Calculation of all-time apparent resistivity for B field based on electrical source TEM

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***Abstract*—Traditionally ∂Bz/∂T is used to obtain the apparent resistivity values in the data interpretation of grounded-wire source transient electromagnetic, which leads to the problem of multiple solutions. Using Bz, this problem can be solved. Because with the change of resistivity, the Bz is a single-valued function. In order to study the all-time apparent resistivity of the grounded-wire source transient electromagnetic based on B field, the relationship between Bz or ∂Bz/∂T response and resistivity is analysised firstly, then all-time apparent resistivity is calculated using method of dichotomy for different geo-electric models. It is concluded that all-time apparent resistivity has high resolution and is sensitive to geo-electric structures. All-time apparent resistivity has nothing to do with the offset. So it is easy for us to obtain data near source.**

***Keywords*—numerical calculation of Bz; electrical source; transient electromagnetic method; all-time apparent resistivity.**

I. INTRODUCTION

In transient electromagnetic sounding, the electromagnetic response is a complex function of geo-electric property, distance between transmitter and receiver and time. It is difficult to get the accurate inverse function of the earth resistivity and electromagnetic response, so we have to use a simplified formula to define the apparent resistivity, which results in difficulties for the fine interpretation for electromagnetic sounding data.

In recent years, the research on B field has been discussed b several authors e [1-3]. Thus, this paper discusses the all-time apparent resistivity response based on the vertical magnetic field $B_z(t)$. It can avoid the problem of binary value in the calculation process of apparent resistivity with induction electromotive force. It can also change with the distance and reflect vary progressive characteristics of field adaptively, which helps to achieve the goal of reflecting the vertical changes of electric property in geo-electric section.

II. COMPARISON BETWEEN Bz AND ∂Bz/∂T OF THE ELECTRIC SOURCE

From Maxwell equation, after multiple mathematical transformations, the formulas of magnetic induction intensity's vertical component Bz(t) and time varying ration **∂Bz/∂T** of electric source transient electromagnetic method in homogeneous half-space respectively are:

$$B_z(t) = u_0 \frac{P_E \sin\theta}{4u^2 \pi r^2}\left[(u^2-3)\phi(u) + 3\sqrt{\frac{2}{\pi}} \cdot u \cdot e^{-u^2/2}\right] \tag{1}$$

$$\frac{\partial B_z}{\partial t} = \frac{3P_E \rho_1 \sin\theta}{2\pi r^4}\left[(\phi(u) - \sqrt{\frac{2}{\pi}} u(1+u^2/3)e^{-u^2/2}\right] \tag{2}$$

In this formula, $P_E = \mathrm{IdL}$ is the dipole moment of electric dipole, $\phi(u) = \sqrt{\frac{2}{\pi}}\int_0^u e^{-x^2/2}dx$, $u = 2\pi r/\tau$ denotes inductance, $\tau = 2\pi\sqrt{2\pi\rho t / u_0}$, u_0 is the permeability in vacuum.

