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Influence of position of measuring electrodes on registration of the self-potentials

Vliv polohy měřících elektrod na registraci vlastních potenciálů

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Well-logging
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Abstract: The self-potential method (SP), as one of the main well-logging methods up to now permanently used, has never been considered from the view of position of a measuring tool. Every measuring tool can be fixed only and only in one of two possible positions. The tool must be either lie on the axis of the borehole or pressed on a wall of the borehole. An influence of technical and geological parameters is given due to the so-called characteristic function which differs for each of the above mentioned positions of the measuring tool. In recent time the level of electric noise is increasing and that is why the SP potential is negatively influenced by that noise. It seemed to be better to consider again the SP lateral which had been early preferred, but later, geophysicists have lost their interest because interpretation of this method was complicated and not exactly explained. Now, the SP lateral described after the electric field theory can undertake a role of the SP potential. In the past the characteristic function of the SP potential, when the tool is centralized, was described. However, the characteristic function of the tool pressed on a wall of the borehole has never been derived. Because of this we were not able to appreciate an influence of the measuring tool in either of the mentioned positions and to compare it.

Any characteristic functions of the SP lateral for both of the above positions were not derived and therefore no comparison of both measuring lateral systems was possible. The aim of this paper is to define all characteristic functions of both the SP potential and SP lateral. Only in this way we can calculate an influence of all the mentioned systems.

But simultaneously it means we are able to use corrections for bed thickness, bed diameter and in the case of the SP lateral also a correction for base of the tool. Since we are interested in the self potential situated on a wall of the borehole, we can compute this potential not only from the SP potential but also from the SP lateral due to its exactly defined characteristic function.

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Introduction

From the experience with registration of the self-potentials in their natural environment we know that using of a correction for the momentary position of the measuring electrodes in a borehole is nearly impossible. The electrodes oscillate in the borehole within registration and they move between two extreme positions there.

The tool can be placed on the borehole axis, which is the first position or to touch a wall of the borehole, which is the second position.

Theory

If we accept the condition to fix the measuring tool within registration in the first or the second position, we can ensure constant conditions of registration in one of the above positions. These conditions will be, of course, for each position different. They become evident by means of different form of a so-called characteristic function, which is the function describing an influence of the bed thickness and the borehole diameter on a registration of the self-potentials.

We shall distinguish between the characteristic function of centralized tool in the borehole axis and the characteristic function of pressed tool on the wall of the borehole.The first case was described by Dachnov (1967) who dealt with the theory of the SP potential. The SP lateral has been resolved by Marušiak (1956), who had used known approach of Dachnov (1947). The second case, in the meantime, has not been concerned.

The SP potential U_{SP} registered by measuring tool lying in a mud is defined by the formula

$$U_{SP} = \eta \, . \, E_{SP} \tag{1}$$

where η is factor of the electric current transmission.

Factor η depends on such physical factors as the specific resistance of an invasion zone, the specific resistance of mud and the specific resistance of adjacent rocks. This function is given by following equation (2)

$$\eta = 2 \, . \, \frac{R_m \, . \, R_i + R_m \, . \, R_s}{R_m \, . \, R_i + R_m \, . \, R_s + R_i \, . \, R_s} \tag{2}$$

where R_i is the specific resistance of an invasion zone [Ω m],

R_m the specific resistance of mud [Ω m], and

R_s the specific resistance of adjacent rocks [Ω m].

We have not taken notice to factor E_{SP} up to now. Let us pay an attention to it, too. We can write it in the following form.

$$E_{SP} = \varepsilon_{SP} \, . \, f\left(\frac{z}{d}, \frac{h}{d}\right) \tag{3}$$

where z is a distance between centre of the bed and the point of observing [cm], d the borehole diameter [cm], and h thickness of the bed [cm].

The factor ε_{SP} holds the Nernst's formula. But the second term – function – is a mentioned characteristic function of the SP potential expressing an influence of the measuring tool position. For the SP lateral is accepted the formula (4):

$$\Delta U_{SP} = \eta \,.\, \Delta E_{SP}. \tag{4}$$

And for $\Delta\ E_{SP}$ we can write then that

$$\Delta E_{SP} = \varepsilon_{SP} \,.\, f\left(\frac{z}{d}, \frac{h}{d}, \frac{L}{d}\right), \tag{5}$$

where L is base of the lateral tool e.g. a distance between both centres of M and N electrodes [cm].

