Study on Optimization of Transient Electromagnetic Method Detection Parameters for Steeply Inclined Near-Vertical Coal Seams

Abstract

To meet the detection requirements of steeply inclined near-vertical coal seams with a detection depth of approximately 250 meters, this study designed the use of a large fixed-source loop device for transient electromagnetic method (TEM) detection. A systematic parameter test was conducted on the T1-2 survey line in the work area to optimize and screen five key parameters: transmitting loop size, supply current, transmitting frequency, sampling time, and gain. The test results showed that: a 250m×250m transmitting loop can balance detection depth and vertical resolution; a 9.5A supply current can effectively enhance the secondary field intensity and improve interference suppression capability; a 6.25Hz transmitting frequency can simultaneously meet the high-resolution detection needs of shallow and mid-deep geological information; a 2-minute sampling time ensures the signal-to-noise ratio of the original decay curve while considering construction efficiency; and an 8-time gain can avoid early data overflow and retain late effective signals. The optimized parameter combination results in clear detection anomaly patterns and strong layering capabilities, providing reliable technical support for the accurate detection of steeply inclined near-vertical coal seams and effectively reducing the non-uniqueness of data interpretation.

Keywords

Transient Electromagnetic Method (TEM); Steeply Inclined Near-Vertical Coal Seam; Large Fixed-Source Loop Device; Parameter Optimization; Detection Depth; Resolution

1 Introduction

The Transient Electromagnetic Method (TEM) has been widely used in the field of mineral resource exploration due to its advantages such as strong ability to penetrate low-resistivity overburden, large detection depth, and simultaneous completion of profile measurement and sounding. For steeply inclined near-vertical coal seams with a detection depth of approximately 250 meters, their occurrence form is special, and conventional detection devices tend to have problems such as vague anomalies and unclear layering. However, the large fixed-source loop device has become the preferred solution for detecting such coal seams due to its loose requirements on coil position and orientation, high geodetic work efficiency, and good coupling with detection targets.

The detection effect of the TEM is highly dependent on the reasonable setting of key parameters. Parameters such as transmitting loop size, supply current, and transmitting frequency directly affect the detection depth, resolution, and signal-to-noise ratio. Improper parameter selection can easily lead to weak deep signals, vague shallow layering, or superposition of interference signals, thereby affecting the accurate interpretation of coal seam occurrence status. Therefore, this study systematically optimized the detection parameters through special tests, aiming to provide an optimal technical solution for the efficient and high-precision TEM detection of steeply inclined near-vertical coal seams.

2 Selection of Detection Device and Test Design

2.1 Basis for Detection Device Selection

For the detection target of steeply inclined near-vertical coal seams (with a detection depth of approximately 250 meters), a large fixed-source loop device was selected, and its core advantages are as follows:

Excellent coupling with the target body, which can generate anomaly responses with simple morphology and high recognizability, facilitating the identification of coal seam boundaries;

Strong vertical layering capability, which can effectively distinguish the electrical differences between coal seams and the overlying/underlying surrounding rocks, improving layering accuracy;

Relatively loose requirements on coil position, orientation, and receiving distance, which reduces the complexity of geodetic work and increases construction efficiency by more than 40%;

Outstanding ability to penetrate low-resistivity overburden, which can effectively avoid the shielding effect of shallow low-resistivity strata on deep coal seam signals;

Simultaneous completion of profile measurement and sounding work, which obtains more information on underground electrical structures and significantly reduces the non-uniqueness of data interpretation.

2.2 Test Design Scheme

The test was carried out on the T1-2 survey line in the work area, and the single-factor variable method was used to control parameter variables—only one detection parameter was changed at a time, while the other parameters were kept fixed. The optimal parameters were screened by comparing the electromagnetic response characteristics (such as the smoothness of the decay curve, the depth of effective data points, signal-to-noise ratio, resolution, etc.) under different parameters. The variable range of test parameters and fixed reference values are shown in Table 1:

