

Estimation of TEM observation time due to conductor covered layer

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Abstract—The low-resistivity covered layer has shielding effects on transient electromagnetic (TEM) field above prospecting target. The probing depth of TEM depends on observation time. So, it is of great guiding significance to study the estimation method of observation time with low-resistivity covered layer. Firstly, the finite-difference time-domain method was used to analyze the change laws of underground electric field with observation time. From FDTD analysis, we know that the low-resistivity covered layer will not only affect the detection depth, but also weaken abnormal response of underground target. Secondly, based on the calculation of 2-layer geo-electric section, formula of departure time for anomaly was set up. Finally, the comprehensive apparent resistivity of layered medium was calculated and the estimated results of observation time with different electrical characteristic were given.

Keywords—low resistivity Layer; shielding effect; TEM

I. INTRODUCTION

Transient Electromagnetic method(TEM) plays an important role in the exploration of underground targets in the fields of coal, mining, railway, transportation and other fields in China, for its high resolution, small size and convenient construction. Because the thick low-resistivity layer of Cenozoic is widespread in the eastern China, whose thickness ranges from tens to hundreds meters, the low- resistivity layer can shield the transient electromagnetic field, which definitely has a shielding effect on exploration of deep coal seam or ore body^[1-5].

Detection depth of transient electromagnetic method has always been a hotspot research. Spies (1989) published a paper on the depth of electromagnetic sounding method, giving the skin depth of harmonic field in frequency domain and diffusion depth in time domain respectively^[4].

As is well known, the detection depth of transient electromagnetic method is mainly determined by the observation time. For the complicated geological conditions, how to choose an appropriate observation time to achieve the expected detection target and ensure the detection accuracy at the same time, is crucial. This article uses the direct time-domain numerical analysis method to analyze the distribution of electric field along with the observation time. Then the estimation results at different observation time with different resistivity and exploration depths are given according to the transient electromagnetic theory.

II. NUMERICAL SIMULATION OF 2D FINITE DIFFERENCE TIME DOMAIN METHOD

Under the condition of the quasi static approximation:

$$\nabla \times \mathbf{E}(\mathbf{r}, t) = -\mu \frac{\partial \mathbf{H}(\mathbf{r}, t)}{\partial t} \quad (1)$$

In this formula, H represents magnetic field, and E represents its corresponding electric field.

$$\nabla \times \mathbf{H}(\mathbf{r}, t) = \mathbf{J}(\mathbf{r}, t) \quad (2)$$

$$\nabla \cdot \mathbf{E}(\mathbf{r}, t) = 0 \quad (3)$$

$$\nabla \cdot \mathbf{H}(\mathbf{r}, t) = 0 \quad (4)$$

The diffusion equation of quasi static electric field can be derived from the passive Maxwell equation:

$$\nabla^2 \mathbf{E}(\mathbf{r}, t) - \mu \sigma(\mathbf{r}) \frac{\partial \mathbf{E}(\mathbf{r}, t)}{\partial t} = 0 \quad (5)$$

The formula is the vector diffusion equation and can be further simplified to the scalar diffusion equation along the direction of the electric field:

$$\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial z^2} = \mu \sigma \frac{\partial E}{\partial t} \quad (6)$$

With the given boundary conditions, finite difference computation is carried on.

III. TRANSIENT ELECTROMAGNETIC RESPONSE OF LOW-RESISTIVITY LAYER

For the low-resistivity covered layer, two-dimensional finite-difference method is used to simulate the distribution of the electric field. Fig.1(a) is contour lines of the transient electric field with the low-resistivity covered layer whose thickness is 40m at t=0.03ms while Fig.1(b) is that without the low-resistivity layer. The resistivity of low-resistivity layer is $10 \Omega \cdot m$, the resistivity of earth is $300 \Omega \cdot m$, and the resistivity of the two-dimension low-resistivity anomaly body is $5 \Omega \cdot m$. The length, width and depth of the abnormal body are 120m, 20m, and 100m. Positive source is located at 0 m and negative source is located at -50 m. H and D represent horizontal distance and depth respectively. The unit of electric field is $\mu V \cdot m^{-1}$.