The above function is called the characteristic function of the SP lateral. The characteristic function of both the SP potential and the SP lateral has different form for a different position of the measuring tool.

If we have the SP potential tool centralized in the borehole axis, we shall use formula (6) defined by Dachnov (1967).

$$f(\bar{z},\bar{h}) = \frac{1}{2}\left[\frac{(2\bar{z}+\bar{h})}{\sqrt{(2\bar{z}+\bar{h})^2+1}} - \frac{(2\bar{z}-\bar{h})^2}{\sqrt{(2\bar{z}+\bar{h})^2+1}}\right]. \tag{6}$$

If the SP potential tool is pressed on the wall of the borehole, we may use the formula derived after information about the space angle (see Dachnov 1967).

$$f(\bar{z},\bar{h}) = \frac{1}{\pi}\cdot\left[\frac{(2\bar{z}+\bar{h})}{\sqrt{(2\bar{z}+\bar{h})^2+4}}\,.\,K\left(\frac{2}{\sqrt{(2\bar{z}+\bar{h})^2+4}}\right) - \frac{(2\bar{z}-\bar{h})}{\sqrt{(2\bar{z}-\bar{h})^2+4}}\,.\,K\left(\frac{2}{\sqrt{(2\bar{z}-\bar{h})^2+4}}\right)\right] \tag{7}$$

where K ( ) is the complete elliptical integral of the first type.

For the SP lateral tool we are using similar formulas. If the SP lateral tool is centralized in the borehole axis, we shall write new equation (8) derived from (6).

$$f(\bar{z},\bar{L},\bar{h}) = \frac{1}{2}\cdot\left[\frac{(2\bar{z}+\bar{L}+\bar{h})}{\sqrt{(2\bar{z}+\bar{L}+\bar{h})^2+1}} + \frac{(2\bar{z}-\bar{L}-\bar{h})^2}{\sqrt{(2\bar{z}+\bar{L}+\bar{h})^2+1}} - \right.$$
$$\left. - \frac{(2\bar{z}+\bar{L}-\bar{h})}{\sqrt{(2\bar{z}+\bar{L}-\bar{h})^2+1}} - \frac{(2\bar{z}-\bar{L}+\bar{h})}{\sqrt{(2\bar{z}-\bar{L}+\bar{h})^2+1}}\right]. \tag{8}$$

When the SP lateral tool is pressed on the wall of the borehole, we may use formula (9).

$$f(\bar{z},\bar{L},\bar{h}) = \frac{1}{\pi}\cdot\left[\frac{(2\bar{z}+\bar{L}+\bar{h})}{\sqrt{(2\bar{z}+\bar{L}+\bar{h})^2+4}}\,.\,K\left(\frac{2}{\sqrt{(2\bar{z}+\bar{L}+\bar{h})^2+4}}\right) + \right.$$
$$+ \frac{(2\bar{z}+\bar{L}-\bar{h})}{\sqrt{(2\bar{z}-\bar{L}-\bar{h})^2+4}}\,.\,K\left(\frac{2}{\sqrt{(2\bar{z}-\bar{L}-\bar{h})^2+4}}\right) -$$
$$- \frac{(2\bar{z}+\bar{L}-\bar{h})}{\sqrt{(2\bar{z}+\bar{L}+\bar{h})^2+4}}\,.\,K\left(\frac{2}{\sqrt{(2\bar{z}+\bar{L}-\bar{h})^2+4}}\right) -$$

$$-\frac{(2\bar{z}-\bar{L}+\bar{h})}{\sqrt{(2\bar{z}-\bar{L}+\bar{h})^2+4}}.K\left(\frac{2}{\sqrt{(2\bar{z}-\bar{L}+\bar{h})^2+4}}\right)\Bigg]. \tag{9}$$

Symbols $\bar{z}$, $\bar{L}$, $\bar{h}$ are normalized by the borehole diameter e.g. it holds that

