vibrational speed and acoustic pressure on the controller. The received signals are transferred through the physical level chip to the local Ethernet network. The power supply board provides the conversion of the external supply voltage to the stabilized power levels corresponding to the power requirements of the electronic circuit board components. To ensure the operation in seawater, the system is enclosed in an external rugged, sealed case equipped with cables connectors.

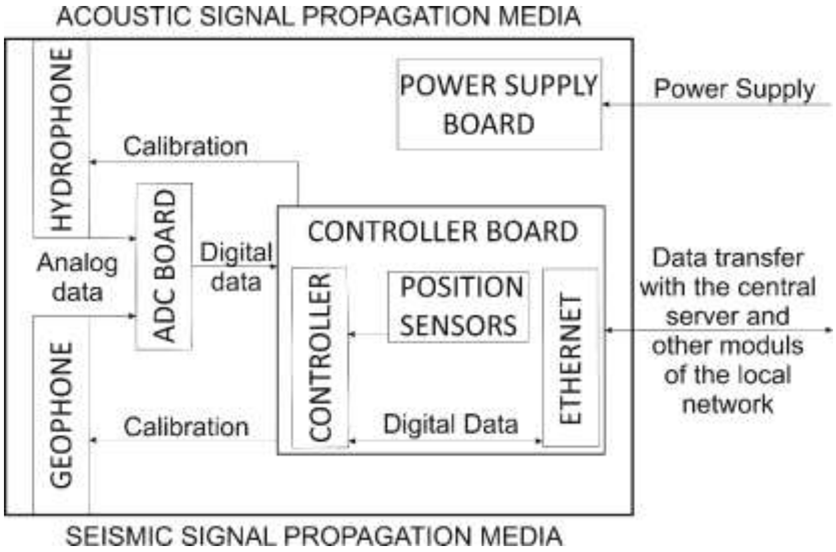

Figure 1. Block diagram of the signal transformation in the digital recording module.

The digital recording module (Figure 2) in the ocean-bottom seismic system is designed to register seismic and acoustic signal and to transmit it digitally to the central server on a vessel, on a platform or on the shore.

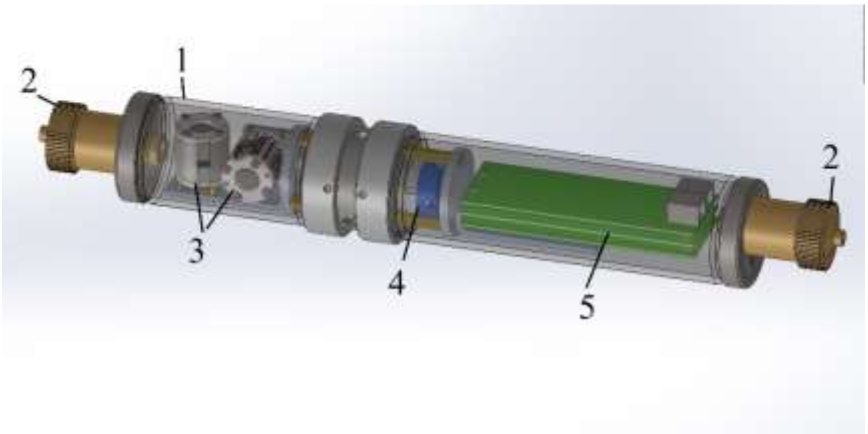

Figure 2. Digital recording module. 1 – case cover of the digital recording module; 2 – sealed connector; 3 – geophones; 4 – hydrophone; 5 – electronic boards.

The digital recording module consists of the following parts:

- Analog part consisting of two sensors of linear seismic signal (geophones) with perpendicular axes of sensitivity, acoustic signal sensor (hydrophone) and electronic power board;
- Digital part consisting of two electronic printed circuit boards, which provide the digitizing of the incoming signal, self-calibration of the sensors and data reception from the orientation module.

Basic technical parameters:

- Working frequency range 1–300 Hz at the level of +-1Db in the range limits;
- Non-uniformity in the working frequency range +-1 Db;
- Nominal power consumption is 15 mA;
- The level of self-noise does not exceed -100 Db in all frequency range and -120 Db at low frequencies (< 10 Hz).

SEA TESTS AND RESULTS

The purpose of the sea tests was to check the output characteristics of the seismic cable system based on molecular-electronic sensors and its suitability for geophysical research. The sea tests have been carried out with the help of JSC "Yuzhmorgeologiya" in the south-western part of the Sea of Kars in the waters of Priyamalskiy shelf and on the basis of JSC "Yuzhmorgeologiya" in the waters of Gelendzhik Bay in the area of Gidrobase in the Black Sea. The task was to check and compare the amplitude-frequency characteristics with the reference, to determine the sensitivity and the level of self-noise of seismic and acoustic sensors in the conditions of seabed investigations.

