A METHOD FOR PARAMETER-FREE INTERPRETATION OF THREE-LAYER ELECTROMAGNETIC SOUNDING CURVES OF TYPES K AND Q

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Fig. 1

Figure 1: Fig. 1

Abstract

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A METHOD FOR PARAMETER-FREE INTERPRETATION OF THREE-LAYER ELECTROMAGNETIC SOUNDING CURVES OF TYPES K AND Q

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Let us consider the simplest case, when we have at our disposal a complete two-layer frequency-sounding (FS) curve for the amplitude of the electric (ρ_e) or magnetic (ρ_m) components of the type $\rho_2 = 0$ and $H_2 = \infty$, obtained with a large spacing (r). By a complete FS curve we mean a curve having at least the left asymptote corresponding to the value ρ_1. The right asymptote of the curve in the present case, as is well known, is inclined to the horizontal at an angle of $63°30'$.

Fig. 1

Figure 1 shows a complete two-layer curve of the type $\rho_2/\rho_1 \approx 0$ ($\rho_1 = 10\ \Omega \cdot \text{m}$) and $H_2 = \infty$ (curve I).

The interpretation of such a curve for the purpose of determining the value of H_1 is extremely simple. For this, a two-layer master chart of the type $\Lambda_1/H_{1\infty}$ is used. The horizontal axis of the master chart ρ_1 is made to coincide with the left asymptote of curve I; in this case the master-chart curve $\rho_2/\rho_1 = 0$ coincides with curve I.

As a result of superposing the curves, the abscissa of the master chart $\Lambda_1/H_1 = 8$ coincides with a definite value f_1 of the horizontal axis of curve I, which in our case is equal to 6.2 Hz. Substituting the values $\rho_1 = 10\ \Omega \cdot \text{m}$ and $f_1 = 6.2$ Hz into the expression

$$\lambda_1/H_1 = 8 = \frac{\sqrt{10\rho_1}}{H_1\sqrt{f_1}} = \frac{\sqrt{100}}{8\sqrt{6.2}},$$

we find $H_1 = 500$ m.

If, instead of $\rho_1 = 10\ \Omega \cdot \mathrm{m}$, one chooses for the interpretation, for example, $\rho = 1.4\rho_1 = 14\ \Omega \cdot \mathrm{m}$, then as a result of superposing the curves the abscissa of the master chart $\Lambda_1/H_1 = 8$ coincides with the abscissa of curve I in Fig. 1, $f_1 = 1.4 f_1 = 8.7$ Hz instead of $f_1 = 6.2$ Hz.

Substituting the new values $\rho = 14\ \Omega \cdot \mathrm{m}$ and $f = 8.7$ Hz into the expression $\Lambda_1/H_1 = 8$, we likewise find $H_1 \approx 500$ m. Further, choosing for the interpretation another value of ρ, equal to $A\rho_1$, we shall obtain, as a result of shifting the master-chart curve along curve I, that the abscissa $\Lambda_1/H_1 = 8$ will coincide with the new abscissa of the curve $f = A^{2/\tan\alpha} f_1$, where α is the angle between the right branch of curve I and the abscissa axis.

Hence the new value of H will be

$$H = \frac{\sqrt{10A\rho_1}}{8\sqrt{A^{2/\tan\alpha} f_1}} = A^{\frac{\tan\alpha - 2}{2\tan\alpha}} H_1 = A^k H_1.$$

In the case $\rho_2/\rho_1 \approx 0$, the right branch of the FZ curve, as was indicated, is inclined to the abscissa axis at an angle $\alpha = 63^\circ 30'$, and $\operatorname{tg}\alpha = 2$. In this case $K = 0$, $A^k = 1$, and $H = H_1$.

Thus, for a two-layer curve of the type $\rho_2 = 0$, irrespective of the value of ρ chosen for the interpretation, the value of H_1 remains unchanged and equal to the true value of H_1, since it remains the same also in the case when, for the interpretation, a value of ρ equal to the true value ρ_1 is chosen.

