Research on new algorithm for dust concentration measurement

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Abstract. When the concentration of dust is detected, it will be affected by temperature, the fluctuation of the light source, detector and other factors. In order to effectively eliminate the errors caused by such factors as the change of ambient temperature, the fluctuation of light source and zero drift of photoelectric devices, we design a new differential algorithm to measure the concentration and obtain the accuracy of the results.

1. Introduction

There are countless mines in our country. In the process of mining, a large amount of dust will be produced. If the monitoring of dust is insufficient, it will cause great harm to the operators and safety in production. Therefore, people pay more and more attention to the monitoring of dust particles, so the detection of dust concentration has become a hot spot of scientific research [1-2]. The traditional optical method is easy to be affected by the change of temperature, the stability of light source and the performance drift of photoelectric device, which makes the error of measurement more error [3]. Study this phenomenon, put forward a new differential method to measure the dust concentration, can be reduced because of the temperature change and instability of light source and photoelectric device zero drift factors such as the impact of MATLAB, and using the method of fitting a straight line to calibrate the system, through the experimental test, in the elimination of errors, a new the difference method is better than the traditional double optical path difference method and single optical measurements method to more accurate measurement, so the measurement of dust concentration of the new algorithm is more reliable.

2. Sensor structure

The detection process of dust concentration is affected by temperature, fluctuation of light source and the detection of electrical components. Single light source, single chamber, single beam structure has stable structure, less components, processing and assembly requirements etc., but only a rough measure of dust concentration and temperature, light source device and can't restrain on the measurement results. Time dual beam structure, as the name suggests, dual optical path structure is relative time, but also a single light source, single chamber structure, the disadvantage is that because of the existence of moving devices, the mechanical properties of the test system is poor, life expectancy is short [3]. The dust sensor adopts space double beam structure, which is a single light source, double beam, double chamber and double detector structure. The spatial dual optical path sensor has the advantages of high sensitivity and fast response.

The structure of the dust sensor is shown in figure 1:
3. Traditional difference algorithm
The light emitted by a light source is collimated and expanded, and a spectroscope is divided into two beams of equal intensity: the measured beam and the reference beam. The measured beam passes through the dust region and is projected onto the photoelectric receiving device, and the reference beam is directly received by the photoelectric conversion device and converted into an electric signal. By differential calculation of the two signals, the dust concentration can be obtained.

The signals of the measuring beam and the reference beam are $I_m$ and $I_r$ respectively. The source fluctuation and the temperature fluctuation are $V$, then the fluctuation light source signal is:

$$S_1 = I_m + I_r$$

The output of light source fluctuations and temperature fluctuations is:

$$S_2 = (I_m + I_r)(1+V)$$

In order to eliminate the fluctuation of light source and the influence of temperature fluctuation

$$S_2 - S_1 = (I_m + I_r)V = S_1V$$

The detected differential signals are

$$S = (I_m + I_r)V$$

When two light path light source changes with temperature, it can eliminate the influence of these two factors, but in practical application, it is difficult to achieve the same light intensity and temperature change, so that these two errors can not be completely eliminated. In order to completely eliminate the influence of light source, temperature and other interference factors, a new difference algorithm is proposed [3-5].

4. New difference algorithm
Dust detection system with double optical path, double chamber structure. The gas chamber is divided into a measuring chamber and a reference air chamber, wherein the gas in the measuring chamber is filled with the gas containing the dust to be measured, and the reference chamber is filled with nitrogen gas. In this way, the measured signal contains the information of the measured dust concentration, and the signal measured by the reference detector does not contain the measured dust concentration information. The infrared light source of the sensor adopts a periodic operation mode, namely, a pulse signal is sent out by a single chip to control the luminescence and extinction of the light source, and the light suitable for the frequency of the detector is obtained. When the light source is luminous, the two light beams with the same frequency and the same intensity are obtained by a collimated amplifier, a
filter and a beam splitter, and the outer light enters the two air chamber and is ejected from the air chamber and is received by the detector. The measured signals measured by the detector and the reference signals measured by the reference detectors are amplified into a single chip microcomputer after amplifying and filtering circuits, and the microcontroller obtains two detection signals at the same time. When the light source goes out, the microcontroller also receives two signals. When the light source goes out, the signal contains fluctuations caused by temperature and background light signals. When the light source is turned on, two signals are generated, such as the fluctuation of the light source, the disturbance of the measuring circuit, the disturbance caused by the disturbance of the detector and the electronic device, etc. By processing the 4 signals, the above disturbances can be eliminated and more accurate results can be obtained. A mathematical model is established based on the laws of Lambert-Beer. The measured voltage signals of the channel and reference background channel are \( V_{11} \) and \( V_{12} \) respectively under the action of the optical signal. The voltage signals detected by the measurement channel and the reference channel under the temperature signal are \( V_{21} \) and \( V_{22} \) respectively.

