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Development of Intelligent Gas and Coal Seam Spontaneous Combustion Sensor Experiment Device Based on Analytic Hierarchy Process

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Abstract: Gas explosion and coal spontaneous combustion disasters exhibit a complex coexistence. This paper introduces the concept of intelligent sensor, working principle and characteristics. Analysis of the status quo of gas explosion and coal spontaneous safety accident, points out that gas explosion and coal spontaneous are main hazards. Summarizes the basic problems of the basic method of coal mine gas detection and the existing gas detection equipment, put forward the research method by combining the intelligent gas sensor technology and traditional gas detection technology. Based on the implementation of an analytic hierarchy process and related investigations, constructed a hierarchical analysis model that optimizes a comprehensive prevention, high-efficiency mining technology. The result showed CO volume fraction at the rear part of the chock of less than 10^{-5}, a gas volume in the upper corner of less than 0.5 % and a gas volume from the air return flow of less than 0.2 %. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Intelligent sensor, Gas explosion, Spontaneous combustion, Optimization, Analytic hierarchy process.

1. Introduction

Coal is the main source of energy in China and bears strategic importance in the energy structure of China; however, coal mining suffers from the serious threat of both gas explosions and coal spontaneous combustions, especially when the two threats coexist. According to the statistics, approximately 32.3 % state-owned key coalmines are at risk of a complex disaster involving both gas explosion and coal spontaneous combustion [1]. In addition, with the rapid development of mechanization and highly intensive coal mining, mining operations in China have entered the deep mining stage, which presents a more severe complex disaster threat involving both gas explosion and coal spontaneous combustion [2]. Currently, disasters involving both gas explosion and coal spontaneous combustion during the coal mining process exhibit diverse, complex and complicated trends; however, studies on the prevention and control technology remain limited to a single level of either a gas explosion or a coal spontaneous combustion, while studies on the complex forms of disasters and their common prevention schemes are very rare.

Gas detection method with electrochemical method, optical method, electrical method, gas chromatography and other kinds of electrochemical method is the use of electrochemical method for gas detection, the use of the electrode and electrolyte; optical method is the use of gas refractive index and optical absorption properties detection gas: electrical method is the use of gas sensors detect gas, mainly using semiconductor gas sensing device, which is suitable for the automatic, continuous process, widely used; gas chromatography is a kind of analysis method of chromatography [3]. Chromatographic analysis is a kind of separation, to the multi-component analysis tool, it mainly uses the physicochemical properties of material for the separation and determination of different the content of each component in the mixture. Gas detection element made the detection principle: the catalytic sensor, infrared sensor, optical fiber sensors.

Based on practical research studies, Zhou Fubao [4] proposed the multi-field convergence mechanism of gas explosion and coal spontaneous combustion and further suggested an appropriate complex disaster prevention technology. Qin Botao [5, 6] conducted a number of experiments that studied an explosive concentration range of a CH_4 and CO mixture, analyzed the potential area of gas explosion, which is determined by coal spontaneous combustion in the goaf, and proposed a new technology of nitrogen three phase. The two researchers conducted research to understand the complex disaster and provided theoretical and technical guidance for personnel in mining fields.

Due to deficiencies in terms of performance and stability, digital gas detection equipment of traditional gas sensors, resulting in the low measurement accuracy, measurement stability is poor, the zero drift phenomenon is serious, the calibration cycle is long, high maintenance cost, low degree of intelligent system, gas single gas sensor intelligent of alarm module there are also the problems. In order to solve the above problem, this paper will research and develop an intelligent gas sensor, which uses a plurality of gas sensitive element gas detection circuit, a microprocessor and both testing and information processing functions. Based on these studies, this paper analyzes the gas explosion and coal spontaneous combustion prevention technology and optimizes this technology using the analytic hierarchy process.