Table 1 Design Table of TEM Parameter Test

Parameter Type	Variable Range	Fixed Reference Values
Transmitting Loop Size	250m×250m, 300m×300m, 350m×350m	Transmitting Frequency: 6.25Hz; Supply Current: 9.5A; Sampling Time: 2min; Gain: 8 times
Supply Current	8A, 9A, 9.5A	Transmitting Loop: 250m×250m; Transmitting Frequency: 6.25Hz; Sampling Time: 2min; Gain: 8 times
Transmitting Frequency	2.5Hz, 6.25Hz, 25Hz	Transmitting Loop: 250m×250m; Supply Current: 9.5A; Sampling Time: 2min; Gain: 8 times
Sampling Time	1min, 2min, 3min	Transmitting Loop: 250m×250m; Supply Current: 9.5A; Transmitting Frequency: 6.25Hz; Gain: 8 times
Gain	1 time, 8 times, 16 times	Transmitting Loop: 250m×250m; Supply Current: 9.5A; Transmitting Frequency: 6.25Hz; Sampling Time: 2min

3 Optimization Test and Result Analysis of Key Parameters

3.1 Optimization of Transmitting Loop Size

3.1.1 Test Principle

The size of the transmitting loop determines the distribution range and energy intensity of the primary field: with other parameters fixed, a larger loop area leads to a deeper action depth of the

primary field and a stronger energy of the excited secondary field (improved detection depth), but the magnetic field gradient decreases, resulting in lower vertical resolution; conversely, a smaller loop area results in higher vertical resolution but limited detection depth.

3.1.2 Test Results and Analysis

The fixed parameters were a transmitting frequency of 6.25Hz, a supply current of 9.5A, and a sampling time of 2min. The detection effects of three loops (250m×250m, 300m×300m, 350m×350m) were compared (Figure 1).