For the tests, a survey area of water bed 5 ÷ 15 meters deep was chosen. The conditions allowed to work up to 40 shot points (SP) (2000m) by the emitting vessel, towing a group of linear pneumatic sources at the depth of 2 to 6 meters. The emitting vessel has been placed onboard the pneumatic complex where it emitted seismic vibrations. On board the controller of the seismic vibrations emitting system (BigShot), compressor equipment and necessary navigational equipment have been installed. The acoustic emitting has been produced in the forward and backward directions along the profile line without the transverse displacement relative to the receiving points (RP). The speed of the emitting vessel was 2.5 knots.

In order to avoid interference from the work of vessel mechanisms, the recording vessel with seismic station has been installed 500–1000 m away from the profile line. The emitting of the acoustic vibrations with the registration of seismograms at the receiving point has been made.

The section of the seismic system consisted of two modules, attached to the seismic cables each was secured to the reference seismic and acoustic sensors. The reference sensors were presented by the geophone GS-32CT and the hydrophone MR-25-250 as parts of the systems of "ARAM ARIES II" [5].

The scheme of connection of the receiving equipment for profiling is presented in Figure 3.

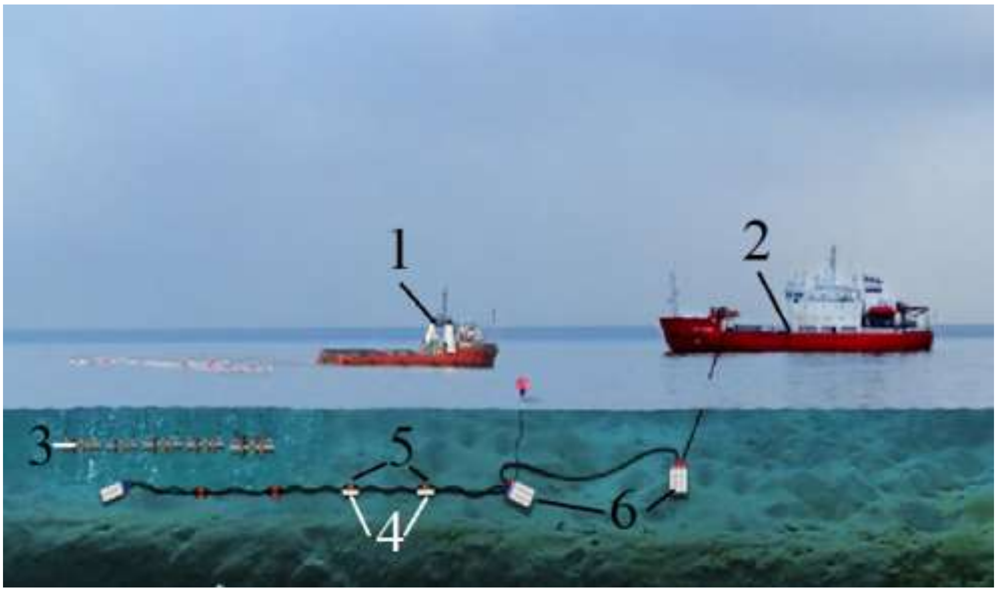

Figure 3. Scheme of connection of receiving equipment for the acoustic vibrations emitting with data registration. 1 – emitting vessel; 2 – receiving vessel; 3 – pneumatic sources; 4 – two modules of the seismic system; 5 – reference sensors; 6 – ARAM ARIES II modules.

During the course of marine tests of the molecular-electronic sensors, 72 series of experiments with different emitting and registration parameters have been carried out.

The measurements results showed that the molecular sensors register a wave pattern similar to the reference sensors. Figure 4 shows the examples of comparison of amplitude spectra of the molecular-electronic geophones and hydrophones signals with the reference sensors for the conditions given in Table 1 (Figures 4, 5). The comparison of the graph of the reference geophone to the molecular-electronic geophone shows that the distribution of the maximum amplitudes on a trace is almost identical.

The molecular-electronic hydrophone shows lower-frequency characteristic then the reference one. The amplitude of its signal in the range of 10–15 Hz exceeded the signal of the reference hydrophone, as is had been expected.

Table 1. The test conditions.

