

CSEM sounding strategy based on the total magnetic field

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SUMMARY

Problems such as angular errors and zero-value bands in single-component acquisition of electromagnetic fields in Controlled-Source Electromagnetic Method (CSEM) are becoming more and more prominent, especially in areas with complex terrain. We proposed a sounding strategy using the total magnetic field, which can be synthesized from orthogonal three-component magnetic fields. Simulation results show that the total magnetic field is uniformly distributed in all directions of the field source, with no zero-value bands and a larger detectable azimuthal angle range. Since the total magnetic field is constant at a fixed station, it is unaffected by angular errors due to attitude changes of sensors. Theoretical analyses indicate that a three-component magnetic field sensor can be used for total magnetic field sounding.

An experiment was conducted in Chongqing, China, targeting an artificially excavated group of buildings in a mountain at a depth of about 150 m. The total magnetic field was synthesized by simultaneously collecting the vertical magnetic field component and the orthogonal two-component horizontal magnetic field on the ground. Experimental data show that the total magnetic field exhibits a clear high-resistivity anomaly in response to the target. Comparison of the results between the total magnetic field and the ground electric field shows that the former responds more significantly to target detection, while the latter is heavily influenced by static effects.

Additionally, it should be noted that the magnetic field data analysed in the experiment was not denoised, yet the data remained high quality. This indicates that the total magnetic field has outstanding immunity to interference. And it is unnecessary to monitor or control the tilt precisely because the measurement system provides rotationally invariant total field data. It is expected to further reduce the lowest frequency available in semi-airborne electromagnetic method (SAEM) and increase the depth of sounding.

Keywords: Controlled Source Electromagnetic Method; total magnetic field; zero-value band; semi-airborne electromagnetic method

INTRODUCTION

The Controlled Source Electromagnetic Method (CSEM) uses a single-component electromagnetic field for deep sounding (Lin et al., 2019; Di et al., 2020; Lu et al., 2022). This method can cause problems such as zero-value bands, limited azimuthal detection range, and angular errors (Ji et al., 2014; Chen et al., 2022). Especially in mountainous, hilly and highland areas with complex topography, inaccurate measured electromagnetic field components lead to errors in the calculated apparent resistivity, affecting subsequent inversion and geological interpretation. We proposed a sounding strategy using the total magnetic field, which can be synthesized from orthogonal three-component magnetic fields. This method provides a new idea to improve the basic theory and detection technology of CSEM, which is expected to solve the problems of zero-value

bands and angular errors in CSEM.

NUMERICAL SIMULATION

According to the vector synthesis theorem, the total magnetic field (H_t) can be obtained by synthesizing the orthogonal three-component magnetic field as the following equation:

$$H_t = \sqrt{H_x^2 + H_y^2 + H_z^2}$$

H_x , H_y , and H_z represent the magnetic field components in the X, Y, and Z directions, respectively. We carried out numerical simulations for the analysis. The model employs a homogenous half-space with an electrical resistivity of 100 Ωm and an excitation frequency of 100 Hz. The source is oriented along the X-axis with its midpoint situated at the coordinate origin, and the polar moment is set at 1 Am. As shown in Figure 1,

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the total magnetic field has a larger detectable range than a single-component magnetic field because it is uniformly distributed around the field source and has no zero-value band. Since the total magnetic field is constant at the fixed measurement point, it is also not affected by changes in the sensor's attitude and has a higher anti-interference capability.

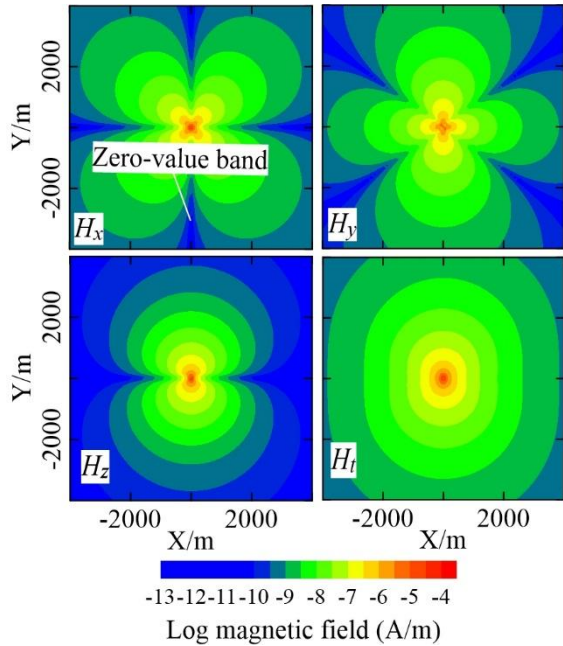


Figure 1. Radiation pattern of H_x , H_y , H_z and total magnetic field H_t .

In actual detection, the total magnetic field can be synthesized by the orthogonal three-component magnetic field collected by the three-component magnetic field sensor.

FIELD EXPERIMENT

In order to verify the validity of the total magnetic field detection, an underground buildings in a scenic area of Chongqing, China was selected for the experiment. The buildings has a burial depth of approximately 150 m, a length of approximately 185 m, a width of approximately 10 m and a maximum height of approximately 80 m. The transceiver distance for this experiment is approximately 2 km, the field source polar distance is 500 m, the maximum transmission current is approximately 25 A and the frequency range is 8000-125 Hz.