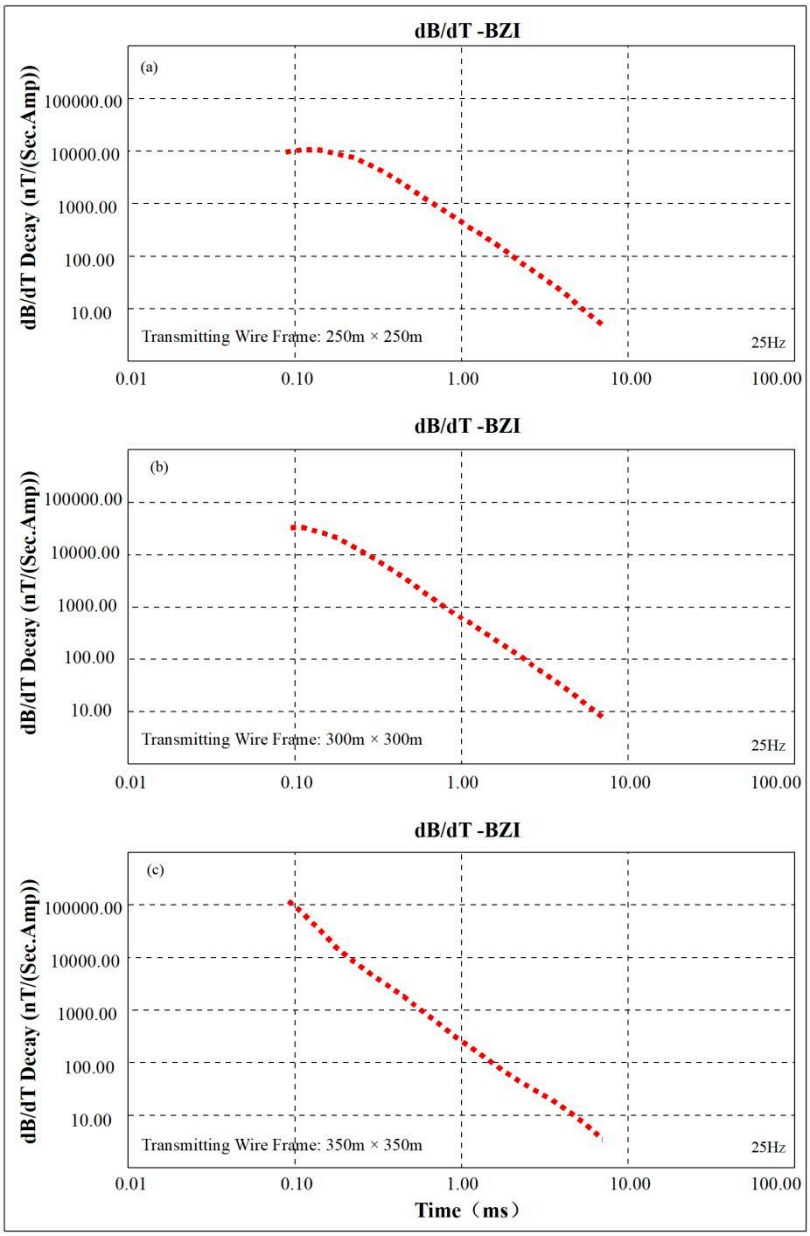


Figure 1 Comparison of TEM Transmitter Coil Configurations (250 m×250 m, 300 m×300 m, 350 m×300 m) on Line T1-2: Evaluating Tradeoffs Between Detection Depth and Resolution

The test results showed that:

The start time of effective data points for the three loops was basically the same (approximately 0.01ms), indicating no significant difference in the response of shallow early signals;

The loop size was positively correlated with the detection depth: the 350m×350m loop had the strongest energy of late deep signals (10~100ms), and its interference suppression effect was approximately 18% better than that of the 250m×250m loop. However, its vertical resolution was significantly lower—the 250m×250m loop could clearly distinguish electrical layers with an interval of 15~20m, while the 350m×350m loop could only distinguish layers with an interval of more than 50m;

In terms of construction efficiency: the labor input for laying the 300m×300m and 350m×350m loops increased by 30% and 50% respectively compared with the 250m×250m loop, and the construction period was extended by 1.5 times and 2.2 times respectively.

3.1.3 Determination of Optimal Parameter

Considering the detection depth, vertical resolution, and construction efficiency comprehensively, 250m×250m was determined as the optimal transmitting loop size.

3.2 Optimization of Supply Current

3.2.1 Test Principle

The supply current is a core factor affecting the intensity of the secondary field: a larger current leads to a stronger magnetization effect of the primary field on underground media, a larger amplitude of the excited secondary field, a deeper signal penetration depth, and a stronger interference suppression capability; however, an excessively large current will increase equipment power consumption and may cause system overheating and overload.

3.2.2 Test Results and Analysis

The fixed parameters were a transmitting loop of 250m×250m, a transmitting frequency of 6.25Hz, and a sampling time of 2min. The detection effects of three supply currents (8A, 9A, 9.5A) were compared (Figure 2).

