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Phase-induced polarization method based on processing noise signals of the natural electromagnetic field of the Earth

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Abstract

The paper deals with the physical fundamentals of the phase geoelectric method of induced polarization (IP) based on the extraction of information from the natural electromagnetic field of the Earth (NEMFE) in the frequency range 0.1–20.0 Hz. Scientific and technical justification is provided for the differential measurement circuit parameters of the NEMFE and the algorithm of processing of the received signals with the calculation of the IP coefficient, assuming the identity of the field characteristics in two receiving lines. The method consists in recording random noise signals from two adjacent receiving electrical dipoles with simultaneous memorizing of the amplitudes and their automatic equalization. Then the difference between the signals is calculated, with subsequent energy normalization. The presented theoretical fundamentals for the calculation of the IP coefficient of the NEMFE and the processing algorithm were tested in laboratory experiments. Under the assumption of the complete identity of the medium beneath the receiving dipoles, the IP coefficient was 0.01–0.03, due to the error in the elemental base of the analog input path. The paper also presents the results of field experiments on the Samson iron deposit in the Republic of Khakassia. The experimental work confirmed the effect of IP on the NEMFE in the anomalous area and showed that the results are consistent with theoretical and laboratory predictions and the data obtained using a KEP-M pulse system. It is concluded that this method can be used to detect productive anomalies and has an advantage of eliminating artificial sources of excitation of geologic sections.

Keywords: induced polarization; natural electromagnetic field; Earth; dispersion; phase; electrodes; telluric currents

Introduction

Electrical prospecting of disseminated polymetallic ores is most effective when using the induced polarization (IP) method based on excitation of a geological section by artificial pulsed or harmonic currents of low frequency in the range below 20 Hz.

Disadvantages of the IP method is the need to lay grounded transmitter circuits in difficult-to-access mountain-taiga areas and use power supply sources of up to 10 kW or more (Bobachev et al., 2006).

Shaidurov (1967) was the first to show the possibility of using the IP method based on the extraction of information from the natural electromagnetic field of the Earth (IP NEMFE), which made it possible to reject the use of artificial sources of excitation of geological sections. Similar experiments were performed later by geophysicists of India (Murali and Rao, 1983). Natural electromagnetic (EM) fields are also used in the AFMAG (audio frequency magnetic) method based on the amplitude-phase processing of NEMFE signals (Shaub, 1971).

The AFMAG method uses relatively high frequencies over 100 Hz, which does not allow detecting slow electrochemical processes at the boundaries of polymetallic ore bodies, so that it is mainly used in apparent resistivity prospecting, which gives ambiguous results, especially in exploration of disseminated ores. The INFAZ VP and VP-F systems were developed for the implementation of the phase IP method (Bobrovnikov et al., 1985).

Since 1972 attempts have been made to develop a method and equipment based on IP NEMFE for operation under conditions of spatially inhomogeneous and time-varying fields (Borisov and Shaidurov, 1972; Borisov et al., 1079). Several modifications of such equipment were developed (Shum1, Shum2, Shum3) (Shaidurov et al., 1991) and field tests were conducted in different ore fields in Russia, Belarus, and Kazakhstan.

However, because the necessary hardware components of digital circuitry and high-speed microcomputers with the

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required RAM size were not available at that time, a field device with the desired algorithm for processing NEMFE signals was not implemented.

Note that the term "spatial inhomogeneity" means that the statistical characteristics of the NEMFE depend on the coordinates of the reception point (Rytov, 1966).

The first stable field results on the implementation of a differential-phase algorithm for processing NEMFE noise using modern computer technology were obtained only in 2012 (Potylitsyn and Shaidurov, 2012).

Physical fundamentals of the method

The method consists of recording NEMFE signals received from two adjacent receiving electric lines (dipoles). In the random access memory (RAM) of a microcontroller, both signals are recorded simultaneously with automatic equalization of the amplitudes using the Powell algorithm (Moiseev et al., 1978). The criterion for the presence of a productive anomaly is the IP coefficient, which is determined by calculating the normalized dispersion of the difference between the signals as follows:

$$\eta_E = \frac{\frac{1}{T}\int_0^T \left(E_1(t) - \tilde{k}\cdot E_2(t)\right)^2 \cdot dt}{\sigma_1^2} \to \min, \quad (1)$$

where $E_1(t)$ and $E_2(t)$ are EMFs which depend on the time t and are taken from the first and second electrical dipoles, respectively; σ_1^2 is the dispersion of one of the signals by which the desired quantity η_E is normalized; T is the signal observation time; $\tilde{k}$ is the compensation coefficient which is automatically set in the device.

The field setup is shown schematically in Fig. 1.

Algorithm (1) is based on the assumption that the signals $E_1(t)$ and $E_2(t)$ are completely identical in time if the setup is located on a geological section containing no ore deposit. The effect of the statistical spatial inhomogeneity of the field is reduced by placing the receiving lines as close to each other as possible. Both signals are simultaneously loaded into the RAM to exclude the effect of the nonergodicity of the statistical characteristics of the NEMFE.

Due to the presence of a productive anomaly under one of the receiving dipoles, which is polarized under the action of the NEMFE currents, the signal $E_2(t)$ received from this dipole acquires a phase shift with respect to $E_1(t)$.

These signals can be represented as the sum of harmonic components with random amplitudes and zero initial phases:

$$E_1 = \sum_{i=1}^{n} E_{i1} \cdot \sin \omega_i \cdot t, \quad (2)$$

$$E_2 = \sum_{i=1}^{n} E_{i2} \cdot \sin(\omega_i \cdot t + \Delta\varphi_i). \quad (3)$$

Taking into account the compensation coefficient $\tilde{k}$ obtained by solving the equation (Moiseev et al., 1978)

$$\frac{\partial (E_1(t) - \tilde{k}\cdot E_2(t))^2}{\partial \tilde{k}} \to \min, \quad (4)$$

we write the difference between $E_1(t)$ and $E_2(t)$ as

$$E_1(t) - E_2(t) = \sum_{i=1}^{n} (E_{i1}(t) - \tilde{k}\cdot E_{i2}(t)). \quad (5)$$

In the case of a nonpolarizable geological section, by self-tuning the coefficient $\tilde{k}$ for the equality of the first and second terms of (5) and for $\Delta\varphi_i = 0$, we should have $\overline{(E_1(t) - E_2(t))^2} = 0$, provided that the characteristics of the

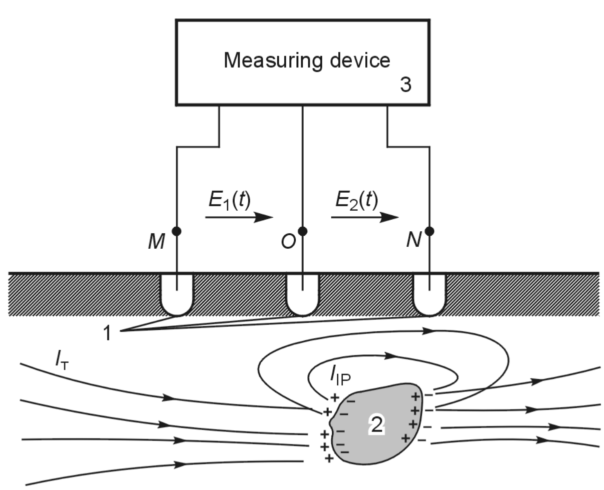

Fig. 1. Differential measuring system. 1, nonpolarizable electrodes; 2, ore body; 3, measurer; $E_1(t)$ and $E_2(t)$ are EMF taken from the respective dipoles; I_T are telluric currents; I_{IP} are the induced polarization currents.