The Detection Method of Fire Abnormal Based on Directional Drilling in Complex Conditions of Mine

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Abstract: In the light of more and more urgent hidden fire abnormal detection problem in complex conditions of mine, a method which is used directional drilling technology is put forward. The method can avoid the obstacles in mine, and complete the fire abnormal detection. This paper based on analyzing the trajectory control of directional drilling, measurement while drilling and the characteristic of open branch process, the project of the directional drilling is formulated combination with a complex condition mine, and the detection of fire abnormal is implemented. This method can provide technical support for fire prevention, which also can provide a new way for fire anomaly detection in the similar mine.

1 Introduction

China is one of the countries with the most serious coal fire disasters. Spontaneous combustion of coals not only affects social economy, destroys coal resources, impacts eco-environment, but also causes series of problems to human survival and safety. As coal mining scale, strength and depth keep increasing, detection of concealed fire source in abnormal area for mine fire treatment has become the most difficult technical problem[1-3].

The main method for locating coal fire area is coal fire temperature measurement. Drilling hole for temperature measurement is generally adopted for detection, i.e., thermodetector and temperature sensor are arranged in the temperature measurement drill hole to measure the heat flow rate or the coal temperature. Currently, as mining conditions become more and more complex and diversified, fire areas primarily concentrate in abandoned roadways and gobs as well as in merged small pit mines, as a result, it is difficult to detect and measure the temperature of abnormal areas using conventional drilling technology. In this paper, directional drilling technology was adopted to bypass gob old pits to finally realize detection of abnormal fire source areas, and successfully implement temperature measurement and fire prevention & extinguishing using directional drilling[4-5].

2 Coal Mine Underground Directional Drilling Technology

Coal mine underground directional drilling technology is to drive downhole screw motor with sludge pump to drive the bit to revolve and cut, during drilling, the drill pipe does not revolve. The design trajectory and the actual drilling trajectory are displayed on the explosion-proof computer at the orifice, the tool face angle is changed by adjusting the PDM drill with elbow joint to control the bit dip angle and azimuth angle, hence controlling the trajectory[6-8]. Comparing to conventional revolving drilling, directional drilling not only can precisely control drill hole trajectory, but also can realize high angle bending of drill hole or in-hole branching through trajectory control, hence bypassing or avoiding obstacle[9]. Directional drilling technology has been widely used in coal mine underground gas extraction, geological structure detection and water control, whereas it's the first time for it to be used in the field of mine underground fire prevention & extinguishing, especially in abnormal fire source area detection and temperature measurement. Results show that directional drilling technology can perfectly complete fire source detection in abnormal area with good performance. Fig. 1 shows the directional drill rig for mine underground abnormal fire source area detection.

Fig 1 Directional drilling equipment of fire abnormal detection

2.1 Principle of mine underground directional

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drilling technology

The coal mine underground directional drilling system comprises directional drill rig, cabled drill pipe, MWD instruments, sludge pump, and screw motor etc. The connection of the drilling system is as shown in Fig. 2.

