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Research Article

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Current Status and Development Trends of Coal Seam Gas Pressure Measurement Technology in China

Zhixiang Li

College of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo 454003, China

Abstract: China, as a global leader in coal production, relies heavily on coal mining as a cornerstone of its national economy. The precise measurement of coalbed methane (CBM) pressure serves as the funda-mental basis for all gas control strategies in underground operations. This critical parameter plays a vital role in ensuring effective mine gas management and operational safety. While extensive research has been conducted on various CBM pressure measurement methodologies with practical field applications, direct measurement techniques remain the most widely recognized and reliable approach in industrial practice. This paper presents a comprehensive analysis of current advancements, persistent challenges, and emerging trends in underground direct measurement technologies for coalbed me-thane pressure assessment. Particular emphasis is placed on technological innovations in measurement instrumentation, site-specific implementation challenges, and recent breakthroughs in data interpretation methodologies within complex geological environments.

Keywords: gas pressure; Direct method; Pressure measurement technology

1. Introduction

China is the world's largest coke producer, and China's coke output remained above 400 million tons from 2011 to 2020, of which China's coke output in 2020 was 471 million tons. At the same time, coal is the main energy source in China, accounting for about 62% of China's power generation industry. Coal plays a very important role in China's development.

However, the process of coal mining is often accompanied by dangers, and gas, as a by-product of coal mining, often causes disasters in the mining process. Nowadays, with the continuous use of coal resources leading to the increase of mining depth, the danger of gas to safety production is increasing, which makes it increasingly difficult to monitor and prevent daily work in coal mines, and coal seam gas pressure measurement is one of the most basic tasks in the process of gas prevention and control in each mine, and accurate pressure measurement results have far-reaching significance for the safety production of mines [1].

Coal seam gas pressure refers to the pressure presented by the free gas contained in the pores of the coal seam, that is, the pressure of the gas acting on the pore wall. Coal seam gas pressure is the driving force for gas gushing and protrusion, and it is also a sign of coal seam gas content. Accurate de-termination of gas pressure is of great significance for the effective and reasonable prevention and control of gas disasters in mines, the prediction and prediction of coal and gas outburst hazards, and the reasonable formulation of outburst prevention and elimination measures [2].

2. The Current Status of Coal Seam Gas Pressure Measurement Technology in Our Country

At present, a large number of studies have been carried out on the measurement methods of coal seam gas pressure, and the direct measurement method is considered to be the most common and reliable method [3].

For the direct determination of coal seam gas pressure, Chinese scholars have carried out a lot of research. Quan Hongxing [4] designed a new type of coal seam gas pressure measurement and sealing device by analyzing the main advantages and disadvantages and applicable conditions of the existing coal seam gas pressure determination and sealing technology and determined the sealing process with pressure. Tong Yanjun [5] and Li Zhiqiang et al. [6] studied the complex geological conditions in the deep part of the mine and the influence of fracture water often encountered in the process of gas pressure measurement and proposed a new sealing process to measure coal seam gas pressure. In order to ensure the accuracy of the gas pressure measurement results, Chen Xuexue et al. [7] adopted the through-bed borehole pressure measurement technology of the designed high-level drilling site to di-rectly measure the coal seam gas pressure and analyzed the accuracy of the test results. Zou Yongwei [8] determined the theory of coal seam gas pressure recovery curve and the calculation method of calculating coal seam gas pressure by using coal seam gas pressure recovery curve according to the theory and method of maturity of pressure recovery curve in oil and gas wells, combined with coal seam gas occurrence and geological conditions. Wang Chaojie et al. [9] theoretically analyzed the in-fluence of the radius of the pressure measurement borehole and the depth of coal entry on the time required for gas pressure measurement. Wu et al. [10] believed that the release of gas from the coal seam had a certain impact on the determination of the original pressure of coal seam gas during the period from the time of drilling to the sealing of the hole and the installation of the pressure gauge. Cui Zhengzhong [11] studied the active gas manometry technology under the mucus sealing method of capsule pressure and found that the time was shortened by 50% compared with the passive manometry. Cui Yongjie, Wang Zhaofeng et al. [12] carried out a feasibility study on the technology of coal seam gas pressure without sealing holes, and the technology of coal seam gas pressure without sealing holes is not limited by the test site and sealing process, which provides a fast and reliable new way for the determination of the original gas pressure in coal mines, especially the residual gas pressure in coal seams after taking gas treatment measures.

