Experimental Research on In-situ Monitoring of Coalbed Methane Extraction Pipes in a Coal Mine Working Face

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Abstract. To study the stress and deformation characteristics of the coalbed methane (CBM) extraction pipe and to overcome the obstruction of the CBM extraction channel, an in-situ monitoring test of the extraction pipe was performed based on a coal mine working face in the Huainan mining area. According to the data of CBM overrun and field situation, the in-situ stress and deformation test of the CBM extraction pipes was designed and implemented, and the actual stress variation and deformation of the extraction pipe in the borehole was measured, which revealed the mechanical properties of the CBM extraction pipe as the working face advanced. The results show that the stress value of each measuring point increased as the working face advanced, and there was obvious stress concentration at the depth of 50 m. When the working face was ~35 m away from the test hole, there was a major increase in the stress growth rate. This work has guiding significance for the reasonable selection of CBM extraction pipes and optimization of extraction schemes in deep coal mines.

Keywords: In-situ monitoring; Coalbed methane extraction; Stress and deformation characteristics

1. Introduction
Coal is one of the primary energy sources around the world, and coalbed methane (CBM) is a valuable non-renewable source as a by-product of coal. As the depth of coal mining increases, the CBM content significantly increases [1]. CBM control is the prerequisite for safe and efficient mining in the mining area and is also a scientific and technical problem [2]. As the depth of coal mining increases, the CBM content and pressure of the coal seam gradually increase, and the danger on the working face rapidly increases [3–5]. CBM extraction is a paramount method for reducing CBM emission, preventing overrun and accumulation of CBM, and preventing CBM explosion. The extraction pipe is installed by drilling into the coal seam and the CBM storage region. It is connected to the special extraction pipeline, and the CBM is pumped to the ground with an extraction equipment. In recent years, the Huainan mining area is gradually shifting to deep mining. High geo-stress is a significant characteristic of deep formations. CBM extraction pipes are made primarily from polymerizing vinyl chloride (PVC). High geo-stress in the coal seam or stress concentration caused by mining disturbance can cause deformation or even closure of the extraction pipe, leading to obstruction of the CBM extraction channel. It is easy to cause CBM overrun and threaten production safety. Therefore, in-situ monitoring tests on the extraction pipe are essential to study the
characteristics of mechanical deformation. The results can provide theoretical support for the efficient extraction treatment of coal seam CBM.

Xiao et al. [6] studied the squeezing deformation failure characteristics of CBM extraction and established a ground-based drilling deformation failure model based on overlying strata in the stope. It provided engineering guidance for selecting and protecting hole locations for surface extraction drilling. Based on finite element theory and statistical damage theory, Zhang et al. [7] simulated the entire process of deformation and instability of mining boreholes in deep mining and analyzed the stress distribution and deformation, the evolution of pressure relief zone and permeability characteristics of coal body around the borehole. Shi et al. [8] studied the deformation characteristics of CBM extraction pipes during loading and unloading and obtained the distribution range of plastic zone and hole wall displacement curves under different loading and unloading stress change rates. Moreover, a calculation model of shear stress around the borehole was established based on the relationship between the stress change rate and the hole wall deformation. Wei et al. [9] used the theoretical and numerical methods to study the relationship between the effective radius of CBM extraction boreholes and hole wall deformation. Focusing on the coal permeability as the primary research object, a dynamic model of permeability considering the change of effective stress was constructed.

Most of the existing literature has studied the characteristics of the deformation and instability of the extraction borehole; however, no work has been performed on stress and deformation monitoring of the CBM extraction pipe. Based on a coal working face in the Huainan mining area, this study measured the stress and deformation law of CBM extraction pipe in the borehole and studied the deformation characteristics of the CBM extraction pipe as the working face advanced. It has guiding significance for the reasonable selection of CBM extraction pipes and optimization of extraction schemes in deep coal mines.

In the early morning of September 7, 2019, a high-value CBM overrun accident occurred on the working face. The accident investigation team concluded that the accident was a significant non-death liability accident because of insufficient CBM extraction in the area, which caused the CBM concentration exceeding 3% and a time exceeding five minutes. The direct cause of this accident is that during the mining of the working face, the coal wall spurs caused the CBM to flow out of the coal body. The primary reason is that the local CBM was enriched and the regional CBM extraction was insufficient. The secondary reason is that the coal seam of the working face was soft and broken, affected by the pressure of the mining cycle, and the coal wall leading flank caused insufficient safety risk identification of CBM overrun.

2. In-situ Monitoring Test of CBM Drainage Pipe

2.1. Engineering situation

In the Huainan mining area, the burial depth of a coal mine working face is 610 m, the cross-sectional shape is trapezoidal, and the mining trend is 2864 m. The measured maximum CBM pressure is 1.04 MPa and the maximum CBM content is 6.0 m3/t. The average daily coal production of the working face is 9230 t, and the CBM emission is expected to be 40 m3/min.

