Features research of ideal ahead-detecting method used in mining roadway and exploitation of a new technology --DFIP

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Abstract. In order to study the new high efficiency advanced detection technology of coal roadway, the characteristics of ideal advance detection are analyzed. Dual- frequency IP method advanced detection technology is based on the Induced polarization effect of coal (rock). The detection range of the angle and length scanning are achieved by simulation comply with the character of electric field superposition. So, the dual frequency IP method can meet the requirement of high efficiency advance detection of coal roadway. The research results provide theoretical support for the development of new advanced detection equipment.

1. Introduction

According to Coal Mine Safety Regulation, hydrologic conditions of coal mine must be surveyed and analyzed comprehensively before mining production [1]. How to effectively predict geologic anomalies, especially hydrologic conditions such as karst caves and karst collapses, of areas which must be excavated has become a hot issue in the mining technology. If the hidden geologic anomalies are failed to be detected or predicted, the security of workers’ lives and colliery property will face the geologic dangers, such as gas outburst, roof falling and water inrush. The situation is even worse in the procedure of roadway excavation, because these hidden geologic anomalies are hardly to be found or located in macroscopic geological survey of mines. The existing geophysical prospecting methods include drilling method, direct current method, transient electromagnetic method, etc. Each geophysical prospecting method has its specific conditions of use and detection characteristics. However, there is still a large gap between the exploration and excavation of the heading face. In order to improve the situation and increase the excavation efficiency, many researchers focus on the study of effective ahead-detection technology and the development of suitable detector used in roadway excavation at present.

2. Characteristics of Ahead-Detection Used in Mechanized Excavation Face and Ideal Features of Ahead-Detection

2.1. Characteristics of Ahead-Detection Used in Mechanized Excavation Face

The working environment of mechanized excavation face of coal mine roadway has special characteristics [2]:

1) High quantity of mechanical equipment
There are many mechanical equipment working at the mechanized excavation face, such as transportation machinery, roadway support equipment, drilling machines and dust settling devices.

2) Confined space for working

Generally, the dimension of coal mine roadway’s excavation face is about 4 meters in width and 3~3.5 meters in height, which is a confined space for many machines and workers. However, many working procedures, such as the excavation, the drilling, the roof supporting, the dust settling and the ahead-detection, must be conducted in the confined space.

3) Efficiency imbalance among working procedures

At present, it is hardly to combine all the working procedures together, which leads to the separation of the ahead-detection, the excavation and the roof supporting. As a result, the excavation efficiency is extremely restricted by stopping for the ahead-detection and the roof supporting.

4) High accident rate

Geologic anomalies hidden underground make the roadway’s excavation faces harmful dangers, like water inrush, gas outburst and roof falling.

5) High dust content

Huge amount of dust could be produced during the excavation and the drilling process. And the dust settling device can only prevent the dust in a very limited extent.

At present, there are several ahead-detection methods used in the mechanized excavation face, for example, drilling method, direct current prediction method and transient electromagnetic method. However, restricted by the special working circumstance of coal mine roadway, almost all of these methods hardly get high prediction accuracy.

1) Separation of ahead-detection and the excavation

Constrained by the characteristics of presently used ahead-detection methods, the ahead-detection and the excavation are conducted separately in different working times. Meanwhile, complicated working process and long detection period of these ahead-detection methods extremely restricts the excavation efficiency. Even worse, in order to raise efficiency, the excavation was conducted without the ahead-detection in some coal mines, which has resulted in grave working accidents and serious casualties.

2) Low prediction accuracy

Affected easily by the geological conditions of roadway’s roof and floor, hidden geologic anomalies’ prediction behind cutting face through present ahead-detection methods are usually inaccurate. On the other hand, full-directional detection of excavation face is hardly realized through present ahead-detection methods. For example, Transient Electromagnetic Method can only detect the geologic conditions right behind cutting face. But it’s hard to find anomalies hidden in the roadway’s roof or floor.

2.2. Ideal Features of Ahead-Detection

In the area faced possible threat of water inrush, if the water is in no condition to be drained, the waterproof pillar must be preserved properly during the roadway’s excavation. The size of the waterproof pillar is mainly determined by geologic structures and hydrologic conditions of coal mine [3]. And the width of the waterproof pillar of faults should be no less than 20 meters according to the regulation [4].

Through the analysis of special features of coal mine and the characteristics of present ahead-detection methods used in mechanized excavation face, several essential characteristics of the ideal ahead-detection method are concluded as follows:

1) Ahead Prediction

First of all, long distance prediction of geologic structures should be realized in the ideal ahead-detection technology. Considering the working arrangement of coal mine, the effective detection distance must be longer than the sum of maximum excavation footage per day and minimum horizontal safety distance.

The excavation velocity is determined by many factors, such as coaly features, excavation machine status and worker states. Presently, the working system called “three shifts” is conducted in the coal mining
enterprises. The workers work in three shifts of eight hours per day, two shifts for the excavation and one for equipment maintenance. Generally, the average excavating distance for one shift is 10 meters and 30 meters at most. Then the maximum daily excavation footage is less than 60 meters. Meanwhile, the minimum horizontal safety distance is mainly determined by water contents of hydrologic structure and hydraulic press. According to research data, the value of the safety distance is about 20~30 meters. In conclusion, the effective detection distance should be longer than 80~90 meters (Fig. 1).

