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# Status and Development of Directional Drilling Technology in Coal Mine

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## Abstract

By reviewing the development status of the Chinese directional drilling technology in coal mine in recent years, the authors described the performance characteristics and R & D direction of directional drilling equipment at home and abroad, and analyzed the key equipment of directional drilling and drilling technology. And then we summarized the application of directional drilling technology in coal seam geological conditions of our country, such as geological exploration, coal seam gas controlling and water prevention engineering. Finally the authors proposed the development direction and application prospect of directional drilling in the future.

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*Key words:* Directional Drilling; MWD; Geological Exploration; Gas Controlling; Water Prevention

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## 1. Preface

Since 1990s, the directional drilling technology in coal mine have developed from the previous phase of "combination of stable drilling tools" to a new period of "screw drilling tool combines directional drilling monitoring instruments (DDM)". In Australia, the directional hole can reach 1000 meters with several branch holes by using the screw drilling tools and steering tools in the relatively hard coal seams. In the middle of 1990s, the coal mining enterprises of our country imported nine sets of directional drilling equipment from the United States and Australia and conducted the field experiments at the Mining Bureau of Songzao, Tiefa, Huainan, Fushun and Pingdingshan. As a result, the experiments failed on the count of loose and soft seams in these coal mines long with the complex

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geological conditions. In February 2002, a directional main hole of 1761 meters was completed with downhole motor by Wadam Industries Pty Co., Ltd.. In April 2003, another directional hole of 1002 meters was completed in Jincheng of Shanxi province with the VLD drilling rig purchased by Shanxi Asian American-Daning Energy Co., Ltd., since then, our nation entered the new period of "screw drilling tool combines directional drilling monitoring instruments (DDM)". The VLD drilling rig gradually promoted and applied in Sihe Coalmine and Shenhua Ningxia Coal Industry Group Co., Ltd<sup>[1][2]</sup>.

In order to narrow the gap in coal mine directional drilling technology between China and foreign country, the Xi'an research institute of China Coal Technology & Engineering Group Corp developed ZDY6000LD series of directional drilling machine and related equipment with independent property rights in our country based on the National Major Scientific and Technological Special Project "The Development of Underground Level Long Drilling Rig and Related Technology" (Eleventh Five-year Plan). In April 2008, we completed a directional main hole of 1046m with the ZDY6000LD series of directional drilling machine in Tingnan Coalmine in Changwu, Shaanxi province, and created a record in the related areas of China at that time. The deviation of borehole trajectory was controlled within 1% of the deep hole. Until now, we have sold 110 machines with the type of ZDY6000LD (A), ZDY6000LD, ZDY6000LD (F), ZDY4000LD in the provinces of Shaanxi, Shanxi, Neimenggu, Henan, Anhui and so on. In November 2010, we completed a directional main hole of 1059m in Sihe Coalmine in Jincheng of Shanxi Province. In August 2011, another directional main hole of 1212m was completed in Dafosi Coalmine of Shaanxi Binchang Mining (Group) Co., Ltd., which kept the record of depth in the related areas in China. While the Xi'an research Institute of China Coal Technology & Engineering Group Corp is promoting the technology of directional drilling, some companies, such as the Chongqing research institute of China Coal Technology & Engineering Group Corp, SANY Group Co., Ltd., Shenyang North Traffic heavy Industry Group, had developed the directional drilling equipment successively, which promoted the development of the coal mine directional drilling technology effectively. At the same time, relying on the project of "The development of technology and equipment in small curvature underground drilling " in the " Eleventh Five-year Plan ", the Xi'an research institute of China Coal Technology & Engineering Group Corp effectively solved the problem of methane in the soft coal seams and voids, which expanded the application area of directional drilling machine.

During the "Twelfth Five-year Period", considering the current application situation of the directional drilling technology in the coal mine, we should further research the directional drilling technology, improve the performance of directional drilling equipment, and expand the applications area of directional drilling technology to better serve the safety of coal mine production.