Parameter	Parameter characteristic
Air gun	BOLT 1800 LL
Air gun volume, square inches	40
Chamber operation pressure, psi (atm.)	2000 (137)
Air gun underwater depth, meters	4
Registration frequency range, Hz	3-656
Registration length, msec	3000

Parameter	Parameter characteristic
Sensor underwater depth, meters	10±1
Quantity of shots	40
Intervals between SP, meters	50
Intervals between RP, meters	50
Minimal distance from SP to sensors, meters	50
Maximum distance from SP to sensors, meters	2050
Profiling Course	Reverse

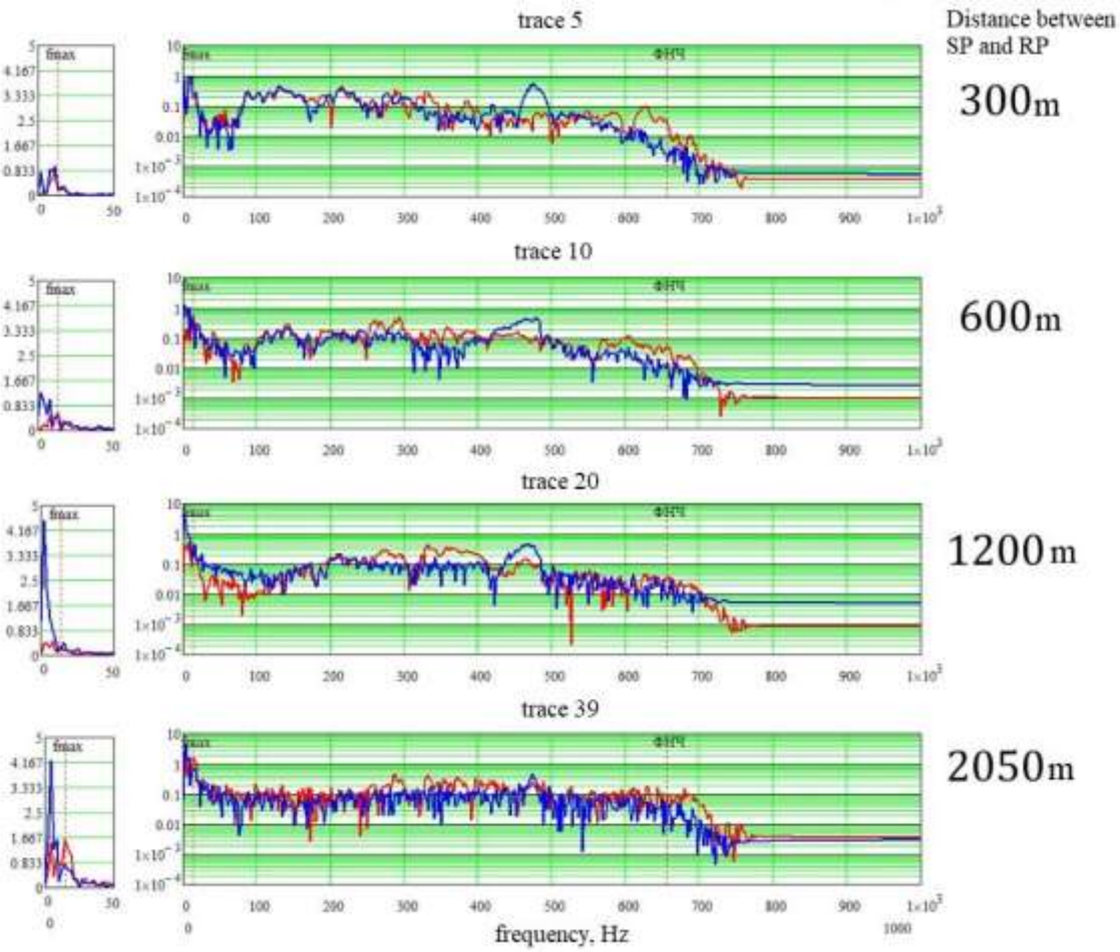

Figure 4. Normalized amplitude spectra of the geophone's signals: traces 5, 10, 20, 39. Blue – molecular-electronic geophone, red – reference geophone.

To determine the sensors sensitivity, comparative analyses of the recorded signals from the pneumatic source of digital recording modules with reference sensors have been carried out. The results of the measurement evaluated that the sensitivity of the geophones of the digital recording modules was 250/M/sec (the sensitivity of the reference geophones was ~ 39/M/sec), the sensitivity of molecular-electronic hydrophones was 30 mV/mBar (the sensitivity of the reference hydrophones was 10.2 mV/mBar).