2. Form of Intelligent Sensor System

2.1. Review of Complex Disaster and Prevention and Control Technology

There are a variety of physical fields in the mining spaces, such as the void fields of tunnel and mining spaces; residual coal fields; gas, oxygen and temperature fields due to gas desorption and oxygen absorption; and, sometimes, local temperature fields formed by external ignition sources such as electrical discharge, blast, rock or metal material impact and friction. All of these physical fields dynamically change under coal seam mining turbulence and converge in space and time.

According to the working principle of catalytic element:

$$V_1 = \frac{Vr_2}{r_1 + r_2} \; V_2 = \frac{VR_2}{R_1 + R_2} \tag{1}$$

When there is a gas, catalytic element is in working condition:

$$V_1 - V_2 = \frac{V(r_2 + r)}{r_1 + r_2 + r} - \frac{V}{2} = \frac{V}{2} \bullet \frac{r}{r_1 + r_2 + r} \tag{2}$$

$$y = A\frac{x}{B + x} \tag{3}$$

The complex disaster of both gas explosion and c oal spontaneous combustion is the result of dynamic convergence in time and space of certain physical fiel ds. Therefore, to prevent such a complex disaster, the key is to minimize the void fields, residual coal fields and the gas, oxygen and temperature fields so that th ere is no convergence among them. Currently, coal se am spontaneous combustion prevention technologies, both in China and abroad, include water injection gro uting, inhibitors, inert gases, liquid inert gases, three-phase foams, gels and curing foams [8-10], and gas explosion prevention and control technologies inc lude gas extraction prevention and ignition source elimination.

With the characteristics of resistance is measured with temperature increases the sensitivity decreases, in normal temperature zone the resistance temperature relation available type description:

$$R_1 = R_o(1 + At + Bt^2) \tag{4}$$

$$\Delta R_t = At + Bt^2 \tag{5}$$

$$I^2 r + \mu Y = \alpha S(T - T_0) + A\sigma S(T^4 - T_0^4) \tag{6}$$

2.2. The Basic Structure of the Intelligent Sensor

Intelligent sensor to the microprocessor as the core, and extends the traditional function of the sensor; the sensor, signal conditioning circuit, and the microprocessor unit is integrated into a chip. The intelligent sensor has certain judgment, analysis and information processing, memory, logical thinking ability, be able to adjust the part with computer according to the working condition of the system data transfer, make the system work at the optimal state of low power consumption and transmission efficiency optimization. Smart sensors are sensors, microprocessor (or computer) and the related circuit, its basic structure was shown in Fig. 1.

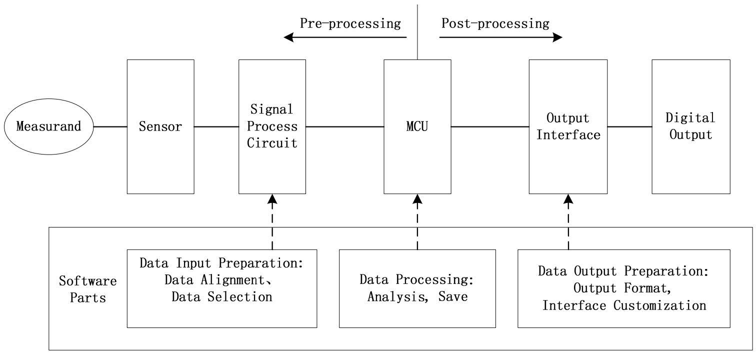

Fig. 1. Basic structure of the gas and coal seam spontaneous combustion sensor experiment device.

