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The Underground Directional Drilling Technology and Equipments for Kilometer Deep Borehole with MWD in Coalmine

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Abstract

The underground nearly-horizontal directional drilling technology and equipments, which are firstly developed by Xi'an Research Institute of China Coal Technology & Engineering Group from 2005, are the most advanced in the industry of mining. The directional drilling equipment came into use in 2008, and up to now has obtained the good effect in China's coalmine. Three hole-depth records of 1046m, 1059m and 1111.6m have been made continuously in underground in-seam directional drilling. In this paper, the technical contents, features and application of the directional drilling technology and equipments are introduced, the future work and trends are subsequently presented.

Keywords: underground coalmine; kilometer deep borehole; measurement while drilling; directional drilling

1. Introduction

China is the country where the largest amount of coal is produced and consumed. A large number of disasters happen in China's coalmine every year, in which gas disaster has the most significant impact on the aspects of society. Gas drainage through in-seam borehole is the most effective means to prevent gas disaster in coalmines of the world [1]. Since the nearly horizontal directional drilling (HDD) has the

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advantages of deep borehole and precise trajectory, it has been the intensive research subject in recent two decades. With the directional drilling technology, the deep borehole can be arranged uniformly in seam, and higher efficiency of gas drainage can be obtained.

The core of underground in-seam directional drilling technology is the controlled drilling process and equipments [2]. The devices and instruments for oil and geology on ground are not suitable to the underground coalmine because of its special conditions. The directional drilling devices and instruments were imported from America, Japan and Australia before 2007. The good effect has not been obtained except the Australia's VLD drill rig in Qinshui basin.

In 2006, the project of underground directional drilling technology and equipments was approved by National Development and Reform Commission of China. The objective of project is to develop the independent intellectual property products for Chinese coalmine. After five years of effort, the drilling technology and equipments have been successfully developed and applied in many mines. This technology has played an important role in the gas disaster prevention and high efficiency productivity.

2. Underground directional drilling system

The underground directional drilling system is composed of directional drill rig, measurement while drilling (MWD) instrument, specialized drill tools and drill process. It can be used to drill borehole for gas drainage, advanced exploration and water proofing in rock stratum whose hardness factor is less than 8 and coal seam whose hardness factor is greater than 1.5 [3].

During the directional drilling process, the bit is rotary to cut coal, whose power is provided by the downhole motor driven by high-pressure fluid. The realtime measuring information is transmitted through the cable fixed in rod from the downhole to the uphole. Then the driller adjusts the direction of motor's tool face through rotating the drilling string to control the inclination and azimuth of hole. The directional drilling system is illustrated in Fig. 1.

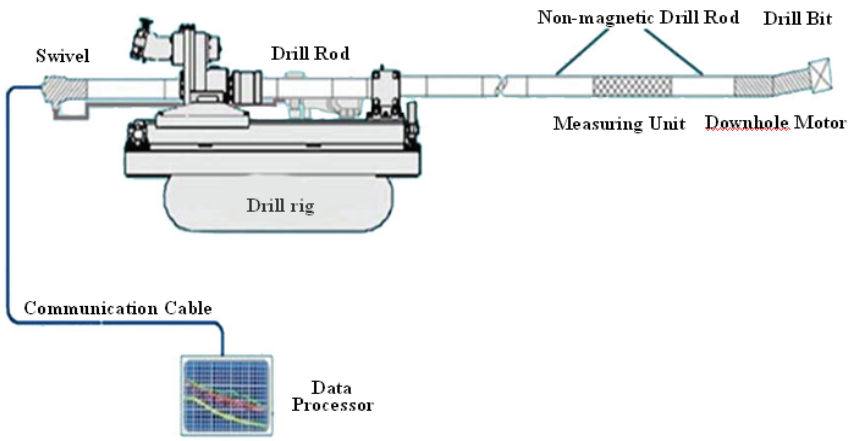

Fig.1. Underground directional drilling system

2.1. Development of directional drilling rig

All tables should be numbered with Arabic numerals. Headings should be placed above tables, left justified. Leave one line space between the heading and the table. Only horizontal lines should be used

within a table, to distinguish the column headings from the body of the table, and immediately above and below the table. Tables must be embedded into the text and not supplied separately. Below is an example which authors may find useful. A track-mounted head-type drill rig is developed, in which mud pump, control console and electromagnetic starter are integrated. Main shaft braking function is realized by a clamping device, which was fixed on the primary drive shaft of gyrator. This device is open-style structure with the function of clamping by oil pressure and opening by spring. The rig can meet the demands of directional drilling, rotational drilling and composite drilling, and tackle with the accidents of pipe-sticking and pipe-covering. In the design of hydraulic system, load sensing, constant pressure variable and proportional pilot control are adopted. Pressure and flow supplied by hydraulic pump always fit the load applied to the mechanism. Because there are no redundant pressure and flow in this hydraulic system, it is energy-saving and has low noise and high reliability.