2) Real-time Detection

There are two kinds of stop time in the process of excavation. One is equipment maintenance shift mentioned above, the other one is the roof support procedure which must be conducted after a few meters of excavation. The real-time detection means to fully use these stoppage times to conduct ahead-detection, not only in the longtime stoppage for equipment maintenance, but also in the short excavation intervals for roof supporting. So the time spent on detection should be limited in an hour and the results of prediction should be figured out and presented in ten minutes. In this way, ahead detection could be conducted many times in the whole excavation procedure and real-time ahead-detection can be realized in a certain extent. And the accuracy of ahead-detection will increase and the detection distance of every single prediction can reduce to 30~50 meters, which can effectively decrease the working power of the detector.

3) Directional Detection

The geologic anomalies can be located in direction and in distance by ideal ahead detection. The direction of ahead detection can be effectively controlled to scan the conical area behind the cutting face longitudinally and laterally, which can accurately predict the direction of the hidden geologic anomalies. On the other hand, the distance between the geologic anomaly and excavation face could be predicted by scanning the conical detection area contained horizontal and vertical safety distance (see Fig. 1).

4) High Predicting Accuracy
The ideal ahead detection predicts not only the types of geologic anomalies, such as accumulated water, faults, collapse and fragmentation, but also the location of the geologic dangers and water contents. Meanwhile, the false and miss alarm can be eliminated as possible to increase the efficiency of detection;

5) Intelligent Operation:
The results of a head-detection can be graphically displayed and easily understood. Foolproof operation interface, automatic judgment of dangerous level and speech alarm are also applied in the ideal ahead detection facility.

6) Integration of Ahead-detection and the Excavation
The ideal ahead-detection facility can be integrated with road header, which reduces the number of the equipment working at the mechanized excavation face. The integration of ahead-detection and the excavation will extremely increase the excavation efficiency.

7) Convenient Usability
The ahead-detection facility has features of light weight, compact size, low cost and convenient operation. And it’s easy to be installed on the road header.

3. Detection Principle of DFIP Used in Mechanized Excavation of Coal Mine
Dual-Frequency Induced Polarization Method (DFIP) is based on the Induced Polarization Effect of rocks and minerals [5]. The induced polarization information contained geologic features of detection area could be measured in the form of dual-frequency current signal. From the information, useful current parameters could be extracted through amplification, frequency selection and detection. And the value of PFE (Percent Frequency Effect), which can characterize the geologic features of detection area, can be figured out properly [6].

3.1. Arrangement Of Detection Probes
As shown in the Fig. 2(a) is the arrangement method of detection probes on the excavation face. A0(+)stands for emitting probe (measuring probe), A1(+)stands for shielding probe series and B(-)is grounding electrode which is set hundreds of meters away from the excavation face. The shielding probe series contain eight symmetrically distributed shielding probes, as shown in Fig2 (b).

During detection, induced currents with identical frequency and polarity are separately emitted to detection area simultaneously from A0 and A1. As a result, the electric field is formed in the rocks and minerals of detection area. According to the principle of like poles repelling, the currents from A0 and A1 will interact with each other, resulting in the focusing of emitting current and the formation of a conical detection area (as shown in Fig. 2(a)). In this way, the direction of induced current can be controlled properly and “full space effect” [2] of electric field could be limited in a certain extent.

![Figure 2. The arrangement of the probes](image)
As shown in Fig. 3, under the conjunct effect of emitting current and shielding currents, the trend of electric field lines reflect the focusing effect of electric field and the controlling effect of detection direction.

In addition to emitting induced current, A0 is still in charge of receiving the polarization information of rocks and minerals.

3.2. Maintaining the Integrity of the Specifications

Considering the complexity of geological condition and diversity of affecting factors in the mechanized excavation face, several conditions are presumed in the research:

(1) Effected by induced current with ordinary frequency, the geologic mass (coal and rocks) behind the excavating face is regarded as Linear Time-Invariant system which has features of isotropy and homogeneous linearity; (2) The resistivity (ρ) of the geologic mass is considered to be constant when the geologic anomalies non-existed; (3) The influences of equipment, temperature, humidity and free electronic could be neglected.

The model of detection current field emitted from emitting probe and shielding probes in excavation face is illustrated in Fig. 4. In order to analyze the electric field property of point M seated at the right of emitting probe, the position of emitting probe is chose as the origin O of the model’s coordinate system.
Based on the half-space property of electric field generated by point power on earth surface, the electric field emitted by emitting probe could be figured out because emitting probe is placed on the excavation surface. In the case of only electric field of emitting probe being considered, the electric potential of point M, which is away from origin O in distance R, can be figured out in formula (1).

\[ \varphi_0 = \frac{\rho I_0}{2\pi} \frac{1}{R} \]  

(1)

Because the shielding probes will be inserted in the coal bed, their electric fields are approximately considered as a full-spaced field. Thus, the electric potential of M generated by shielding currents can be calculated in formula (2). In the formula, \( I \) stands for the current intensity emitted by shielding probe \( i \)th, and \( R \) stands for the distance between M and shielding probe \( i \)th:

\[ \varphi_p = \frac{\rho}{4\pi} \sum_{i=1}^{8} \frac{I_i}{R_i} \]  

(2)

In (2) is the electric current strength of the \( i \)th shielding probe.

