Research on gas drainage technology and equipment of high-level directional drilling in coal mine

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Abstract: The gas overrun at the upper corners of the goaf and return air lanes has been restricting the development of China’s coal mining industry. To solve the problem of over-limit gas concentration at the upper corners, the fundamental reason is to reduce the gas concentration in the "fracture zone" of the coal roof. At present, the most commonly used methods such as high extraction roadway, buried pipe extraction, and high-level drilling in the "fracture zone" gas control of the goaf have the disadvantages of excessive cost and heavy workload, and the drilling trajectory of conventional drilling rigs cannot be accurately positioned problem. Therefore, it is proposed to use high-position roof directional long drilling technology to replace traditional high-drainage roadway for gas control, and analyze the influence of directional drilling diameter, position, depth and other parameters on gas drainage efficiency. Based on the analysis of four drilling cases of the directional drilling rig ZYWL-13000DS of China Coal Science and Industry Group Chongqing Research Institute Co., Ltd. at 33 (4) 13 working face of Shuangliu Coal Mine, from the perspective of construction effect, the directional drilling is a more reasonable construction level 5-8 times the mining height above the roof is appropriate; the construction diameter should be as large as possible when conditions permit; when the drilling depth is 20m deep into the fissure zone, the pumping capacity will increase greatly, and with the construction of the mining, pumping Capabilities tend to stabilize. Compared with the traditional high-drainage road control effect, the use of directional long drilling technology for gas drainage can reduce the cost by more than 70% and shorten the effective construction period by more than 75%. It is finally verified that the use of high-directional directional long drilling technology can replace the high-drainage roadway for "fracture zone" gas drainage.

1 Introduction

Coal mine is currently one of the main energy sources in China, because coal is a porous medium, the coal seam is usually rich in gas, and about 90% of the coal mines in China are high gas mines, gas concentration is high will seriously threaten the life safety of underground workers [1-2], restricting the development of coal mine industry.

In recent years, China’s coal mining capacity has been continuously strengthened, the coal mining depth has been continuously deepened, the geological conditions are becoming more and more complex, and the difficulty of gas control has been significantly increased, leading to an increasing number of high gas mines. Under the influence of mining, the overlying rock of the coal seam roof in the goaf produces a large number of cracks, which increases the air permeability of the rock layer and significantly enhances the gas passage rate. The "gas channel" formed by the overlying rock fissure makes the gas move along the fissure and form the gas enrichment zone. Restricted by the shape of the channel, a secondary vortex will inevitably form in the upper corner. With the generation of secondary vortices, the energy of gas flowing through the upper corner is consumed, the flow rate is slowed down, and the gas in the vortex cannot flow out in time, resulting in aggregation, causing the gas concentration in the upper corner and the return air lane, affecting the construction safety of coal mining face construction. Therefore, how to carry out the fissure band gas extraction efficiently and quickly is the key to solve the gas concentration overlimit in the upper corner and the return air lane.

Generally speaking, before coal mining, the ground rig should be used to pump gas in the coal seam. However, in the actual construction process, affected by the terrain, cost and other factors, ground extraction is rarely used, and the commonly used control scheme is underground gas control. In China, the gas control in underground goaf in coal mines usually uses the methods of high extraction roadway, buried pipe extraction, high drilling and other [3], etc., among which the most important one is the use of high extraction roadway extraction, that is, a special gas extraction channel is dug out in the crack zone formed by the coal seam mining at the top of the mining layer. This kind of practice extraction efficiency is high, but the engineering quantity is large, the construction cycle is long, and the early cost input is too high. Relatively speaking, it is more
economical to use high drilling for gas extraction, but the traditional high drilling adopts conventional drilling rig, and the drilling track is uncontrollable and cannot accurately locate the extraction crack band. With the deeper and deeper tunneling surface, the geological conditions are more and more complex, and the limitations of conventional drilling RIGS are increasingly prominent. Therefore, it is urgent for a high drainage roadway extraction technology and equipment to realize the efficient extraction of the underground roof crack zone gas.