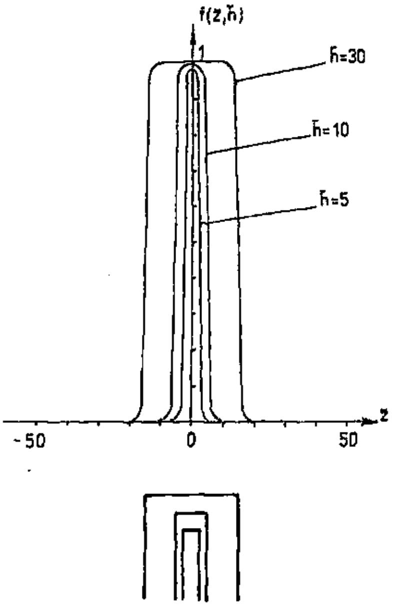
$$\bar{z}=\frac{z}{d}, \tag{10}$$

$$\bar{h}=\frac{h}{d}, \tag{11}$$

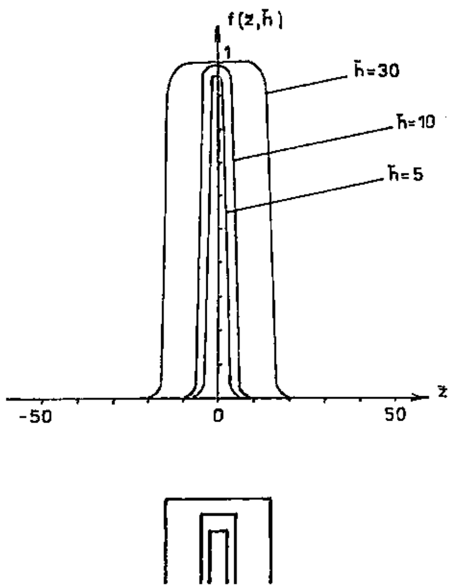
$$\bar{L}=\frac{L}{d}. \tag{12}$$

Both potential characteristic functions are symmetrical after the bed centre. The lateral characteristic functions are asymmetrical after bed centre. Marušiak (1956) defined formula of the SP lateral by means of derivation the equation (6). The character of the lateral curves was similar like in our case, but the mathematical form was another. He studied only the centered lateral tool.

The characteristic function has two extreme positions – centered tool in the borehole axis and pressed tool on the wall of borehole. It was given by situation that the space angle of an observing point was not defined for a general position of this point but for each of the extreme positions as well. But in practice we need to use only the tool steady fixed in one of the above positions and therefore I did not define the general formula.