**Figure 4.** The modeling in excavating face

**Figure 5.** The angle and length scanning
Based on an overall consideration of formulas (1) and (2), we could get the electric potential of point M under the interaction of emitting current and shielding currents, as illustrated in formula (3). And formula (4) expresses the current intensity of point M.

\[
\varphi = \varphi_0 + \varphi_p = \frac{I_0}{2\pi R} + \frac{D}{4\pi} \sum_{i=1}^{8} \frac{I_i}{R_i}
\]

\[
E = -\nabla \varphi
\]

Formulas (3) and (4) express the mathematical model of electric field in the mechanized excavation face. The model is founded on the basis of superposition of half-spaced electric field generated by emitting current and full-spaced field generated by shielding currents.

4. Control Strategy of Detecting Location
The direction and the distance of detection are two aspects of detection location. The location of geologic anomalies can be fixed when the two aspects are confirmed.

4.1. Angle Scanning
Angle scanning means through the control of current intensities of shielding currents, the direction of the focus electric field’s axis can be turned in angles to realize the full-directional scanning of the excavation face.

When the current intensities of all shielding currents are equal, the focus axis is forward and the direction of ahead-detection will be right ahead, as shown in Fig 5(a).

If the current intensities of shielding currents emitted from shielding probes of one side increase, the detection direction will turn to the other side.

As shown in the Fig. 5 (b), when the current intensities of right-sided shielding currents increase (or left-sided shielding current intensities decrease), the axis of the detection conical area will turn to left in a deflection angle \( \alpha \).

When the left-sided shielding current intensities increase (or right-sided current intensities decrease), the axis will turn to right in a deflection angle \( \alpha \), as shown in the Fig. 5 (c).

The more relative difference between the current intensities of right-sided and left-sided shielding currents, the angle \( \alpha \) will be greater.

Above and under-sided detection can also be realized in the same way. Therefore, the angle scanning is realized through changing intensities of shielding currents.

4.2. Length Scanning
Because the attenuation of electric field depends on the features of geologic mass and hidden geologic structures of detection area, the increase of detection distance is implemented by increasing emitting current intensity. Therefore, the length scanning is realized through the control of current intensity.

When the direction of ahead-detection is fixed, the detection area will expand with the increase of detection current intensity. As shown in the Fig. 5 (a) and(c), the detection boundary will expand from section 2 to section 1 as the increase of current intensity.

When the detection current intensity is constant, the detection direction can be controlled to realize scanning in a conical area with certain radius, as shown in Fig. 5 (b).

In conclusion, through the control of the intensities of detection currents and the close sequence of detection probes, a conical area scanning of detection can be realized in different depths and angles. Thus, the direction and distance of geologic anomalies can be judged through the combination of scanning in depths and in angles.
5. The Constituents of DFIP Facility Used in Mechanized Excavation of Coal Mine Roadway and the Realization of Integration with Road Header

5.1. The Constituents of DFIP Facility
The main constituents of DFIP facility used in mechanized excavation face of coal mine roadway are as follows:

1) Emitting Facility
Emitting facility, which is consisted of induced current generator, emitting probe, shielding probe series and earth electrode, is in charge of the emission of induced current and shielding currents. It’s also in charge of the control of the frequency and the intensity of the induced current, as well as the close sequence of shielding probes.

2) Receiving Facility
The polarization information of geologic structures in the detection area can be received by receiving facility in form of current signals. Receiving facility will deal with these signals and extract useful information to figure out and display prediction results.

3) Data Interpretation Software
Data interpretation software is used for further processing the gathered data to get more adequate and detailed interpretation. The result will guide the excavation process by providing the prediction of geologic anomalies’ location and dangerous level.

5.2. The Realization of Integration with Roadheader
In order to realize the integration with road header, the structural features and the working mechanism of boom-type road header is considered in the arrangement method of detection probes. Meanwhile, the special characteristics of roadway is also utilized.
For example, a special hydraulic cylinder is installed on the road header. The emitting probe is set on the head of the piston rod which could be pushed on the excavation face when detection conducting. Meanwhile, the anchors set around the roadway are taken advantage as shielding probes.

6. Conclusion
This paper emphasizes on the research of ideal features of ahead-detection used in mechanized excavation face of coal mine and puts forward essential features of the ideal ahead-detection method. The geologic anomalies hidden behind the excavation face can be located both in direction and in distance through the detection. The new ahead-detection technology can provide reliable geologic data and security assurance for coal mine roadway excavation.

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