2 Kong for lane technique

In the process of coal seam mining, affected by the formation pressure, the coal wall support area in mining direction, from the layer and compaction area [4], in the longitudinal collapse on the top of the bending subsidence, the bottom formation collapse, the middle formation is affected by both growth fissure to make the fissure concentration extended to full thickness, form the crack zone. The gas in the coal seam is divided into free gas and attached gas. Affected by the mining of coal mine, the gas originally attached to the coal seam rises up along the crack, and the concentration of gas rises from bottom to up. In the subsidence zone, because the rock did not grow more cracks, internal attached gas less, so most of the gas will gather in the junction of the fracture zone, but affected by the underlying stress here, lead to extraction negative pressure extraction efficiency is low, and the falling zone to the fracture zone this position due to crack development, uniform gas distribution, become the core area of gas extraction.

With the mature application of long-hole directional drilling technology [5] in coal mine, it has gradually become one of the important methods of conventional drilling because of its simple construction method and controllable construction track for underground gas extraction. And with the innovation of drilling equipment technology, the diameter of hole is getting bigger and bigger, the efficiency of hole is getting higher and higher, and the influence radius of drilling gas is getting bigger and bigger. The process of "substituting the hole for the hole" has been greatly developed. Compared with the traditional extraction way, roof large diameter high long drilling trajectory can be accurately controlled, large hole aperture, high efficiency, drainage range, long cycle, at the same time, in the mining area of roadway construction, can effectively avoid the current situation of the overlap between extraction and tunneling, the construction cost is lower, shorter cycle.

As shown in figure 1, figure 2 is the method of numerical simulation for gas extraction analysis results[6], by comparison, can obviously see that with the high drilling gas extraction, along the working direction gas concentration distribution, reduce the gas content, the gas transition more smooth, low concentration gas area to the goaf, the upper corner gas content is significantly reduced, so using high directional drilling has a very positive influence on safe coal mining. At present, the three technical problems of high directional drilling gas extraction are mainly: drilling layer position, drilling diameter and drilling depth.

2.1 Selection of drilling location

At present, the division methods of "three belts" of goaf attached rock are mainly divided into empirical formula method [7], simulation calculation method [8-9] and drilling measurement method [10].

At present, the most accurate coal seam division method is the drilling measurement method. Distribution of the "three belts" of covered rock can be accurately and intuitively determined by geological drilling with [11], so as to guide drilling. However, this method has high
economy and time cost, and it is difficult to implement in the drilling process.

In recent decades, it has been found that the position of rock cover on the mining surface affected by coal mining is exponential to the height of coal mining, but it is less affected by the length. Therefore, the empirical formula of the gas conduction zone (falling zone and fissure zone) is proposed:

$$H_1 = \frac{100M}{aM + b} + c$$  \hspace{1cm} (1)

Where $H_1$ represents the thickness of the guide gas belt, $M$ represents the thickness of the coal mining, and the values of the constants $a$, $b$ and $c$ are affected by the hardness of the rock layer.

Due to falling zone upper fracture is given priority to with layer fissure development, the lower fissure is more broken fracture[12], and falling zone is more likely to appear by the top fracture belt compaction gas extraction efficiency is low, so the lower layer of the fracture zone for gas extraction of gold area, to determine the thickness of the fracture zone, can introduce falling band thickness empirical formula:

$$H_2 = \frac{M}{(K-1)\cos \alpha}$$  \hspace{1cm} (2)

Where $H_2$ is the maximum thickness of the falling band, $M$ is the thickness of the coal seam, $K$ is the coefficient of layer breaking, and $\alpha$ is the inclination of the coal seam. Formula 1 and formula 2 can find out the position of the crack band in the coal seam.

The position of the crack band obtained by using the empirical formula is relatively rough, When the coal seam thickness is greater than 3 m, The fracture band calculated using the empirical formula are inaccurate[13], 11 Occasionally, ineffective drilling. To address this situation, At present, the optimal solution is to use a small amount of drilling data combined with a numerical simulation method to simulate the recovery face, Wei Yousheng[14], Lu Huiqing[15], Through ANSYS and FLCE3D, The trend of the overrock simulation is similar to the actual rock formation, It is believed that the simulation results can guide the actual production.

