

## Mathematical simulation and experiment of CBM detection

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### ABSTRACT

In order to accurately detect the underground Coal Bed Methane (CBM) accumulation in coal mining faces by mine radio wave perspective method, this study simulated the characteristic curve of received values through coal seams and discussed the feasibility of CBM. The experiments were conducted in Chinese mines. The study concluded that the existence of CBM could cause abnormal areas. Compared to the normal reception curve, the abnormal curve of CBM showed a much smaller value, and the attenuation was larger in the middle area and smaller on both sides. The pattern formation was a "saddle" shape. The radio wave penetration method could be a more reliable method for the detection of CBM in underground coal mines.

Coal Bed Methane (CBM) has a great influence on the normal production of coal mines. When coal mines are enriched there is a chance of explosion. Mining methods have changed in order to avoid this. Coal and CBM total mining technology is a main research direction for coal mines in China. The distribution of CBM is irregular and the physical parameters of CBM are not obvious, therefore, research into CBM detection technology and equipment is difficult. At present, there exists no effective method to detect CBM in the working face of coal mines in China. Previous studies have not been concerned with radio wave instrument detection through CBM. There has been no research on the characteristic curve perspective of radio waves for CBM detection. For the present study, the authors conducted curve theory perspective detection on radio waves through CBM using mathematical simulation tools, combined with coal mine experiments to verify the reliability of the theoretical analysis in order to make reference for similar mines.

### 1. THE BASIC PRINCIPLES

Mine radio wave perspective is used to detect various geological formations through two tunnels. The transmitter and receiver are located in different tunnels. The transmitter is in a relatively fixed position within a predetermined time and the receiver received field strength values are within a certain range (Liu et al., 2014; Wan et al., 2011) point by point, as shown in Figure 1.

Assume that the radiation source midpoint O is the origin, in the approximately uniform and the same nature seam, the distance from the observation point P to the point O is  $r$ , electromagnetic field strength at

point P  $H_p$  is represented by (Liang et al., 2009; Liu et al., 2012; Li et al., 2011; Wu, 2002):

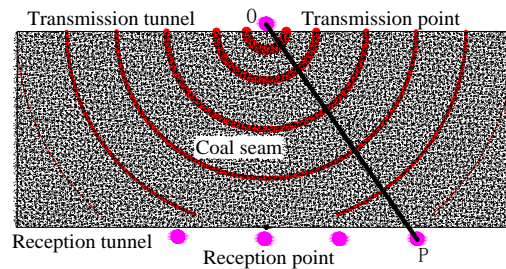


Figure 1: Schematic diagram of radio wave tunnel perspective instrument.

$$H_p = H_0 \frac{e^{-\beta r}}{r} f(\theta) \quad (1)$$

In formula (1),  $H_0$  is the initial field intensity around the antenna seam at a certain transmission power, A/M.  $\beta$  is the coal absorption coefficient of electromagnetic waves.  $r$  is the straight-line distance of P point to O point, m.  $f(\theta)$  is the directivity factor.  $\theta$  is the angle between the dipole axis and the direction of the observation point, which is generally used to calculate  $f(\theta) = \sin(\theta)$ .

According to the literature (Liang et al., 2010), take  $\ln(H_p) = H'_p$ ,  $\ln(H_0) = H'_0$ :

$$H'_p = H'_0 - \beta r - \ln(r) \quad (2)$$

$\ln(r)$  is little change in the formula (2), it can be approximated that formula (3) is the slope of the straight line  $-\beta \cdot H'_p$  and  $r$  are considered to have an approximately linear relationship.

## 2. MATHEMATICAL MODELLING STUDIES OF CBM

According to most of the coal mining face features in China, the length of the tunnel model was 500 m, and width was 200 m. The transmission point was below the midpoint in the tunnel, with the tunnel below the midpoint as origin  $O(0,0)$ , as shown in Figure 2. According to the experience of underground exploration,  $H'_0$  was generally in the 110-155 dB range, and the  $\beta$  varied between 0.2 and 0.55. Most simulation parameters were selected as coal mine normal physical parameters.

Here  $H'_0 = 130\text{dB}$  and normal seam  $\beta = 0.3$ .

According to formula (3), the change in  $H'_p$  with  $r$  can be simulated.

