

# Down-hole electromagnetic method for detecting water hazard of coal mine

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## Abstract

Hidden trouble of water gushing at coal face always results in water gushing accidents, which will discontinue the production and even cause mine flooding and accidents with casualties. In order to ensure mining safety at the coal face, it is of great significance to find out distribution condition of hidden trouble of water gushing from the coal face in advance, and then take effective prevention and control measures. This article introduces principles, methods, technologies and application effects of several electromagnetic methods for detection of hidden trouble of water gushing at coal face, and lays emphasis on expounding method principles and effects of down-hole detections by electric transmission tomography and transient electromagnetic method. It is shown by the results of actual measurement that the mine electromagnetic method is sensitive to water-bearing low-resistivity body and can play a unique role in detecting hidden trouble of water gushing at coal face.

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## 1. Introduction

Hydrogeological condition of coal mines in China is complicated, and water hazard is very serious. Water hazard of coal mine ranks second only to gas explosion accident as greatest hazard. Many mines are under the threat of floor water or roof water gushing, especially North-China type coalfields, whose coal series directly lies above Ordovician limestone. Under threat and becoming endangered to different extents due to karst water of the Ordovician limestone below the coal seam floor, a lot of mines have suffered from water gushing and mine flooding for many times in history, causing severe economic loss and casualties.

Hidden trouble of water gushing from fracture zone of water conducting and bearing formation, water conducting and bearing karst collapse column, relatively thin section of aquifuge, aquifer and especially aquifer containing pressure-bearing water in strata at coal face, roof and floor always results in water

gushing accidents, which will discontinue the production and even cause mine flooding and accidents with casualties. It is of great significance to find out distribution condition of hidden trouble of water gushing at coal face in advance, and then take effective water prevention and control measures to ensure safe mining at coal face. Therefore, studying theories and methods of detection and precise positioning on hidden trouble of water gushing of coal mine to find out water-bearing parts at coal mine and evaluate the impact of water-bearing bodies on safe coal mining production is a very significant work as well as one of the important measures of preventing and solving the safety accidents of coal mines.

Physical characteristic of underground water-bearing bodies is relatively good electric conductivity, represented as the feature of low resistivity, that is, the stronger the water-rich feature is, the lower the apparent resistivity is. The earthquake exploration method is insensitive to water-bearing bodies, while the electromagnetic method is very sensitive. As a result, many electromagnetic methods are all available for detecting underground water-bearing bodies, such as high-density electrical method, transient electromagnetic method, electric transmission tomography and etc., which can be applied to electric conductivity imaging for searching water-bearing low-resistivity abnormal zones.

Electromagnetic methods adopted to detect hydrogeological condition of coal mines can be classified into two main types, ground electromagnetic method and mine electromagnetic method. Because construction of the mine electromagnetic method is in the coal mine, its working place is closer to detecting objective strata or geological bodies and the resolution is relatively high, extensive geophysical practitioners have carried out a large amount of tests and researches for a long term, trying to make methods and technologies of the ground geophysical exploration applicable to the down-hole detection. Taking forecasting of water hazard in coal mines for example, our country has formed an integrated geophysical prospecting technology system in the long-term production and practice, giving priority to the mine electrical exploration and taking technologies like mine high-resolution earthquake exploration, radio-wave penetration, down-hole microgravimetry, radioassay and infrared temperature measurement as auxiliaries, all of which provide effective technical measures for safe production of coal mines and play an unique role in water prevention and control of coal mines<sup>[1,2]</sup>. At present, the commonly-used mine electrical exploration methods include mine DC electrical method, electric transmission tomography, mine transient electromagnetic method and etc., which are mainly applied to hydrogeological detection on supply source of mine water-gushing, insidious water-conducting passage, fissure zone, thickness of aquifuge, water-bearing formations in front of heading face of the roadway and etc., as well as detection on small water-bearing formations and karst collapse columns in the coal face<sup>[3-5]</sup>.

## **2. Mine DC Electrical Method**

The mine DC electrical method belongs to whole-space electrical exploration, which is based on differences between electric conductivities of rocks and used to research into geological problems of mine by building up a field under the condition of whole-space and then through measuring, analyzing distribution and changing rules of stable current field near roadway or stope.

In accordance with working principle, the mine DC electrical method can be classified into mine electrical section method, mine electrical depth-measuring method and etc., each of which can be subdivided into several branch methods complying with device forms. The former can be divided into dipole section method, symmetrical quadrupole section method and etc; while the later can be classified into symmetrical quadrupole electrical depth-measuring method and three-pole electrical depth-measuring method.