The direct measurement technology of gas pressure corresponding to the direct measurement method refers to the pressure measurement method adopted by designing a reasonable pressure measurement scheme when the conditions of the mine roadway permit, and then using a drilling rig to construct the pressure measurement borehole in the rock roadway or coal roadway, and using reliable sealing materials and pressure measuring instruments to determine the coal seam gas pressure [13]. The most critical method in the direct pressure measurement process is "hole sealing", which mainly includes yel-low clay hole sealing, grouting (cement mortar, cement slurry, chemical materials) hole sealing, rubber ring sealing, capsule sealing, rubber ring (capsule)-pressure mucus (three-phase foam) sealing, polyurethane-pressure mucus (three-phase foam) sealing, etc. [14].

The direct determination method is to drill a hole into the coal seam from the rock roadway or coal roadway, and then use the sealing material and manometer to determine the coal seam gas pressure. According to the different positions of borehole openings above and below the well, the direct manometric method can be divided into two categories: geological exploration borehole pressure measurement and downhole borehole pressure measurement.

Ground exploration borehole pressure measurement

The KZWY91-1000 borehole coal seam gas pressure tester developed by the Hunan Coal Research Institute makes it possible to accurately determine the coal seam gas pressure [15]. The manometer is mainly composed of three parts: a sealing mechanism, a pressure relief mechanism and a pressure gauge. The sealing mechanism consists of a set (3) of clamping partitions between the cartridges and stringing them on the core tube. Its function is to expand the rubber cylinder under the weight pressure of the drilling tool after the pressure of the pressure measuring instrument to the bottom of the hole and isolate the mud above and below the rubber cylinder. The pressure relief mechanism is composed of piston couples, pressure relief springs and pressure relief cylinder couples. Its function is to promote the action of the pressure relief mechanism to relieve the pressure state of the lower sealing mud under the drive of mud pressure. The manometer is mainly composed of a clock, a recording system and a pressure sensing system. Its function is to transmit the coal (reservoir) pressure to the recording system through the sensor and draw a pressure curve [16].

The instrument can be directly connected with the coal geological exploration drilling tool, and the schematic diagram of on-site pressure measurement is shown in Figure 1.

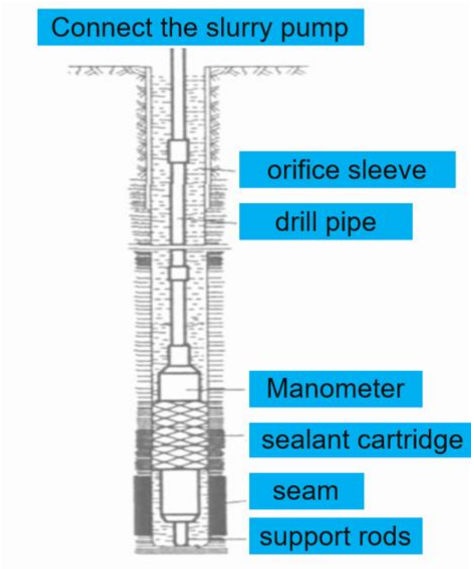

Figure 1: Schematic diagram of the field test

From 1989 to 1999, the instrument was used to test the gas pressure of 40 boreholes in 40 boreholes in 10 mining areas, and some valuable gas pressure parameters were obtained. However, due to the influence of subjective and objective factors (such as the integrity of the hole wall rock and the lithology of the coal seam roof, the slope of the hole, the diameter of the hole and the thickness of the coal seam, etc.), the success rate and reliability of the pressure measurement are not very high.

The ZY-73 borehole gas tester developed by Li Zizhang [17] et al. adopts a new electronic pressure sensor, and combined with the characteristics of borehole measurement, the drilling tool loaded with pressure sensor is innovatively designed, which better solves the problems of drilling tools that are not under the bottom and easy to induce accidents in the hole.

The instrument is composed of four mechanisms, including a sealing and torsion transmission mechanism, a discharge channel, a pressure relief mechanism, and a pressure gauge mechanism, as shown in Figure 2.

