On the development and method of ground-underground probing for the study of the physical state of the overhead strata of rocks

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Abstract. *A method for obtaining information about the physical state of the environment is considered in relation to the developed method of ground-underground probing, implemented on the basis of a numerical analysis of a quasi-stationary electromagnetic field for a given set of frequencies generated by a linear source, which has shown the promise of its practical application.*
Keywords**:** *electrical prospecting, ground-underground probing, anomaly, quasi-stationary magnetic field, numerical modeling.*

Monitoring the physical state of the water-bearing layer (WBL) during mining operations, especially in the conditions of salt deposits, is one of the urgent modern tasks.

In order to develop information capabilities for predictive control of the physical state of WBL, we are developing an electrometry method based on the use of electromagnetic ground-underground probing (GUP), which has the potential to significantly increase the information content of the results [3, 4]. One of the problems in its implementation is the creation of a method for solving the inverse problem as applied to this method. Many scientists have dealt with similar issues [1, 2, 5, 6, etc.], but in view of the complexity of the analytical solution of this problem, it has not yet been adequately implemented and requires the search for an approximate, simplified method for assessing the physical state of the supra-drift water-bearing layer (WBL).

In this paper, one of the variants of such a method is considered, based on the assessment of the degree of anomalousness of the observed field by its comparative analysis with the background component of the magnetic field, which is the closest to the features of the problem being solved.

The implementation of this method is carried out on the example of the underground-ground probing (UGP) method (which is a variant of the GUP method), which provides the possibility of ground-based survey when the AB linear source is located at the depth of the mine opening (fig. 1). Let's consider the process of this implementation.

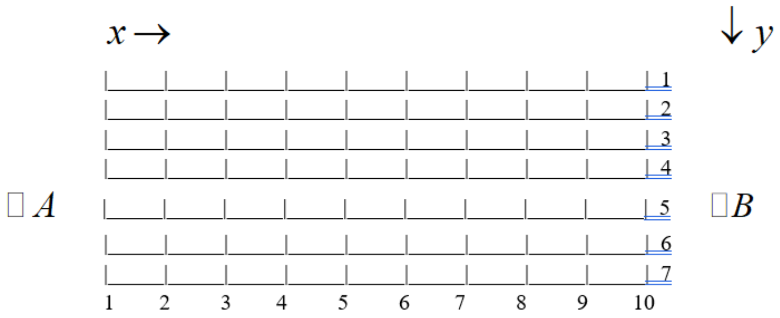

Fig. 1. Scheme of areal observations using the UGP method

To determine the strength of the magnetic field created by a linear source AB in a homogeneous medium (H_0), the Bio-Savart-Laplace law was used, taking into account the possibility of its application not only for a constant field, but also for a quasi-stationary field:

$$dH_0 = \frac{I \sin\alpha}{4\pi r^2} dl \ . \tag{1}$$

According to fig. 1, $\sin\alpha = \frac{r\,d\alpha}{dl}$; and correspondingly, $dl = \frac{r\,d\alpha}{\sin\alpha}$; or considering that $r = \frac{r_0}{\sin\alpha}$ value $dl = \frac{r\,d\alpha}{\sin\alpha} = \frac{r_0\,d\alpha}{\sin^2\alpha}$. In accordance with these relations, formula (1) will be written in the form

$$dH_0 = \frac{I \sin^3\alpha}{4\pi r_0^2} \cdot \frac{r_0\,d\alpha}{\sin^2\alpha} = \frac{I \sin\alpha}{4\pi r_0} d\alpha \cdot \tag{2}$$

By integrating this expression in the range from α_1 to α_2, we obtain the formula for calculating the magnitude of the magnetic field strength at the observation point located at a distance r_0 from the supply line AB in the direction orthogonal to it, in the case of a homogeneous model of the medium:

$$H_0 = \frac{I}{4\pi r_0}(\cos\alpha_2 - \cos\alpha_1) = \frac{I}{4\pi r_0}\left(\frac{x}{\sqrt{x^2 + r_0^2}} + \frac{(l-x)}{\sqrt{(l-x)^2 + r_0^2}}\right) \cdot \tag{3}$$

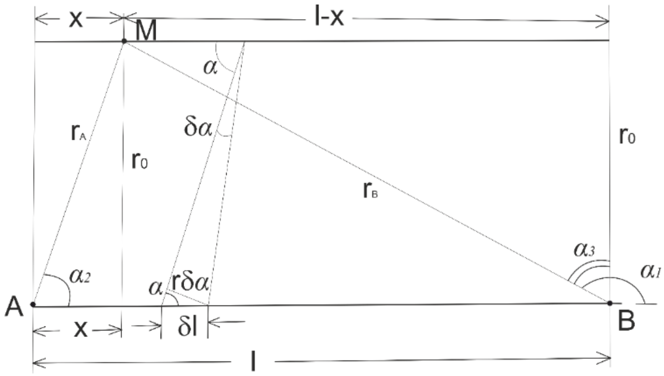

Fig. 2. To the calculation of the magnetic field generated by a linear source of limited length AB