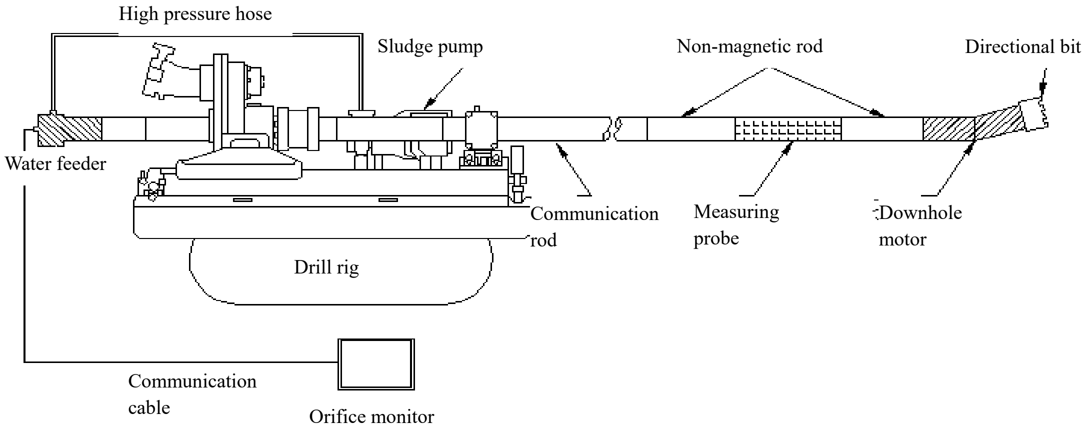

Fig 2 Connection diagram of MWD system in directional drilling

2.2 Characteristics of directional drilling technology

2.2.1 Measurement & calculation of directional drilling trajectory

The spatial pattern of the directional drilling axis can be manifested with some parameters of the axis. The spatial elements of the directional drilling hole axizzs include: the dip angle, azimuth angle and hole depth at different points of the drilling hole axis, vertical depth, horizontal displacement and horizontal deviation of the hole, and the curvature or bending strength of the curve section etc. Based on the basic elements of the drilling trajectory and using a certain calculation method, the spatial coordinate of each relevant point on the trajectory can be obtained[10-11]. Wherein the dip angle, azimuth angle and hole depth are the main basis for the design and control of directional drilling hole axis trajectory.

The MWD system of the directional drilling jig collects a group of drilling data every 3 meters. On this basis, the accurate coordinate of a certain measurement point on the drilling hole trajectory in the drilling hole design coordinate system can be obtained by calculation using formula (1), formula (2) and formula (3), complete drilling hole trajectory is obtained through replacing the arc of the measurement points with chord. Fig. 3 is the calculation principle.

$$X = \sum_{i=1}^{n} \Delta L_i \times \cos\left(\frac{\alpha_{i-1} + \alpha_i}{2}\right) \times \cos\left(\frac{\theta_{i-1} + \theta_i}{2} - \theta_0\right) \tag{1}$$

$$Y = \sum_{i=1}^{n} \Delta L_i \times \cos\left(\frac{\alpha_{i-1} + \alpha_i}{2}\right) \times \sin\left(\frac{\theta_{i-1} + \theta_i}{2} - \theta_0\right) \tag{2}$$

$$Z = \sum_{i=1}^{n} \Delta L_i \times \sin\left(\frac{\alpha_{i-1} + \alpha_i}{2}\right) \tag{3}$$

Where, ΔL is the distance between two measurement points during drilling; αi is the dip angle of point i of the drilling hole; θi is the azimuth angle of point i; $\theta 0$ is the main design azimuth angle of the drilling hole (i.e, azimuth angle of axis X); X is the horizontal displacement of point i; Y is the left-right displacement of point i; Z is up-down displacement of point i.