Purpose of data processing of the mine DC electrical section method is to identify and classify anomaly. And processing methods adopted include relevant analysis, superposition processing and sliding mean method.

Data processing and interpretation of the mine DC electrical depth-measuring method differs from the ground electrical depth-measuring method. Main procedure of the data processing and interpretation of the mine DC electrical depth-measurement is: firstly carrying out semi-space—whole-space correction on resistivity curve observed, calculating whole-space theoretical curve, eliminating influence of roadway and stratified stratum, executing resistivity inversion, extracting anomaly of objective and finally carrying out geological inference and interpretation.

The following is an example of adopting the mine DC electrical method to detect fracture zone in the coal seam floor, in order to interpret the effect of the mine DC electrical method on detecting hidden trouble of water gushing at coal face.

What is mined from Coal Face 9107 of Dafeng Coal Mine of Feicheng Mining Bureau, Shandong, is coal No. 9, with an average distance of 20m from limestone No. 5 below, whose average thickness is 9.37m, and a distance of about 50m from Ordovician limestone below. Because of the complicated structure, the aquifuge of coal seam floor is seriously destroyed by the faultage. For the purpose of preventing water gushing of the limestone No. 5 and Ordovician limestone, the DC electrical method is adopted to detect development degree of the fracture zone in the floor of coal No. 9.

In order to accomplish this detection task, exploration is implemented by adopting symmetrical quadrupole depth-measuring method and axial dipole section method, so that the two methods can confirm each other to enhance reliability of the detection result. Maximum electrode distance of the symmetrical quadrupole depth-measuring method is 90m; while maximum electrode distances of both power-supply electrodes AB and measuring electrodes MN of the axial dipole section method are 5m respectively, and that of B M is 20m.

The detection result can be found from Fig. 1 and Fig. 2, from which we can see obviously that in the Curve Diagram of Apparent

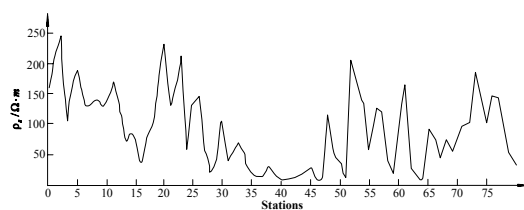


Fig. 1 Section curve of apparent resistivity

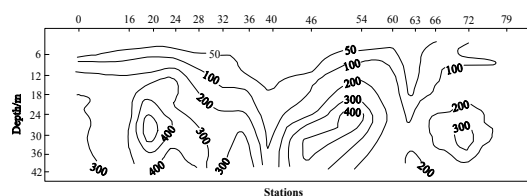


Fig. 2 Section isoline diagram of apparent resistivity

Resistivity Measured by the Dipole Section Method (Fig. 1), points of No. 33-46 and No. 60-64 are two low-resistivity abnormal zone; while in the Section Diagram of Apparent Resistivity Measured by the Depth-Measuring Method (Fig. 2), points of No. 33-46 and No. 60-64 are all concave distortions of isolines, whose shapes intuitively reflect the shapes, positions and influence scopes of the two fracture zones.

The detection result of the mine DC electrical method provides scientific basis for drilling, grouting and reinforcing the floor with a definite goal. Since the transformation of grouting, coal of 82 thousand tons has been mined safely.

### 3. Mine high-density resistivity method

Mine high-density resistivity method is a combined method with multi-device and multi-electrode-distance, integrating electrical section method and electrical depth-measuring method into one. Its characteristics are that multi-device data acquisition can be carried out through arranging electrodes once and abnormal information can be shown up by calculating ratio parameters. It also can be considered as section measurement.

Compared with normal mine electrical depth-measuring method and mine electrical section method, the mine high-density resistivity method has features like high efficiency in construction and abundant information acquired. It can use measurement results of different device forms to calculate different ratio parameters and show the abnormal information, and also be capable to suppress inference and decompose compound anomaly to a certain degree, thereby greatly increasing the detecting precision and exploration capability of this method and making it extensively applied in the detection of hidden trouble of water gushing from the roadway floor. Due to its outstanding effect, it becomes one of the ideal methods for mine geophysical prospecting.