2.2 Selection of drilling diameter

The diameter of the borehole plays a decisive role in the efficiency of gas extraction. Studies have shown that the flow of gas in the crack is mainly in two forms of penetration and diffusion, which is affected by the size of the crack. Secondary stress generated during drilling will lead to deformation of the rock mass around the drilling hole, affecting the permeability coefficient of the rock layer. The pressure relief radius $R$ around the drilling hole can be expressed by formula (3) [16]:

$$R = \left[1 + \frac{1}{\sqrt{2fK_p}} \ln \left( \frac{\sigma_0}{\sigma_c} \right) \right] r_0$$  \hspace{1cm} (3)

$$K_p = \frac{(1 + \sin \varphi)}{(1 - \sin \varphi)}$$  \hspace{1cm} (4)

In formula: $\sigma_0$: Rock mass stress before drilling, MPa; $\sigma_c$: Uniaxial compressive strength, MPa; $f$: Friction factor between moving rock mass and moving rock mass; $r_0$: Drilling radius; $\varphi$: Internal friction angle of the coal.

It can be seen that the pressure relief radius is inversely proportional to the strength of the rock mass and is proportional to the diameter of the borehole. The larger the pressure relief radius, the smoother the gas flow, and the better the extraction effect.

Wu Aijun[17] et al. conducted numerical simulation on the second _2 coal seam in Xuehu Coal Mine, and analyzed the drainage hole with a diameter of 80mm / 100mm / 120mm respectively under the fixed gas pressure, extraction negative pressure and the constant permeability coefficient of the coal seam. When the aperture of 80mm, 0.35 m3/min, 0.4 m3/min at 100mm and 0.45 m3/min at 120mm.

It can be seen that with the increase of the diameter of directional drilling, the gas extraction capacity shows a trend of enhancement, and the larger gas drainage hole can provide a larger hole wall for gas circulation. Therefore, in order to achieve a good extraction effect, large aperture and multiple channels are mostly used for gas extraction operations. However, combined with rock mechanics, the larger the hole diameter, the more likely it is to cause the hole collapse, but cause losses. Qi Qingjie[18] et al. simulated a working face of flat coal found that the drilling diameter had little influence on the gas pressure attenuation in the early stage of extraction. According to incomplete statistics, at present, only Chengzhuang Mine of Jincoal Group adopts high directional drilling with diameter ofφ193, while other mines such as Sihe Mine of Jinmei Group, Fenxi Group, Hecuo Group, China Coal Xinji and other groups all adopt high directional drilling with diameter of φ153. The construction process is after the directional drilling hole top120, the hole expansion top153 / φ193 drilling process.

2.3 Selection of drilling depth

Because the falling zone is a porous medium, the natural movement speed of the gas distribution is slow, so the depth of the borehole is required to increase the efficiency of the gas contacting the hole wall. The drilling depth will affect the distance of the invalid drilling section. In order to draw out more gas, after the drilling line, at least the boundary between the center of the fissure zone or the zone and the compaction zone should be extended. The minimum drilling length calculated according to the dividing line is:

$$L = \frac{(1.5h + a + h_1)(w + l - h_1 \cot \beta + h_1 \tan \alpha)}{(w - h_1 \cot \beta + h_1 \tan \alpha) \sin \theta}$$  \hspace{1cm} (5)

$$\theta = \arctan \frac{1.5h + a + h_1}{w + (1.5h + a) \cot \beta + h_1 \tan \alpha}$$  \hspace{1cm} (6)

Where: $h$ is the mining height of coal seam (m), $h_1$ is the height of the coal seam roof (m), Width of the $w$ coal...
pillar along the inclined plane (m). The 1 is the period step (m), f is fall (°), α is coal seam inclination (°), β is the angle (°) of drilling hole and coal seam tendency.

According to the analysis of the gas extraction situation of ZYWL-6000DS directional drilling rig in [19] high mazhuang Mine, the gas extraction effect is significantly improved after 16-20 meters. With the excavation of the mining face, the distance between the borehole deep and the cracks gradually increases, and the effect of gas extraction continues to increase. With the increase of time, the content of the gas enrichment area in the fissure zone decreases, and the gas extraction in the drilling hole reaches the peak and gradually decreases. In the later stage, with the advance of the mining surface, the formation of new cracks will permeate the new free gas, making the high borehole flow out into a balance state. However, when the hole collapse phenomenon occurs in the borehole, the gas content extracted in the hole will decrease sharply. Therefore, the construction of deep holes requires more on the geological conditions of the coal mine, the skills of the boreand the performance of the drilling equipment. At present, the group mine uses high directional drilling for gas control in the upper corner, the depth is mostly 450-500m.