The developed drill rig of ZDY6000LD(A) is shown in fig. 2, and its technical parameters is illustrated in table 1. This drill rig has the advantages of easy movement, wide range of rotational speed, large torque and adaptability. So far, three types of drill rig named by ZDY4000LD, ZDY6000LD and ZDY6000LF have been developed to meet the demands of different tunnel condition in coalmine.

Fig.2. ZDY6000LD (A） drill rig

Table 1. The parameters of ZDY6000LD (A) drill rig

Technical parameters of drill rig	Value
Drilling rod diameter /mm	73/95
borehole inclination /°	-10~20
Rotation speed /rpm	50~190
Rotation torque /Nm	6000~1600
Rating braking torque of main shaft /Nm	1500
Feeding/pulling force /kN	180
Walking speed /km/h	0~2.5
Feeding/pulling stroke /mm	1000
Maximum climbing ability /°	20
Hydraulic rating pressure /MPa	26(main pump)/ 21(assistant pump)
Electrical motor power /kW	90

2.2. Development of high-strength drill rod with cable assembly inserts

During the drilling process, drill rod has been pulled, pressed, bended and twisted. Considering deep hole drilling and accident handling, drill rod must have enough strength and ductility against the larger flexing deformation. In order to transmit the signal effectively, cable assembly is sealed to resist water and pressure. The cable assembly inserts is designed as small as possible to enlarge the size of hole for drill rod to reduce the energy loss of flushing fluid. The strength of thread and whole tension and torsion of drill rod are guaranteed by optimal material and advanced process. It is shown as Fig. 3.

Compared with flat drill rod, the developed drill rod has advantages as follows. With big through hole, the kinetic energy loss of drilling fluid is decreased. The signal can be transmitted from the downhole to the uphole through the cable fixed centrally with rigorous sealing. The tensile strength of 1000 kN can meet the requirements of directional drilling, rotary drilling and settlement of downhole accidents. The application in mine for several years has demonstrated the performance of drill rod.

Fig.3. Drill rod with cable assembly inserts

2.3. Development of MWD system

Real-time measurement is the key to drilling along with the designed trajectory. The MWD system for underground directional drilling in coalmine has been developed, which is composed of upper and lower non-magnetic drill rods, measurement tube, drill rod with cable assembly inserts, swivel, communication cables, uphole monitor, etc. This system can survey primary drilling parameters such as inclination, azimuth and angle of toolface. These parameters can be displayed on the screen of uphole monitor, so that drillers know about the downhole situation and adjust drilling direction.

The MWD systems of YHD1-1000 and YHD2-1000 have been developed for different conditions. The difference between two systems is the size of measurement tube and uphole monitor. Firstly, we adopted anti-vibration method in the design of monitor to improve its reliability. We also used accelerometer and flux sensor in the measurement tube to decrease temperature drift and improve its stability and precision.Six inch LCD screen and chargeable power have been used in the uphole monitor of portable YHD1-1000. On the basis of high precision and long working hours, the length and diameter of tube in YHD2-1000 are both smaller. A flame-proof and intrinsically safe computer with 12 inch LCD screen is used as uphole monitor in YHD2-1000. A 127V power from starter is used to run this computer,

on which Windows XP operating system and Borehole measurement and analysis software are installed to display and analyze drilling trajectory. The above two MWD systems are shown in Fig.4.