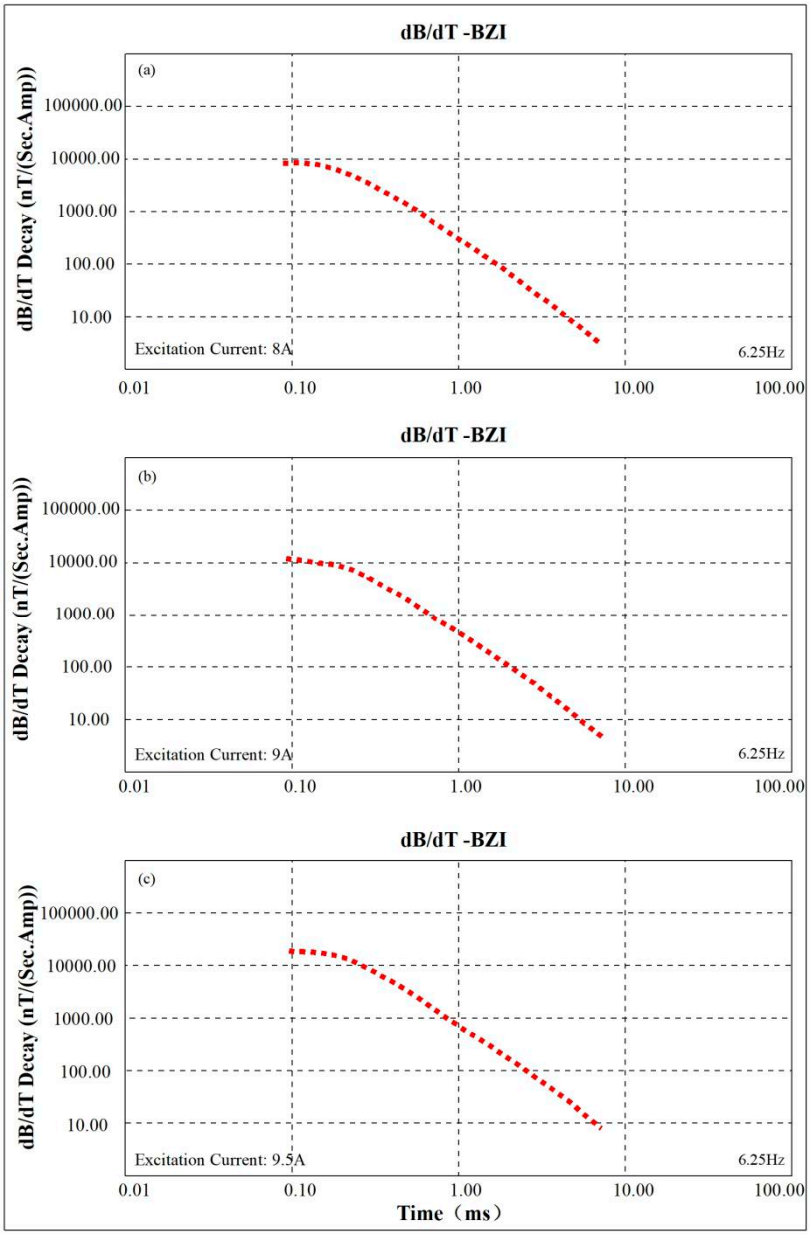


Figure 2 Comparison of TEM Signal Decay Curves for Different Excitation Currents (8 A, 9 A, 9.5 A): Evaluating Impact on Detection Depth and Noise Suppression

The test results showed that:

The supply current was positively correlated with the signal energy: the amplitude of the secondary field (dB/dT) under a 9.5A current was approximately 35% higher than that under 8A, and the signal-to-noise ratio of late deep signals (50~100ms) was increased by approximately 28%, with a significantly enhanced interference suppression capability;

The difference in detection depth between the 9A and 9.5A currents was small (approximately 5~8m), but the signal stability of the 9.5A current was better, and the smoothness of the decay curve was improved by approximately 15%;

All three currents did not exceed the rated load of the equipment (the maximum withstand current of the equipment was 10A), and the equipment power consumption under the 9.5A current was within a reasonable range.

3.2.3 Determination of Optimal Parameter

Considering the signal intensity, signal-to-noise ratio, and equipment safety comprehensively, 9.5A was determined as the optimal supply current.

3.3 Optimization of Transmitting Frequency

3.3.1 Test Principle

The transmitting frequency determines the charging time and measurement time: a low frequency (e.g., 2.5Hz) corresponds to a long charging time and measurement time, which can receive deep late signals, but the collection of shallow early signals is insufficient, resulting in low shallow resolution; a high frequency (e.g., 25Hz) corresponds to a short charging time and measurement time, which has high resolution for shallow early signals, but cannot effectively receive deep late signals, leading to limited detection depth.

3.3.2 Test Results and Analysis

The fixed parameters were a transmitting loop of 250m×250m, a supply current of 9.5A, and a sampling time of 2min. The detection effects of three transmitting frequencies (2.5Hz, 6.25Hz, 25Hz) were compared (Figure 3).