## 2. Status and Research Direction of Directional Drilling Equipment

Directional drilling equipment currently in our coal mine are CCTEG Xi'an Institute ZDY6000L series, Australia VLD series, CCTEG Chongqing Institute ZYWL-6000D series and Northern Traffic ZDY3500 series. It is mainly composed of Directional drilling Rig, MWD, Screw drill, Drill pipe, Mud pump, etc.

### 2.1. Directional Drilling Rig

The major equipment of directional drill holes construction are Directional Drilling Rig that can not only meet the working conditions of conventional rotary drilling, but also achieve the directional drilling by using screw drill due to the hold device. The existing directional drilling rig with crawler can fulfill quick relocation, for example, ZDY6000LD (F) and VLD1000 rig, which are the most advanced drilling rigs and their main parameters are listed in Table 1. The currently several common directional drilling rigs have little difference, and all can meet the requirements of basic constructions. The ZDY rig has the collaboration function during the drilling. So it has the relatively quick and easy operation as well as the slightly more complicated oil passage, while VLD rig owns the clear handle and the slightly complicated operation<sup>[4][5]</sup>.

Table 1 Main Performance Parameter of Two Typical Directional Drilling Rigs

main performance parameter	ZDY6000LD(F)	VLD1000
Rotary rated torque /N.m	6000/3000	3000

Feed stroke/mm	1000	900
The spindle inclination angle /°	-10 ~ 20	-5 ~ 10
Maximum feed and pull force /kN	180	150
Total Power /kW	90	90
Overall dimensions (L × W × H)/m	3.23×1.36×1.86	3.74×2.1×1.67
	2.87×1.41×1.5	
Weight /kg	5930	9800
	3500	

The underground transport of existing directional drilling rig is inconvenient due to the limited space of mines. We often have to disassemble the big drilling rig, sometimes even the underground small throttle, and then assemble the machine in the underground drilling field, which makes the transport work hard. Directional drilling rig in the future should be designed to small size and easy dismounting. At present, the flatbed tricycle dimensions used in China coal mine is long×1.2m wide×0.4m high. Considering the safety distance between two flatbed tricycles and the height of the common cage, the maximum size of the rig should be not more than 4m long × 1.2m wide×1.6m high with modular design. Furthermore, these modules should be easy assembled and meet the need of mine hoisting.

## 2.2. Directional Drilling Rig

MWD instrument, as the "eye" of the directional drilling, is used to measure the inclination angle, azimuth, tool face, etc., as well as can display the drilling parameters and the trajectory. It is convenient for the drilling workers to adjust the angle of tool face and process parameters timely, in order to keep the drilling hole in accordance with designed trajectory. Currently MWD systems are YHD1-1000 MWD system, DGS orientation system, ZSZ1000 MWD system. These devices can display the drilling trajectory by the underground anti-explosion computer. The probe tube powers of the first two devices use rechargeable battery at bottom of the hole, and the third device power is the orifice supply.

The communication way of MWD has wired and wireless. Currently coal mine communication way of MWD use wired, and transmit signal by the central cable drilling pipe. Its advantage is the rapid and efficient signal transmission (each data needs 4-5s). But the signal cannot be transmitted in long-distance due to the serious signal attenuation which is result from the sealing problems of the two plastic connectors. Furthermore, the thin drilling pipe wall and the limited strength reduce the capability of incident handling, which is caused by the big inner diameter of the central cable drilling pipe. So the communication way of MWD should develop the wireless way in the future, reduce the no signal link due to the sealing problems between multiple drilling pipes, and ensure the reliability of long-distance signal transmission. Meanwhile the drilling pipes strength should be increased to improve the incident handling capability of directional drilling.

Currently MWD main is divided as "mud pulse" and "electromagnetic wave" type.

