On the application of differential phase parameter in spectral IP

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Differential phase parameter (DPP) was brought forward in late 1970's and since then has been successfully used for suppression of inductive noise in IP phase measurements. In the near-field zone approximation, the phase shift of electric signal due to inductive effects in medium is directly proportional to frequency (Hallof 1974). In this context DPP was constructed in such a way that it eliminates the linear component of the phase shift, leaving the frequency-independent component untouched. Hence, DPP was originally invented for the constant phase angle (CPA) model of IP spectrum. We show the usefulness of DPP in more general case, when the IP phase curve is represented by a superposition of those of several models such as CPA and Cole-Cole. By doing so, we significantly expand its application area.

For two frequencies ω_1 and ω_2 DPP is defined as an operator Δ, which acts on an arbitrary continuous function $\varphi(\omega)$ as follows (Kulikov and Shemyakin 1978):

$$\Delta\varphi(\omega_1,\omega_2) \overset{\text{def}}{=} \frac{\varphi(\omega_1)\omega_2 - \varphi(\omega_2)\omega_1}{\omega_2 - \omega_1}. \qquad (1)$$

Using the definition (1) it could be easily shown, that for any set of functions $\varphi_k(\omega)$ and coefficients a_k the following statements hold:

$$\Delta\left(\sum_k a_k \varphi_k\right) = \sum_k a_k \Delta\varphi_k\,, \qquad (2)$$

$$\Delta(a_k) = a_k \text{ and} \qquad (3)$$

$$\Delta(\omega a_k) = 0\,. \qquad (4)$$

Thus, operator Δ turns out to be linear (2) and does not affect the constant part of the signal (3) while entirely suppressing its linear component (4). These properties of DPP shows that it may be successfully used to extract the IP phase value φ_{ip} from the phase $\varphi(\omega)$ of the measured electric signal if the former is virtually frequency-independent: in this case the value of $\Delta\varphi(\omega_1,\omega_2)$ equals to φ_{ip} for any frequencies ω_1 and ω_2.

Although the CPA model has found its application in practice – for example, it describes well the IP spectra of some highly dispersive in grain size sedimentary deposits (Börner et al. 1993) – its field of use remains limited since most types of rocks show the frequency-dependent behaviour of IP phase and thus require alternative models to describe them. The highest popularity among such models was gained by the Cole-Cole function (Pelton et al. 1978), whose phase curve on logarithmic plot has a peak and two smooth branches, symmetrically tending towards zero. Chargeability η primarily affects the amplitude of the phase curve, time constant τ the peak frequency, and exponential parameter C the spectral width of the response. In case of asymmetrical phase behaviour one could use the so-called generalized Cole-Cole model (Pelton et al. 1983), with an additional independent parameter a.

In practice, the actual IP phase curve over an arbitrary geological section usually could be approximated with reasonable accuracy by that of one of the mentioned models or by their superposition. To get an idea of the distorting influence of DPP on a weighted sum of model curves (regarding the linearity of operator Δ and its perfect applicability to the CPA model), it is sufficient to give a consideration to its influence on a stand-alone Cole-Cole function. For that purpose we used the most popular in practice form of DPP with $\omega_2 = 3\omega_1$ and a Cole-Cole model with $\eta = 0.2$ and a set of C from 0.2 to 0.5. Chargeability was fixed in the modelling as it barely affects the IP curve shape, while the chosen range of C is typical for vast majority of rocks with most common values from 0.2 to 0.35 (Pelton et al. 1978; Seigel et al. 1997). The result is given on Fig. 1.

It is clearly seen from Fig. 1 that for small *C* the Cole-Cole phase curve (solid line) virtually coincides with the DPP curve (dashed line). With a rise of parameter *C* the curvature of the Cole-Cole line increases, resulting in larger misfit with the corresponding DPP graph. It is also notable that this misfit tends to give the DPP curve more "contrast" – with slightly overestimated peak value and increased branch steepness. It is thus important to understand that for large *C* the resulting curve is not of the Cole-Cole type anymore, but some of its distinctive features such as spectral width or peak frequency remain almost the same or change negligibly.

