Design of dust monitoring system in coal mine

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Abstract. Coal dust is one of the main factors affecting the safety of coal mine production and the life and health of workers. In order to accurately and efficiently monitor the coal dust generated in the production process, the measurement system is designed and the non-contact dual-light proportional difference detection method is adopted. Through calculation and simulation, the parameters of the key link are calculated, and the on-line concentration monitoring system, which is suitable for wide field and wide measurement range is designed. Experimental data show that the reliability and accuracy of the measurement system meet the design requirements.

1. Introduction

In the process of coal mining, a large amount of coal dust will be generated in the roadway, which will not only affect the operation and production, but also cause great harm to the health of coal workers and cause coal lung disease. Moreover, when the concentration of coal dust reaches a certain limit and there is open fire, coal dust explosion accidents will occur, threatening the safety of mine production. Therefore, coal dust concentration monitoring has become one of the important links of coal mine safety production. It is necessary to monitor coal dust generated in the production process in a timely and effective manner. Effective dust removal and dust removal measures should be taken to ensure the safety of workers on the site.

At present, based on the different measurement methods and principles, the measurement methods of coal dust concentration in various countries are generally divided into sampling method and non-sampling method. The sampling methods include filter membrane weighing method, piezoelectric sensor measurement method, beta ray attenuation method, etc. Non-sampling measurement is directly using the physical characteristics of coal dust to measure the concentration of coal dust, including gravimetric method, photoelectric method and so on. Based on the analysis and comparison of common coal dust concentration detection methods at home and abroad, a coal dust concentration measurement method based on the combination of lambert-beer law and Mie scattering theory is proposed, and an online concentration monitoring system suitable for various occasions with a wide measurement range is designed.

2. Overall scheme design of measurement system

In the in-depth study of the principle of the measurement and on the basis of the analysis of experimental results, found that using single laser transmission method to measure the coal dust concentration, due to external factors such as temperature, power supply fluctuation semiconductor laser power supply current changes, laser output beam volatility will ensue, eventually led to the incident light intensity...
measurement system is not stable. At this time, other constant conditions will also lead to changes in the transmitted light intensity received by photoelectric sensors, resulting in errors in the measurement results of the measurement system, and thereby affecting the measurement accuracy of the whole measurement system [1].

Through the above analysis, we should avoid the above factors and improve the reliability of the measurement system from the source when designing the online measurement system of coal dust concentration. In this paper, a dual-beam proportional difference method is adopted to divide the laser beam into two parts by using a splitter, with one beam as the measuring light and the other as the reference light. Finally, photoelectric sensors are used to collect signals respectively for differential operation, so as to obtain the real change of light intensity and determine the change of coal dust concentration. According to the actual situation, the composition of coal dust concentration measurement system in this paper is determined, as shown in figure 1:

![Figure 1. differential schematic diagram of dual optical path](image)

In practical design, photoelectric sensors are placed at equidistant positions from the spectrometers to avoid the influence of optical path on the measurement results. For the double-path measurement system, it is assumed that the laser beam will fluctuate, and the measurement beam \( I_0 \) will follow the change, the reference beam \( I_{0}' \) will become \( I_{0}'' \), and the transmitted light intensity will become \( I' \), and the light intensity difference \( \Delta I = I_{0}'' - I' = I_{0}'' - I' \) will basically remain unchanged, thereby greatly reducing the influence of the light source fluctuation on the accuracy of the coal dust measurement system.

The coal dust concentration detection device mainly includes the system power module, extraction module, optical circuit measurement system, signal acquisition and amplification circuit, microprocessor circuit, communication module, liquid crystal display circuit, sound and light alarm circuit, and each part of the circuit is coordinated to form the coal dust concentration detection device. The system block diagram is shown in Figure 2.

![Figure 2. The system block diagram](image)

3. Analysis of measurement key link

In the design of the coal-dust concentration measurement system, the incident light \( I_0 \) and outgoing light \( I \) intensity can be measured by the sensor, but some other system parameters, such as the measurement area width \( L \), light source wavelength lambda \( \lambda \), extinction coefficient \( k_{ext} \) value, need to be selected and designed at the beginning of the system design. Choosing the right parameter is helpful to improve the measurement accuracy of the whole system.
In the process of calculating the scattering coefficient, the amount of calculation and the difficulty of calculation are challenging. In this paper, MATLAB software is used for calculation and simulation, and various parameters are calculated.

3.1 System light source selection
In chapter 2, we know that the wavelength of the light source should be known when obtaining extinction coefficient and other parameters through Mie theory. The selection of the light source will affect the system design to some extent, and then affect the measurement performance of the coal dust concentration measurement system. According to lambert-beer law, we know that the extinction coefficient is proportional to the wavelength of the light source, that is, the larger the wavelength of the light source, the greater the attenuation degree of the measuring beam in the air containing coal dust, and the higher the measuring sensitivity of the coal dust concentration measurement system. Conversely, the lower the sensitivity.

When designing the measurement system, it is obviously expected that the sensitivity of the system should be as large as possible. Therefore, the light with a relatively large wavelength is selected for the measurement system in this paper. In this paper, the system design takes various factors into consideration and selects the red light with the largest wavelength in visible light, which ranges from 630nm to 780nm[2].

After studying the characteristic parameters of the measured material, the selected wavelength is 650nm. Because of its high brightness, good monochromaticity, high directivity and high coherence, laser has been widely used in many fields. In this paper, the red semiconductor laser with small volume and light weight is selected. In addition, semiconductor lasers also have radiation resistance, high reliability, information transmission speed, low cost, long service life and other advantages.