### (1) "Mud Pulse" MWD

Considering the open annular gap between the coal mine directional drilling pipe and the direction hole wall, we recommend to measure the pressure inside the drilling pipe. The pressure pulse signal is generated to the probe controlled institutions at the hole bottom by controlling the switch of the mud pump. And then the appropriate treatment are made so that the hole bottom pulse generator encodes the information of pressure pulse. At last, the information is decoded by the receiving orifice monitors, and the appropriate measurement parameters are displayed.

### (2) "Electromagnetic Wave" Type MWD

Considering the low resistivity of seams and easy electromagnetic transmission decay, the electromagnetic wave transmits power has to be increased in order to ensure the signal transmission distance. But the transmit power is limited by the coal mine explosion-proof environments. The receiving antenna is suggested to mount on the roadway (The distance to the electromagnetic wave emitted end is less than the mining width) for the construction of more than 500m directional holes. Generally the width of working face is 200m, which ensures to meet MA and achieve the reliable transmission of electromagnetic signals.

In order to control the signal transmission, the "mud pulse" MWD needs start and close pump with the low speed signal transmission (each set of data required 180 ~ 300s), but its transmission distance is long and not limited by the formation. The "electromagnetic wave" type MWD has the general signal transmission (each set of data required 20 ~ 40s, adjustable) with limitation of the formation resistivity, but fulfills the requirement of 1000m hole signal transmission. Therefore, MWD will develop toward the electromagnetic wave way in the future.

### 2.3. Screw Drill

Screw drill (also known as screw motor) is the power source of drill bit rotary crushed rock, and also is the positive displacement volumetric power conversion devices which can convert the pressure emerge which generated by mud pump to the mechanical energy of the rotary drill bit. The drill string using the screw motor drilling generally don't rotate, which reduces the friction between the drilling pipe and the hole wall and debases invalid power of the rig, so that the greater drilling depth can be achieved in case of the same power. In addition, drilling is extended by a predetermined direction, due to that the drill string is generally no rotation when the drill bit broken rock, and the bending direction of curved outer tube guarantee (tool face) unchanged in drilling. When the direction of drilling needs to be changed, directional drilling can be implemented only by adjusting the direction of the curved outer tube. In the coal mine tunnel drilling, we often used  $\Phi 73$ mm single bend screw motor of USA with  $1^\circ$ ,  $1.25^\circ$ ,  $1.5^\circ$ , and achieved different effect of deflecting.

At present, the triple screw drill tool can meet the requirements of crushed rock and orientation. For harder rock of roof and floor, the triple screw drill tool has the low drilling efficiency because of the output torque (maximum torque is 257Nm) and the low power. So we suggest used the level 4 screw drill tool with the lager output torque (maximum torque is 450Nm) and power.

Furthermore, the variable flow of high-power mud pump needs to be developed to meet the high power of screw drill need and long holes (depth > 800m) construction.

### 2.4. Drill Pipe

Currently there are two kinds of  $\phi 73$  directional drilling pipe with non-magnetic and the central cable. The central cable drilling pipe can transmit the signal of probe, rotary torque, drilling pressure, and other loads to the drill bit, and is the channel of high-pressure water which used driven screw drill rotation. The Non-magnetic drilling pipe is produced by beryllium-copper, and mainly used in place the measuring instruments during drilling to avoid the interference of ordinary steel drilling pipe and ensure the accuracy of measurement data.

For the Non-magnetic drilling pipe, it is easy to cause non-magnetic drilling pipe breakage when encountered sticking accidents during drilling, because its material is beryllium-copper with brittle characteristic. Its anti-shear ability is much weaker than the steel drilling pipe. Therefore we recommend that the non-magnetic steel oil drilling pipe should be used to improve the force strength non-magnetic drilling pipe.

For the central cable drilling pipe, we develop  $\phi 89$  drilling pipe, and improve the force strength of the drilling pipe as well as the ability to deal with accidents in drilling hole. If the non-magnetic MWD successfully developed, we can use the available ordinary thick drilling pipe to improve the strength of the drilling pipe and the flow area of pressure water.