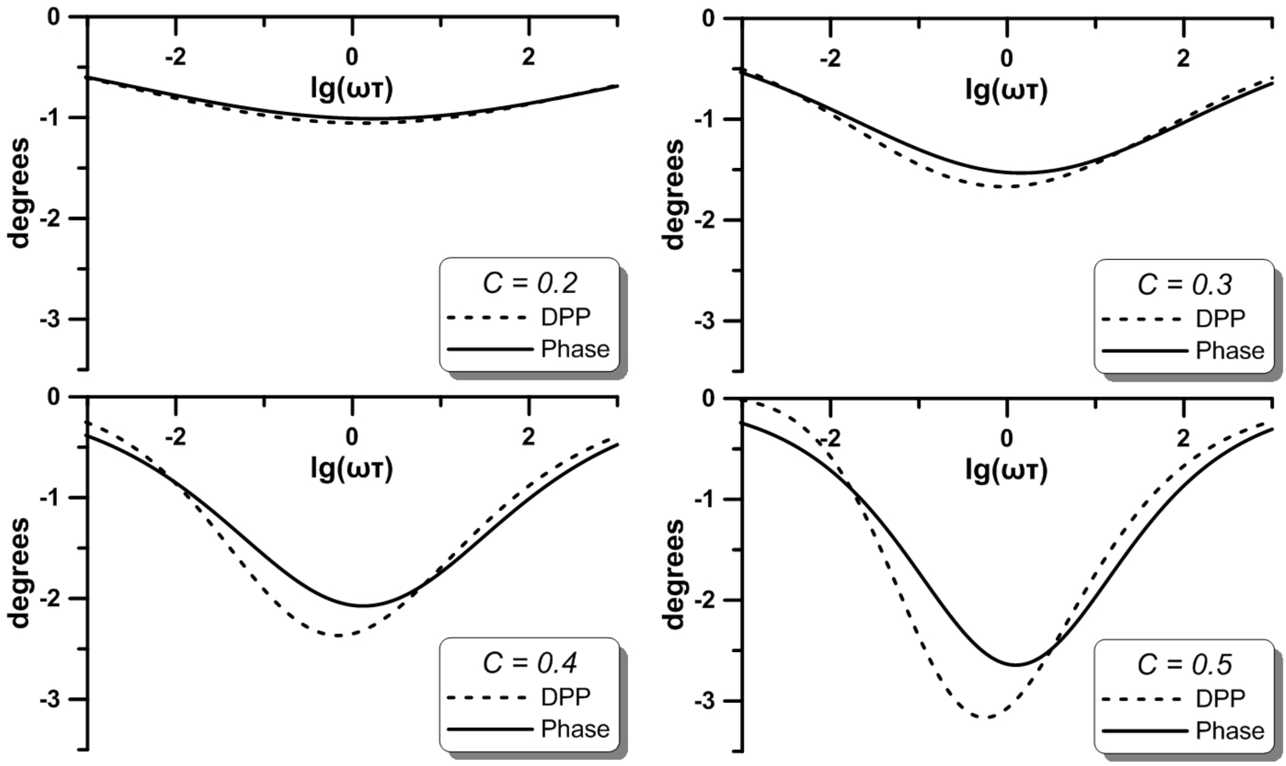

Fig. 1: Comparison between Cole-Cole phase curves (η = 0.2) and corresponding DPP curves.

To summarize, it may be concluded that DPP could be successfully applied not only for measurements of frequency-independent IP phase values, but also for discrimination of rocks distinguished by the standard IP parameters such as τ and *C*. Furthermore, by virtue of having more contrast, DPP curve may turn out to be even more useful than the IP curve itself. Taking into account high accuracy of obtained data and the significant suppression of inductive noise, it makes differential phase parameter a powerful instrument of low frequency electromagnetic prospecting.

References

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