2.2. Determination of field test plan

The experimental plan was to drill a 50-meter deep hole from the working surface within a range of 65–75 m and install a CBM extraction pipe in the hole. It was equipped with stress and deformation monitoring instruments to test the stress and deformation characteristics of the extraction pipe during the working face advance. The pressure monitoring adopted a micro pressure box pasted on the extraction pipe surface, and the measuring range is 0–10 MPa; the deformation monitoring adopted the method of the pre-embedded endoscope through the intuitive image.

The CBM extraction pipe was composed of 1.5 m PVC pipes with inner diameters of 33 mm at each section. The drilling machine drilled 50 m along the layered hole, connected the PVC pipes end to end.
to form a long pipe, and slowly pushed it into the drill hole. The top three PVC pipes (with a total length of 4.5 m) were equipped with miniature pressure boxes at each intermediate position, and a miniature pressure box was placed in the middle of the extraction pipe at a position of 25 m to monitor the stress state. Moreover, a strain gauge was attached to both sides of the pressure cell at 90° at the first measuring point: one side was perpendicular to the axis direction of the extraction pipe, and the other side was parallel to the axis direction of the extraction pipe. The last three measuring points were pasted with strain gauges on the side 90° from the pressure box. The direction of the strain gauges was perpendicular to the axial direction of the extraction pipe, which was used to verify the stress condition of the extraction pipe measured by the pressure box in the early test stage. The outer ends of the pressure box and strain gauge wires were extracted of the drill hole, enclosed in a special protection box, and connected to a data acquisition instrument. The stress state of the extraction pipe was analyzed according to real-time data. Figure 2 shows the specific locations of the pressure boxes and strain gauges.

![Figure 1](image1.png)  
**Figure 1.** The specific location of pressure box and strain gauge

White paint was pre-sprayed inside the extraction tube to improve the quality of endoscope imaging. The endoscope, 6.5 mm in diameter was slowly pushed through the wire into the tube from the outside. This endoscope lens has its own illuminated light-emitting diode lamp, and the wire is connected to the external output electronic screen to visually observe the deformation state of the extraction pipe. The endoscope had a photo function, which can visualize the deformation of the extraction pipe according to the photo. Figure 2 shows the schematic of the endoscope monitoring device.

![Figure 2](image2.png)  
**Figure 2.** The schematic of the endoscope monitoring device

2.3. **Monitoring instrument layout**

Four extraction pipes were selected, three of which were placed at the forefront of the 50 m hole (Sections 1, 2, and 3), and the other at 25 m deep (Section 17). The four extraction pipes were numbered, and the painting work in the pipes was completed. The corresponding position on the extraction pipe had to be sanded before attaching the miniature pressure boxes. After the sanding was completed, the pressure boxes were glued to the sanding places of the extraction pipe, and the electrical conductor tape was finally used to fix the rear end of the pressure boxes. To prevent knocking and misalignment of the pressure boxes or even installation failure, wedge-shaped logs should be arranged at the front of the pressure boxes. The corresponding position of the extraction pipe had to be sanded before the strain gauges were pasted, the strong glue was placed uniformly on the strain gauges, and then the polyethylene was used to fix the corresponding strain gauges. When pasting, ensure that the selected strain gauge was 90° to the corresponding miniature pressure box, and the strain gauge direction should be perpendicular to the axial direction of the extraction pipe. The pressure box and strain gauge required to be wired after sanding. Considering the wiring protection, the tail wire was routed from the inside of the extraction pipe. The test instrument and joint parts had to be waterproofed using a waterproof silicone to avoid the influence of liquid water and water vapor in the coal seam hole during the testing process. The bridge resistance of the miniature pressure box is 350 Ω, and the bridge resistance of the strain gauges is ~120 Ω. According to this, each pressure box
and strain gauge were tested separately with an ohmmeter to ensure that the equipment and wires are in good condition. Figure 3 shows the layout of the monitoring equipment.

![Image](a) the pressure box was glued
![Image](b) the strain gauge was glued
![Image](c) Waterproof treatment
![Image](d) Wiring protection

**Figure 3.** The layout of monitoring equipment

### 3. Monitoring results and analysis

#### 3.1. Stress monitoring results

After summarizing the data, Figure 4 shows the stress curves of each miniature pressure box with the coal working face advances. As the coal working face advances toward the test hole, the stress value at each measuring point on the extraction pipe shows an increasing trend. The stress value of pressure box No. 1 is larger than the stress value measured at the later measurement points; moreover, the stress change trend of pressure boxes No. 2, 3, and 4 are the same, indicating that the stress concentration occurred close to the position of 50 m.

