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SHORT COMMUNICATIONS

Stochastic Electrochemical Approach to Detecting Microseismic Noise Fields

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Abstract—Low-frequency acoustic equipment for microseismic oil and hydrocarbon 3D-exploration is developed by using equipment produced by OOO NTK Anchar (Moscow, Russia). By using stochastic electrochemical collating calibration and stochastic electrochemical Chebyshev spectroscopy, the Anchar equipment noise properties are studied in the Russian Arctic zone of Kola Peninsula, under the conditions of rather low natural microseismic noise. The Anchar equipment's intrinsic noise turned out to be an order of magnitude lower than the microseismic noise. This means that the Anchar equipment can be used for the 3D-detection of microseismic noise fields in oil and gas accumulations in the Russian Arctic zone.

Keywords: stochastic chemistry, stochastic electrochemistry, stochastic microseismic monitoring, Russian Arctic zone

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INTRODUCTION

This work studies the field of stochastic chemistry [1]. Stochastic physico-chemical processes occurring in a geological medium containing oil and gas accumulations are accompanied by the emission of infrasonic noise waves called oil and gas microseisms [2]. Fossil fuel deposits represent a multicomponent heterogeneous inclusion of complicated fluid in the solid-state medium of sedimentary rocks. Such a system stays in a state of permanent motion and transformation with the corresponding emission of specific microseisms in the frequency range of 2 to 8 Hz. This emission can be registered as a local anomaly of the microseismic noise field [3]. The latter phenomenon allows understanding the ever increasing interest in the development of a green technology for noise-microseismic-based monitoring of oil and gas accumulation [4–6]. experience has shown [7] that taking the microseismic noise field into consideration raised the correct prognosis of geophysical exploration for oil and gas up to 80%. This high probability of a correct oil pool discovery by a passive noise method can be obtained only by using geoacoustic instruments possessing low intrinsic noise. With this goal in mind, the geoacoustic equipment of the Anchar production is of great interest [8, 9].

The Anchar geoacoustic equipment is a joint production of the Frumkin Institute of Physical Chemistry and Electrochemistry, Russian Academy of Sciences, and OOO NTK Anchar. This equipment is destined for detecting anomalies of the microseismic noise field (in particular, involving oil and gas accumulations) on the surface of Earth during daylight in the infrasonic frequency range from tenths of a hertz to 45 Hz and has sufficiently low intrinsic noise. The Anchar geoacoustic equipment benefits from the experience of the development and geophysical applications of electrochemical seismodetectors [10, 11]. In this work we aim to evaluate the intrinsic noise level of the Anchar geoacoustic equipment in a direct experiment under the conditions of the Russian Far North. The tool for studying the Anchar geoacoustic equipment is based on information-cognitive technologies; it includes methods of stochastic electrochemical collating calibration [12] and stochastic electrochemical Chebyshev spectroscopy [13].

STOCHASTIC ELECTROCHEMICAL CHEBYSHEV SPECTROSCOPY

The method of stochastic electrochemical Chebyshev spectroscopy was developed by a joint research team of Frumkin Institute of Physical Chemistry and Electrochemistry and the Institute of Problems of Chemical Physics, Russian Academy of Sciences. The method is stable with respect to the drift component of electrochemical noise and, unlike the Fourier spectroscopy, remains informative at frequencies exceeding the discretization half-frequency.

The spectral presentation of the stochastic process depends functionally on the algorithm that was used in evaluating the spectrum. We used stochastic electrochemical Chebyshev spectroscopy. Below we describe the structure of the microseismic noise Chebyshev spectra.

Let $r(t)$ represent the discrete realization of a stochastic microseismic process. We can denote any component of the microseismic noise vector $(x(t), y(t), z(t))$ by $r(t)$. We take the discretization time interval as unity.

We partition the entire interval of realization (NM) into M segments. Each mth segment has the same length N. We denote the stochastic function $r(t)$ in the mth segment as $r(m,t)$ $(m = 0, 1, 2, \ldots, M-1$, $t = 0, 1, 2, \ldots, N-1)$. We introduce the orthonormal system of Chebyshev polynomials $P(k,t)$ of the discrete variable t $(t = 0, 1, 2, \ldots, N-1)$. The polynomial number k runs over the same integer values as the time variable t $(k = 0, 1, 2, \ldots, N-1)$. The representation of Chebyshev polynomials using a discrete variable is described in work [14].