## 3. Directional Drilling Technology

The key technologies of directional drilling in coal mine are branch borehole drilling technology, drilling trajectory prediction and control technology, and safety & security technology, which are also the future of improvement and development of directional drilling technology.

### 3.1. Branch Borehole Drilling Technology

Branch borehole drilling technology is the main technology of directional drilling in coal mine, and also the technical foundation in construction of comb borehole, horizontal multi-branch holes, and directional exploration

drilling. According to the hardness of the formation and the form of the branch hole, branch borehole drilling technology is divided into open hole sidetrack method and using retrievable whip stock method.

#### (1) Open Hole Sidetrack Branch Borehole Technology

Branch Borehole is drilled in the sidewall of the original borehole by using downhole drilling screw motor, mainly for the down branch construction in coal holes and rock holes. The branch borehole is commonly drilled on the larger changes point in the angle and azimuth, and increased inclination of angle in the drilling trajectory. It is useful to drill the branch borehole and cuttings discharge, and gas extraction cannot be affected in the branch borehole. Downward face angle is selected in branch borehole, drilled slowly and repeatedly<sup>[3][4]</sup>.

#### (2) Retrievable Whipstock Branch Borehole Technology

Branches borehole is drilled by using retrievable whip stock with an expansive packer fixed on the borehole. When branches borehole is ended, whip stock is draw out packer from the hole wall by pressure release. This method is mainly used in the rock borehole with a high success rate and no special requirements to the drilling trajectory. It is also useful to gas extraction, because cuttings can be limited into other drill borehole.

In the hard rock, compound drilling technique is used to drill the branches borehole, with rotary drilling pipe and drilling screw motors at the same time. Designed face angle is selected to drill without rotary drilling pipe when branches borehole becomes to emerge. The whipstock with a higher coefficient of expansion will be needed to drill branch borehole with kickoff bit.

### 3.2. Branch Borehole Drilling Technology

The control of directional drilling trajectory is related to whether the design requirements and safety in coal mine. And the basis is to predict the trajectory accurately.

#### (1) Drilling Trajectory Prediction

Currently, directional drilling trajectory controls come true by MWD getting the location between the borehole and the target and changing the face angle in the screw motor with experience controlling the directional drilling trajectory. There is an obvious variation to control the directional drilling trajectory by different people with various degree technical skills, result in a deviated from the design trajectory. So it is needed to study the prediction technology for guiding the drilling trajectory control<sup>[6]</sup>.

Directional drilling trajectory is affected by formation conditions, the degree of drilling pipe bending and kickoff performance of drilling screw motor. It is shown that kickoff performance of drilling screw motor is the main factor from a large number of field data. So drilling trajectory prediction software can be developed from the principle of motor how to change the trajectory.

#### (2) Drilling Trajectory Control

There are two purposes to control the trajectory. One, it ensures trajectory "smooth" to reduce the hole "dogleg" and avoid drilling too large friction resistance as well as risk. The other, it also ensures that the trajectory of borehole drilled according to the design. This is subject to study friction resistance of the BHA in further, to find the smaller friction with specific face angle by using the drilling trajectory prediction software. The goal of intelligent drilling will be realized<sup>[7]</sup>.

Then geometry steerable drilling and rotary steerable drilling technology offer references to develop the slim hole rotary steerable drilling in coal mine. It is helpful to explain lithology changes near the drill bit by measuring different Gamma and resistivity values. It can make trajectory "smooth" to ensure drilling safety.

### 3.3. Directional Drilling Safety & Security Technology

Sticking accidents always happen in the course of directional drilling in the mine with complex geological conditions, and caused large risk and economic losses. Thus research should be strengthened from borehole and reservoir protection, accident prevention and treatment, to protect the safety of directional drilling technology in coal mine.

#### (1) Borehole and Reservoir Protection Technology

Low Solid Mud and plugging device should be used in unstable formations, so that drilling mud fill annulus space to protect the borehole. Gas permeability must be considered for coal hole by use of mud. For example, chemical decomposition mud is used to ensure gas' drainage effect.