1. The SP potential curves of a measuring tool centralized in the borehole axis for beds of different thickness.

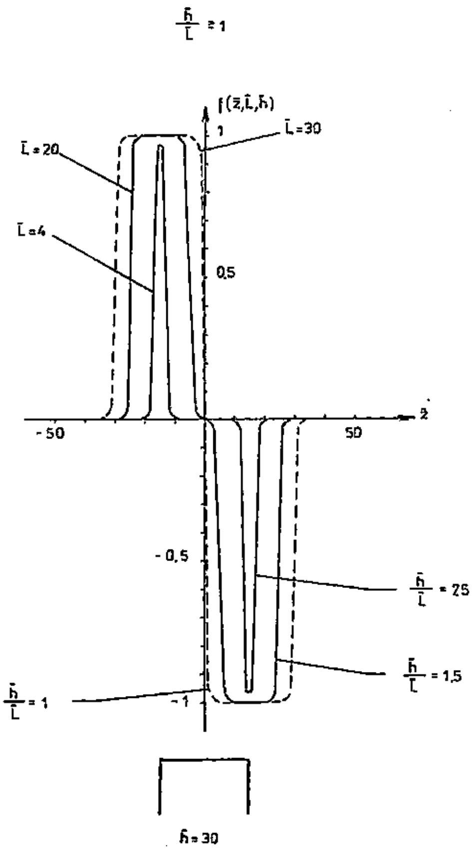


2. The SP potential curves of a measuring tool pressed on the wall of borehole for beds of different thickness.

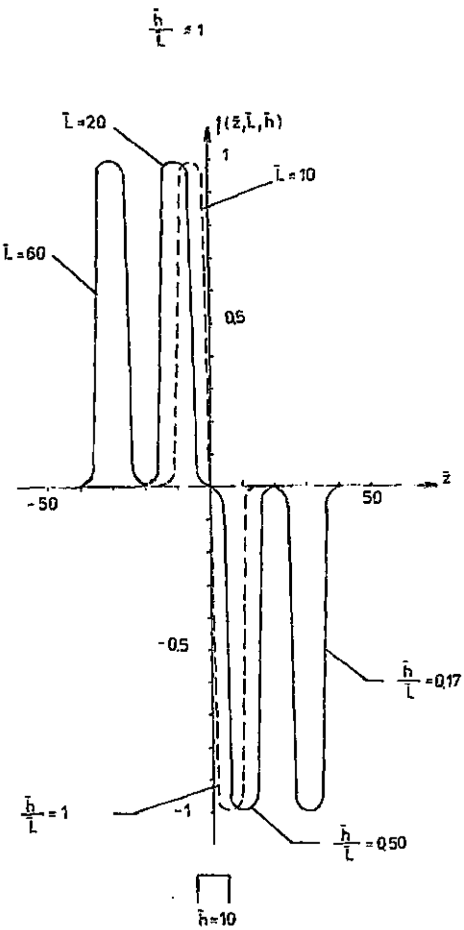
Discussion

The results of mathematical analysis of all four events are completed by illustrations of the characteristic functions. On Fig. 1 and 2 there is the SP potential centered in the borehole axis and the SP potential pressed on a wall of the borehole. The graph of the characteristic function is made for several beds having different thickness. It is evident that bounds of the bed lay in points of inflection of the characteristic function and this holds for both centralized and pressed measuring systems. More, it is evident the thick beds of both above systems have almost identical characteristic function. But the thin beds are better characterized by centralized measuring tool having higher deflections of the characteristic function and this function has also higher steepness.

For the SP lateral tool is a similar situation. On Fig.3 and 4 there is the characteristic



3. The SP lateral curves of a measuring tool centralized in the borehole axis for $h \geq L$

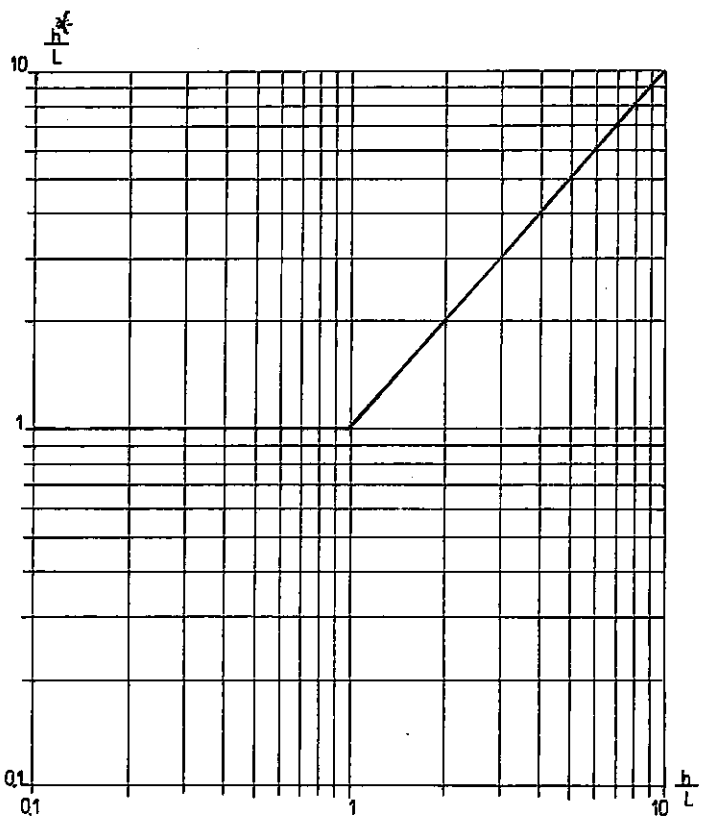


4. The SP lateral curves of a measuring tool centralized in the borehole axis for $h \leq L$.

function of the SP lateral illustrated. We must distinguish between events, when $h > L$ and $h \leq L$, because it has a fundamental significance for an evaluation of bed thickness. By comparison of curves we shall conclude that the characteristic function of thick beds is almost identical for both the centralized and pressed tool. However, the thin beds or a short spacing of the tool are better characterized by centralized tool.

A graph common for both mentioned lateral systems is drawn on Fig. 5. It is the technical characteristic curve transforming the apparent bed thickness into the real bed thickness. From illustration it is evident that in all events for $h < L$ it holds $h^* = L$. In contrary for $h > L$ it holds $h^* = h$. The event $h = L$ is common for both mentioned cases.