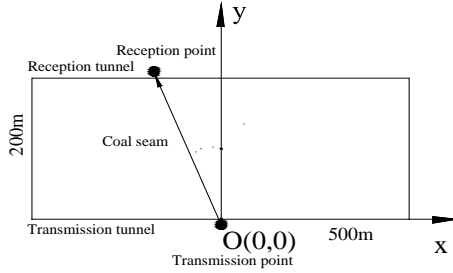


Figure 2: Normal coal seam simulation model.

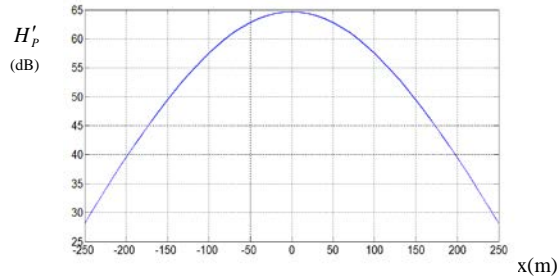
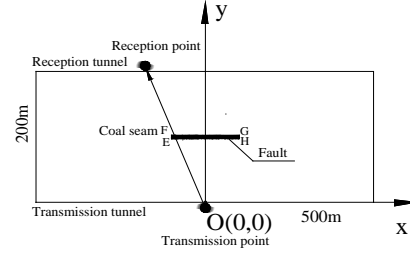


Figure 3: The reception value changes of abnormal cases.

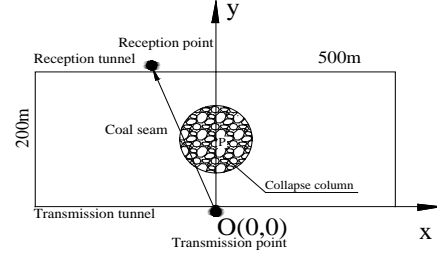
In the normal case, coal seam function was  $F(x,y) = \{-250 \leq x \leq 250, 0 \leq y \leq 200\}$ . According to formula (2), when the reception points moved in a straight line, we had:

$$H'_p = \begin{cases} 130 - 0.3\sqrt{x^2 + y^2} - \ln\sqrt{x^2 + y^2} \\ (y = 200, -250 \leq x \leq 250) \end{cases} \quad (3)$$

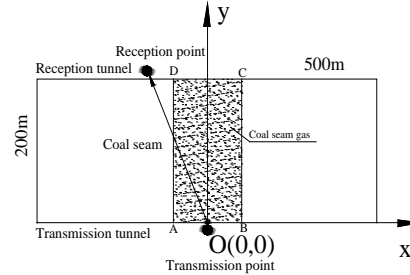
According to formula (3), using the MATLAB simulation, the field-strength curves of the normal coal seam reception values were found, as shown in Figure 3.



4-a Model of a fault



4-b Model of a collapse column



4-c Model of CBM

Figure 4: The simulation model of various abnormal cases.

**Impact of fault simulation:** To simplify the calculations, the intermediate simulation model was a fault with a fault length of 100 m and distance of 5 m (Figure 4-a). The attenuation coefficient of the fault was  $\beta = 0.5$  and changes on the fault model abscissa were  $x: -50 \sim 50$ , ordinate  $y: 100 \sim 105$ . Fault function was  $F_1(x,y) = \{-50 \leq x \leq 50, 100 \leq y \leq 105\}$ . When electromagnetic waves went through the fault:

$$H'_{pf} = \begin{cases} 130 - 0.3\sqrt{x^2 + y^2} - \ln\sqrt{x^2 + y^2} - 1 \\ (y = 200, -100 \leq x \leq 100) \end{cases}$$

**Impact simulation of collapse column:** A circular collapse column was in the middle of the model (Figure 4-b). The attenuation coefficient was  $\beta = 0.5$  and the radius was 50 m. The circular collapse column equation was:  $x^2 + (y - 100)^2 = 2500$ .