For formations of high ground pressure or high gas coal seam, mud protection is still unable to stabilize the hole-wall. Cement injection and casing running technology are studied for broken bore. In addition, plugging device of good sealing can be used to hold pressure, which can balance the pressure of rock hole-wall or gas, and reduce the accident of hole collapse gas blowout

(2) Borehole Accident Prevention and Treatment Technology

There are two aspects needed to research in dealing with accident directional drilling, accident prevention and accident treatment technology. More technicians are needed to be trained in operating the directional drill for borehole accident prevention. With the development of monitoring instruments, parameter reflecting working condition will be monitored. Feeding or pulling pressure, rotary pressure, pump pressure, return water quantity and lithology of drilling cutting are helpful to test the performance or prevent borehole accidents.

The main accident in directional drilling borehole is borehole collapse accident sticking the drilling pipe. The handling process is shown in Fig. 1. That concludes by "pulling / feed with swing", casing milling tools of  $\phi 95$  pipe /  $\phi 105$  bit, draw bench with strong pulling, salvage by positive wire  $\phi 73$  drill and die tap or box tap, salvage by anti-wire  $\phi 73$  drill and anti-wire die tap or box tap, etc. Other drilling tools and technologies should be learned from oil drilling or geological drilling in the future, to deal with borehole accidents in coal mine [8].

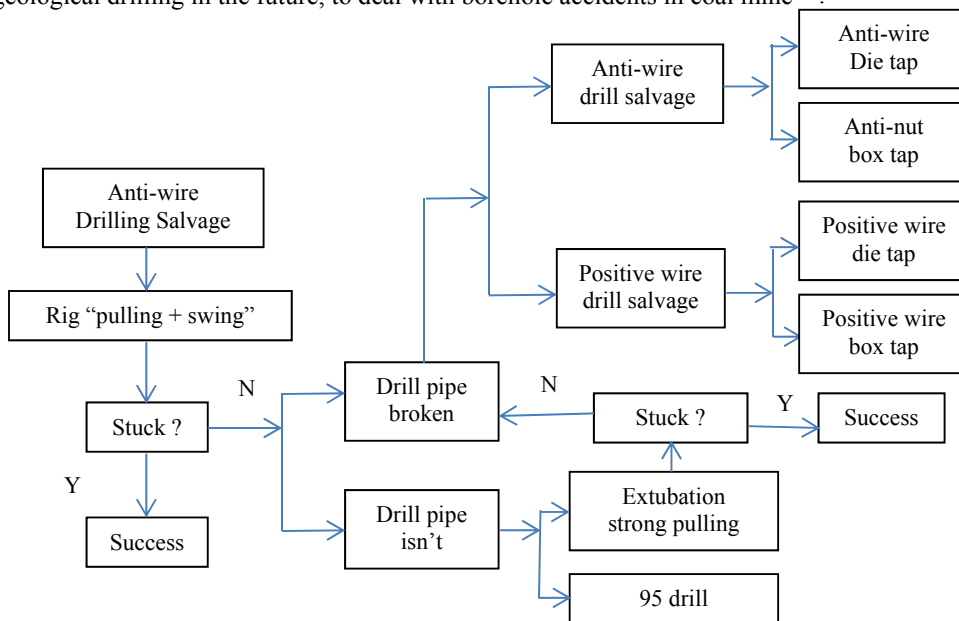


Fig. 1 Handling Process of Sticking

In addition, safety joint is recommended to install between the drilling screw motor and lower non-magnetic drilling pipe. When there is sticking and the drilling pipe couldn't be pulled out, the valuables MWD can be drew out more easily.

4. Status and Prospects of Directional Drilling Technology

With the recent promotion and application, the coal mine directional drilling technology mainly was used in geological exploration, prevention and treatment of water engineering, coal mine gas control and other applications.