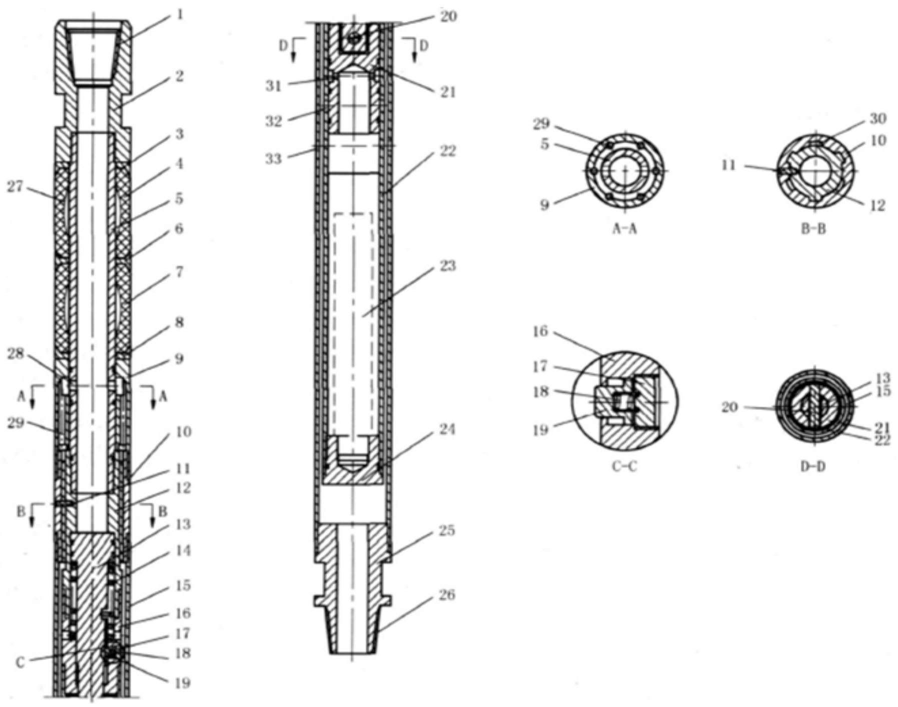

Figure 2: Schematic diagram of the structure of ZY-73 borehole coal seam gas pressure tester

The sealing and torsion transmission mechanism is composed of an upper joint 2, a central pipe 5, an upper positive ring 3, a rubber cylinder 4, an intermediate ring 6, a rubber cylinder 7, a lower positive ring 8, a spline sleeve joint 9, a spline sleeve 10, a shear pin 11 and a splined shaft 12.

The function is that when the drilling is blocked, the torque can be transmitted to the drill bit through the mechanism, and the blocked hole section can be expanded until it is smoothly lowered to the bottom of the hole, and then the rubber cylinder is expanded by the weight of the drilling tool or pressurized by external equipment, isolating the medium in the upper and lower hole sections. The mechanism avoids the need to drill and sweep the hole again when the drilling is blocked, so as to achieve the purpose of not lifting the drill in the middle, reduce the auxiliary time of measuring pressure, and improve the efficiency of measuring pressure.

The discharge channel is made up of a discharge hole 28, a discharge hole 29 and a discharge channel 30. In the process of drilling or lifting, the mechanism effectively discharges the water or mud in the hole, eliminates the back pressure effect when drilling, the suction effect when drilling, reduces the damage to the hole wall, makes the work more reliable, and reduces or avoids the accident in the hole.

The pressure relief mechanism is made up of a piston 13, a spring 14, an outer tube 15, a piston cover 16, a check screw cover 17, a check spring 18, a check pin 19, a suspension pin 20, a sealing short joint 21, an inner tube 22, a sealing end cover 24, and a lower joint 25. The function is to promote the action of the pressure relief mechanism under the drive of clean water or mud pressure and relieve the pressure state of the lower sealing mud.

The pressure gauge mechanism is composed of an electronic downhole manometer 23 and is arranged in the cavity composed of a sealing short joint 21, an inner pipe 22 and a sealing end cover 24. The function is to record the coal seam gas pressure with the change of time, improve the accuracy of coal seam gas pressure measurement, and shorten the time to read the pressure data.

Zeng Jianfeng et al. [9] used the ZY-73 gas pressure tester to analyze and summarize the test results of ZK0602 M1 coal seam gas in Xifeng County, Guizhou Province. They have been verified by the existing engineering, the structure and test principle of the ZY-73 coal seam gas tester are reasonable, the discharge channel eliminates the back pressure effect when drilling, the suction effect of drilling, the sealing and torsion mechanism can drill at low speed, and avoid drilling and sweeping holes under the resistance, the components of other mechanisms of the tester have good performance, the test success rate is high, and it is easy to use, and the consumables of the instrument are rubber sealing rubber cylinders and sealing rubber rings, so the cost is low, and it is suitable for the promotion and use of coalfield exploration, and the pressure gauge adopts the pressure gauge applied to the coalbed me-thane well test, with high sensitivity , large storage capacity, good working condition, never failed.