The following is the introduction of detection condition of hidden trouble of water gushing from the floor in the excavation roadway of Coal Face 1116 of Shaanxi Xinghuo Coal Industry Co., Ltd., adopting the mine high-density resistivity method. The Coal Face 1116, located in the south wing of Xinghuo Mine Field, has a length of 1283m and a inclined width of 140-160m. The mining coal seam is 11<sup>#</sup> and its thickness is about 4.69m and the average angle of inclination is 3.5°. Roof of the excavation roadway of the coal face is sandy mudstone, mudstone and siltite; and the floor is mudstone with Ordovician limestone below. Task of this detection is to detect the water-conducting formation of fracture zone, fissure development zone and etc. and the scope of water-rich area 80m below the floor of the excavation roadway of Coal Face 1116, in order to provide basis for design of water prevention, control scheme, arrangement and implementation of the water prevention and control engineering to ensure the safe mining on the coal face.

Fig. 3 and fig. 4 are the floor detection results respectively of headentry and tailentry of Coal Face 1116 by adopting the mine high-density resistivity method.

As is shown in fig. 3, the resistivity on this section changes greatly both longitudinally and transversely, indicating the relatively complicated geoelectric structure. In the diagram, change from blue to red represents the change of apparent resistivity from low to high. There are mainly two places where the apparent resistivity is lower than the wall rock in fig. 3, and they are shown as blue low-resistivity abnormal zones.

Based on the analysis of apparent resistivity value, we take the abnormal segment with its apparent resistivity lower than 30  $\Omega \cdot m$  as low resistivity segment., and regard it as possible hidden trouble of water gushing. Therefore, two low resistivity anomalies are outlined according to the above principle. One of which with 332-355m as its horizontal extent and 50m approximately as its central buried depth on section; the other one with 440-470m as its horizontal extent and 40m as its central buried depth. The explanation on low resistivity in Figure 4 can be made in the same way: 490-520m as horizontal extent and 85m as its central buried depth. Thereby, drilling hole layout and verification can be adopted by mining party when abscissa of haulage way is at 510m and abscissa of air-return way is at 345m respectively. As the maximum water discharge is 67m<sup>3</sup>/h and 45.7m<sup>3</sup>/h respectively when drilling enters into the abnormal zone, grouting shall be taken to bottom plate immediately to reinforce.

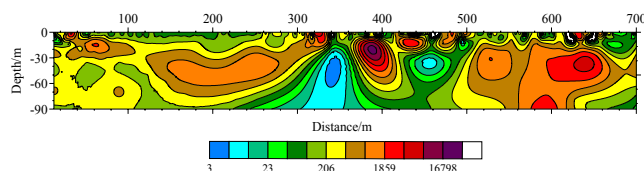


Fig. 3 Head entry resistivity at coal face 1116 that detected by high-density resistivity method-depth section

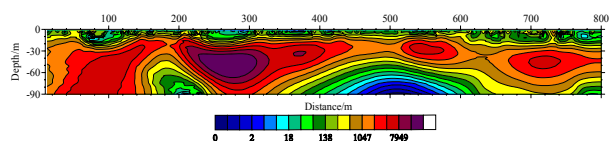


Fig. 4 Tailentry resistivity at coal face 1116 that detected by high-density resistivity method-depth section

The detection achievements of mine high-density resistivity method provides scientific basis for design of water prevention, control scheme, arrangement and implementation of the water prevention and control engineering at Coal Face 1116. Relying on these results, the coal floor of abnormal zones of this mine have been processed by drilled grouting; after the transformation of grouting, coal mined safely from this coal face has reached 210 thousand tons.

#### 4. Electric Transmission Tomography

The principle of the electric transmission tomography is similar to that of mine radio-wave penetration method and the difference is that the electric transmission tomography adopts stable and constant current field. Adopting monopole-dipole device, the electric transmission tomography uses point electrode A to supply power in one roadway (for instance, the headentry), locates electrode B at a place infinitely far away and uses measuring electrodes MN to measure potential difference in another roadway (for example, the tailentry), which is the most basic method for data acquisition. Actual construction layout is one-supply and multi-collection, forming a densely-covered bidirectional sector observation system, just like the radio-wave penetration, to research the distribution rules of electric fields in coal faces between two roadways as well as in the wall rock, detect anomalies of water-bearing and water-conducting formations at the coal faces and strata of their roofs and floors, work out tomography imaging of data and then implement the geological interpretation<sup>[1, 6]</sup>.

In the following part, results of water gushing detection by electric transmission tomography at Coal Face 1031 in Taoyuan Coal Mine of Anhui Huaibei Mining Group are introduced.

Diagram 5 is the achievement diagram of electric transmission detection on water-bearing feature of strata near to segment below the floor of Coal Face 1031 by a certain depth. As is shown in the diagram, values of apparent electric conductivities of strata in the segment are changing within 0.16-8.2 S/m, with an average of 1.5 S/m. According to the general rule, that is, if the electric conductivity is high, the water-bearing feature will be good, we can come to the conclusion that the water-bearing abnormal zones in the coal face are mainly in the inner segment (southern segment), which shall be treated with water prevention & control measures during mining at the coal face.