Pay a little attention to the SP lateral. Up to now there has it been held to determine the bed thickness only when $h > L$. But from the made analysis we can evaluate the bed thickness also at that case, when $h < L$. Even though the apparent bed thickness equals to base e.g. $h^* = L$, the real bed thickness is coded for a such event in latitude of positive and negative lateral deflection, which is determined by distance between both pair points of inflection. And just this fact we must use.



5. The transforming characteristic curve of the SP lateral from the apparent bed thickness into the real bed thickness.

Conclusions

Finally, we can summarize the procedure analysis to the following conclusions :

1. The bounds of beds are defined by position of inflection points for every beds in the case of the SP potential.

2. By comparison of pressed and centralized systems it is evident that for thick beds the both systems are equivalent but for thin beds the centralized system is giving more outstanding deflections. This holds both for the SP potential and the SP lateral.

3. For the SP lateral the bounds of beds are directly determined only if $h \geq L$. When $h < L$, for an evaluation we must use another method of interpretation, because the bed thickness is not defined by distance between maximum and minimum of deflections but by distance between the pair inflection points of positive and negative deflection.

4. As the potential is influenced by very large electric noise we can calculate now with the repeated evaluation of the SP lateral. The characteristic function can give for it all prerequisites.

For interpreters this method can have quite new significance, because they will be able to use corrections for the bed thickness, the borehole diameter and in the case of the SP lateral also a correction for base of the tool. Due to them it will be possible to compute factor ε_{SP} situated on the wall of the borehole, which has the direct significance for interpretation.

K tisku doporučil A. Těžký
Přeložil F. Ryšavý

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Vliv polohy měřících elektrod na registraci vlastních potenciálů

(Résumé anglického textu)

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Vliv polohy měřících elektrod ve vrtu můžeme posoudit prostřednictvím tzv. charakteristické funkce, udávající váhové zastoupení vlivu průměru vrtu, mocnosti vrstvy a u gradientu SP navíc i báze sondy, což je vzdálenost středů obou měřících elektrod. Existují dva krajní případy polohy měřících elektrod hlubinné sondy :

- kdy je centrována v ose vrtu,
- kdy je přitlačována na stěnu vrtu.

Byly studovány charakteristické funkce pro obě polohy jak pro potenciál SP, tak i pro gradient SP. V předložené práci jsou tyto charakteristické funkce uvedeny. Následuje diskuse výsledků a analýza výsledných rovnic, doplněná řadou obrázků.

Na základě této diskuse je možno dojít k závěrům:

1. Hranice vrstvy u metody potenciálu SP jsou jednoznačně určeny polohou inflexních bodů křivky charakteristické funkce.

2. Z porovnání centrovaného a přitlačovaného měřicího systému vyplývá, že u mocných vrstev nevzniká takřka žádný rozdíl. U tenkých vrstev je centrovaný systém vhodnější, neboť dává strmější a výraznější výchylky. To platí jak pro potenciál, tak pro gradient.

3. Až dosud bylo možno u gradientu SP určovat ty vrstvy, jejichž mocnost byla větší než báze sondy gradientového systému. Práce ukazuje na možnost interpretace i těch vrstev, jejichž mocnost je menší než báze sondy gradientového systému. Vzdálenost mezi pozitivní a negativní výchylkou je v takovém případě rovna bázi sondy, avšak informace o mocnosti vrstvy je dána vzdáleností mezi párovými inflexními body pozitivní a negativní výchylky.

4. Pro interpretaci Nernstovy rovnice je potřebné znát parametr ε_{SP}. Pomocí charakteristické rovnice určíme tento parametr nejen podle potenciálu SP, ale i podle gradientu SP. V době, kdy dochází ke zvýšení úrovně elektrických šumů, je měření gradientu SP výhodnější, neboť výpočet parametrů ε_{SP} je potom přesnější.

Vysvětlivky k obrázkům

1. Křivky potenciálu SP měřicí sondy centrované v ose vrtu pro vrstvy rozdílné mocnosti.
2. Křivky potenciálu SP měřicí sondy přitlačované na stěnu vrtu pro vrstvy rozdílné mocnosti.
3. Křivky gradientu SP měřicí sondy centrované v ose vrtu, když platí $h \geq L$.
4. Křivky gradientu SP měřicí sondy centrované v ose vrtu, když platí $h \leq L$.
5. Transformační charakteristika gradientu SP mezi zdánlivou a skutečnou mocností vrstvy.