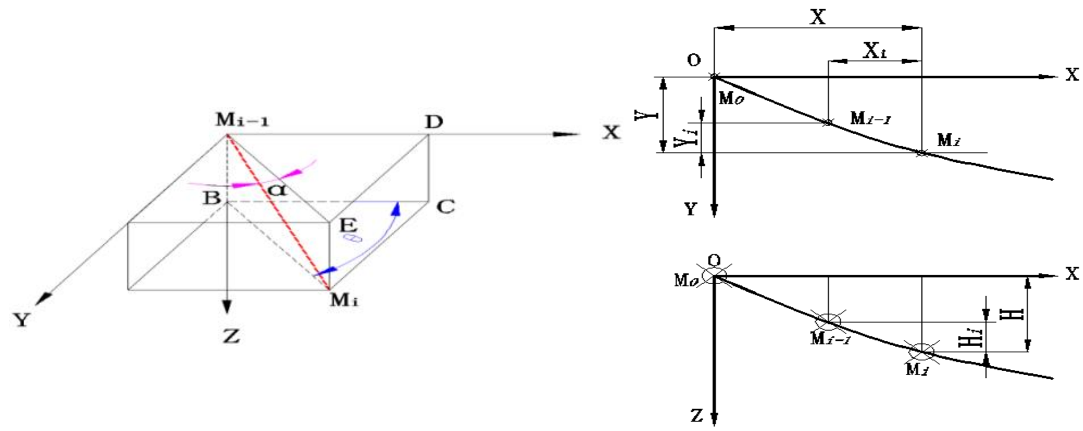

Fig 3 Calculation principle of surveying point coordinates for borehole track

2.2.2 Control of directional drilling trajectory

In the directional drilling system, screw motor is adopted to realize transmission of rotary speed, torque and trajectory control. It is a volumetric power conversion device and downhole motor that translates hydraulic pressure into mechanical energy. Through real-time monitoring of the hole-bottom trajectory by the MWD system while adjusting the tool face angle and the direction of the outer pipe elbow of the screw motor, the drilling hole trajectory control is realized.

2.2.3 Branching of directional drilling

In addition to controlling the trajectory, the PDM drill adopted by the directional drilling system can bypass or avoid encountered obstacle areas such as gob, old pits & small roadways and collapse columns through branching for safe drilling.

For the purpose of bypassing and avoiding obstacle, branching of directional drilling primarily adopts bypassing side drilling method, i.e., branch against the tool face angle at the hole section around the branching point, adopting depressurized (feed pressure) and timed drilling. Cut key grooves on the main hole wall and keep on making grooves, as the key groove gets deeper and deeper, new eyelets are gradually formed, the dip angle and azimuth angle are detected by the MWD instrument to compare with the original drilling hole trajectory, and when the feed pressure increases, and the sludge pump pressure increases slightly, and the returned rock (coal) powder at the orifice increases, it can be determined that the branching is successful, as shown in Fig. 4.

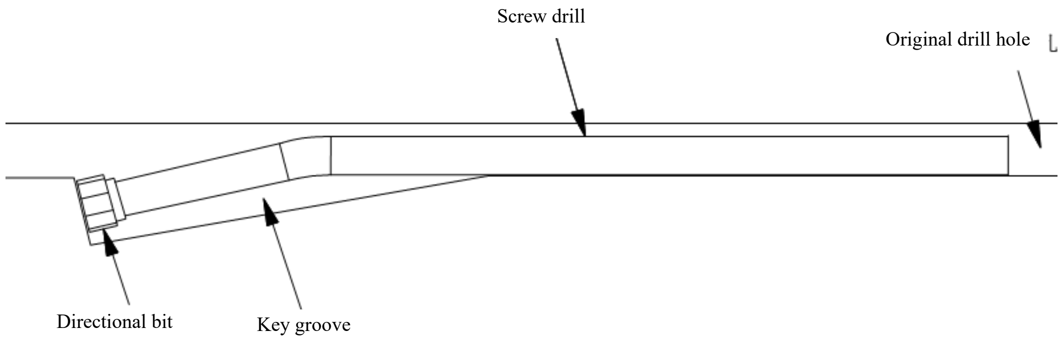

Fig 4 Open branch process of directional drilling

3 Mine Overview

The mine of Shanxi Huanjin Hanju Coal Industry Co., Ltd. is located at the south edge of Lvliang Mountain in Xipo Township, Xiangning County, Shanxi Province. The mine area is 26.5467km2, the geologic reserve is 307 million t, the recoverable reserve is 198 million t, the main mining beds are coal beds No.2-10, the design production capacity is 3 million t/a. Hanju Mine consists of multiple integrated old mines. There are many surrounding mines and small pits, there are exposed coal beds at the south east edge of the mine, there may be small pit mining area at the location where the coal bed is exposed, however, the location of the old pit entrance is unclear, the underground abandoned gob roadways proven already are complex, multiple times of spontaneous coal combustion and serious high CO concentration accidents occurred in the gob, resulting in multiple times of mine shutdown for rescuing, seriously affecting the safe production of the mine[12].