Downhole borehole pressure measurement

There are many ways to directly determine the gas pressure in coal seams using downhole drilling. According to the pressure measurement method, it can be divided into active pressure measurement and passive pressure measurement; According to the different sealing materials, it can be divided into yellow mud (clay) sealing method, cement mortar sealing method, rubber ring sealing device method, rubber ring-pressure mucus sealing method, capsule-sealing mucus sealing method, and polyurethane foam sealing method [18].

(1) Yellow mud, clay or cement mass sealing hole manometry method

The sealing material is semi-dry clay, yellow mud, cement mass or yellow mud-cement mixture with fine texture and plasticity, and the sealing method is manual operation. In order to make the borehole seal reliable, in the process of sealing the hole, a wooden plug can be driven into every 1m or so filled and tamped with a plugging rod. This manometry method is mainly suitable for the determination of gas pressure in Shimen coal mining.

(2) Grouting sealing manometry

This is currently the most widely used method of sealing holes, especially in the case of long drilling, generally tend to use this pressure measurement method. The sealing material is cement mortar or expansion and non-shrinkage cement slurry. The pressure measuring device includes a pressure measuring pipe, an inspection pipe, a grouting pipe, a grouting pump, a wooden wedge and a baffle. In the case of good construction conditions, it is also possible to do without the installation of the inspection tube, or even without the installation of the baffle.

(3) Rubber ring sealer manometry

The hole sealer is composed of an inner and outer sleeve, a retaining ring, a rubber ring, a pressure measuring tube and a pressure gauge. The basic principle is that when the compression nut is tightened, the outer sleeve moves forward to compress the rubber ring, so that the rubber ring expands radially to achieve the purpose of sealing the hole. This enclosed manometry technique is suitable for conditions where intact tight rock formations are present. When the No. 10 coal seam (outburst coal seam) was unveiled at the West 5 Shimen of the -550m level, the gas pressure of the coal seam was as high as 8.1MPa measured by a rubber ring sealer.

(4) Rubber ring (capsule) - sealing mucus sealing manometry

In the 80s of the 20th century, Professor Zhou Shining of China University of Mining and Technology invented a new type of hole sealing method - rubber ring-sealing mucus sealing hole manometry, the basic principle of which is "solid sealing liquid, liquid sealing gas". That is, the rubber ring is used as the sealing end of the closed high-pressure liquid, and the high-viscosity sealing liquid is injected between the two groups of rubber rings, so that it cannot only fill the space between the pressure measuring tube and the borehole wall, but also can penetrate into the natural cracks around the bore-hole and the cracks of the pressure relief ring, and play the role of tightly sealing the borehole. As long as the mucus pressure is always higher than the gas pressure in the pressure chamber inside the borehole, it is impossible for the gas to leak into the roadway, so that the accurate coal seam gas pressure value can be measured.

(5) Capsule-three-phase foam fluid sealing method

On the basis of capsule-sealing mucus sealing technology, Zhou Shining et al. proposed the use of solid-liquid gas three-phase foam fluid to replace mucus as the sealing material, and inject three-phase foam with higher pressure into the two sealing capsules, because the expanded foam liquid can completely fill the drilling space, and the ability to automatically plug the cracks is stronger than that of simple mucus, as long as the foam pressure is slightly higher than the gas pressure, the coal seam gas pressure can be quickly and accurately measured.

(6) Polyurethane foam-pressure mucus sealing manometry technology

The capsule-seal mucus sealing manometry method is costly, and the manometer can be reused, so Wang Yibo et al. proposed to use polyurethane foam instead of two capsules. Polyurethane foam is produced by the reaction of black and white material (with a towel wrapped inside) and its sealing manometry principle is exactly the same as that of the capsule-seal mucus sealing manometry. The application practice in Kangjiatan Coal Mine and other places shows that the pressure measurement technology is feasible, and its accuracy and reliability are similar to those of the capsule-seal mucus sealing manometry method.