According to fig. 3, which reflects the nature of the location of the source and observation points, we obtain formulas for determining the components of the magnetic field in relation to the UGP method:

$$H_{0,x}(x,r_0)=0 \tag{4}$$

$$H_{0,y}(x,r_0)=H_0(x,r_0)\cdot\sin\alpha \tag{5}$$

$$H_{0,z}(x,r_0)=H_0(x,r_0)\cdot\cos\alpha\,, \tag{6}$$

where $H_0(x, r_0)$ - the total field determined by the formula (3);

$r_0=\sqrt{Z_0^2+y^2}$, Z_0 - AB line depth;

The value of the angle α is found from the relation

$$\alpha+\alpha_1=90^0\,, \tag{7}$$

where $\alpha_1=artg\dfrac{y}{Z_0}$; y - distance from the projection of the AB line on the earth's surface to the observation profile.

Based on this, we obtain

$$\alpha=90^0-\alpha_1=90^0-artg\frac{y}{Z_0}\,. \tag{8}$$

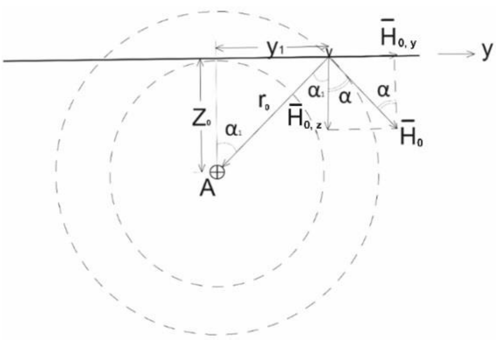

Fig. 3. Determination of the magnetic field components for the UGP method

The plots reflecting the behavior of the magnetic field components ($H_y(y)$, $H_z(y)$)along the profile intersecting the linear source AB for different values of X are shown in fig. 4 (at AB=1000 m, I=1A, $\rho_0 \geq 1000\ Ом\cdot м$).

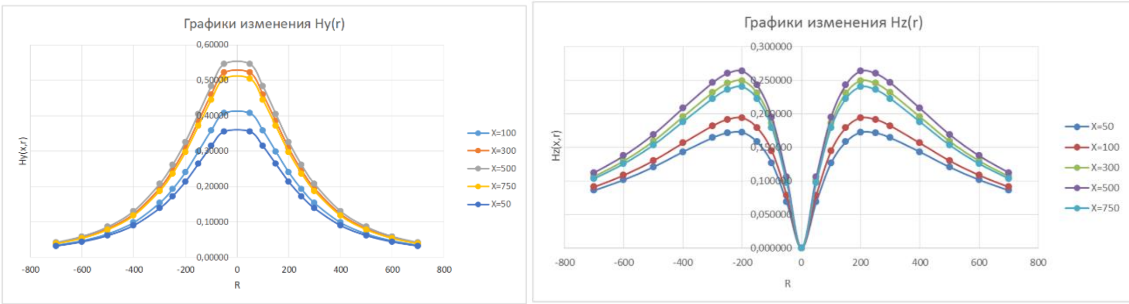

Fig. 4. Graphs of the components of the magnetic field Hy (y) and Hz (y) for different values of X, displaying the influence of the finiteness of the supply line AB on the magnitude of the measured magnetic field

In order to optimize the formation of the background field model, the following operations were used.

1. Determination and accounting of the coefficient associated with the reduction of the magnetic field for a homogeneous medium to its constant value, which removes the influence of the features of the nature of its behavior with distance from the linear source AB and the influence of its limited length:

$$k(x,y) = \frac{H_{0,\max}(\mathrm{X{=}AB}/2, y{=}min)}{H_0(x,y)}, \quad (9)$$

$$H_1(x,y) = k(x,y) \cdot H_0(x,y),$$

where $H_{0,max}(x{=}AB/2, y{=}min)$ and $H_0(x,y)$ are calculated by the formula (3).

According to the results of the performed 2D numerical simulation (fig. 5), in the case of a homogeneous medium with a resistance of more than $1000\ Ом \cdot м$ and a field frequency in the range of 39–3125 Hz, the magnitude of the magnetic field does not actually depend on the resistance of the medium and the frequency; therefore, the resulting background field has a constant value for the subject. section ($H_1(x,y) = const$). At the same time, the performed numerical analysis showed a significant increase in the degree of manifestation of a low-resistance medium (with a resistance less than $10^3\ Ом \cdot м$) in a quasi-stationary magnetic field. This information can also be used, if necessary, in shaping the background magnetic field.