2.3. The Overall Architecture of Coal Mine Monitoring and Control System

In the coal mine environment, there are a variety of monitoring system of substation and a large number of sensors, which we need to expand the CAN bus. The specific method by CAN/RS232 gateway expand; or by the CAN bus PCI card, PC machine. Fig. 2 for the mine monitoring system structure based on CAN bus typical:

3. Overall Design of Sensor System

3.1. Prevention and Control Technology Optimization of Complex Disaster

According to the interdependence between the physical fields and the complex disaster prevention technologies, a hierarchical analysis model can be drawn, as shown in Fig. 3, in which *A* is the target layer, i.e., the target is to prevent the complex disaster from occurring; *B* is the criterion layer, i.e., $B_1 \sim B_6$, which includes the remaining coal fields, gas fields, temperature fields, oxygen fields, gas fields and ignition sources; *C* is the measure layer, which includes twelve specific prevention technologies of $C_1 \sim C_{12}$; and C_{12} includes $D_1 \sim D_5$, which represent electrical discharge, blast, open flame, friction impact and other ignition sources, respectively.

To determine the coalmine acceptance of each prevention technology option, the score sheet, similar to that of Table 1, is designed and distributed to each representative mine to score and summarize the results (criterion: the score is made by the item, including a reasonable economy, simple process and high efficiency, with 0~2 denoting very poor; 2~4 denoting relatively poor; 4~6 denoting average; 6~8 denoting better; 8~10 denoting very good).

The gas concentration range of gas explosions determines the scope and degree of the disasters. Therefore, in the prevention and control technologies for a complex disaster, gas field suppression and elimination is much more important than the other physical fields, and other physical fields exhibit similar levels of importance.

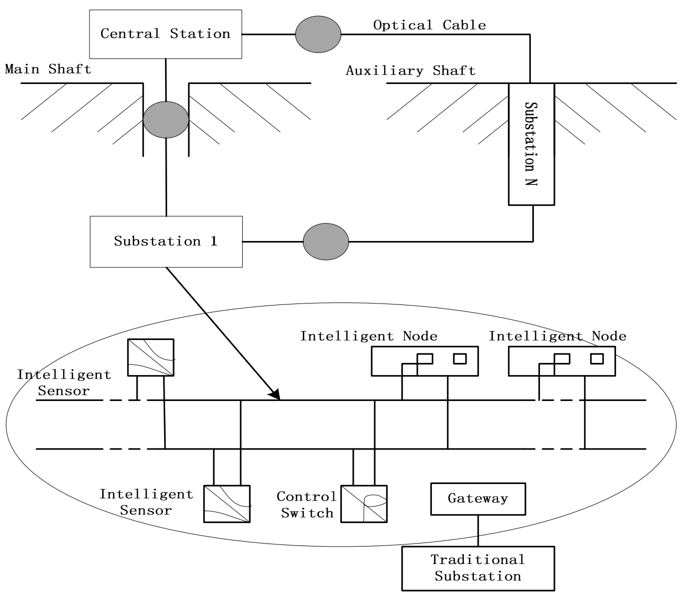

Fig. 2. The mine monitoring system structure based on CAN bus typical.