**The function of collapse column:**  $F_2(x,y) = \{x^2 + (y - 100)^2 \leq 2500\}$ . When electromagnetic waves went through the collapse column:

$$H'_{pcc} = \begin{cases} 130 - 0.3\sqrt{x^2 + y^2} - \ln\sqrt{x^2 + y^2} - \\ 0.4\sqrt{50^2 - [100\sin(\arctg \frac{x}{y})]^2}, (y = 200, -\frac{200}{\sqrt{3}} \leq x \leq \frac{200}{\sqrt{3}}) \end{cases}$$

Impact simulation of CBM: CBM was located in the middle of the model (Figure 4-c). The attenuation coefficient was  $\beta=0.5$ . The influence scope of CBM was:  $-50 \leq x \leq 50$ ,  $0 \leq y \leq 200$ . CBM function:  $F_3(x,y) = \{-50 \leq x \leq 50, 0 \leq y \leq 200\}$ . When the electromagnetic wave through the CBM:

$$H'_{P_{wz}} = \begin{cases} 130 - 0.3\sqrt{x^2 + y^2} - \ln\sqrt{x^2 + y^2} + 10\sqrt{x^2 + y^2} / x, \\ y = 200, -250 \leq x < -50 \\ 130 - 0.5\sqrt{x^2 + y^2} - \ln\sqrt{x^2 + y^2}, \\ y = 200, -50 \leq x \leq 50 \\ 130 - 0.3\sqrt{x^2 + y^2} - \ln\sqrt{x^2 + y^2} - 10\sqrt{x^2 + y^2} / x, \\ y = 200, 50 < x \leq 250 \end{cases}$$

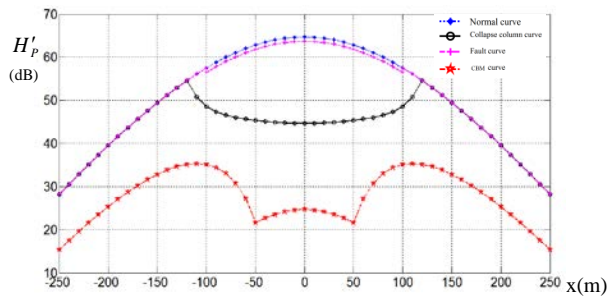


Figure 5: The reception value changes of various abnormal cases.

Based on the above abnormalities, the comparison diagram of various abnormal conditions could be simulated, as shown in Figure 5. With respect to the reception value for normal seam, the fault curve was relatively gentle; however, the received values were significantly decreased at the fault. The values of the collapse column curve were gradually smaller, and then gradually became larger. In contrast, the values of the CBM curve were small, further intermediate region attenuation was larger, and the sides relative attenuation were relatively smaller, forming a "saddle" shape. Therefore, under the conditions of CBM the reception value of radio wave perspective was significantly decreased, and curves showed the overall attenuation characteristics, a typical characteristic of CBM. The conclusion of this curve has been verified in the thesis of Dr. Wu Yanqing (2002), and has also

been verified many times in actual detection experiments.

In the actual detection process, due to the influence of other factors, changes in the data might not be in strict accordance with this rule, but the basic trend is substantially the same.

### 3. EXPERIMENTAL STUDY ON CBM

Yanmazhuang mine had a CBM enrichment phenomenon in Henan Province of China, which brought some difficulties to the production and safety of coal. In order to discover the enrichment of CBM the coal seam was detected.

The coal seam thickness of 27131 working face was 5.9-6.5 m in Yanmazhuang mine, the length was 370 m, the inclination was 110 m, and the average dip angle of the coal seam was  $5^\circ$ . To ensure the penetration distance and detection accuracy, a frequency of 0.5 MHz was chosen and the fixed point scanning method was selected. The reception points space was 5 m and the transmission point space was 50 m. The results of the survey are shown in Figure 6, from left to right of the upper roadway: 800 to 895, from left to right of lower roadway: 200 to 274. Through the computer data processing, two more concentrated anomaly areas were drawn and numbered the no.1 and no.2 areas. The detected anomaly areas colour was mainly gray and black.

No.1 abnormal area: The abnormal area was located in the right of Figure 6 and was the largest area of electromagnetic wave attenuation. Combined with coal mine geological data, there was no large geological structure. Coal gas content was 16-18  $\text{m}^3/\text{t}$ , therefore, the anomaly analysis was mainly caused by the change of gas concentration, and this area was a coal and gas outburst danger area.

No.2 abnormal area: The abnormal area was located in the left of Figure 6. The coal gas content in this area was relatively low, at 3-4  $\text{m}^3/\text{t}$ , but there was a large F147 fault. Therefore, the regional anomaly was mainly caused by large faults, which was not in danger of outburst.