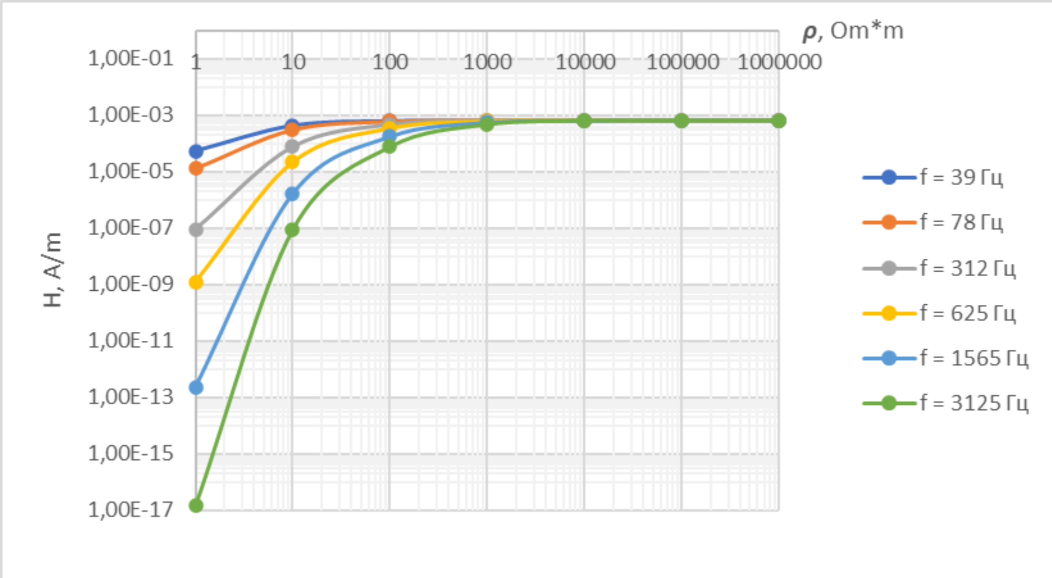

Fig. 5. Dependence of the magnetic field of a linear source on the resistivity of a homogeneous medium for a given frequency range (from 39 to 3125 Hz)

2. Determination of the background field for a heterogeneous medium.

2.1. Reducing the influence of the limb of the supply line and the nature of the change in the magnetic field with distance from the linear source

$$H^0_{obs}(x, y, f) = k(x, y) \cdot H_{obs}(x, y, f). \qquad (10)$$

In this case, the frequency f is selected depending on the distance of the observation point from the supply line AB ($f = f(y)$) using the analysis of parametric probings.

2.2. Statistical analysis of the field $H^0_{obs}(x, y, f)$ in order to highlight its most stable values with an accuracy of a given value (10-15%).

2.3. Determination of the background magnetic field in the form of the average value of the set $H^0_{obs}(x, y, f)$, determined from the results of statistical analysis (or taking into account the degree of its background variability over the area (x, y)

$$H^0_{ср}(x, y, f) = \frac{1}{n}\sum_{j=1}^{n} H^0_{набл}(x, y, f) \qquad (11)$$

3. Determination of anomalous values of the observed magnetic field $H^0_{аном}(x, y, f)$:

$$H^0_{аном}(x, y, f) = \frac{H^0_{набл}(x, y, f) - H^0_{ср}(x, y, f)}{H^0_{ср}(x, y, f)} \cdot 100\% \cdot \qquad (12)$$

4. Repetition of subp. 2-4 to assess the anomalousness of the components of the magnetic field X $\bar{H}_y(x, y)$, $\bar{H}_z(x, y)$.

The results of testing the developed algorithm in order to analyze the nature of the manifestation of low resistance anomalies in the case of GUP and UGP for model data are shown in fig. 6.

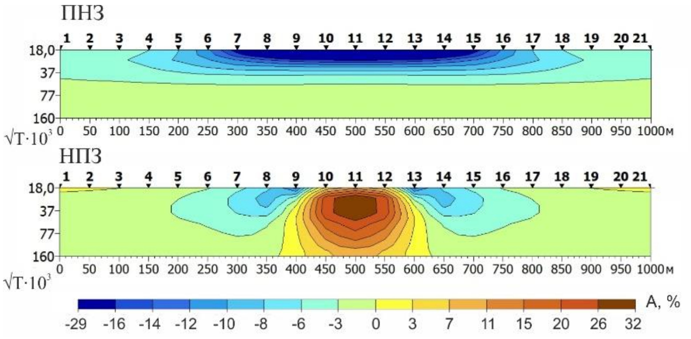

Fig. 6. Anomaly parameter sections

As a result of the conducted studies, an approximate method of interpreting the results of observations by the UGP method was developed, which provides the possibility of obtaining express information about the presence of zones of increased disturbance of the water-protective properties of the rocks of the overhead section of the section.

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