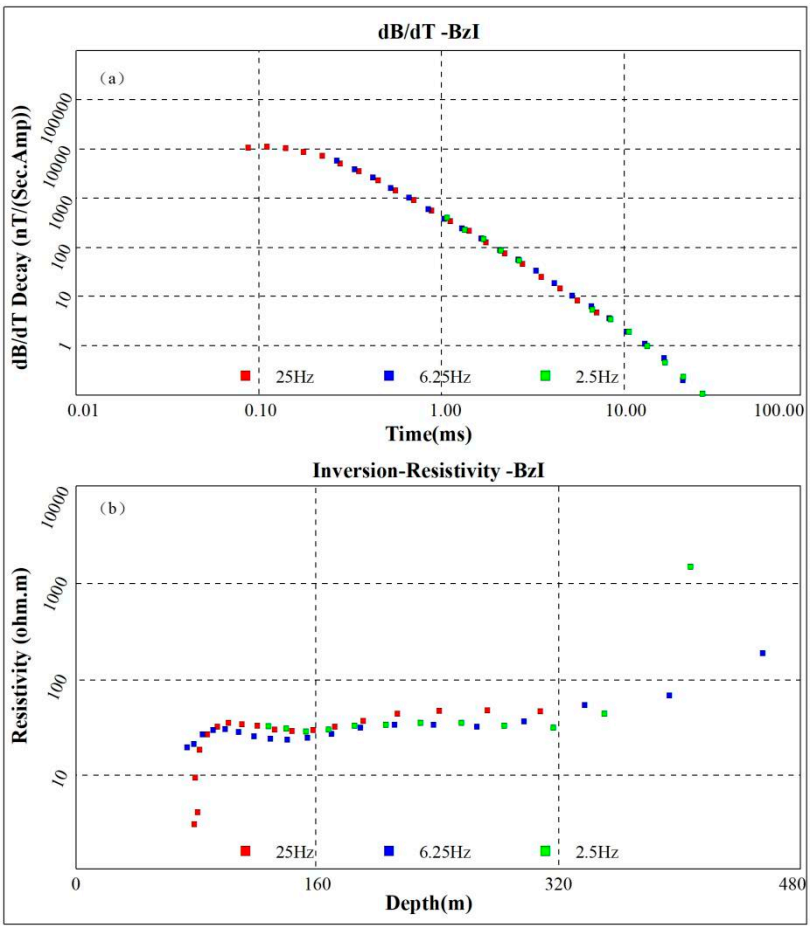


Figure 3Comparison of the emission frequency selection ρ -h

Analysis of Figure 3 showed that:

The 2.5Hz frequency had the largest depth of effective data points (approximately 280m), but the start time of shallow initial data points was late (approximately 0.1ms), resulting in vague shallow layering and inability to clearly identify shallow strata within 20m;

The 25Hz frequency had the highest shallow resolution (capable of distinguishing layers with an interval of 5~10m), but the depth of effective data points was only approximately 150m, which

could not meet the detection requirement of 250m;

The 6.25Hz frequency balanced shallow and mid-deep detection: the start time of shallow initial data points was early (approximately 0.05ms), which could clearly identify shallow layers with an interval of 10~15m; the depth of effective data points was approximately 260m, and the data point density was high (approximately 40% higher than that of 2.5Hz), resulting in the best overall data quality.

3.3.3 Determination of Optimal Parameter

Combining the detection depth and resolution requirements, 6.25Hz was determined as the optimal transmitting frequency.

3.4 Optimization of Sampling Time

3.4.1 Test Principle

The sampling time determines the number of signal superpositions: a longer sampling time leads to more superpositions, a better cancellation effect of random interference signals, and a higher signal-to-noise ratio of the original decay curve; however, an excessively long sampling time will reduce construction efficiency and increase the cost of field operations.

3.4.2 Test Results and Analysis

The fixed parameters were a transmitting loop of 250m×250m, a supply current of 9.5A, and a transmitting frequency of 6.25Hz. The detection effects of three sampling times (1min, 2min, 3min) were compared (Figure 4).