![Graph](a) No. 1
![Graph](b) No. 2
Figure 4. The stress curves of each miniature pressure box with the coal working face advances

3.2. Strain gauge deformation monitoring results

After summarizing the data, Figure 5 shows the strain curves of each miniature strain gauge with the coal working face advances. The positions of strain gauges No. 1, 2, and 3 correspond to the measuring point positions of pressure boxes No. 1, 2, and 3, respectively. In the early stage of the test, when the distance from cut eye to test hole is larger than 55 m, the deformation of the extraction pipe is small, the value measured by the strain gauge, and the pressure box can basically correspond in the change trend. When the extraction pipe was deformed to a certain degree, i.e., the distance from the cut eye to test hole is 20–45 m, the strain value measured by the strain gauge at each measurement point tended to be gentle, indicating that the strain caused by bending at this time remained stable. By mechanical tests, the elastic modulus of the extraction pipe was determined to be 3.5 GPa. Clearly, the peak strain measured by the strain gauges is 1000; therefore, the peak stress is 3.5 MPa, which is smaller than the stress measured by the pressure boxes in Figure 4. It is analyzed that in the later stage of the test, the extraction pipe was bent to closed and that the strain no longer increased while the mining stress was still increasing.
Figure 5. The strain curves of each miniature strain gauge with the coal working face advances

3.3. Endoscopic deformation monitoring results

The endoscope was used for examining the deformation of the extraction pipe during the test monitoring period. Figure 6 shows typical image data in three stages: pre-, mid-, and post-test. The shooting time corresponds to the distance from the cut eye to test holes of 75, 42, and 5 m, respectively. The visibility of the lens was reduced because if the significant deformation of the extraction pipe in front of the endoscope, then the invisible area becomes significantly larger. Comparing the initial and later images, in the beginning, the cable position of the extraction pipe moved directly from below to the left. According to this situation, it is inferred that the deformation of the extraction pipe was attributed to a large force in the upper right direction.

![Image](image.png)

Figure 6. Typical image data in three stages before, during, and after the test.

4. Conclusions

(1) The stress value at each measuring point of the extraction pipe increased as the working face advanced. When the coal working face was ~35 m away from the extraction pipe, the growth rate of the stress value of the extraction pipe was significantly accelerated.
(2) There was stress concentration close to the hole depth of 50 m, while there was no stress concentration at the hole depth of 25 m. The stress magnitude and change trend of the extraction pipes in the non-stress concentration area were consistent.
(3) The extraction pipe bends under confining pressure at the site that generates compressive stress first. When the deformation was very close to closing, the stress remained stable and changed to compression. When the extraction pipe was completely closed, the force was approximately equal to the stress value at this point.
(4) The upper right compression deformation of the extraction pipe was obvious, which was caused by a strong force in the upper right direction.
References

[1] Xie, H.L., Zhou, H.W., Xue, D.J., et al. Theory, technology and engineering of simultaneous exploitation of coal and coalbed methane in China[J]. Journal of China Coal Society, 2014, 39(08): 1391-1397.

[2] Yuan, L. Theory of pressure-relieved coalbed methane extraction and technique system of integrated coal production and coalbed methane extraction[J]. Journal of China Coal Society, 2009, 34(01): 1-8.

[3] Tezuka, K., Niitsuma, H. Stress estimated using microseismic clusters and its relationship to the fracture system of the Hijiori hot dry rock reservoir[J]. Engineering Geology, 2000, 56(1-2).

[4] Wang, Z., Liang, Y.P., Jin, H.W. Analysis of mechanics conditions for instability of outburst-preventing Borehole[J]. Journal of Mining & Safety Engineering, 2008, 25(04): 444-448.

[5] Zhai, C., Li, Q.G., Sun, C., et al. Analysis on borehole instability and control method of pore-forming of hydraulic fracturing in soft coal seam[J]. Journal of China Coal Society, 2012, 37(09): 1431-1436.

[6] Xiao, C.M., Li, J.H. Analysis of Coalbed methane Borehole Squeezing Deformation[J]. Coal Technology, 2011, 30(01): 109-112.

[7] Zhang X.B., Gao, J.L. Study on deformation characteristics of drainage borehole in soft coal seam with deep mining[J]. Journal of Safety Science and Technology, 2017, 13(08): 152-158.

[8] Shi, Z.S., Liang, B., Wang, Y., et al. Deformation characteristics of coalbed methane drainage borehole in loading and unloading[J]. Journal of China Coal Society, 2017, 42(06): 1458-1465.

[9] Wei, J., Wu S.Y., Wang F., et al. Study on relation between effective drainage radius of borehole and drilling wall deformation in outburst coal seam[J]. Coal Engineering, 2018, 50(07): 87-91.