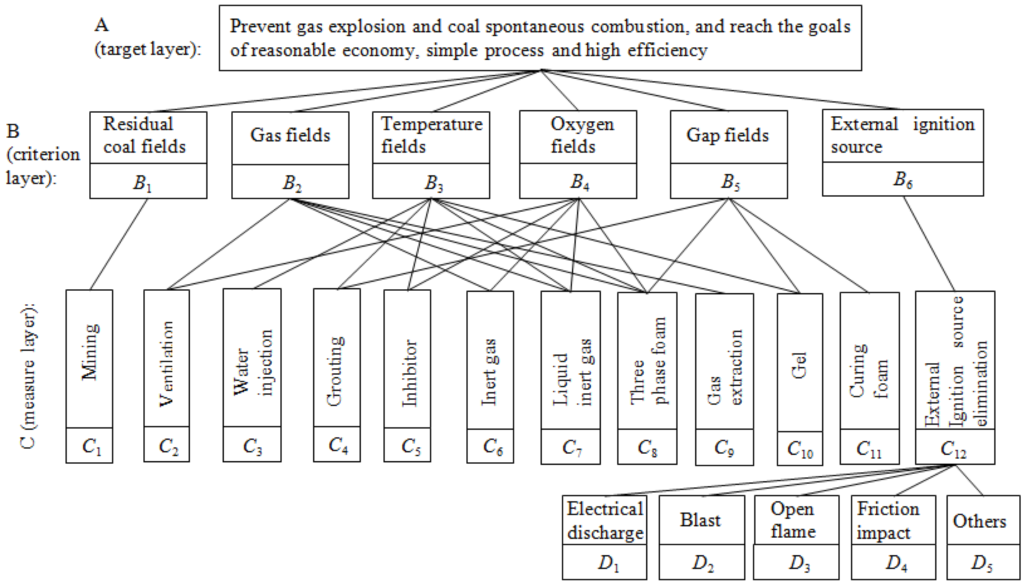

Fig. 3. The analytic hierarchy process model of selected field technologies.

Table 1. Field technology score sheet.

Item		Score			
		Reasonable economy	Simple process	Efficiency	Average score
B_1	C_1	8.2	7.6	9.4	8.4
B_2	C_2	9.2	6.4	5.1	6.9
	C_6	7.6	8.1	8.5	8.1
	C_7	5.2	3.1	9.4	5.9
	C_8	7.3	8.3	6.1	7.2
	C_9	8.5	9.2	9.8	9.2
B_3	C_3	9.8	9.4	6.3	8.5
	C_4	9.5	9.1	6.3	8.3
	C_5	8.7	8.6	6.2	7.8
	C_7	5.2	3.1	5.7	4.7
	C_8	7.3	8.3	9.2	8.3
	C_{10}	6.1	5.7	4.1	5.3
B_4	C_2	9.2	6.4	5.1	6.9
	C_5	8.7	8.6	4.6	7.3
	C_6	7.6	8.1	8.5	8.1
	C_7	5.2	3.1	9.4	5.9
	C_8	7.3	8.3	6.1	7.2
B_5	C_4	9.5	9.1	5.3	8.0
	C_8	7.3	8.3	8.1	7.9
	C_{10}	6.1	5.7	7.4	6.4
	C_{11}	3.4	4.5	7.8	5.2

The physical fields relative to the judgment matrix A-B are shown in Fig. 2, in which scale 1 indicates the same level of importance for two physical fields and scale 3 indicates that the previous field is more important than the latter field. For example, if B_2 is more important than B_1 and B_1 has the same level of importance as B_3, then according to the average score of each technology option in Table 1, the judgment matrix of each technology relative to the physical field can be formed after comparing the fields and the technologies: B_1-C, B_2-C, B_3-C, B_4-C, B_5-C, B_6-C. According to the statistics, in 2000 – 2011, severe fire and explosion accidents in Chinese coalmines with 10 or more deaths were caused by external ignition sources, with the disasters caused by electrical discharge, blast, open flame and friction impact accounting for 45.8 %, 30.2 %, 11.3 % and 8.8 %, respectively; the remaining other cases accounted for 3.9 %. The comparison of the physical fields and the technologies is shown as the C_{12}-D judgment matrix in Fig. 4.

After the judgment matrix is constructed, the maximum value relative to the normalized feature vectors can be calculated as the weight vector. The results are summarized in Table 2. The random consistency ratio (*CR* value) of the *B* and *C* layers is equal to 0, with satisfactory consistency. From the statistics presented in Table 2, compared to the main goal, the importance of the technology ranked from high to low is as follows: three-phase foam technology, high-efficiency mining technology, external ignition source elimination technology, liquid inert-gas technology and gas extraction technology. It can be concluded that the comprehensive prevention and control system integrating three-phase foam technology, high-efficiency mining technology, external ignition source elimination technology, inert gas technology and gas extraction technology is the most effective.