#### 4.1. Geological Exploration

Faults, collapse column, the old tunnel kilns and other anomalies goaf area are prevalent in our mines, which is a serious threat for the mine safety and production. Because coal mine drilling trajectory can be controlled accurately measure borehole trajectory, drilling long, etc., Directional drilling technology not only are widely used in gas extraction respect, but also plays an increasingly important role in the coal mine geological exploration, particularly available trends in the coal seam, gob, collapse column, faults and other geological exploration.

##### (1) Along the Seam Coal Holes for Geological Exploration

In the drilling process, the drilling motor initially drills to the roof along the seam hole in the depth intervals (typically 60m ~ 100m), which probes seam roof and downs. Then mentions of drilling in a certain distance (typically 18m ~ 24m) open branch holes, ensure drilling trajectory in the roof extends forward seam drilling stable, and repeat construction and exploration of geological circumstances seam dip, folds. When the hole is drilled to the design depth, the backward branches are opened seam to the bottom hole drilling to detect the seam floor. According to detect seam roof and floor elevation, it can calculate the thickness of the seam, dip and other parameters. Typical examples are an area 3# coal seam cladding trend exploration in Sihe Coal Mine, Shanxi.

##### (2) Exploration of coal mined-out area

Several targets in the exploration area are designed directional drilling with the distance of 20m among them. The targets can be hit by the directional drilling technology. If the phenomenon of drilling back water, or drilling slow after the sudden sticking appears, that indicates that the position of the drill is the mined-out area, which can be measured out to each coordinate point by the drilling systems measure. Gob distribution can be drawn to guide the construction of coal mine safety. Typical examples are exploration of the 534 faces gob area in Ningxia Rujigou Coal Mine.

##### (3) Exploration of collapse column

It can be designed a number of directional drilling targets in the coal exploration area of multiple collapse column. The directional drilling technology can accurately hit the target, if the coal seam construction suddenly drills slow-speed, or drills back to see the slag crushing rock grains sticking limp pump phenomenon. It indicates that the location of the drill is collapse column, which can be measured out to the coordinate point of collapse column by various drilling systems. Then we draw the collapse column in the coal mining to guide the construction of coal mine safety. A typical example is the collapse column exploration of the North West three extents in Shanxi Duerping coal mine.

##### (4) Exploration of tunnel fault

Coal roadway needs to long-range exploration of roadway before digging. It has to construct some long-range directional holes in the coal, roof, floor, as well as a number of branches holes along seams direction, measure point coordinates of coal, plotter coal seam coordinates, analyze the faults by the geological structures, and guide the coal roadway tunneling. Typical example is the roadway fault probe of 16,141 faces in Henan Jiulishan coal mine<sup>[11]</sup>.

#### 4.2. Seam Gas Control

Seam coal mine gas control is the most important application areas of the directional drilling technology. The principles of coal mining, "drain gas before mining coal", ensure the safety of coal mining. The gas concentration mining mainly is reduced by drilling pumping gas in coal seams. Directional drilling can extract gas remotely because of drilling long and the controlled boring trajectory. According to characteristics of coal into the hole, directional bore gas control types are: (1) the hard coal seam gas control holes, (2) soft coal seam gas control comb holes, shown in Fig. 2. The hard coal seam hole is mainly used in Shanxi coal, Fenxi, Xishan Coal, Shaanxi Binchang, Shaanxi coal, Huangling, Ningxia Coal and other 30 mines. The maximum deep principal of hard coal drilling holes is 1212 meter (currently the domestic underground coal deepest hole record), and the maximum deep principal of branch holes is 915 meter. The total construction drilling footage is over millions of meters<sup>[7]</sup>. Comb directional drilling is mainly used in Huainan, Huaibei, Jiaozuo, Pingdingshan coal and other soft prominent mining<sup>[9]</sup><sup>[10]</sup>, in which the rock comb directional bore hole depth reaches maximum 603 m of Zhuxianzhuang mine.

