Research on hidden fire source detection in goaf of Hengyi coal mine

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Abstract; Coal fires cause waste of coal resources, air pollution, and threaten the safe production of coal mines, but concealed fire source detection is difficult, and a single detection method has limitations, which makes it difficult to accurately determine the location of fire source. In order to verify the detection effect of the composite detection method on the concealed fire source, according to the isotope radon detection method and magnetic detection principle, the proton magnetometer and radon meter were used to detect the hidden fire source detection area of Hengyi Coal Mine. According to the verification of subsequent anomalous area drilling, the results show that when detecting hidden fire sources, a variety of fire source detection methods can improve the accuracy and efficiency of fire source detection. The exploration and research in Hengyi Coal Mine has laid a solid foundation for the subsequent work of extinguishing coal fires, which is conducive to the safe production of coal mines.

1. Introduction

The effectiveness and practicality of the detection technology of spontaneous combustion coal seam ignition source has always been a topic of great importance in the field of coal mine safety, and after a lot of research and practice, a variety of detection technologies have achieved good application results, such as magnetic detection[1], radon detection[2] and so on. However, each method has certain limitations, in different geological conditions and fire source conditions, the detection accuracy can not be well guaranteed[3], therefore, a variety of detection technology combination, gradually become a common method of fire source detection[4.]

According to the appraisal report of Shaanxi Xi'an Coal Mine Safety Equipment Testing Center Co., Ltd. in June 2016, the coal seams 3^{-1} and 3^{-2} of Hengyi Coal Mine are Class I coal seams prone to spontaneous combustion, and a large amount of hot steam is found on the slope outside the coal washing plant, which may be caused by spontaneous combustion in the failure area of the old kiln of the 2# coal seam.

2. Principle of magnetic detection and radon detection

There are many types of coal spontaneous combustion fire source position detection technologies, such as magnetic detection, radon measurement, infrared thermal imaging, and other methods have a wide range of practicality, but each has certain application limitations[5]. Therefore, the combination of multiple methods, that is, to make up for their own shortcomings and repeat their respective advantages, is the method used more often for spontaneous combustion ignition sources in coal mines. In this paper, the magnetic detection and isotope radon detection method are combined to detect the position of the ignition source, and the working principle of the two methods is first studied here[6].

2.1. Principle of magnetic detection

There is a geomagnetic field around the Earth, which is distributed over a wide range, from the core to the edge of the space magnetosphere. Another part that makes up the endogenous stable magnetic field is the magnetic field generated by the magnetization of the basic magnetic field in the rocks, minerals and geological bodies in the earth's crust, which is called the crustal magnetic field or magnetic anomaly. Magnetic anomalies are the result of the action of paramagnetic, diamagnetic, and ferromagnetic substances[78]. Among them, the magnetic susceptibility of the diamagnetic substance is less than zero, and the magnetic susceptibility of the paramagnetic substance is greater than zero. Ferromagnetic substances have a large magnetic susceptibility, up to 10^4 orders of magnitude[10]. Studies have shown that the Ordos coal-forming basin, like many coalfields, has a large number of mineral components that can form ferromagnetic substances at high temperatures. Therefore, the high temperature fire zone will produce obvious magnetic anomalies.

In the early stage of spontaneous combustion, the magnetic susceptibility of coal rock was small, the value was $1.37\text{-}125.46\times10^{-5}$ SI,[11] and the temperature was low before it developed into the combustion period. Then when the combustion period is reached, the magnetic

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susceptibility of the coal rock suddenly drops to 0, and the intensity of the coal fire reaches its maximum. Then the cooling and extinguishing period is reached, the magnetic susceptibility of the coal rock suddenly increases, and then until the coal rock finally cools, the magnetic susceptibility of the coal rock after the fire remains at 149-155×10^{-5} SI[12]. Accordingly, by detecting magnetic anomalies at the surface, it is possible to analyze whether there are high temperature anomalies in the formation. Since magnetic anomalies are also affected by other factors, interference factors should be eliminated during exploration.