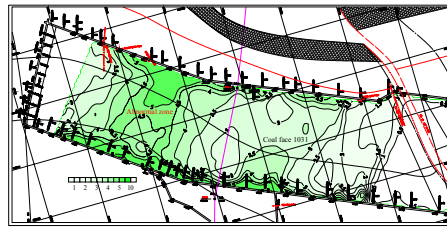


Fig. 5 Plane figure of apparent electric conductivity by electric transmission tomography in the coal seam floor of coal face 1031

## 5. Mine Transient Electromagnetic Method

Application of the mine transient electromagnetic method in down-hole hydrogeological detection of coal mine arises in recent years. Similar to other methods, like mine DC electrical method, this method is also moved from the ground to the down hole. However, corresponding construction and interpretation methods need to be improved to a certain degree.

The mine transient electromagnetic method is carried out in the down-hole roadway; as a result, devices have to be arranged in the limited down-hole space, the coils shall be small and must reach a certain detection depth, all of which require to increase emission current. However, in consideration of down-hole safety, the emission current shall not be too high, even under the condition that the down-hole ventilation is enhanced to the largest extent in the low-gas mine. Therefore, the mine transient electromagnetic method must adopt instruments of high sensitivity and special working modes, so as to extend the distance of pilot detection as long as possible in the premise of low emission current. With respect to construction, the down-hole measurement is in the whole space; during pilot detection on the heading face of excavation roadway, angle between transmitting coil and receiving coil shall be changed based on actual conditions and requirements for continuous observation to acquire sector sections<sup>[7]</sup>.

The mine transient electromagnetic method is very sensitive to water-bearing low-resistivity bodies and of fine directional property (orientational property); as a result, it can be applied to down-hole omnibearing detection (not only available in front of heading end, but also for detection of lateral wall of roadway and roof, floor of coal seam and etc.); In addition, its advantages like long detecting distance and quick construction create a bright prospect for its application in detecting hidden trouble of water gushing at coal face.

The following is the introduction of results on pilot water-bearing formation detection in blind roadway of mine coal by the down-hole transient electromagnetic method in Shandong Xinwen Mining (Group) Co., Ltd.

In view of the field working conditions, device of coincident loops is used to measure; additionally, method test has been implemented according to actual field conditions in order to increase signal-to-noise ratio to the largest extent. The final working parameters selected are as follows: transmitting wire frame: 1.3m×1.3m (10 windings in total); receiving wire frame: 1.1m×1.1m (20 windings in total); emission current: 20 A; delay time of sampling: 20ms; superposition times: 256 times.

Fig.6 is the vertical section figure of pilot detection in blind roadway by the down-hole transient electromagnetic method. As is shown in the diagram, there is an obvious low-resistivity abnormal zone about 275-320m in front of the excavation face, and the center is at 310m. After analyzing based on the geological condition, we deduce that the anomaly is reflection of the fissure zone of water-bearing

formation. In the process of subsequent roadway excavation, water-bearing fissure zone is found at 282-317m, whose amount of water gushing is  $60 \text{ m}^3/\text{h}$ . Due to the water detection & drainage adopted by the mine, safety of the excavation construction is ensured. Thereby the detection result of mine transient electromagnetic method is verified.

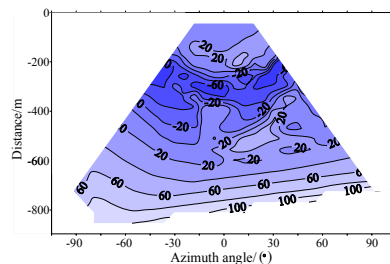


Fig. 6 Resistivity section diagram of pilot detection in blind roadway of coal mine by the mine transient electromagnetic method

## 6. Conclusion

Based on electrical differences between rocks, the electromagnetic method exploration is the main method for mine geophysical prospecting. Because of its sensitivity to water-bearing low-resistivity bodies, it shows a strong superiority in aspects of solving mine structures related to water and evaluating the water-bearing property. It has been proven by practice that the mine electromagnetic method is simple in construction, fast and economic, is an effective method for detecting hidden trouble of water gushing from the coal face and can provide reliable and correct basis for design of water prevention and control scheme for the coal face, as well as layout and implementation of water prevention and control project; thereby it plays a unique role in water prevention and control work of the coal mine and is very significant for ensuring the safe mining at the coal face.

## Acknowledgment

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