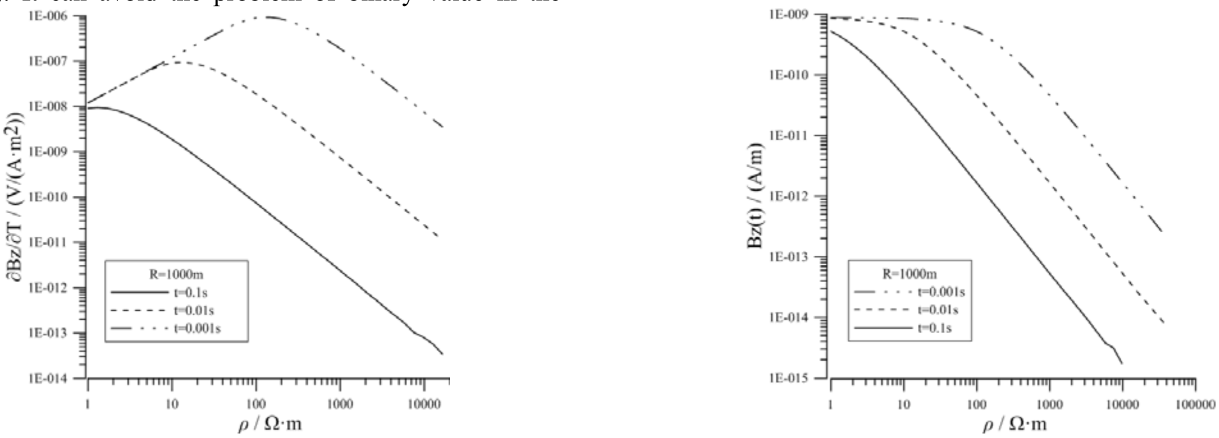

Fig.1 Contrastive curves of Bz and ∂Bz/∂T changing with resistivity ρ

Researching on the correlation of resistivity change with Bz(t) and **∂Bz/∂T** respectively, the relationship between **∂Bz/∂T** and resistivity's change is not corresponding, namely, for a **∂Bz/∂T**, there are usually two resistivities corresponding with it (Fig.1left), which makes the numerical solution difficult to be obtained. However, the relationship between Bz(t)and resistivity's change is monotonic (Fig.1), which provides reliability and uniqueness when applying formula (1) to define the all-time resistivity.

III. APPARENT RESISTIVITY RESPONSE OF B FIELD DUE TO ELECTRIC SOURCE

The formula of magnetic induction intensity's vertical component Bz(t) in homogeneous half-space in electric source transient electromagnetic field indicates that Bz(t) is the complex function of resistivity ρ ,time t ,permeability μ_0 and the relative location of observation point and source, r and ϕ. Formula (1) indicates that r, t, ρ and μ_0 do not affect the property of the field individually, but appears in the form of $u = 2\pi r/\tau$, so we convert formula (1) in this form:

$$B_z(t) = u_0 \frac{P_E \sin\theta}{4u^2 \pi r^2}\left[(u^2-3)\phi(u) + 3\sqrt{\frac{2}{\pi}} \cdot u \cdot e^{-u^2/2}\right] \tag{3}$$

Since $u^2 = \frac{u_0 r^2}{2\rho t}$:

$$B_z(t) = \frac{\text{IdL}\rho t}{2\pi r^4}\sin\theta \cdot F(u) \tag{4}$$

In this formula,

$$F(u) = \left[(u^2-3)\phi(u) + 3\sqrt{\frac{2}{\pi}} \cdot u \cdot e^{-u^2/2}\right] \tag{5}$$

Formula (4) indicates that B_z varies directly with the earth resistivity, in other words, B_z is sensitive to the changes of electric property underground.

Assuming:

$$K_{B-B_Z} = \frac{2\pi r^4}{t\text{dL}\sin\theta} \tag{6}$$

Solving the simultaneous equation of (4), (5), (6):

$$\rho = K_{B-B_Z} \frac{B_z(t)}{\text{I} \cdot F(u)} \tag{7}$$

It is not difficult to find that the upper formula is a complex function. It is difficult to calculate the resistivity directly. With the development of computering technology, it can be solved with iterative method. Firstly, subtracting an arbitrary resistivity, transmission current I , transmission source's length dL , transceiver distance r , azimuth θ, time t into formula (3), programming and calculating the difference between the obtained Bz and actual Bz. Modifying the value of ρ and iterating repeatedly until the difference between the obtained Bz and the actual Bz meet the requirement of accuracy.