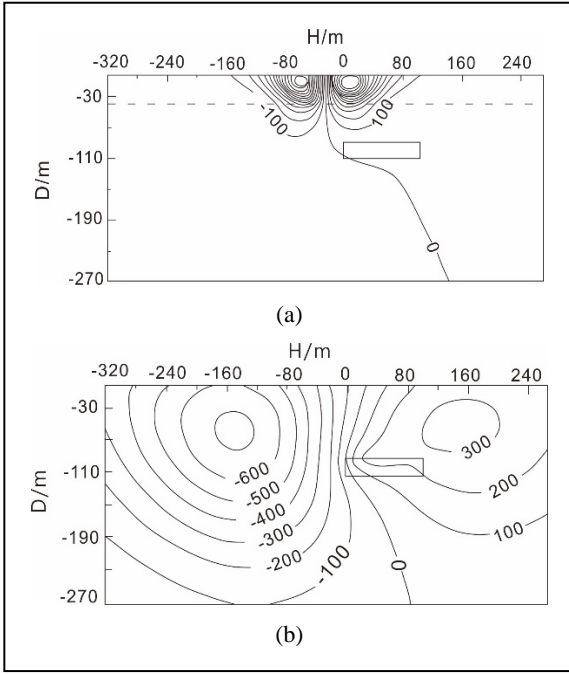


Fig. 1. Contour lines of transient electric field with low-resistivity layer (a) and without low-resistivity layer (b)

From the figure above, it can be seen clearly that the diffusion velocity of the field is much slower at the same observation time $t=0.03\text{ms}$, the induced eddy current is distributed in the covered layer, and the target is not detected when there is a low-resistivity layer. At the boundary of the two-layered mediums, contour lines of the electric field turn concave. In homogeneous earth, the electric field reaches 270 m underground and the target body can be detected because that the diffusion velocity of transient electromagnetic field is slow in the low-resistivity medium and fast in the high-resistivity layer. For the same observation time, the low-resistivity layer affects the detection depth.

IV. THE ESTIMATION OF OBSERVATION TIME OF TWO-LAYER MEDIUM

The propagation time of pulse signal is the round-trip time from the ground to a certain depth.

As is well known, the high frequency of the step pulse has attenuation and the pulse front becomes flat after a distance of propagation in the conductive earth. According to the formula of phase velocity for the good conductors

$$v_p = (2\omega\rho / \mu_0)^{1/2} \quad (7)$$

By the formula above, the dispersion of the earth makes the group velocity dominated gradually by the low-frequency components slow. So it takes twofold propagation time for field reaching the target layer and then carrying the geological information back to the ground, the separation time is:

$$t = d^2 \frac{\mu_0}{\rho} \quad (8)$$

To verify Eq. (8), we designed two groups (D, G) of different two-layer geo-electric models, and calculated the transient electromagnetic response. Fig.2 (a) and (b) are result