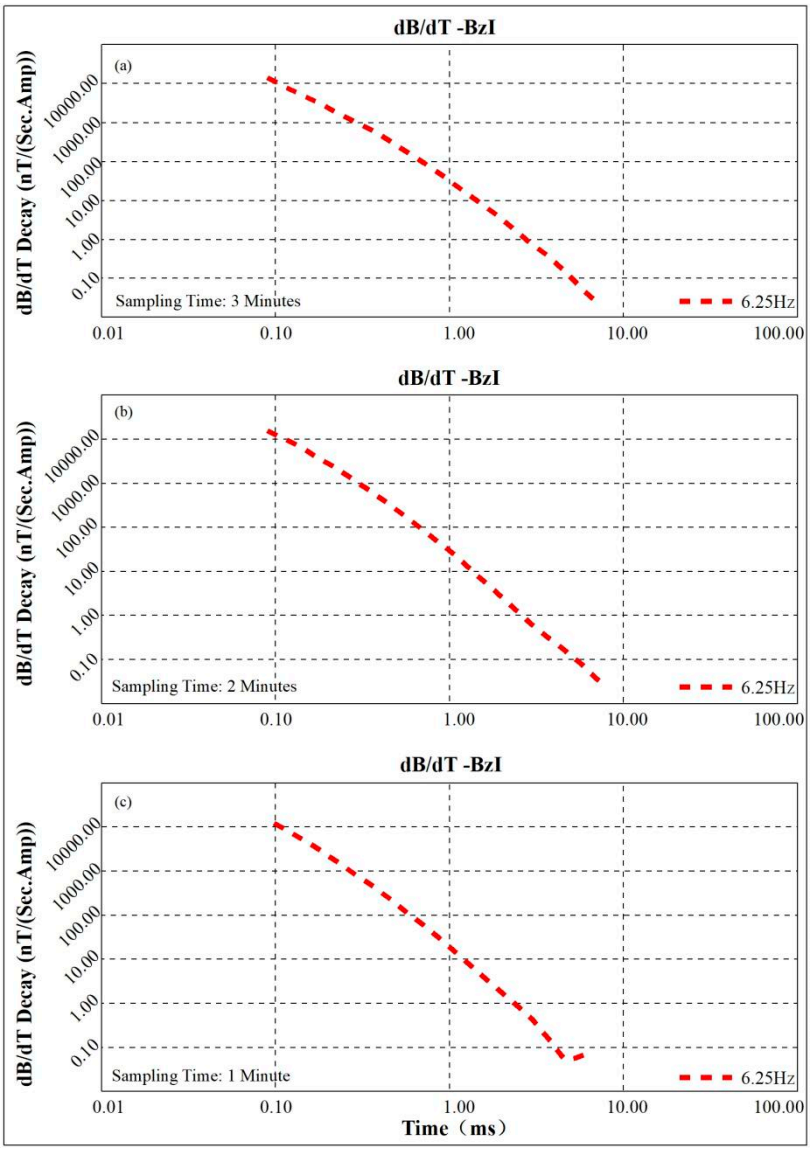


Figure 4 Comparison chart of sample time selection

The test results showed that:

The decay curves of the 3-minute and 2-minute sampling times were both smooth, with no obvious fluctuations in the late signals (80~100ms), and the difference in signal-to-noise ratio was less than 5%;

The first branch (0.01~10ms) of the decay curve with a 1-minute sampling time was relatively smooth, but the tail branch (50~100ms) showed significant fluctuations, and the interference suppression effect was approximately 30% lower than that of the 2-minute sampling time, which could not ensure the effectiveness of deep signals;

The construction efficiency of the 3-minute sampling time was 50% lower than that of the 2-minute sampling time, and the completion time of a single survey line was extended by approximately 1.5 hours.

3.4.3 Determination of Optimal Parameter

Considering the signal-to-noise ratio and construction efficiency comprehensively, 2min was determined as the optimal sampling time.

3.5 Optimization of Gain

3.5.1 Test Principle

Gain is used to adjust the signal amplitude: insufficient gain will cause late weak signals to be masked by noise, resulting in a low signal-to-noise ratio; excessive gain will easily cause overflow of early strong signals and may eliminate some effective signals, affecting data authenticity. A reasonable gain needs to balance the integrity of early data and the signal-to-noise ratio of late data.

3.5.2 Test Results and Analysis

The fixed parameters were a transmitting loop of 250m×250m, a supply current of 9.5A, a transmitting frequency of 6.25Hz, and a sampling time of 2min. The detection effects of three gains (1 time, 8 times, 16 times) were compared (Figure 5).