In order to detect the condition and temperature of the abnormal fire source area, conventional drilling method is generally adopted to drill to the suspicious area to arrange temperature sensor for temperature detection, so as to draw the temperature field map of the high temperature area, in a bid to locate the fire source location to guide subsequent fire prevention & extinguishing work. Hanju Mine has complex exploitation conditions, the abnormal areas and the abandoned roadway gobs cross with each other, the old pits are in chaos mining conditions, multiple times of conventional drilling have been attempted, encountering the upper layer of abandoned roadways and the lower layer of gobs etc., ending up in failure. To overcome this difficulty, in this paper, directional drilling technology and jig are utilized for temperature measurement and hazard elimination of the abnormal areas.

4 Design of Directional Drilling for Abnormal Fire Source Area Detection

4.1 Principle of design

(1) The directional drilling area for detection of abnormal fire source area is complex, therefore, potential hazards shall be fully taken into consideration in the design, for example, whether hole collapse may occur when crossing the coal-rock boundary, drill jamming when encountering unknown matters in abandoned roadway, so as to ensure safe drilling.

(2) Due to the importance and uncertainty of detection drilling , and abnormal gas may erupt when hitting the target fire source area, emergency response plan and measures must be provided in directional drilling design, e.g., arrange hazard gas interception device at the orifice of the directional drilling hole.

(3) Due to uncertainty and possible sudden occurrence situation in complex area detection and the need of temperature sensor arrangement, smooth design is adopted as the directional drilling trajectory design, this also facilitates emergency drilling accident handling. Specifically, limit the basic bending angles, horizontal

direction (azimuth angle): 0.75-1.0 degrees, vertical direction (dip angle): 0.75-1.0 degrees, common curvature radius: r=57.3/(1 /6)=344m.

4.2 Design of directional drilling

Mining engineering plan (consisting of coal bed roof & bottom contour line, roadway distribution and geological structure distribution etc.) accurately reflecting the coal bed space tendency of the hole arrangement area as well as the coal bed histogram are required for the directional drilling design, first, parameters of the control points of the drilling hole trajectory need to be calculated, then the directional drilling trajectory is obtained through interpolation calculation. As to the detection area of this paper, relevant geological data are barely available, only the coal bed dip angle and a few abandoned roadways are determined based on deduction. The opening location is determined at the central substation, the elevation of the roadway roof at the opening point and coal 2 roof is 667m, the design opening elevation is 665.2m, the drilling trajectory lowers first then rises in a concave shape (Fig. 5), the design hole depth is 230m, 2 directional drilling holes are subsequently designed.

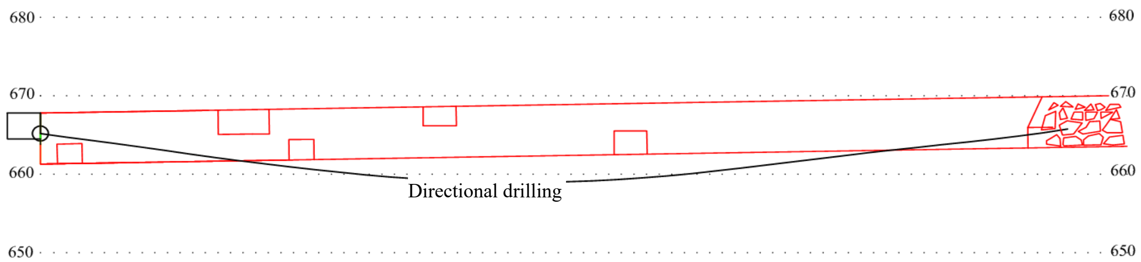

Fig 5 Design sketch of directional drilling trajectory

In addition, when the directional drilling reaches the abnormal fire source area, abnormal gas may erupt, therefore, at the opening section, straight drilling shall be ensured, 12m steel casing of φ127 shall be inserted, and fast sealing materials shall be injected to seal the hole and pressure test shall be satisfied, then check valve shall be arranged at the casing head to close the orifice to prevent hazard gas from erupting. For the hole structure and drilling parameters of the directional drilling, refer to Table 1.

Table 1 Borehole structure and drilling parameter of directional drilling

Drilling sequence	Hole diameter mm	Bit pressure KN	Rotary speed rpm	Pump displacement L/min	Remark
Surface section opening	Φ98	10~20	55~65	230	Opening
Surface section reaming	Φ153	10	25~30	230	Insert orifice casing
Second section orientation	Φ98	30~50		320	Directional drilling

For specific drilling design parameters, refer to Table 2.