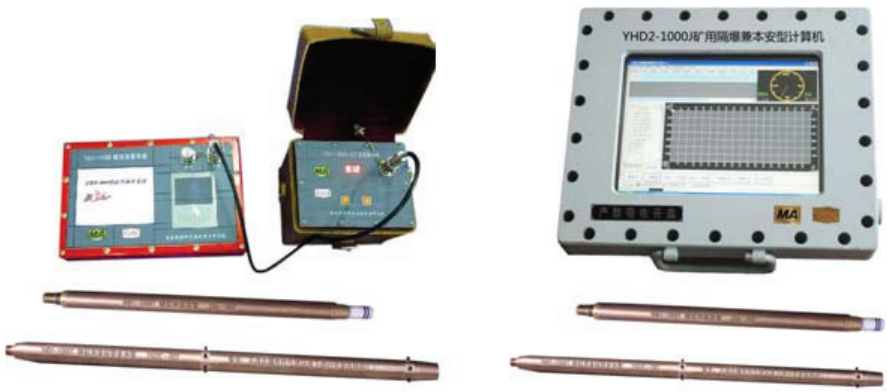

Fig. 4. (a) YHD1-1000; (b) YHD2-1000

2.4. Development of HDD process

The calculation of borehole trajectory is the key of the design and construction for HDD borehole. The calculation model of HDD borehole trajectory is established based on technologies in the fields of oil and trenchless drilling, with which three-dimensional trajectory is obtained. A trajectory software is developed to arrange a cluster of boreholes in coal seam uniformly.

The diameter of borehole is usually 96 mm for the rock stratum and coal seam whose hardness factor is from 1 to 6. By combining the stabilizer with downhole motor, the main hole and branch holes are constructed. The control method of borehole trajectory and the technology of multi-bottom directional drilling are formed. Fig. 5 has shown the borehole trajectory in No. 32215 work face at Ruqigou Coalmine in Shenghua Group. It has shown that the boreholes are distributed in the whole work face for balanced gas drainage.

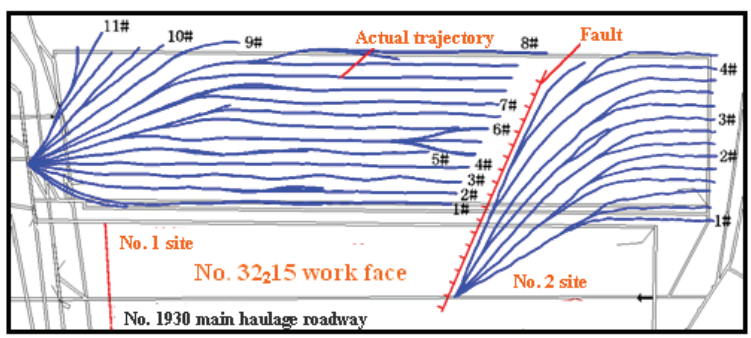

Fig.5. The borehole trajectory in No. 32215 work face at Ruqigou Coalmine

3. Applications

The achievements of this project were firstly used in Chinese coalmine in August 2006. Till May 2011, it has been successfully promoted in 27 mining areas, such as Bingchang Coalmine Inc., Ningxia Coal Group, Jingcheng Coal Group, Yangquan Coal Group, Coking coal Group of Shanxi province, Wuhai Energy Inc. and Shendong Coalmine of Shenhua Group. The achievements have three merits as the following. 1) With a 60% reduction of failure rate and drilling efficiency of 2 to 3 times compared with conventional rig, the directional rig has more advantages of large power, reliable work, and easy movement. 2) The drill rod with cable assembly inserts is high-strength and has the ability of reliable transmission of signal. 3) With high accuracy of MWD system, the horizontal deviation is less than 5‰ of hole depth, and vertical deviation is less than 1‰ of hole depth.

In June 2010, a borehole of 1111.6 meter, with the largest branch hole of 915 meter was directionally drilled at Baode Coalmine of Shenhua Group. It is a new record of underground in-seam directional drilling with domestic equipment in China's coalmine. The application in Baode Coalmine has shown that the gas drainage efficiency of long borehole is 4 times compared with conventional boreholes.

The first HDD technology and equipments developed by Xi'an Research Institute of CCTEG meet the urgent demand of safe production in coalmine. The advancement from uncontrolled drilling to accurate directional drilling has been obtained for underground gas drainage. The technology and equipments accelerate the progress in the field of gas prevention and control, and will apply in more fields in the future.

4. Outlook

Compared with international rivals, the directional drill rig, MWD system and borehole trajectory control method developed by Xi'an Research Institute are advanced. However, the underground directional drilling technology in coalmine is still falling behind the other industries, such as petroleum, geology, etc. In the future we will focus on the following work.

- Developing the new drill rig and tools for 1500 meters of borehole to meet the needs of united ground and underground gas drainage.
- Investigating the wireless MWD and geosteering technologies for underground drilling in coalmine based on directional drilling technology in the industry of petroleum .
- Applying the MWD to other fields, such as geology exploration, waterproof, mine construction, and rescue drilling.
- Improving the underground directional drilling tools, instruments, process and software for the enlarged application area.

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