3.2. Technical Applications

To effectively prevent and control the complex disaster of both gas explosion and coal spontaneous combustion during the No. 3 seam mining operation in the coalmine, the following measures were taken during the work face mining:

A-B	B_1	B_2	B_3	B_4	B_5	B_6
B_1	1	1/3	1	1	1	1
B_2	3	1	3	3	3	3
B_3	1	1/3	1	1	1	1
B_4	1	1/3	1	1	1	1
B_5	1	1/3	1	1	1	1

B_1-C	C_1
C_1	1

B_2-C	C_2	C_6	C_7	C_8	C_9
C_2	1	0.85	1.17	0.96	0.75
C_6	1.18	1	1.37	1.12	0.88
C_7	0.85	0.73	1	0.82	0.64
C_8	1.04	0.89	1.22	1	0.78
C_9	1.33	1.14	1.56	1.28	1

B_3-C	C_3	C_4	C_5	C_7	C_8	C_{10}
C_3	1	1.02	1.09	1.81	1.02	1.60
C_4	0.98	1	1.06	1.76	1	1.57
C_5	0.92	0.94	1	1.66	0.94	1.47
C_7	0.55	0.57	0.60	1	0.57	0.89
C_8	0.98	1	1.06	1.75	1	1.57
C_{10}	0.62	0.64	0.68	1.12	0.64	1

B_4-C	C_2	C_5	C_6	C_7	C_8
C_2	1	0.94	0.85	1.17	0.96
C_5	1.06	1	0.90	1.24	1.01
C_6	1.18	1.11	1	1.37	1.12
C_7	0.85	0.81	0.73	1	0.82
C_8	1.04	0.99	0.89	1.22	1

B_5-C	C_4	C_8	C_{10}	C_{11}
C_4	1	1.01	1.25	1.54
C_8	0.99	1	1.23	1.52
C_{10}	0.80	0.81	1	1.23
C_{11}	0.65	0.66	0.81	1

B_6-C	C_{12}
C_{12}	1

C_{12}-D	D_1	D_2	D_3	D_4	D_5
D_1	1	1.52	4.05	5.20	11.7
D_2	0.66	1	2.67	3.43	7.74
D_3	0.25	0.37	1	1.28	2.90
D_4	0.19	0.29	0.78	1	2.26

Fig. 4. Judgment matrixes.

Table 2. Sequence diagram of the hierarchical weight vectors.

Measure layer	Criterion layer						Compared to the target layer, the general sequence of the measure layer
	B_1	B_2	B_3	B_4	B_5	B_6	
	0.125	0.375	0.125	0.125	0.125	0.125	
C_1	1						0.125
C_2		0.18		0.19			0.091
C_3			0.21				0.026
C_4			0.19		0.29		0.06
C_5			0.18	0.21			0.049
C_6		0.22		0.23			0.111
C_7		0.16	0.11	0.17			0.095
C_8		0.19	0.19	0.2	0.29		0.156
C_9		0.25					0.094
C_{10}			0.12		0.23		0.044
C_{11}					0.19		0.024

1) 3D gas extraction.

After the analysis, the coalmine was found to exploit extremely close distance seams, and most of the gas at the work face comes from local and nearby areas; as a result, gas control was achieved by extracting gas in the goaf area. According to the workface tunnel arrangement, a 3D gas extraction technology was used for high drilling intercrossed in the air return tunnel, sideways high drilling and nearby goaf area drilling.

2) Grouting three-phase foam technology.

To quickly cover the residual coal in the goaf, fill the voids and reduce the coal temperature, a large flow of three-phase foam was grouted in the goaf, which prevented and controlled the coal spontaneous combustion due to its wide diffusion, high accumulation and strong resistance.

3) Grouting nitrogen.

With the development of coal mining operations, according to the caving and coal geological situation, nitrogen pipes were alternatively buried into the goaf. When such a pipe is buried in the appropriate area, a large amount of nitrogen is injected to reduce the oxygen and gas concentrations, which prevents gas explosions.