### 4.3. Water Control Project

The groundwater flooding accident often occurred for water-rich of coal seam formations, which need for water control project construction. The current water control projects are often using 70~120m ordinary drilling. Because of the short drilling length, the small water-rich layer hole in the target segment, and the non-drilling trajectory monitoring, it requires many conventional drilling engineering fields, a lot of conventional drilling work, the directional drilling floor grouting technology, and the directional drilling escape hole technology.

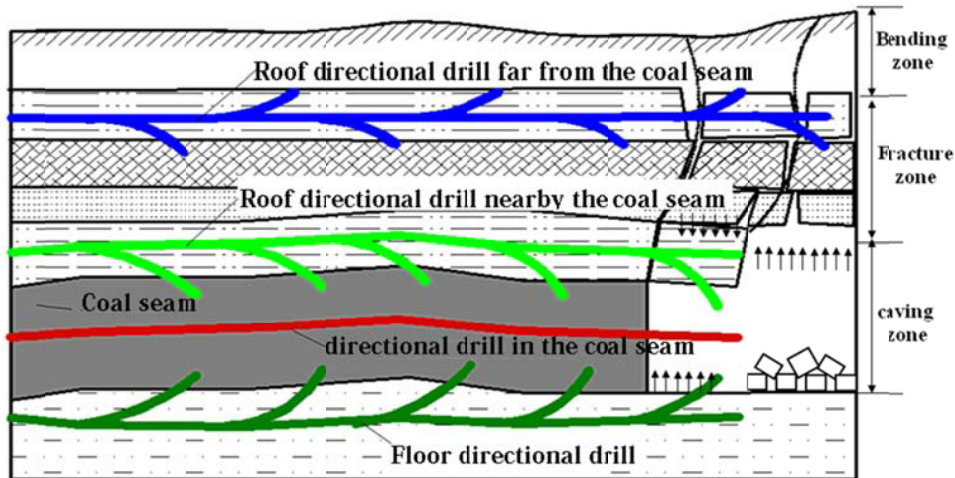


Fig. 2 Types of Common Directional Drilling

#### (1) Directional Drilling Floor Grouting

The coal mine near horizontal directional drilling technology is used to replace traditional floor grouting hole (see Fig. 3), which increases the chance aquifer of nearly horizontal borehole drilled, advance detection the conduct geological structure of the seam floor, accurately calculate water point coordinates position, and achieve the ahead governance of regional seam floor by grouting<sup>[13]</sup>. The technology is currently using in Jiaozuo ZhaoguYi Mine, in which the deepest drilling up to 620m and the maximum grouting hole reaching 14 889.303 m<sup>3</sup>.

#### (2) Directional Exploration and Drain Hole

In exploration drainage of coal seam roof, directional exploration drain hole in roof replaces the traditional escape hole (see Fig. 4), which controls drilling trajectory in the aquifer an increasing the length of hole in the aquifer, reduces a lot of drilling engineering, and extends Dewatering time and enabling efficient exploration ahead drainage. Typical examples are Roof directional drilling escape drilling in Ningxia HongLiu Coal Mine (7 holes, the maximum Hole depth 552 m, the maximum displacement of 130m<sup>3</sup>/h.), and roof drainage directed exploration drilling in NeiMeng Muduchaideng mine (3 holes, the maximum Hole depth 708m, the maximum amount of water 14m<sup>3</sup>/h).