Magnetic induction intensity B describes the strength and direction of the magnetic field, and for isotropic magnetic media, the magnetic induction intensity (magnetic flux density) generated by the external magnetic field H at any point inside it is:

$$B = \mu H \quad (1)$$

where B is the magnetic induction intensity in Tesla (T) or nat (nT); μ is the magnetic permeability, or absolute permeability, of the medium in H • m^{-1}. If the medium is vacuum, there are:

$$B_0 = \mu_0 H \quad (2)$$

where $_0$ represents the magnetic permeability of the vacuum, is a constant with a numerical magnitude of μ_0= 4π ×10^{-7} H·m^{-1}, and in general, the relative permeability μ_r is used, which is defined as:

$$\mu_r = \frac{\mu}{\mu_0} \quad (3)$$

If the relative permeability of air (non-magnetic material) is 1.

In the range of the fire zone, there are two magnetic fields acting together on the area, one is the earth's magnetic field $\mathbf{B}_{earth}$, the other magnetic field is the magnetic field generated by the rock being baked at high temperature, which is recorded as $\mathbf{B}_{anomaly}$, and the vector superposition of these two magnetic fields forms the total magnetic field of the area, which is recorded as $\mathbf{B}_{total}$. The relationship is shown in Equation (4). In general, the Earth's magnetic field changes over time, and the magnitude of the change is small compared to the magnetic field caused by high temperatures. The magnetic field anomalies in a certain area are caused by high-temperature baking. Other conditions can also be caused, but the range is small and easy to distinguish. Therefore, the determination of the threshold is inseparable from the $\mathbf{B}_{anomaly}$, and the magnetic anomaly caused by the lowest temperature of coal combustion (or smoldering) is the threshold of the magnetic field in this area.

$$\mathbf{B}_{total} = \mathbf{B}_{earth} + \mathbf{B}_{anomaly} \quad (4)$$

From Figure 1, we can see the curve of the magnetic field strength of the rock mass as a function of temperature. In order to determine the threshold, it is also necessary to understand the natural warming process of the coal body. The strength of the magnetic field generated by the sudden point of coal warming is used as a critical point to divide the high temperature region.

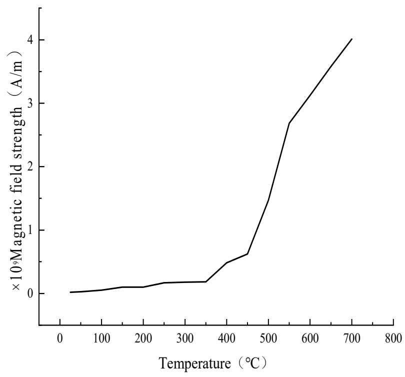

Figure 1 The strength of the magnetic field generated by the rock mass curves with temperature

2.2 Radon measurement principle

Uranium, thorium, actinide is the existence of three natural radiation systems in the spontaneous combustion world, because of its long half-life characteristics, it is often widely present as a parent nuclide in rock mass, soil, coal seam and other geotechnical media, which leads to a high content of radioactive isotopes in coal formations, uranium, thorium, actinide after decay are produced radon progeny, under the same geological conditions, when spontaneous combustion occurs in the coal seam, the radon rich in its interior and surrounding rock layers will be analyzed in large quantities, and the radioactive anomalies reflected to the ground are reflected in the action of ion exchange, This abnormal change can be detected by a certain detection instrument, and then after the calculation and analysis of the computer, the location and scope of the fire area can be known[9].

At present, the widely used radon measurement method has high applicability, and can usually measure the fire source at a depth of 800~1200 m. The precipitation and transport of radon is affected by mineral particle size, lithology, in-situ stress, groundwater, fracture degree of rock formation, ventilation state, temperature and other

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factors, of which temperature has a great influence on radon production, which is also the basis for radon detection of ignition source, for the influence of temperature on radon precipitation, Professor Wu Jianming of Taiyuan University of Technology has studied this, believing that the higher the temperature, the increase in radon precipitation, the specific radon precipitation and temperature change curve, as shown in Figure 2.