IV. THE CONVERTED CALCULATION OF MAGNETIC INTENSITY BZ(T)

When using electric dipole source transient electromagnetic sounding method, it is usually to observe the induction electromotive force Vz(t) in the horizontal loop induced by the vertical change of secondary field in the field value that the vertical component of magnetic induction intensity's change rate with time multiplies by the loop's parameter[4].Thus:

$$\frac{\partial B_z(t)}{\partial t} = \frac{1}{sn} V_z(t) \tag{8}$$

In this formula, sn is effective area of receiving loop. It can be converted into the vertical component of magnetic induction intensity Bz(t) through integral equation method. According to electromagnetism:

$$B_z(t) = \frac{1}{sn}\int_t^{\infty} V_z(t)dt \tag{9}$$

Since the sampling time of electric source transient electromagnetic sounding is wide, it is necessary to use high accuracy method to calculate electromagnetic field. Otherwise, error accumulation will be caused and the resistivity curve will distort. In order to increase the integral accuracy of formula (9), cubic spline function integral method is used to calculate B_Z(t). Assuming $V_z(t) = C_3 t^3 + C_2 t^2 + C_1 t^1 + C_0$ and sampling the solution coefficient C3, C2, C1, C0 of cubic spline quasi-function. Its integral form is:

$$\int V_z(t)dt = \frac{C_3}{4}t^4 + \frac{C_2}{3}t^3 + \frac{C_1}{2}t^2 + C_0 t + C \tag{10}$$

Subtract formula (10) into (9) to obtain B_Z(t). *Fig. 2* is the comparing curve of the theoretical vertical component B_z of magnetic induction intensity in homogeneous half-space and the magnetic induction intensity's vertical component that converted with V_Z(t). The comparing results indicate that the magnetic induction intensity's vertical component obtained by this method fits the theoretical result well; the average relative error is about 1.63%.

V. MODEL ANALYSIS

In order to testify the applicability of formula (7), using dichotomy method on multiple types of model to obtain their apparent resistivity curve map, their field source parameter is that: $dL = 1000m$, $\varphi = 90^\circ$, $I = 10A$, transceiver distance is $r = 500m$. *Fig. 3* gives the all-time apparent resistivity curve in homogeneous half-space. As shown *Fig. 3*, for homogeneous earth, the apparent resistivity curve is a horizontal line which is equal to the true resistivity of models.

Fig. 4 shows the theoretical measuring for all-time apparent resistivity two-layer curve. The geo-electric parameter is $\rho_1 = 100\Omega \cdot m$, $h_1 = 200m$, ρ_2/ρ_1 is equal to 10, 7, 3, 1, 0.3, 0.1, 0.02. *Fig. 4* indicates that this apparent resistivity calculation method can reflect the electric characteristics of geo-electric model well.

Fig. 5 is the comparing result of the all-time apparent resistivity curves of H-type geo-electric model when the thickness of middle layer is changed. Geo-electric parameters of each electric layer are shown in *Fig. 5*. *Fig. 5* also indicates that this apparent resistivity calculation method can reflect three-layer geo-electric structure well. Each sounding curve can reflect the first layer's resistivity well; its tail branch tends to the true resistivity of the second layer.

VI. CONCLUSIONS

For electric source instrument, the all-time apparent resistivity defined by the vertical component of magnetic induction intensity is single-value and solvable. Compared with the induction electromotive force, it has several adavantages .

The all-time apparent resistivity curve of homogeneous half-space is a line. For layered medium, this line can reflect the true resistivity of each electric layer well. For the middle layer of multi-layer medium, this curve can reflect low resistivity layer better than high resistivity. All-time apparent resistivity can extract the information of geo-electric section effectively. It also has a good electrical property resolution and vertical resolution.

All-time apparent resistivity is only related with the difference of electric layer's electrical property and has nothing to do with transceiver distance, which can decrease computational task and reflect transient electromagnetic sounding method's superiority.