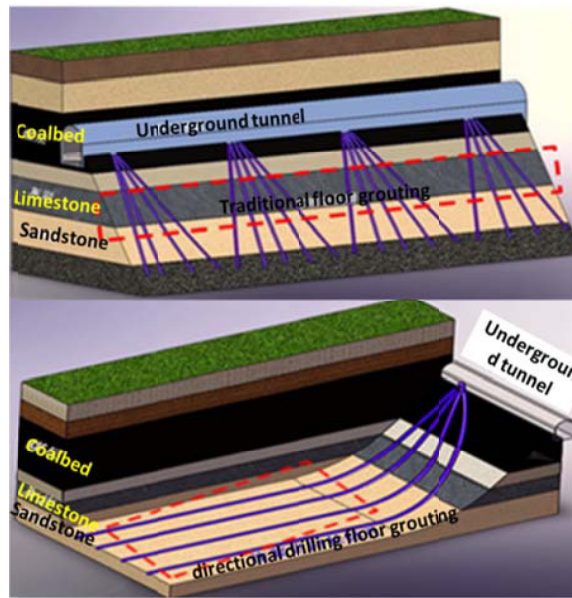


Fig. 3 Directional Drilling Floor Grouting and Traditional Floor Grouting Hole

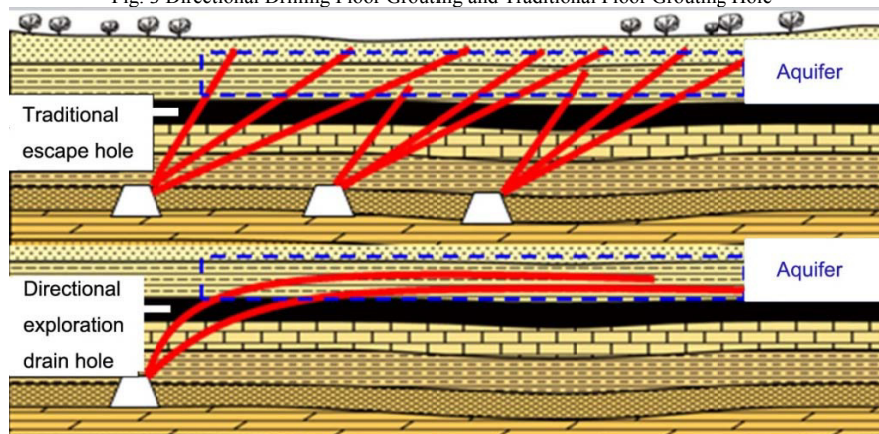


Fig. 4 Directional Exploration Drain Hole and the Traditional Escape Hole

## 5. Conclusions and Prospects

In recent years, the directional drilling technology had made considerable progress in underground mine in China. Particularly, ZDY6000LD series of directional drilling equipment came out with our own property, which were produced by Coal Technology & Engineering Group, Xi'an Institute. It breaks the foreign monopoly of technology for Chinese coal mine and provides an efficient technical means for efficient regional gas control, geological exploration, water prevention project. To promote the future development of underground coal mine directional drilling technology, prospects are as follows.

(1) Radio MWD technology and equipment should be developed, which was applicable to coal mine conditions, such as, electromagnetic waves and mud pulse. Combined with thick-walled high-strength drilling pipe, we should research combined drilling technology and equipment to improve drilling depth, the ability to deal with accidents and drilling efficiency. After study of geology steering technology and rotary steerable technology at home and broad, the rotary steerable technology suitable for underground slim-hole should be developed<sup>[12]</sup>.

(2) When hydraulic screw drill was used to do comb-like holes in the soft outburst seam, some problems, such as gas outburst, collapse, segment seam holes short, sticking often occurred. Therefore, we should research a drilling

process which is suitable to do slag comb-like hole with wind-force in soft outburst seam. It was able to increase coal branch bore hole length, avoid restrictions that the mud and broken rock act on screw drilling, and improve the pore-forming efficiency of comb holes in the rocks.

(3) Because the underground space was small, and the construction environment was harsh in underground coal mine, the design of directional drilling equipment should be small, modular, easily assembled and transported, which is the future development direction.

(4) We should research the relationship between design, prediction and control of directional drilling trajectory, and develop integrated directional drilling services software which combined MWD, drilling trajectory design, trajectory prediction and trajectory control. It will prompt the coal mine directional drilling technology to more intelligent development<sup>[14]</sup>.

(5) The combination of the comb-like directional drilling technologies, hydraulic fracturing techniques and CBM technologies is an important research direction of low permeability seam on gas control.

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