(7) Capsule-cement slurry-polyurethane combined pressure grouting sealing hole pressure measurement [19]

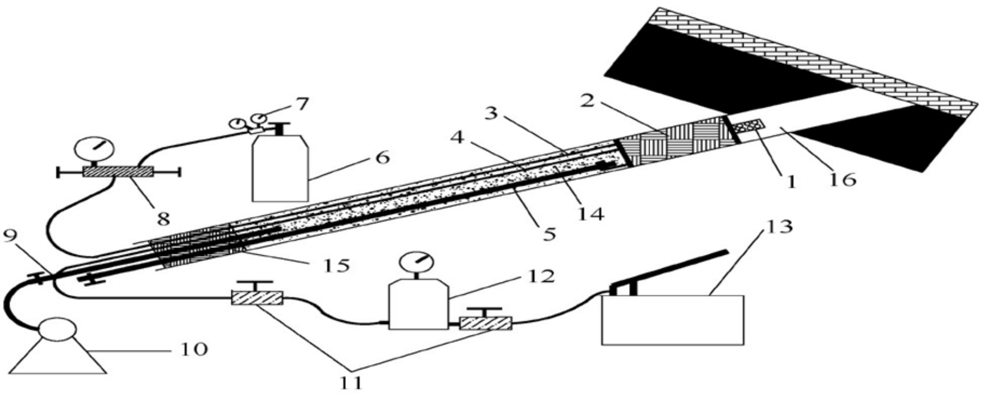

Figure 3: Capsule-cement slurry-polyurethane combined with pressure grouting sealing hole pressure measurement principle

1-Eye-draining this; 2-water-filled sealed capsule; 3-Tuns drainage; 4-water injection pipe; 5-four in charge; 6-nitrogen cylinder; 7 one minus pressure valves; 8-tee; 9-grouting pipe; 10-grouting pump; 11-shut-off upper valve; 12-an energy storage tube; 13-manual pressure test pump; 14- Water Slurry; 15 polyurethane; 16-pressure measuring chamber

The principle is shown in Figure 3. Here's how it works:

(1) first connect the water injection pipe and the pressure pipeline with the capsule, connect the four pipes with the pipe hoop welded on the capsule, send the capsule into the borehole to a certain depth with the four pipes, if the borehole is an elevation hole, the four pipes that send the capsule are left in the borehole as the return pipe of the slurry pipe, and then, then plug into the four pipes of the section as the grouting pipe; If the borehole is a depression hole, the four pipes of the capsule are used as the grouting pipe, and the four pipes of the -section are used as the slurry return pipe, and then the polyu-rethane is mixed evenly and quickly plugged into the orifice.

(2) After the orifice polyurethane is expanded and fixed, the water injection pipe is connected with the energy storage tank, and the energy storage tank is connected with the manual pressure test pump, and water is injected into the capsule with the manual pressure test pump to ensure that the capsule is al-ways in an expanded state.

(3) determine the amount of grouting material according to the sealing depth, and inject the cement slurry into the enclosed space between the polyurethane and the capsule in the borehole with a grout-ing pump; When there is cement slurry flowing out of the slurry return pipe, close the ball valve of the return pipe to continue grouting, and close the ball valve of the grouting pipe when the cement slurry pressure reaches the demand, and stop the grouting when the cement slurry pressure reaches the demand.

(4) After the cement slurry is solidified, the pressure measurement can begin.

The advantages of this method are that the sealing material is cheap, the operation is convenient, and the sealing length is deep, but the requirements for grouting pressure control and grouting stop timing control are relatively high, and the grouting material shrinks after solidification, and the sealing ability of surrounding micro-cracks is limited.

3. The Development Trend of Coal Seam Gas Pressure Measurement Technology in China

Combined with the applicable conditions and advantages and disadvantages of various pressure measurement methods, there are two main development trends of downhole drilling pressure measurement technology: one is cement mortar sealing hole pressure measurement, and the other is capsule sealing mucus sealing hole pressure measurement. In view of the fact that cement slurry sealing may leak due to the fact that the packing material is not filled with the upper part of the borehole or the cracks that occur after the cement solidifies, further research needs to be carried out on the performance of the sealing equipment and sealing materials. In terms of sealing materials, in addition to expanding cement, two-component or even multi-component sealing fluids, such as three-phase foam, can be considered, so that the multi-component sealing fluid can produce high multiple expansion through reaction after being injected into the borehole, and tightly seal and plug all cracks, which is expected to obtain better sealing effect. The research focus of capsule-seal mucus (or three-phase foam) sealing manometer technology is to further optimize the structure of the manometer, reduce the operation to simplify the operation, and improve the reliability of the manometer.

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