Table 2 The design parameter of directional drilling

Hole No.	Design opening azimuth angle	Design opening dip angle	Design finished hole azimuth angle	Design finished hole dip angle	Design hole depth
1-1	171°	-7°	167°	20°	230m
1-2	182°	-7°	167°	20°	230m

5 Directional drilling for detection

5.1 Hole opening and sealing

Φ98mm straight drill bit + Φ73mm drill pipe assembly is adopted for hole opening to drill to the depth of 13m, then change to reaming drill rig assembly, i.e., Φ98mm/Φ153mm reamer bit + Φ73mm straight packed hole assembly to ream to the design depth, then insert Φ127mm orifice pipe×12m, inject special hole sealing material to seal the hole, after curing for 24 hours, conduct pressure test, and install orifice device and check valve.

5.2 Directional drilling

After drilling is started, in order to ensure the drilling reaches the target area safely, drilling must be strictly controlled in accordance with the design concave drilling trajectory, in addition, drilling shall also facilitate conditions for the final arrangement of temperature measurement lead and sensor, under the precondition of hitting the target by the trajectory, the drilled hole shall be as smooth as possible without high fluctuation and steps.

During work progress, due to lack of geological data, the abandoned roadways and gobs in the trajectory design are all obtained from deduction, this makes the directional drilling work very difficult.

(1) Directional drilling 1-1 encountered abandoned roadways respectively at 30m and 123m, causing drill jamming, almost resulting in near-miss drilling hole accident. Reopening had to be conducted after first time roadway penetration. In the second time of attempt, directional drilling branching is adopted to ensure safe drilling of directional drilling 1-1;

(2) The location of the suspicious abnormal area was unclear, no abnormality was observed at 230m depth of the hole of the original design. Through branching and expanding scope of detection, the target was finally detected during the third time of branching drilling.

(3) The detection under complex conditions determines the trajectory of the directional drilling is a concave one, assuming demanding test on smooth slagging and safe drilling. During the directional drilling, even bit pressure was maintained, pressure increase or decrease was conducted continuously and evenly, ream down frequently, advance moderately and impact frequently, drill rig operator shall closely observe drill torque, pump pressure and the returned water and slags, for any abnormality, stop drilling immediately, and promptly lift the drill rig to safe area for handling. The static duration of the drill rig in the mine was strictly controlled, except for measuring data, the static duration of the drill rig didn't exceed 10 minutes.

(4) Abnormal area was detected through directional drilling 1-1, directional drilling 1-2 conducted temperature measurement directional drilling by utilizing the geological conditions detected by hole 1-1, finally, cabled temperature measurement lead and sensor were arranged in the common drill pipe to complete temperature measurement of abnormal fire source area.

From design scheme preparation to safety measures implementation, to emergent equipment transport and to directional drilling 1-1 and 1-2 detection and completion of temperature measurement, it took 7 days and 20 shifts totally. For the actual drilling parameters, refer to Table 3.

Table 3 The actual parameter of directional drilling

Hole No.	Actual drilling opening azimuth angle	Actual drilling opening dip angle	Actual drilling finished hole azimuth angle	Actual drilling finished hole dip angle	Finished hole hole depth
1-1	168.2°	-7.5°	169.1°	8.4°	303m
1-2	171.5°	-9°	172.3°	11.2°	228m

The actual drilling horizontal trajectory and profile trajectory of directional drilling 1-1 and 1-2 are as shown in Fig. 6, Fig. 7 and Fig. 8.