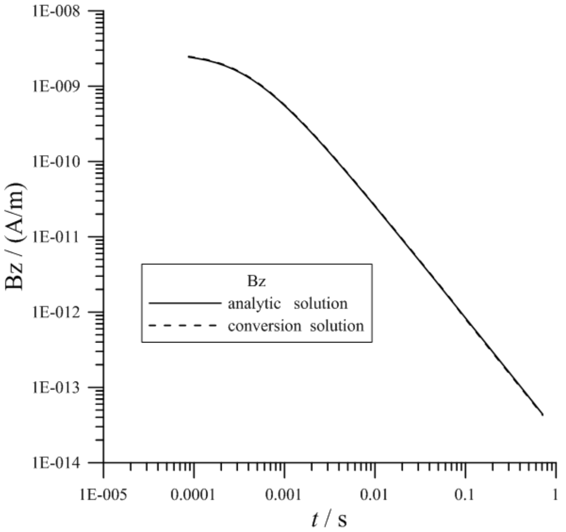

Fig.2 Contrastive curves of Bz calculated value and theoretical value

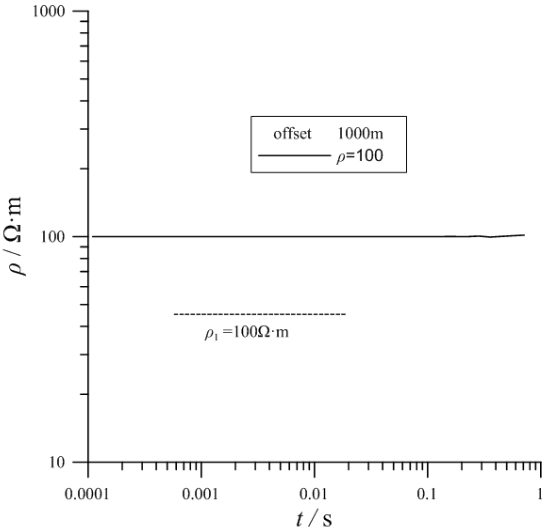

Fig.3 Apparent resistivity curves of homogeneous full space model

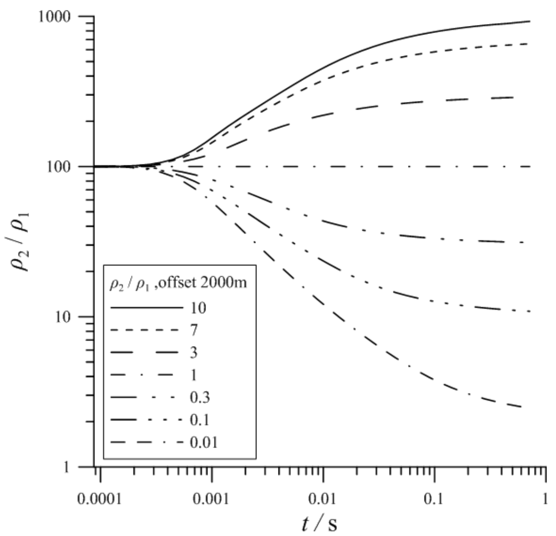

Fig. 4 All-time apparent resistivity curve of the two layer model

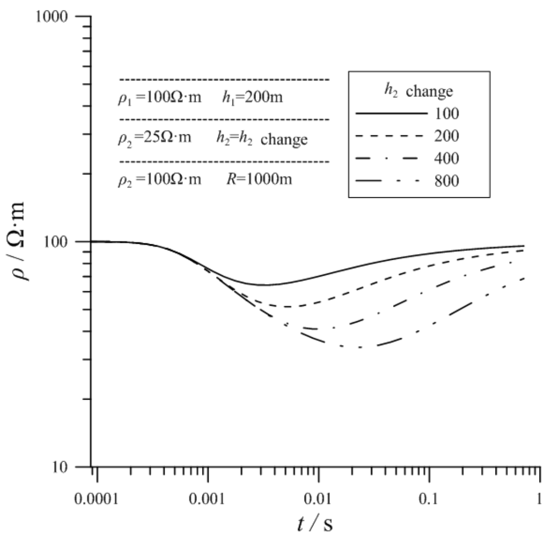

Fig. 5 All-time apparent resistivity curve of the H-model

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