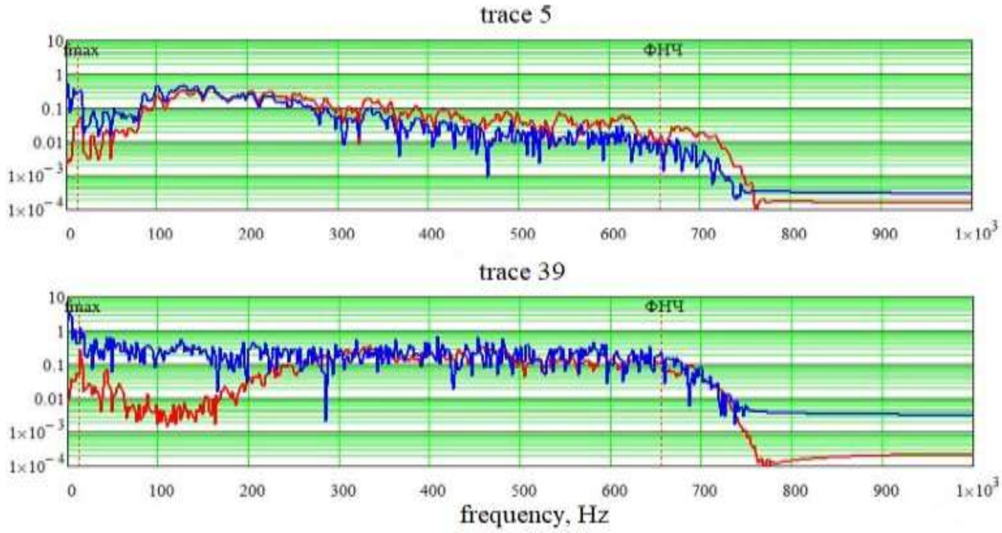

Figure 5. Normalized amplitude spectra of hydrophone signal: traces 5 and 39. Blue – molecular-electronic hydrophone, red – reference hydrophone.

The measurement of the noise level of the digital module, as well as the calibration of the system, have been carried out in the absence of a disturbing signal from the pneumatic source. According to the presented data of the sensors signal power spectral density (Figure 6), it can be concluded that the stated and measured characteristics are consistent.

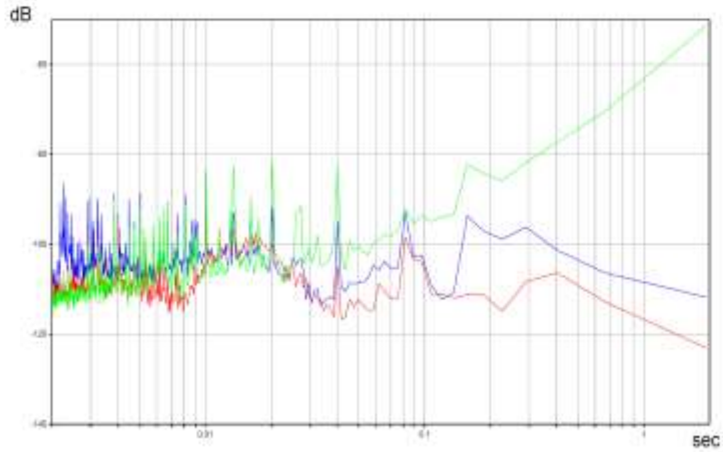

Figure 6. The power spectral density of the signal (in normalized acceleration units) of three molecular-electronic sensors in the digital module: green – hydrophone, blue and red – geophones.

It should also be noted that despite the design features of the molecular-electronic hydrophone, when placed in an aqueous medium, it demonstrates proper performance and is not sensitive to seismic signals that could distort the picture of the pressure field.

CONCLUSION

The purpose of this work was to get a new instrumental decision, which would expand the possibilities of the marine hydrocarbon search technology. In difficult conditions of the seabed and sea-land transition zones, the use of a simple combination of standard for land and sea seismic technics and equipment is not always possible. To obtain a high-quality results, the ocean-bottom seismic cable system based on molecular-electronic low-frequency (1–300 Hz) geophone and hydrophone has been developed. The marine tests aimed at checking and comparing the amplitude-frequency characteristics with the reference, determination of the sensitivity and self-noise level of the seismic and acoustic sensors in the conditions of seabed investigations have been carried out. The results of the marine tests have shown that the molecular-electronic seismic sensors and hydrophones provide output parameters exceeding such parameters of accepted as industrial standards sensors, as the width of the frequency range in the area of low frequencies and sensitivity, and can be used as a part of a two-component seismic streamer. The system has demonstrated its reliability and suitability in the conditions of real marine geophysical investigations, particularly on the seabed.

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