In the absence of an ideal three-component magnetic sensor, this experiment used a naturally orthogonal two-component hollow coil magnetic sensor to collect the horizontal component and a single-component hollow coil magnetic sensor to collect the vertical component, and the two are synthesized into the total magnetic field. In addition, an E_x -mode sounding of wide field electromagnetic

method (He, 2010) was carried out and used for comparison.

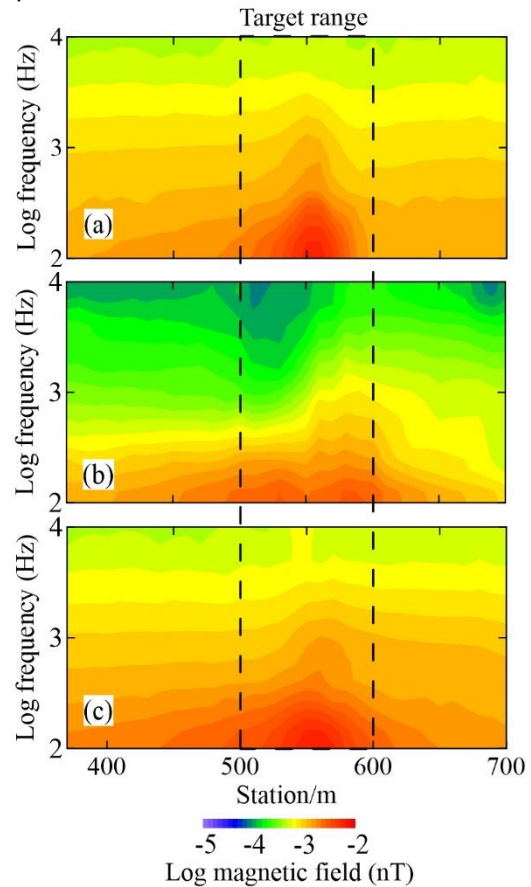


Figure 2. Results of horizontal magnetic field (Synthesized by the components from two-component hollow-coil magnetic sensor), H_z and total magnetic field H_t .

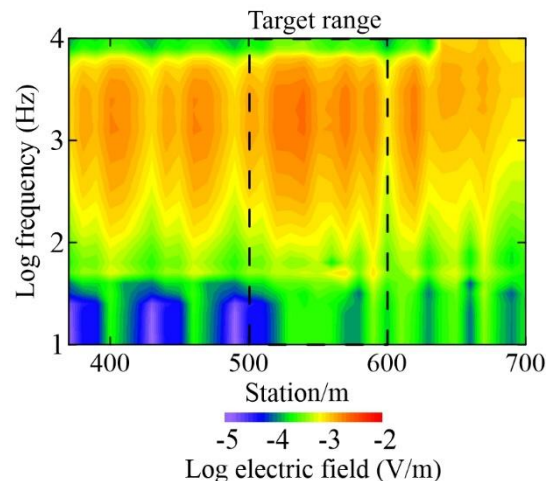


Figure 3. Result of electric field E_x

As shown in Figure 2, the horizontal magnetic field collected in the air has a significant high field value response to the target, but the vertical magnetic field response is not significant due to interference from the high voltage power lines within 200m of the experiment site. The total magnetic field has a significant response to the target, similar to the

horizontal magnetic field.

The results of the electric field experiment is shown in Figure 3, where the electric field was tested at an emission frequency of 8192-24 Hz. As can be seen in Figure 3, the electric field shows many high amplitude anomalies and it is difficult to determine which anomaly is that of the target. This is due to the fact that the electric field is affected by terrain and surface inhomogeneities, resulting in less effective detection than the magnetic field.

DISCUSSION

The total magnetic field enables wide azimuth detection, and the concept of “wide azimuth” encompasses two aspects. Firstly, it considers the orientation of the measurement station with respect to the source. The total magnetic field can be observed in any orientation relative to the source, thus resolving the zero-value band problem in single-component magnetic fields. This extension enhances the detection range and optimizes the utilization of the source. Secondly, it refers to the angle between the sensor and the source. Theoretically, the total magnetic field is not affected by the attitude of the sensor, thus solving the angular error problem.

However, since the connection between the magnetic sensor and the unmanned aerial vehicle (UAV) is flexible, this can lead to drastic changes in both the sensor's altitude and attitude in a moving state, thus creating potential interference.

It is also important to note that the results presented in this paper have not undergone de-noise processing. The magnetic field demonstrates a high degree of resistance to interference, while the electric field component is susceptible to static effects, making it challenging to achieve satisfactory results in regions with complex terrain.

Due to the lack of high-performance three-component magnetic sensors, we employed a synthesis of ground magnetic fields to obtain the total magnetic field. While our experiments is not as rigorous as it could be, the results demonstrate the feasibility of the total magnetic field approach. Those interested in pursuing this line of inquiry are encouraged to conduct more rigorous experiments and are welcome to discuss the results with us.

CONCLUSIONS

Based on the theoretical analysis and experimental study of the total magnetic field, the following conclusions are drawn: it is feasible for frequency-domain CSEM to use the total magnetic

field for sounding, and the total magnetic field can eliminate the angular error and the limitation of zero-value band when observing the single-component electromagnetic field. Wide azimuth sounding can be achieved by utilizing the total magnetic field, which has wide application prospect.

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