3 Construction cases of high-level and large-diameter directional drilling

In order to solve the problem of high large diameter directional hole, Chongqing Research Institute of China Coal Science and Industry Group Co., Ltd. launched three types of large diameter directional drilling rigs, namely ZYWL-6000DS[20], ZYWL-13000DS and ZYWL23000DS[21] drilling rigs in various coal mines and achieved good results. The technical parameters of the three drilling RIGS are shown in Table 1. Unlike traditional conventional rig, directional rig will form a complete set with drilling measurement system, make inclined bits, track display computer for real-time drilling trajectory control, with the drilling measurement system is in the process of the drilling of the orientation, inclination Angle, tool for Angle and other technical parameters of equipment[22], the mainstream use wired with drilling measurement system and wireless mud pulse with drilling measurement system.

<table>
<thead>
<tr>
<th>parameter</th>
<th>ZYWL-6000DS</th>
<th>ZYWL-13000DS</th>
<th>ZYWL23000DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated output torque/(N·m)</td>
<td>6000~150 0</td>
<td>13000~3000</td>
<td>23000~4000</td>
</tr>
<tr>
<td>Rated output speed/(r/min)</td>
<td>50~210</td>
<td>45~150</td>
<td>35~110</td>
</tr>
<tr>
<td>Advance / pull out force/kN</td>
<td>170/220</td>
<td>280/280</td>
<td>400/400</td>
</tr>
<tr>
<td>Advance / pull up trip/mm</td>
<td>850</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Final hole diameter/mm</td>
<td>93/133</td>
<td>120/153</td>
<td>153/193/300</td>
</tr>
<tr>
<td>Main motor power/kW</td>
<td>55</td>
<td>132</td>
<td>200</td>
</tr>
</tbody>
</table>

3.1 Drill-accompanying measurement system

The wired drilling measurement system is to connect the measurement system to a random computer through a special cable drill bar to transmit data. Traditional drilling measurement device adopts the built-in large capacity rechargeable nickel metal hydride battery [23], each charge need to take the measurement system from the hole, increase the working hours, China coal Chongqing research institute developed using the cable drill rod signal transmission line for power supply new type with the drilling measurement system, effectively overcome this problem.

Mud pulse technology is gradually mature new technology in recent years, the equipment abandon the traditional directional drill pipe cable, using drill medium can transfer pulse signal to know the drill azimuth, tool Angle information, the system for battery power, to save electricity, in normal drilling operations for sleep. When need for azimuth determination, stop drilling, awaken the measurement system through a pulse signal, then open the mud pump to detect the system orientation information, finally close the mud pump, the system will seal some water in the drill pipe, through the part of the water signal to the sensor on the braid, decoding after display location information on a random computer. At present, Chongqing Research Institute and Xi'an Research Institute of China Coal Science and Industry Group have mature solutions[24-25].

3.2 Construction cases of Shuangliu Coal Mine

Shuan gliu Coal Mine is affiliated to Shanxi Coking Coal Fenxi Mining Group, located in Mengmen Town, Liulin County. The mine is rectangular and covers an area of about 29.6km². Since the construction of the mine in 1998, the current output is 3 million tons / year.

The drilling rig serving the mine is ZYWL-13000DS directional drilling rig, which is standard with BC480 pump truck, mud pump flow reaches 480 L/min, ZS21500 drilling measurement system, directional drilling φ120mm, reaching the final hole φ153mm through one hole expansion, the drilling efficiency is higher than that of ZYWL-6000DS.

The construction site is 33 (4) 13 working face in the third mining area of Shuangliu Coal Mine, the working face length is 1673m, the tendency length is 201m, the gas emission is 14-26 m³/min, and the average thickness of coal seam is 3.56m. The coal seam is directly topped by gray-black mudstone, horizontal bedding, homogeneous, semi-smooth, about 3m thick. The old top is gray black medium grain sandstone, semi-hard, horizontal bedding, thickness of about 3.23m. Above the old top is mostly gray medium grain sandstone, mainly quartz, feldspar, hard texture.

