The Forward Modeling for Surface-borehole Observation Responses of Polarized Target

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Abstract. Surface-hole induced polarization method is a typical deep resource exploration technology, which plays an important role in the mineral survey. The traditional surface-hole induced polarization method is mainly to observe a single polarized secondary field. At present, the time spectrum observation of polarization fields is becoming more and more popular, which greatly enriches the interpretation technology of induced polarization data. In this work, the time spectrum induced polarization method is expounded, the decay polarization fields were numerical calculated and analyzed for the typical 2-dimensional geoelectric model. The results show that for a single polarized target, the time spectrum obtained from different azimuth observation responses are basically the same, which can effectively reflect the time-varying characteristics of the polarized fields. The observation responses of polarized target at different depths can still reflect the time spectrum of decay fields. The main change of the observed response of the polarized target closer to the borehole is the response amplitude. The conclusions and simulations of this study can provide working mode for relevant research and reference for similar work.

1. Introduction

Surface-hole induced polarization (SHIP) method is one of the most used methods in various drill-hole induced polarization method. It can be used to survey polarized ore bodies near or at the bottom of boreholes, and can also be used in hydrological exploration [1]. It has achieved good application results. The main target of surface-borehole IP method is local polarization body, including ore and aquifer [2]. Predecessors have done a lot of relevant research, including observation responses forward modeling of polarized conductors such as sphere, plate and thin plate has been realized by physical simulation or numerical simulation [3][4]. The simulation results of observed responses can equivalent simulate a variety of actual geological conditions such as ore body and ore bed, which is of great practical significance [5]. Since then, based on the above forward modeling method, a series of inversion methods for solving local polarized target spatial parameters, geometric scale parameters, resistivity and polarizability have been proposed one after another, which has played a key role in experiment and actual work [6].

Spectrum IP method is the main improved branch of IP method [7]. The time domain spectrum IP method is an important part of direct current IP method [8]. It can reflect the IP characteristics of different polarized target through the time spectrum of IP field, which has great application and
development potential [9]. At present, the time spectrum observation technology of IP field is becoming more and more mature and widely used. Identifying different types of polarization targets through time spectrum has become an important exploration means [10]. Therefore, the forward modeling of time spectra of different polarized target for surface-borehole IP method has become an important research goal.

In this work, we study the time spectrum simulations modeling of IP fields for the polarized sphere under the condition of typical geoelectric model. Select the applicable forward modeling formula of sphere polarization field and Cole-Cole model describing time spectrum to forward the observation response of SHIP observation of polarized sphere, and analyze the forward results. The results of forward calculation and analysis can provide work results and theoretical support for the related research and actual work.

2. Forward algorithm

Based on the electric dipole equivalent model, for the SHIP fields of polarized sphere, the formula of forward modeling for surface-borehole IP response can be written as follows [11]:

$$V_2 = K \frac{D^2 - 2(z - H)^2 \sin i - 3D(z - H) \cos i}{\left[D^2 + 2(z - H)^2\right]^{2.5}} E.$$  

(1)

Where the $H$ represents the depth of polarized sphere centre, the $D$ represents the horizontal distance from the centre of the polarization sphere to the drill-hole, the $z$ is the drill-hole measurement point, the $i$ is the angle between the surface source and measurement point, the $E$ is the distance between two observed electrodes, the $r$ is the offset between drill-hole and surface source, the $K$ is the related parameter for the observed device.

Cole-Cole model is an important tool to describe the time spectrum of IP fields, and its basic formula is as follows:

$$V^*_{(\omega, r, \tau, m)} = V_0 \cdot \left\{1 - m \left[1 - \frac{1}{1 + (i\omega\tau)^c}\right]\right\}.$$  

(2)

where $\rho_0$ represents the zero-frequency polarized resistivity in $\Omega \cdot m$, $m$ represents the chargeability of polarized fields in $\%$, $\omega$ represents the angular frequency in rad/s, the $c$ represents the relaxation coefficient and dimensionless constant, $\tau$ represents the time constant in seconds.

By applying the "frequency-time" transformation to equation (2), calculating the secondary IP field through the image principle, normalizing the initial secondary IP field, and finally multiplying by equation (1), the time-varying secondary IP field can be obtained.

3. Forward modeling

Figure 1. The SHIP measurement configuration and the geo-electric model with polarized sphere. The ground fields sources at the A0, A1, A2, A3 and A4. The M and N are the observation electrodes of vertical drill-hole.

-D with surface-borehole observation. The surface sources include
The observation device of surface-borehole IP method and typical geoelectric model are shown in Figure 1. The ground field sources are arranged at different positions, such as A0 to A4. The distance from these field sources to the borehole is the offset distance.

Figure 2. Polarized secondary field observed in azimuth A4.  
Figure 3. Polarized secondary field observed in azimuth A0.  
Figure 4. Polarized secondary field observed in azimuth A2.  
Figure 5. Polarized secondary field observed in azimuth A3.
The geoelectric model of the observed device and the polarized sphere nearby the drill-hole as shown in the Figure 1. The polarized sphere near the borehole has a certain depth and distance from the hole, and has a certain polarization and spectral characteristic parameters. By observing the potential difference in the borehole, the spatial information about the target can be obtained indirectly. Model parameters in Figures 2 to 4: offsets are 0 m (A0), 100 m (A1), 200 m (A2), 300 m (A3) and -100 m (A4) respectively, \( z = 300 \) m, \( d = 200 \) m, \( m = 50\% \), \( \tau = 1 \) s and \( c = 0.25 \). MN distance 10 m, observation depth 40 ~ 580 m, the distance of observation points 20 m.

The time-varying secondary field responses in different directions are shown in Figure 2 to Figure 4. It can be seen that the closer to the polarized target, the greater the anomalous response amplitude, and the response intensity decreases gradually with the time delay. For the field sources located on both sides of the target, the profile shape of the observed response is symmetrical, and the main anomalies are located on the upper and lower sides of the target respectively. The profile shape of the response of the field source directly above the target is relatively regular, and the main anomaly area is located at the depth of the anomaly body. The amplitudes of response profiles observed in all directions are not exactly the same, but the attenuation characteristics are basically the same.

The surface-borehole observation responses of abnormal target at different depths are shown in Figure 6. It can be seen that the main abnormal area is deeper, which is basically consistent with the position of the abnormal body. As shown in Figure 7, the smaller \( d \), the higher the anomaly amplitude and the smaller the main anomaly area.

4. Conclusion
For the single polarized target, there are differences in amplitude and basic shape of surface-borehole observation responses from different directions, but the characteristics of time spectrum are basically the same.

The spatial position (depth and distance from borehole) of polarization target will affect the profile characteristics of ground well observation response, but its basic attenuation state is less affected.

The time spectrum characteristics of IP fields are relatively stable and can be used as an effective tool to identify polarization targets.
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