4) Strict management of the mining procedures, electrical equipment and blasts.

During mining operations, to strictly manage mining procedures, the following procedures have been implemented: try to create a clean roof cave; prevent big and slack coal from remaining in the goaf; and strictly manage the installation, operation, inspection and maintenance of electrical equipment in the work face to ensure that the equipment correctly shuts down when the gas is over the limit.

4. Experiment and Result

4.1. Software Design of the Sensor System

The system software was used the modular design method, the software process is shown in Fig. 5. The system power up or reset, analog sensor output voltage value is converted to digital quantity corresponding, in order to improve the detection accuracy, call the data processing module of digital filtering operation to the collected data, avoid to produce big error, then further linear interpolation. The gas concentration and the alarm value comparison, if the density exceeds the limit, then call the light alarm module.

4.2. Data Analysis

The Fucun coalmine of Shandong Zaozhuang Mining Industry mainly exploits the No. 3 coal seam, with its 7.83 m average thickness. The No. 3 seam is a spontaneous seam, with certain areas of abnormal gas outbursts. The No. 3 seam can be spontaneously ignited due to the residual coals in the goaf during mining operation. The concentration of CO at the work face was over 2 %, and both C_2H_4 and C_2H_2 emerged; as a result, the work face was closed.

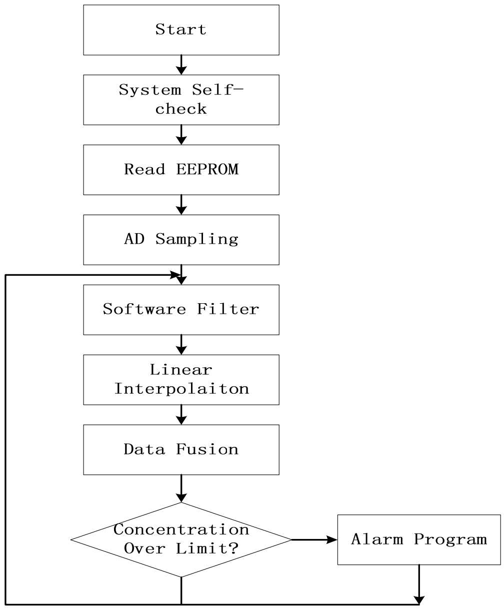

Fig. 5. The system software process.

The gas absolute outburst volume is over 22.5 m^3/min during mining operations, when the ventilation is 1400 m^3/min at the work face, the gas of the air return flow is still over 0.9 %, and the gas in the upper corner is frequently over the limit. The mine No. 3 seam mining operation represents a severe complex disaster threat of both gas explosion and coal spontaneous combustion and poses a challenge for coalmine safety during the mining process.

Through the above measures, the max CO volume fraction at the back of the chocks does not exceed 10^{-5}, the gas in the upper corner is less than 0.5 % and the gas volume of the air return flow is less than 0.2 %, which effectively prevents and controls the threats of gas explosion and coal spontaneous combustion at the No. 3 work face. The technical system has been successfully promoted in many coalmines of the Shandong and Anhui Provinces as demonstrations.

5. Conclusions

According to the detection accuracy of existing coal mine gas detection instrument of low, poor stability, high maintenance cost, puts forward the multi gas sensor intelligent gas sensor system, based on theoretical research, system development, debugging, successfully developed a mining intelligent gas sensor, realize the digitization, gas detection instruments intelligent, miniaturized, able to meet the requirements of coalmine gas concentration detection. A complex disaster involving both gas explosion and coal spontaneous combustion is the result of the dynamic convergence in time and space of certain physical fields, including residual coal fields, gas, oxygen and temperature fields and local ignition sources. Therefore, to prevent these disasters, the key is to minimize the void fields, the residual coal fields and the gas, oxygen and temperature fields so that there is no convergence.

Acknowledgements

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