According to the operation requirements, design 4 large diameter directional boreholes with horizontal spacing 1m, inclination 9, diameter 153mm and depth 300m. The 1 # hole is 26m from the coal seam roof, bending length 168 and horizontal length 132. 2 # hole is 28m from the coal seam roof, the bending length is 162m and the horizontal length is 138m. The 3 # hole is 30m
away from the coal seam roof, the bending length is 156m, and the horizontal length is 144m. The 4 # hole is 30m away from the coal seam roof, the bending length is 150m, and the horizontal length is 150m. The drill hole trajectory map is shown in Figure 3.

(1)Drilling hole drift up and down

(2)Track diagram of left and right offset of borehole

Figure 3. Drilling track of Shuangliu mine.

All boreholes were compared by high and low negative pressure extraction system and observed for 40 days. The purity performance of gas in each hole is shown in Figure 4:

Figure 4. Comparison of suction negative pressure and gas purity of each hole.

It can be seen from Figure 5 that the purity of gas has been maintained below 0.5%, so it can be judged that the hole does not play the role of gas extraction. Figure 5 shows the total purity volume of large diameter drilling on the high roof compared with that of high extraction roadway.

Figure 5. Comparison of gas drainage effect.

As can be seen from Figure 5, in the case of a failure of the high roof directional drilling, the difference between the total amount of gas extraction and the high roadway is also maintained at 2 m³/min, which proves the feasibility of the large diameter directional drilling rig of the high roof replacing the high roadway. See Table 2 for the economic comparison of high-rise directional long hole, through hole and high mining roadway.
Table 2. Economic comparison of high-level directional long hole, common hole and high extraction roadway.

<table>
<thead>
<tr>
<th>High-level directional long drilling hole</th>
<th>Ordinary drilling</th>
<th>High lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal lane drill yard 5×3.4×9m</td>
<td>Coal lane drill yard 4.5×3.4×4m</td>
<td>rock gangway 2.7×2.6×300m</td>
</tr>
<tr>
<td>Φ153mm 4 boreholes with a total of 1200m</td>
<td>Φ 75mm drilled 50 holes totaling 5500m</td>
<td>300m gun digging rock roadway</td>
</tr>
<tr>
<td>4 People / class</td>
<td>3 People / class</td>
<td>About 10 people / class</td>
</tr>
<tr>
<td>360 Thousand</td>
<td>three hundred and ninety-seven thousand</td>
<td>one million, five hundred and thirty-four thousand</td>
</tr>
<tr>
<td>30 Days</td>
<td>50 Days</td>
<td>140 Days</td>
</tr>
</tbody>
</table>

4 Conclusion

Introduced the hole generation lane gap zone gas control theory, analyzes the influence of extraction drilling parameters, and introduces the roof mine case large diameter directional drilling construction technology, the conclusion proves that using roof high large diameter directional long drilling process instead of high roadway gas control is feasible, can effectively reduce the cost of gas mining, shorten the gas control cycle. The gas control results meet the requirements of "Coal Mine Safety Regulations", and it has a good application prospect for high drilling with large diameter directional rig.

Combined with the construction case, it can be seen that the reasonable construction level of directional drilling is 5-8 times the height of the roof. The drilling diameter should be constructed in the light of the actual capacity of the drilling equipment. The drilling depth is mainly affected by the current construction technology. In the case of no hole collapse, the gas extraction efficiency will be significantly improved after the drilling goes deep into the crack zone of about 20m. Combined with the quality of operators and drilling equipment, 500m-750m is a more reasonable construction depth for high directional drilling.

Each high drilling field generally has 4-5 holes arranged close to the return air side. The hole spacing is 10 m. It can achieve the problem of exceeding the gas concentration in the upper corner. The gas concentration in the upper corner after the extraction of high directional drilling is similar to that of high drainage lane and ordinary high penetrating layer drilling, but the cost is low, the time is short, and the benefit is remarkable.

References