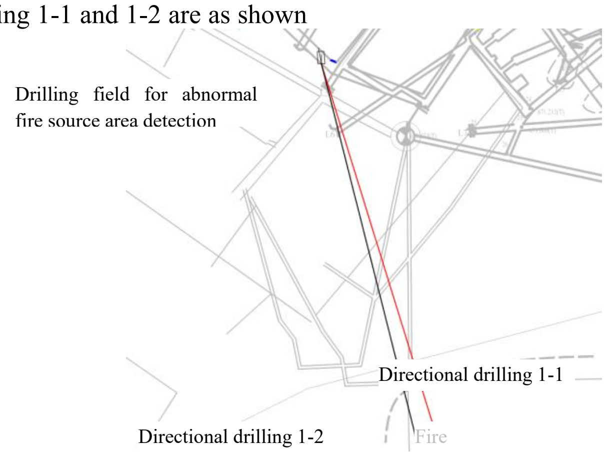

Fig 6 Planar trajectory of directional drilling for fire anomaly detection

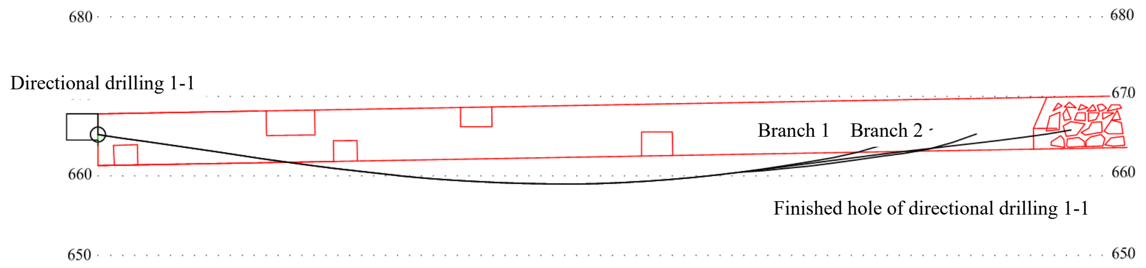

Fig 7 Profile trajectory of directional drilling 1-1

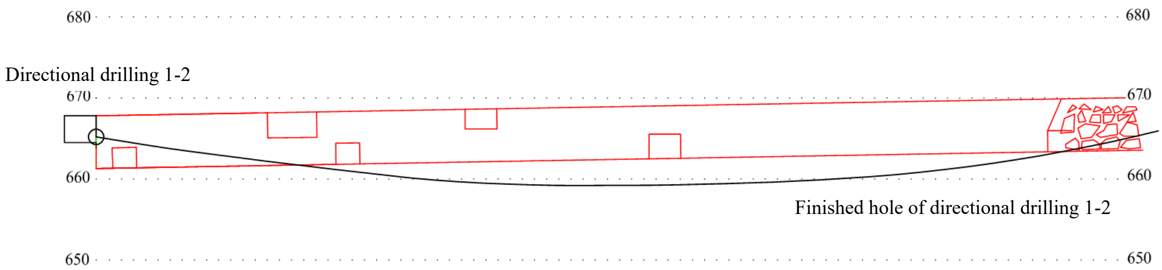

Fig 8 Profile trajectory of directional drilling 1-2

After the directional drilling was completed, temperature information of the abnormal fire source area was accurately obtained through arranged temperature measurement lead and sensor, then further fire prevention & extinguishing measures were taken, i.e., pour yellow mud, totally abut 50000m³ was poured, the effluent water temperature decreased from 110℃ to 18℃ gradually, and the CO eruption amount also decreased to normal value. Implementing abnormal fire source area detection and temperature measurement using directional drilling technology provides support for conducting targeted fire prevention & extinguishing work, ensuring safe production of mines with complex conditions.

6 Conclusion

Directional drilling technology was applied in the field of detection and temperature measurement of abnormal fire source area with complex conditions in coal mine underground for fire prevention and extinguishing for the first time. Through delicate organizing and bold innovation under unusual conditions, and artificially controlling the drilling trajectory by utilizing directional drilling technology to bypass and avoid abandoned roadways and gobs, through branching process, wide scope detection of the target abnormal area was completed. Finally the abnormal fire source area was detected, and the temperature was successfully measured through directional drilling, not only obtaining necessary condition information for subsequent fire prevention & extinguishing, but also providing a new concept for handling similar coal mine underground complex problems in the future.

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