When the light source is switched off, the voltage of the measuring channel is:

\[
V_1 = V_{11} + V_{12} \quad (5)
\]

The voltage of the reference channel is:

\[
V_2 = V_{21} + V_{22} \quad (6)
\]

When the light source is turned on, the voltage of the measuring channel is:

\[
V_3 = I_0 \times e^{-\alpha gas \times C \times L} \times \eta gas \times J gas + V_{11} + V_{12} \quad (7)
\]

The voltage of the reference channel is:

\[
V_4 = I_0 \times R ref \times \eta ref \times K ref \times J ref + V_{21} + V_{22} \quad (8)
\]

Formula:

- \( \alpha_{gas} \) — measuring the responsivity of detectors and reference detectors;
- \( \eta_{gas} \) — the amplification coefficient of - measuring circuit and the reference circuit.;
- \( K_{gas}, K_{ref} \) — the loss coefficient of light through measurements of gas chambers and reference chambers;
- \( J_{gas}, J_{ref} \) — Measuring transmissivity of filter and reference filter;
- \( \alpha \) — the absorption coefficient of the dust gas under test;
- \( I_0 \) — incident light intensity of light;
- \( C \) — the concentration of dust to be measured;
- \( L \) — length of air chamber.

In order to eliminate the error caused by the fluctuation of the background signal and the temperature signal, the formula (5) and (7) and formula (6) and (8) are subtracted respectively

\[
V_{gas} = V_3 - V_1 \quad (9) \quad V_{ref} = V_4 - V_2
\]

(10)

Formula:

- \( V_{gas} \) — measure the amplification voltage of the circuit signal;
- \( V_{ref} \) — amplifying voltage of reference circuit signal.

In order to eliminate the errors caused by infrared light sources, air chamber disturbances, detectors and electronic devices, the following equations are dealt with (9) and formula (10), and differential equations are obtained:

\[
F = \frac{V_{gas} - V_{ref}}{V_{gas} \times V_{ref}} \quad (11)
\]

The formula (5), formula (6), formula (7) and formula (8) are substituted into formula (11):

\[
C = -\frac{1}{\alpha_{gas} \times \ln \left( \frac{\eta_{ref} \times K_{ref} \times J_{ref}}{\eta_{gas} \times K_{gas} \times J_{gas}} \right)^{1+\frac{F}{1-F}} - 1} \quad (12)
\]

function: \( y = \ln \left( \frac{1+F}{1-F} \right) = \ln \left( 1 + \frac{F}{1-F} \right) \)
In the design, two amplification and filtering circuits have the same amplification factor. By formula (12), \( f(-1,0) \), \( \frac{2F}{1-F} \) is an increasing function, but \( \frac{2F}{1-F} \in (-1,0) \), and \( \frac{2F}{F-1} \in (0,1) \). The function \( y \) is expanded by the Taylor formula:

\[
y = \ln \left( \frac{1+F}{1-F} \right) = \ln \left( 1 + \frac{2F}{1-F} \right) = \ln \left( 1 - \left( -\frac{2F}{1-F} \right) \right) \approx -\frac{2F}{1-F}.
\]  

(13)

The formula (13) is substituted into (12) formula, and the formula of dust concentration is obtained:

\[
C = -\frac{1}{\sigma_{gal}^2} \ln \left( \frac{\eta_{ref} \eta_{gal}^2 \eta_{gal}^2 \eta_{gal}^2}{\eta_{ref} \eta_{gal}^2 \eta_{gal}^2 \eta_{gal}^2} \right) + \frac{1}{\sigma_{gal}^2} \frac{2F}{F-1}.
\]  

(14)

5. Calibration of a new difference algorithm

Under normal temperature and pressure, different concentrations of dust gas are produced, and they are filled into the air chamber at the same time by the constant speed of the air pump, and the dust gas is measured every time after the concentration of the dust gas is constant.

In the experiment of 11 m diameter of coal pulverized coal were measured, the extinction coefficient of pulverized coal coal is 0.9246, the optical path of 0.12m. The measurement data are shown in table 1:

| number | \( \frac{2F}{F-1} \) | dust concentration (mg/m³) |
|--------|-----------------|--------------------------|
| 1      | 0.1911          | 304                      |
| 2      | 0.1610          | 266                      |
| 3      | 0.1332          | 224                      |
| 4      | 0.1000          | 186                      |
| 5      | 0.0700          | 145                      |
| 6      | 0.0366          | 104                      |
| 7      | 0.0051          | 68                       |

The data in Table 1 is linear fitting with the MATLAB software, and the result is shown in figure 2. From the fitting line of Figure 2 can be seen, the correlation coefficient was 0.9882, indicating the dust concentration and \( 2F/(F-1) \) is consistent with a linear relationship, to verify the reliability of the dust concentration measurement method based on Lambert-Beer's law as the principle.

![Fig. 2 coal dust concentration diagram](image-url)
6. Conclusion
In the measurement of dust concentration, the error mainly comes from the fluctuation of light source and the change of temperature. The light fluctuation is caused by some interference factors of system power supply voltage instability or outside, the instability of light source will make the dust in the air chamber can not be fully absorbed, resulting in detecting current of photoelectric detector received unstable, thus affecting the voltage amplification. When the ambient temperature is unstable, besides the influence of dust and gas, it will also affect the responsivity and sensitivity of the detector's photoelectric cell, so it will have a negative impact on the detection results. The new dust measurement method will eliminate the adverse effects of the above factors.

Acknowledgment
Fund Project: Fundamental Scientific Research Service Fee for Central University (3142017044)

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