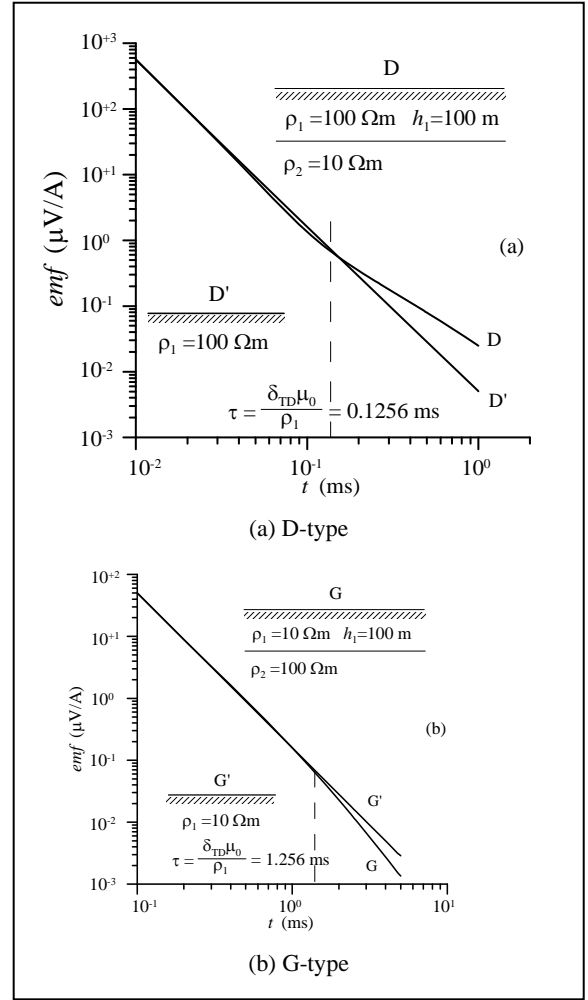


Fig. 2. Departure Time for 2-layer earth

curves of two-layer geo-electric models, D and G respectively. Compared with the uniform half space, it is clear that the separation time of two-layer curves for Fig.2 (a) and Fig.2 (b) fully meet Eq. (8), which can illustrate the correctness of Eq.(8).

V. ESTIMATION OF THE EFFECTIVE TIME OF THE ELECTRICAL CHARACTERISTICS OF DIFFERENT COVERED LAYERS

For the layered media, comprehensive resistivity in the direction perpendicular to the bedding is:

$$\rho_n = \frac{h_1\rho_1 + h_2\rho_2 + \dots + h_n\rho_n}{h_1 + h_2 + \dots + h_n} \quad (9)$$

In the formula, h_n is the thickness of the n layer, ρ_n is the resistivity of the n layer, n is corresponding layer.

According to the Eq.(8) and (9), the variation law of observation time can be calculated and shown in below table.

TABLE I. OBSERVATION TIME OF DIFFERENT APPARENT DEPTH(WITH THE SAME RESISTIVITY)

$d(m)$	$h(m)$			
	50	100	200	400
50	0.21	0.21	0.21	0.21
100	0.23	0.84	0.84	0.84
300	0.73	1.17	3.43	7.53
500	1.90	2.17	4.10	13.47
800	4.91	4.93	6.35	14.72

Among them, h is the thickness of low-resistivity layer, d is the detection depth, the resistivity of low-resistivity layer is $30\Omega \cdot m$, and the resistivity of second layer is $300\Omega \cdot m$.

As shown in the above table, when the resistivity of the low resistivity layer is constant, the observation time at the same depth increases gradually with its thickness, which further illustrates the influence of the low-resistivity medium on the propagation velocity and the observation time.

The above calculation is given in the ideal conditions without considering the length of transmitting loop and the power of transmission system. It is analyzed only from the electromagnetic propagation characteristics, but the calculation results are of some guiding significance for field example.

VI. CONCLUSION

The diffusion depth of the transient electromagnetic field increases with the time going by. The diffusion velocity

with the resistivity of medium. The diffusion velocity is fast in the high-resistivity medium but slow in the low-resistivity medium. Through the analysis of the results of the The diffusion depth of the transient electromagnetic field increases with the time going by. The diffusion velocity changes with the resistivity of medium. The diffusion velocity two-dimension simulation, we can see that the low-resistivity covered layer can lead to useful signal weakening and affect the detection depth.

In low-resistivity medium, the eddy current density is large and the attenuation is slow, while the eddy current is weak in the high-resistivity medium and the loss of energy is small. Therefore, in the area of the low-resistivity covered layer with large thickness, it is recommended to increase the transmission power of instrument to achieve larger detection depth. The estimation of observation time can reduce the blind selection of the pulse frequency, loop side length, and emission current in the design and construction, which is helpful to improve the efficiency of exploration. We should choose different observation time with different geological conditions.

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