This conclusion is also valid for three-layer and multilayer sections underlain by a layer whose resistivity ρ_{n} is considerably lower than the average resistivity of the overlying layers, as shown in ([2]).

The described method of interpreting curve I can be extended to an incomplete curve of a similar type, i.e., to a curve that has no left asymptote and for which ρ_1 cannot be determined directly from the curve (part AB of curve I). In this case it is sufficient to assign an arbitrary value of ρ (for example, the same $14\ \Omega \cdot \mathrm{m}$) and to match the incomplete curve with the $\rho_2/\rho_1 = 0$ chart curve; in doing so, the abscissa $\Lambda_1/H_1 = 8$ of the chart coincides with the abscissa of the curve $f = 8.7$ cps. Substituting $\rho = 14\ \Omega \cdot \mathrm{m}$ and $f = 8.7$ cps into the expression $\Lambda_1/H_1 = 8$, we obtain the exact value $H_1 = 500$ m.

Let us consider the second case of a two-layer section, when ρ_2/ρ_1 is a finite quantity $(1/4, 1/8$, etc.).

If the amplitude FZ curve has a left asymptote (curve II, Fig. 1) and, consequently, the value of ρ_1 is known, then, using the method described above, it is possible, with the aid of a two-layer chart, to determine the value H_1. If, however, the FZ curve is incomplete (there is no left asymptote), then it is not possible to determine separately from it the values ρ_1 and H_1. In this case, as shown in ([1]), only the value H_1/ρ_1^k can be determined correctly. However, the situation changes fundamentally if, in addition to the incomplete amplitude FZ curve, we also have the corresponding incomplete phase FZ curve. In this case, as shown in ([1]), the quantities H_1 and ρ_1 can be determined separately.

The complete curve II of Fig. 1 can be interpreted by another method. We match the horizontal axis $\rho = 1$ of the two-layer chart with the left asymptote of curve II; in doing so it is best matched with the chart curve $\rho_2/\rho_1 = 1/4$. Now, without disturbing the achieved matching, we transfer to the sounding sheet the chart curve $\rho_2/\rho_1 = 0$ (curve III, Fig. 1), which corresponds to a two-layer section with the same parameters of the upper layer (H_1 and ρ_1), but with an underlying layer having $\rho_2/\rho_1 = 0$ instead of $\rho_2/\rho_1 = 1/4$. The interpretation of such a curve is known, but in the present case the important circumstance is that H_1 can be determined from this curve by a nonparametric method and, what is especially important, independently of the actual value of ρ_1 and of what value of ρ_1 is chosen for the interpretation.

Of course, in the case of a two-layer section there is no need to use such a transformation of the curves, since H_1 can be successfully determined from the original curve II. But for more complex multilayer curves, as will be shown below, the use of this method, which we shall call the "curve-transformation method," makes it possible to determine quantitatively the characteristics of the layers of a geoelectric section, and to do so by a nonparametric route.

Let us use the transformation method for the interpretation of a three-layer curve of type K, shown in Fig. 1 (curve IV).

The interpretation of the left branch of the curve for determining the quantities ρ_1 and H_1 is carried out by the known method ([1]); in this case the value $\rho_1 = 6\ \Omega \cdot \mathrm{m}$ is read directly from the left asymptote of the curve, and the value H_1 is obtained equal to 165 m.

For the interpretation of the entire FZ curve, in order to determine the quantities H_2 and ρ_2, a set of three-layer palettes with curves of type K, constructed according to the following principle, is used.

On each palette, 5 groups of curves are collected. The curves of each group are characterized by constant values of H_2 and ρ_2 and by different values of ρ_3.

In Fig. 2 such a palette is presented, used for interpreting curves of the type of curve IV in Fig. 1.

Fig. 2

The first group (the lower one) corresponds to $\rho_2 = 32\rho_1$, $H_2 = H_1$, and $\rho_3/\rho_1 =$

Fig. 2

Figure 2: Fig. 2

0, $^1/_{32}$, $^1/_{16}$, $^1/_8$, $^1/_4$, $^1/_2$, and 1.

