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Abstract

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PALETTES FOR INTERPRETING THE ESTABLISHMENT OF A MAGNETIC FIELD

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Geophysical prospecting by the method of establishment of an electromagnetic field, the foundations of which were laid by A. N. Tikhonov ([1,2]), is at present finding wide application, especially for elucidating the regional tectonics of oil-bearing areas. In most cases the establishment of a magnetic field is studied when a rectangular current pulse is switched on in a grounded supply circuit. The graph of the transient process is interpreted by selecting a suitable curve calculated for a model of a horizontally layered medium. Such calculations ([1−4]) have clarified a number of important properties of the process of field establishment. However, the volume of these calculations is insufficient for interpreting the results of field work, taking into account the great variety of geoelectric conditions in different regions of the USSR. Proceeding from this, we carried out the calculation of three-layer and four-layer theoretical curves of magnetic-field establishment. The calculation was based on the relation between sounding of the upper layers of the Earth by means of a transient process (field establishment) and frequency sounding. This relation is expressed by the Fourier transform:

$$\rho_\tau = \frac{1}{2\pi}\int_{-\infty}^{+\infty} \rho_\omega \frac{e^{i\omega t}}{i\omega}\, d\omega \quad \text{for } t \geq 0,$$

where ρ_ω is the complex apparent resistivity in the frequency-sounding method, and ρ_τ is the apparent resistivity in the field-establishment method ([5]). Using the absence of singular points in the complex frequency function ρ_ω, the Fourier integral can be represented in the form

$$\rho_\tau = \frac{1}{2\pi}\int_0^{\infty} \operatorname{Re}\rho_\omega \frac{\sin\omega t}{\omega}\, d\omega \quad (7).$$

Taking into account that at sufficiently high frequencies $\omega > \Omega$, we write

$$\rho_\tau = \frac{1}{2\pi}\int_0^{\infty} (\operatorname{Re}\rho_\omega - \rho_1)\frac{\sin\omega t}{\omega}\, d\omega + \frac{\rho_1}{2\pi}\int_0^{\infty} \frac{\sin\omega t}{\omega}\, d\omega =$$

Figure 1

Figure 1: Figure 1

$$= \rho_1 + \frac{1}{2\pi}\int_0^{\Omega} (\operatorname{Re}\rho_\omega - \rho_1)\frac{\sin\omega t}{\omega}\,d\omega \quad \text{for } t > 0.$$

The first stage of calculating ρ_τ is the computation of ρ_ω. It was carried out with the aid of the high-speed electronic computer of the Computing Center of the Siberian Branch of the Academy of Sciences of the USSR, as described in work ([8]). For computing the Fourier integral, a modified Filon method ([6]), also known as the trapezoidal method ([7]), was used. According to this method, the intermediate values of the complex frequency function ρ_ω, needed for computing the Fourier integral, are found by means of linear interpolation, taking which into account we have:

$$\rho_\tau \approx \rho_1 + \sum_p \frac{1}{2\pi}\int_{\omega_p}^{\omega_{p+1}} (a_{0p} + a_{1p}\omega)\frac{\sin\omega t}{\omega}\,d\omega,$$

where

$$a_{1p} = \frac{\operatorname{Re}\rho_{\omega(p+1)} - \operatorname{Re}\rho_{\omega p}}{\omega_{p+1} - \omega_p}, \qquad a_{0p} = \frac{\omega_{p+1}\operatorname{Re}\rho_{\omega p} - \omega_p \operatorname{Re}\rho_{\omega(p+1)}}{\omega_{p+1} - \omega_p}.$$

The integral

under the summation sign is expressed in terms of the sine integral $\operatorname{si}(\omega t)$ and $\cos\omega t$:

$$\int_{\omega_p}^{\omega_{p+1}} (a_{0p} + a_{1p}\omega)\,\frac{\sin\omega t}{\omega}\,d\omega = a_{0p}(\operatorname{si}\omega_{p+1}t - \operatorname{si}\omega_p t) -$$

$$-a_{1p}(\cos\omega_{p+1}t - \cos\omega_p t).$$

In accordance with the last formula, a program was compiled for calculating the apparent resistivity ρ_τ on a high-speed electronic computer.

Fig. 1. Template for the establishment of the magnetic field for $\rho_2/\rho_1 = 1/8,\ \rho_3 = \infty,\ h_2/h_1 = 2$. The numbers beside the curves are the ratios r/h_1.

Using the method described above, theoretical curves of the establishment of the magnetic field were calculated for three-layer sections with parameters: $h_2/h_1 = 1/8,\ 1/4,\ 1/2,\ 1,\ 2,\ 4,\ 8$; $\rho_2/\rho_1 = 1/16,\ 1/8,\ 1/4,\ 1/2,\ 2,\ 4,\ 8,\ 16$; $\rho_3 = \infty$, and for four-layer sections with parameters: $h_2/h_1 = 1/2,\ 2,\ 8$; $h_3/h_1 =$

1/2, 2, 8; $\rho_3/\rho_1 = 1/16,\ 1/4,\ 1,\ 4$; $\rho_2/\rho_1 = \infty,\ 2,\ 1/2,\ 1/8$; $\rho_4 = \infty$; where ρ_i and h_i are the resistivity and thickness of the layer with number i. The apparent resistivity was calculated as a function of time for 6 fixed values of r, the distance of the observation point from the source. The value of r was chosen so that it exceeded the depth of the reference horizon by a factor of 3–8. The theoretical curves are plotted on a double logarithmic scale, with ρ_τ in fractions of ρ_1 plotted along the vertical axis, and the dimensionless ratio $\sqrt{\frac{1}{2}t\rho_1\mu_0/h_1^2}$ along the horizontal axis, where t is the time from the moment the current is switched on, and μ_0 is the magnetic permeability, which we assume everywhere to be equal to the magnetic permeability of vacuum.

We shall call the quantity $\sqrt{\frac{1}{2}t\rho_1\mu}$ the establishment parameter of the electromagnetic field, τ_1. It is not difficult to verify that τ_1 has the dimension of length. Figure 1 shows theoretical curves of magnetic-field establishment for a three-layer section with $\rho_2/\rho_1 = 1/8$, $h_2/h_1 = 2$, $\rho_3 = \infty$. At small values of τ_1/h_1, the apparent resistivity approaches ρ_1; as τ_1/h_1 increases, the value of ρ_τ decreases, reflecting the low resistivity of the second layer. At maximum values of the establishment parameter, the graph has a maximum characterizing the influence of the nonconducting reference horizon. With the aid of the calculated templates of magnetic-field establishment, it is possible to interpret the results of field work, and also to determine the resolving power of the new method of electrical prospecting.

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