The intensity $r^{(2)}(k)$ of the Chebyshev spectral line with the number k for the stochastic process $r(t)$ can be calculated by the following formula [13]:

$$r^{(2)}(k) = \frac{1}{M}\sum_{m=0}^{M-1}\left[\sum_{t=0}^{N-1} P(k,t) r(m,t)\right]^2. \tag{1}$$

Algorithm (1) assumes calculation of the Chebyshev discrete transform (it is given in brackets). Then, the Chebyshev discrete transform squared is averaged over all segments. In our experiments the full length of the stochastic signal realization was 2^{15} points $(NM = 2^{15})$; and the segment length, 2^4 $(N = 16)$. Such a segment length is required to achieve the minimally acceptable resolution of the Chebyshev spectra (15 lines); the segment number $(M = 2^{11})$, to decrease the random error in the statistical processing of the noise signal. The discretization frequency (about 100 Hz) is determined by the Anchar equipment used, which also ensured the signal registration in the chosen low-frequency range.

STOCHASTIC ELECTROCHEMICAL COLLATING CALIBRATION

stochastic electrochemical collating calibration [12] assumes the arrangement of two seismic 3D-modules at the same point of the Earth's surface. In this case the measured seismoacoustic stochastic vector signal doubles. As a result, we obtain two records $r_A(t)$ and $r_B(t)$ of the same seismoacoustic stochastic signal realization along any coordinate axis:

$$r_A(t) = R(t) + \xi_A(t), \tag{2}$$

$$r_B(t) = R(t) + \xi_B(t). \tag{3}$$

Equations (2) and (3) contain the same external noise signal $R(t)$. Internal noise of the seismic module A is denoted by $\xi_A(t)$, while that of the seismic module B is denoted by $\xi_B(t)$. Evidently, the stochastic processes $\xi_A(t)$ and $\xi_B(t)$ are independent. We denote the difference of the realizations $r_A(t)$ and $r_B(t)$ by $r_{A-B}(t)$:

$$r_{A-B}(t) = r_A(t) - r_B(t) = \xi_A(t) - \xi_B(t). \tag{4}$$

According to Eq. (1) of the stochastic electrochemical Chebyshev spectroscopy, we obtain, with due allowance for Eqs. (2)–(4),

$$\begin{aligned}&\left[r_A^{(2)}(k) + r_B^{(2)}(k)\right]/2 \\ &= R^{(2)}(k) + \left[\xi_A^{(2)}(k) + \xi_B^{(2)}(k)\right]/2,\end{aligned} \tag{5}$$

$$\frac{1}{2} r_{A-B}^{(2)}(k) = \left[\xi_A^{(2)}(k) + \xi_B^{(2)}(k)\right]/2. \tag{6}$$

In the left-hand-parts of Eqs. (5) and (6), we have the measured quantities. In the right-hand-parts of Eq. (5), we have the intensity of the kth spectral line, $R^{(2)}(k)$, of the useful noise and its error, which is a half-sum of the spectral intensities of the seismic modules' internal noise. According to Eq. (6), the error is a measurable quantity.

GEOACOUSTIC EXPERIMENT ON THE KOLA PENINSULA

The geoacoustic experiment was carried out on the Kola Peninsula near the Dal'nie Zelentsy settlement. Two Anchar seismic modules, A and B, were arranged in a small depression in the earth about 10 cm apart. The modules' orientation accuracy on mounting was sufficient to separate the 40 dB channels. The recording synchronicity of the two independent modules was ensured by the incorporated GPS-GloNaS satellite system at a level of not less than 1 ms. These parameter values met the requirements of the problem to be solved.

The simultaneous recording of the stochastic microseismic 3D-signal was carried out independently. In Fig. 1 we show the typical microseismic signal. We see that the microseisms are stochastic and are not suitable for direct interpretation; however, they are rather stable, steady, and subject to statistical treatment. The experimental data were processed according to the theory of stochastic electrochemical Chebyshev spectroscopy and the theory of stochastic electrochemical collating calibration. We used Eqs. (5) and

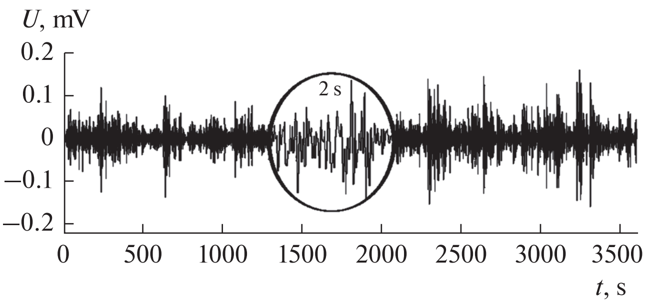

Fig. 1. typical microseismic noise signal U in 1 h-time interval, obtained during measurements near Dal'nie Zelentsy settlement.

(6) of this work in the stochastic analysis of the seismoacoustic stochastic vector signal.