The following groups of curves of the palette correspond to the same ρ_2 and ρ_3, but to different H_2, namely: $H_2 = 2H_1,\ 4H_1,\ 8H_1,\ 16H_1$. The palettes in the set differ from one another in the value of ρ_2. To determine H_2 and ρ_2, the entire curve IV of Fig. 1 is matched with the most suitable curve of one of the three-layer palettes of type K. Curve IV is best matched with curve I of the palette (Fig. 2), for which $\rho_2 = 32\rho_1$, $H_2 = 8H_1$, and $\rho_3 = \rho_1$.

If, at the base of the section with the same characteristics of the two upper layers, the ρ_3 of the lower layer were equal to zero rather than to ρ_1, then instead of curve IV in Fig. 1 one would obtain curve II in Fig. 2. Consequently, if, without disturbing the superposition of curves IV in Fig. 1 and I in Fig. 2, curve II in Fig. 2 is transferred onto the FZ blank (Fig. 1), then this thereby effects the transformation of the three-layer FZ curve with parameters ρ_1, H_1, ρ_2, H_2 and $\rho_3 = \rho_1$ into a three-layer FZ curve with parameters ρ_1, H_1, ρ_2, H_2 and $\rho_3 = 0$ (curve V in Fig. 1).

The interpretation of FZ curves of type $\rho_3 = 0$ by means of the method described above is extremely simple. We choose an arbitrary value of ρ, for example, $20\ \Omega \cdot$ m, and match the right branch of curve V with the curve of the two-layer palette $\rho_2/\rho_1 = 0$ in such a way that the ordinate of the palette $\rho = 1$ coincides with the value $\rho = 20\ \Omega \cdot$ m on the FZ blank, while the abscissa of the palette $\lambda_1/H_1 = 8$ coincides with the abscissa of the curve $f = 1.1$ Hz. Substituting $\rho = 20\ \Omega \cdot$ m and $f = 1.1$ Hz into the expression $\lambda_1/H_1 = 8$, we find $H = 1685$ m. By this we have determined the total thickness of the layers $H = H_1 + H_2$, and $H_2 = 1685 - 165 = 1520$ m. Knowing the quantities ρ_1, H_1, and H_2, we find, among the above-mentioned group of three-layer palettes, such a curve as best coincides with curve IV in Fig. 1. This will determine the value of ρ_2. In our case ρ_2 turns out to be approximately $200\ \Omega \cdot$ m.

The methodology described above for interpreting three-layer sounding curves of type K is fully preserved also for curves of type Q (curve VI in Fig. 1). Its use requires no detailed explanation. Briefly, it reduces to the following procedures:

a) we take the value ρ_1 directly from the left asymptote of the VES curve ($24\ \Omega \cdot$ m);

b) using the value $\rho_1 = 24\ \Omega \cdot$ m and the method described in (1), we determine H_1(350 m);

c) we match the entire curve VI with the most suitable curve from one of the three-layer type-Q master charts, constructed according to the same principle as the type-K charts, and, in accordance with the transformation principle, transfer onto the VES form the master-chart curve with the same values of ρ_1, H_1, H_2, and ρ_2, but with $\rho_3 = 0$ (curve VII);

d) we choose the value $\rho = 20\ \Omega \cdot$ m and match the right branch of curve VI with the curve $\rho_2/\rho_1 = 0$ of the two-layer master chart in such a way that the master-chart ordinate $\rho = 1$ coincides with the value $\rho = 20\ \Omega \cdot$ m on the VES form, and, using the method described in (1), obtain $H = 1410$ m, $H_2 = 1410 - 350 = 1060$ m;

e) we choose the master-chart curve with the ratio $H_2/H_1 = 3$, which matches well with the curve being interpreted; in this case ρ_2 turns out to be $\sim 2\ \Omega \cdot$ m.

In conclusion, we note that the described method of parameter-free interpretation of three-layer curves of types K and Q is equally valid for transient-field soundings and magnetotelluric soundings.

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CITED LITERATURE

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Note: Figure translations are in progress. See original paper for figures.