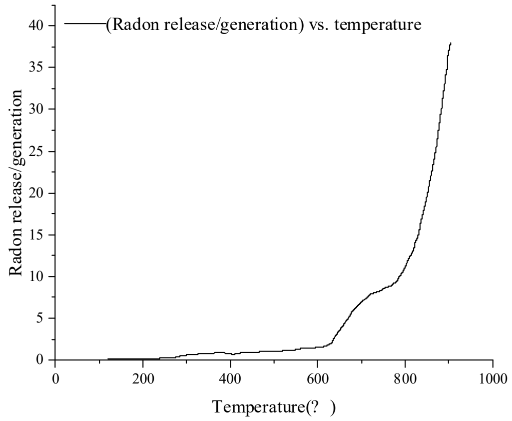

Figure 2 The amount of radon resolution varies with temperature

3. Fire location detection and analysis

Magnetic anomaly detection of the detection area using a proton magnetometer. Set the direction of the survey line to be roughly arranged in the north-south direction and east-west direction, with one measurement point every 10m. The measurement results were analyzed and integrated using the origin software to obtain Figures 3and 4.

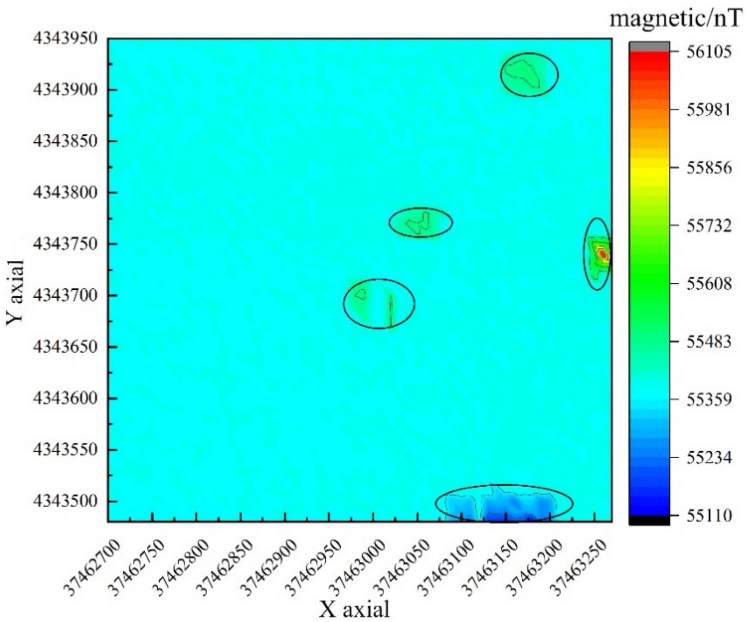

Figure 3 Floor plan of the overall magnetic outlier in the detection zone

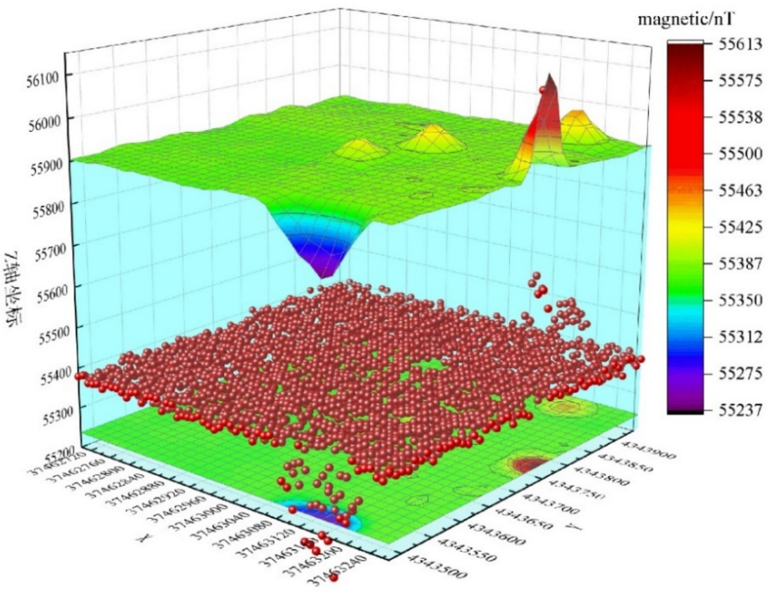

Figure 4 Stereogram of the overall magnetic outlier in the detection zone

After obtaining the anomaly area and coordinate points, radon method verification exploration was carried out on the magnetic anomaly area, radon measurement points were arranged every 10 meters, and the results of two exploration were comprehensively analyzed:

Combined with the results of magnetic detection and radon detection to judge the fire area, it can be seen from the figure that a total of five abnormal areas were detected, and the specific analysis is as follows:

(1) In the core coordinates of (37463256, 4343745) high magnetic anomaly area one, the magnetic field strength is 56105NT, radon method to detect this area, no radon method abnormality was found, it is speculated that there may be a long time of high temperature baking there, at this stage in the coal fire spontaneous combustion extinguishing period, the ferromagnetic material caused by coal combustion leads to large magnetic detection results, but a large amount of radon has been produced and released.

(2) In the low magnetic anomaly zone two with core coordinates (37463130, 4343480), the magnetic field strength is 55210NT, the magnetic change is obviously drastic, and the extension direction spreads along the slope, forming a magnetic anomaly area about 30m wide and 100m long, the radon method detects this area, no radon anomaly is found, the core coordinates of the magnetic detection are located on the comparison map of Hengyi coal mine, and it is found that the place is where the alley is located. It is speculated that the magnetic anomaly is the retromagnetism caused by the roadway metal support materials, the magnetic detection value is small, the radon method detection is not abnormal, and it is speculated that there is no spontaneous combustion phenomenon of coal seam in this area. The area can be drilled and validated at a later stage.

(3) In the high magnetic anomaly zone three with core coordinates (37462990, 4343680), the magnetic field strength is 55520NT, the magnetic change is obviously drastic, the maximum value of radon detection is 32Kbq, and there are both magnetic anomalies and radon anomalies, and the terrain of this area is a deep pit, and there may be spontaneous combustion of coal seams.

(4) The core coordinates are (37463040, 4343770) high magnetic anomaly region four, the maximum magnetic field strength is 55500NT, and the inflection coordinates of the anomaly range are (37463030, 4343760), (37463070, 4343760), (37463030, 4343780) and (37463070, 4343780), The terrain in this area is the gentle slope area at the upper left of the CO exceeding the standard during the water exploration and release process of the return wind and trough excavation face, and there is no abnormality detected by radon method, and it is speculated that there may be long-term high temperature baking there, and it is in the spontaneous combustion extinguishing period of coal fire at this stage.

(5) The core coordinates are (37463200, 4343930) of high magnetic anomaly region five, and the maximum magnetic field strength is 55510NT.

The inflection coordinates of the anomaly range are (37463150, 4343900), (37463190, 4343900), (37463150, 4343940), and (37463190, 4343940). After radon detection there is no abnormality, it is speculated that there may be a long time of high-temperature baking in the place, and it is in the spontaneous combustion extinguishing period of coal fire at this stage.

now be number 6.

4. conclusion

1) Through theoretical analysis, radon detection is achieved by detecting the abnormal area by detecting radon and its daughter body excited by high temperature. The detection method is due to the change of magnetism of the coal rock mass itself caused by the high temperature roasting of the coal rock mass, and the detection of the ignition source is realized by detecting the magnetic change. The two methods have their own advantages and disadvantages, and the combined use can better determine

the location of the fire area and improve the accuracy of detection.

2) After the composite analysis of the two methods of isotope radon detection and magnetic detection, spontaneous combustion of coal seam may exist at the core coordinates (37462990, 4343680).

3) Subsequently, we carried out drilling exploration in the anomalous area with core coordinates (37462990, 4343680), and smoke came out of the borehole, which fully verified the feasibility of the composite detection method. The two methods can complement each other and accurately locate the position and range of the ignition source

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