3.2 Selection of absorption layer thickness
According to the lambert - beer's law, in the coal dust particles being measured concentration is larger, at the same time, the coal dust measuring width is bigger also, there will be a condition, in the process of the incident light \( I_0 \) measured area after completely absorbed, lead to incident light through measured area. That is, the intensity of outgoing light \( I \) is 0, photoelectric sensor without receiving signals, leading to system for greater concentration coal dust can't measure, measuring system range is limited. On the contrary, there are also some situations: the width of the measurement area is too small, and the concentration is too small, the attenuation range of transmitted light \( I \) is too small, and the photoelectric sensor is saturated or unable to distinguish; In this case, the measuring system can measure the higher concentration of coal dust, but it cannot detect the low concentration of coal dust, forming a blind area of measuring range, reducing the lower limit of measuring range and measuring sensitivity of the measuring system.

| Table 1. Measurement area width and concentration measurement range |
|---------------------------------------------------------------|
| Width of measuring area (cm) | Mass concentration range (g/m³) |
| 5  | 0~500 |
| 6  | 0~400 |
| 13 | 0~200 |
| 24 | 0~100 |
| 43 | 0~60 |
| 60 | 0~40 |
| 130| 0~20 |
| 250| 0~10 |
| 500| 0~5  |

Therefore, according to the extinction law, the relationship between the mass concentration and the width of the measurement area \( L \), the outgoing light intensity and the incident light intensity ratio \( I_0/I \), was found through computer simulation, so as to select the appropriate measurement area width \( L \) for
the measurement system. Table 1 shows the concentration measurement range corresponding to the width of the measurement area.

3.3 Measuring system sensitivity
Based on the extinction law, the measurement system in this paper can simplify the formula of lambert-beer law:

$$I = I_0 e^{-xCL}$$

(1)

Where,
- $L$ is the width of the measurement area;
- $x$ is the unit optical absorption index;
- $I_0$ is the intensity of the incident light.

Then its sensitivity can be obtained:

$$S_x = \frac{\Delta I}{\Delta C} = -xLI_0 e^{-xCL} = -xLI$$

(2)

As can be seen from formula 2, the larger the width of the measurement area $L$, the absorption coefficient $x$ and the incident light intensity $I_0$ are, the higher the sensitivity of the measurement system will be.

To improve the sensitivity of the measurement system can be designed comprehensively according to the above parameters. However, for determining the measured substance, its absorption coefficient is a constant value, which can only be started from the width of the measured area or the incident light intensity. From the measurement area width selection section above, we know that the measurement area width also affects the measurement range and sensitivity of the measurement system. The wider the measurement area is, the smaller the measurement range of the system is. Therefore, comprehensive measurement range is needed to improve the measurement sensitivity. Relatively speaking, increasing the incident light intensity is a good solution to improve the sensitivity, but it will also increase the power of semiconductor laser, increase the power consumption of the system. Therefore, it is necessary to balance the performance of the measurement system design when improving the measurement sensitivity.

4. Design of coal dust concentration measurement system
The on-line measurement system of coal dust concentration designed in this paper consists of two parts: photoelectric conversion part and hardware signal acquisition and processing circuit part. The most important part of the photoelectric conversion design is the optical path system, whose principle has been described above. The hardware circuit signal acquisition and processing design is mainly the hardware circuit realization of signal amplification, filtering, conversion and output. The system block diagram is as follows[3].

Figure 3. Coal dust measurement system block diagram
4.1 Optical system design
In the optical path system designed in this paper, after comprehensive analysis of the error of the measurement system, this paper designs the dual-optical path proportional difference optical path structure, the principle is shown in Figure 4.

![Figure 4. Schematic diagram of dual optical path measurement](image)

The experimental results show that this method can eliminate the interference of stray light and source fluctuation, and reduce the error in the measurement system from the source.

Since the light emitted by the laser is neither plane wave nor spherical wave, it conforms to gaussian distribution. Gaussian beam will produce phase difference when interference occurs. Moreover, since the semiconductor laser selected in this paper has the property of poor directivity, it is necessary to conduct collimation and expansion of the beam emitted by the laser when designing the optical path system to avoid measurement errors caused by the above factors[4].

4.2 Hardware circuit design
The main control part of the system in this paper is composed of FPGA, which amplifies, filters and analog-to-digital conversion data at the receiving front end, conducts noise removal and analysis on the received data, and outputs measurement results and sound-light alarm through liquid crystal screen and CAN bus. The system designs each part of the hardware circuit to complete the corresponding function, the test result completely achieves the design target.

The structure of coal dust concentration measurement system designed in this paper is shown in Figure 5. We can divide it into two large modules: FPGA control module and peripheral circuit module.

![Figure 5. Electrical system structure drawing](image)

Field programmable gate array (FPGA), which is characterized by strong function, low power consumption and high integration, has been widely used and is a promising chip [5]. FPGA is a programmable chip, and software and hardware design is required for development a [6].

In the control acquisition module designed in this paper, EP4CE6F17C8 chip of Altera corporation, a high cost performance mainstream supplier with an efficient development platform and development tools, is selected. Its wide application, low development cost, can effectively reduce the development resistance, to bring convenience for later maintenance and upgrading.

4.3 Material object of coal dust concentration measurement system
The physical diagram of the measurement system is as follows:
5. Conclusions
This paper puts forward the system design scheme according to the measurement theory, analyzes and discusses the key factors and parameters in the measurement system, selects the parameters and devices that meet the requirements of the measurement system design in this paper, and finally completes the optical circuit system and hardware circuit system design of the system. A large number of simulation experiments have been carried out in the laboratory. The reliability and accuracy of the measurement system designed in this paper are in line with the design requirements through experimental measurement data.

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