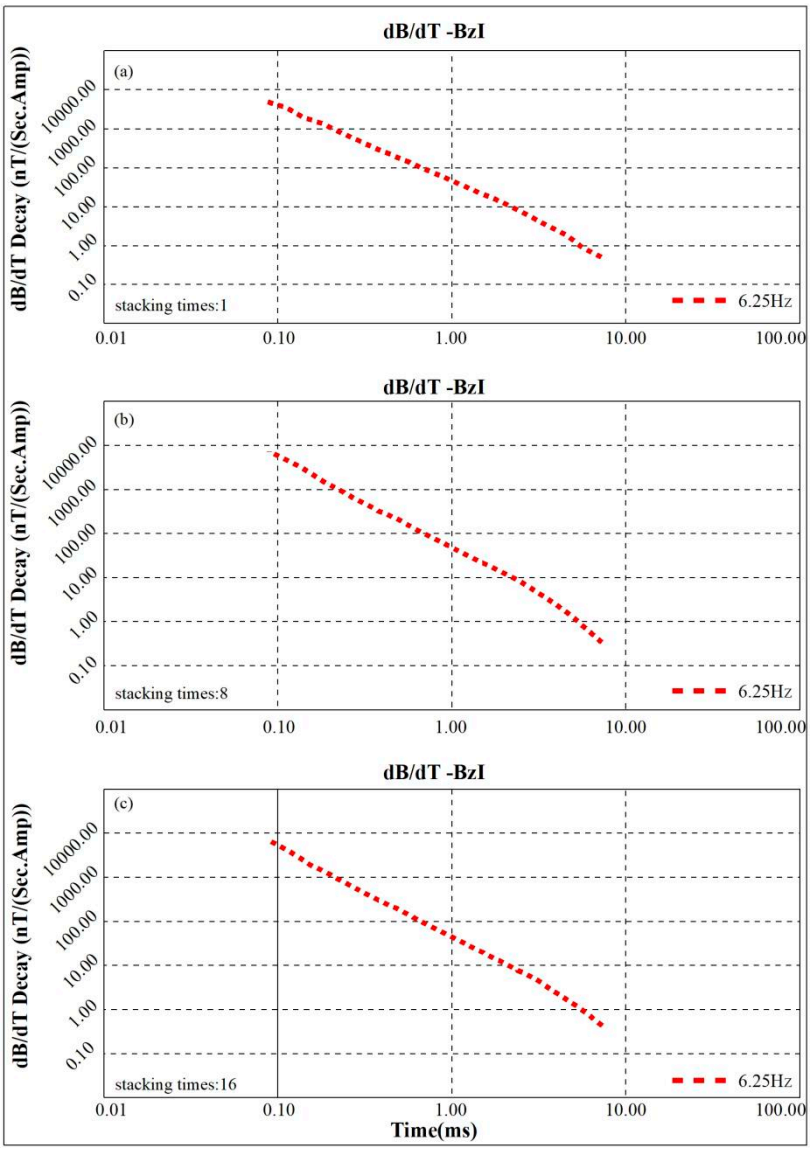


Figure5 Signal Quality Comparison for Different Stacking Levels

The test results showed that:

When the gain was 1 time, the decay curve had obvious fluctuations, and the signal-to-noise ratio of late signals (60~100ms) was low, making it impossible to extract effective deep information;

When the gain was 16 times, the decay curve was too smooth, and the early signals

(0.01~5ms) showed flat-top distortion, with approximately 15% of shallow effective signals eliminated;

When the gain was 8 times, there was no overflow of early data, the late curve was smooth, the integrity of both shallow and deep signals was guaranteed, and the signal-to-noise ratio was optimal.

3.5.3 Determination of Optimal Parameter

Considering the signal integrity and signal-to-noise ratio comprehensively, 8 times was determined as the optimal gain.

4 Conclusions

For steeply inclined near-vertical coal seams with a detection depth of approximately 250 meters, the optimal detection parameter combination for the TEM is: 250m×250m transmitting loop, 9.5A supply current, 6.25Hz transmitting frequency, 2min sampling time, and 8-time gain;

This parameter combination can realize simultaneous high-precision detection of shallow (0~50m) and mid-deep (50~250m) geological information, with a vertical resolution of 10~15m, a signal-to-noise ratio of late signals increased by more than 30%, clear anomaly patterns, and strong layering capabilities;

The optimized parameters effectively balance detection performance and construction efficiency, providing reliable technical reference for the TEM detection of steeply inclined near-vertical coal seams and can be promoted and applied in similar coal seam exploration projects.