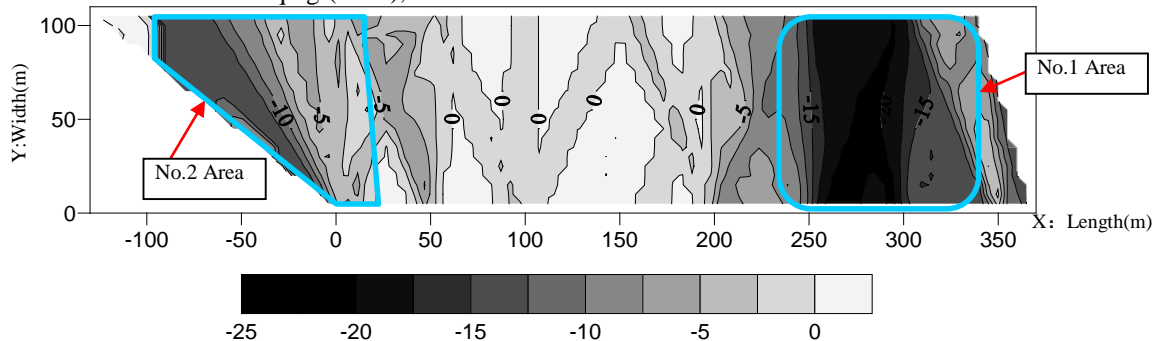


Figure 6: Radio wave penetration result map of 27131 working face in Yanmazhuang mine.

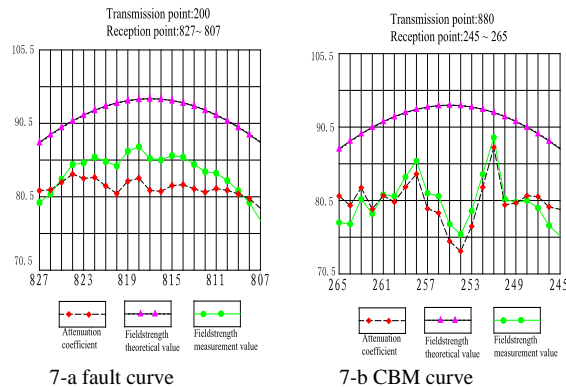


Figure 7: Typical curves of CBM and fault in mine.

The typical curves of Figure 7 were analyzed. Figure 7-a was a variation of the fault curve. The coordinate of transmission point number 200 was (x:0, y:0) in Figure 6, and the coordinate of reception point number 807-827 was (x: -100-0, y: 110) in the vicinity of the No.2 abnormal area. The measurement curve was below the theoretical curve in Figure 7-a, and the basic form was similar to the theoretical curve. It was in line with the change of the abnormal fault curve in Figure 5.

Figure 7-b was a variation of the CBM curve. The coordinate of transmission point number 880 was (x:265, y:110) in Figure 6, and the coordinate of reception point number 245-265 was (x: 225-325, y: 0) in the vicinity of the No.1 abnormal area. From the CBM curve, the measurement curve was below the theoretical curve. The curve changed from relatively flat at the beginning to a more rapid decay, and then quickly climbed to the initial value. The characteristic of the measurement curve was in agreement with the theoretical curve of Figure 5. The existence of a gas enrichment zone in the area was described, and it was also proven that the curve of the simulation was correct.

#### 4. CONCLUSIONS

Because of the differences between CBM and normal coal seam, the exist of CBM made the electromagnetic wave refraction, reflection and absorption vary. The CBM could be seen as a loss of electromagnetic energy, therefore CBM could cause abnormal erosion areas on radio wave perspective. After the scene of the experiment in coal mine, radio waves perspective method could be more reliable to detect CBM. In the actual detection process, changes in the data were affected by other factors, which would not change in strict accordance with this law, but the basic trend was roughly the same. This required a

comprehensive analysis based on the analysis of the data.

From the simulation analysis of the radio wave perspective curve, with respect to the reception value for a normal seam receiver, the values of CBM curve were smaller. The values for attenuation were bigger in the middle region and smaller in the side edge, forming a 'saddle' shape. Therefore, in the conditions of CBM, the reception value of radio wave perspective was significantly decreased and the curves showed a large area of overall attenuation characteristics typical of CBM.

Detection and qualitative analysis of CBM enrichment area by radio wave perspective method broke through the blind zone of the CBM accumulation area, filling a gap in the research. The technology of underground CBM detection has strong practical significance for safe production in coal mines.

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