In Fig. 2 we present the results of the stochastic analysis for stochastic signals $x(t)$, $y(t)$, and $z(t)$, respectively, as Chebyshev spectra, that is, as the dependence of the $R^{(2)}$ line intensity on its order k. The intensity value was calculated from the seismic module signal; it is given in the [mV^2] dimensionality. We clearly see that in any coordinate direction the inner noise of the Anchar geoacoustic instrument is smaller by an order of magnitude than the microseismic noise of the environment. This conclusion is the main result of this work.

CONCLUSIONS

The fluctuation–dissipation theorem [15] affirms that even at equilibrium each dissipative process is accompanied by fluctuations. It is the stochastic chemical kinetics that deal with the chemical parameter fluctuations. The fluctuations in the electrochemical systems give rise to electrochemical noise whose level and stochastic properties are used in the noise nondestructive diagnostics. The physico-chemical processes occurring in a geological medium containing oil and gas accumulations must also be accompanied by microseismic noise emission. By using low-noise geoacoustic instrumentation, we can register anomalies of the microseismic noise field (in particular, caused by the presence of oil and gas accumulation) on the surface of the Earth during daylight and thus implement the direct search method for oil and gas fields.

Our experiments carried out on the Kola Peninsula near the Dal'nie Zelentsy settlement demonstrates that the geoacoustic equipment developed by the Frumkin Institute of Physical Chemistry and Electrochemistry, Russian Academy of Sciences, and OOO NTK Anchar has a low inner noise level and can be used to detect microseismic noise fields in hard-to-reach areas of the Russian Far North.

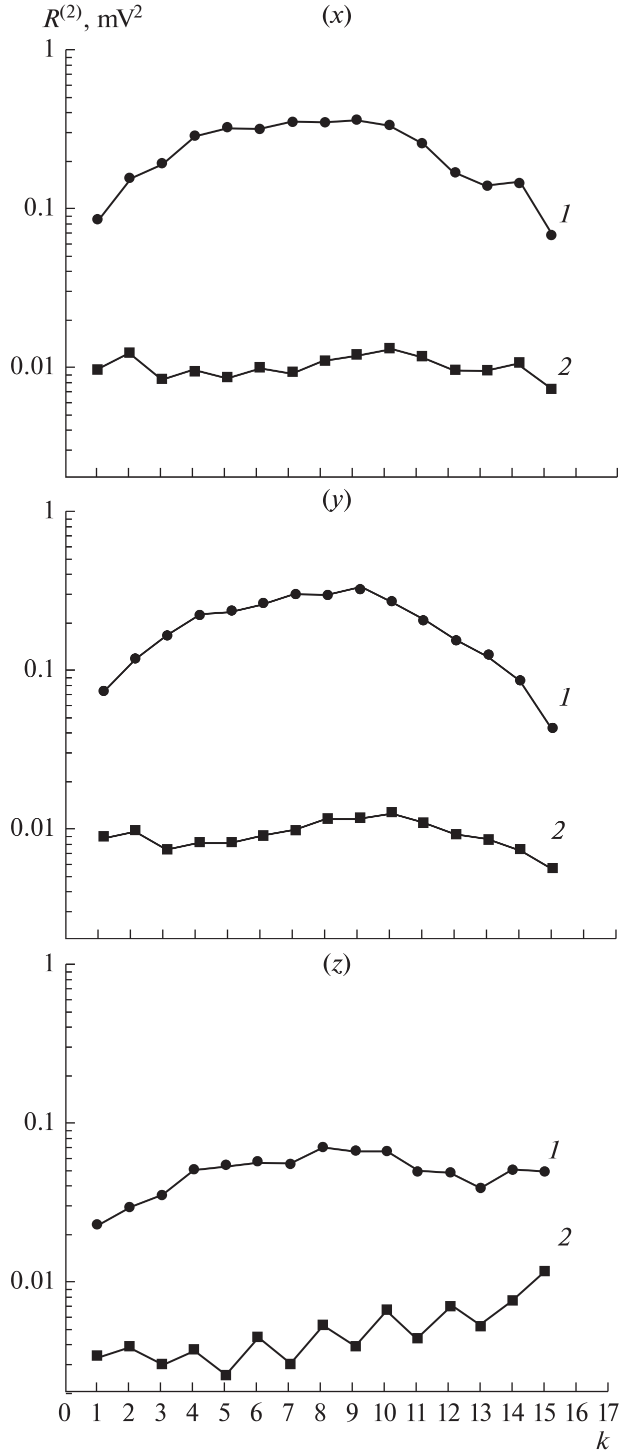

Fig. 2. Chebyshev spectra $R^{(2)}(k)$ of microseismic noise signal along horizontal directions (x), (y) and vertical direction (z): (*1*) summary spectrum of useful noise signal and intrinsic noise; (*2*) intrinsic noise spectrum.

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