Signal Processing Circuit Design of Infrared Detection System with SO_2 Concentration Based on Correlation Filter Technology

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Abstract – **Signals from infrared detector are very weak in SO_2 concentration measuring system. In order to improve the sensitivity of detection, combining with filter correlation technology and infrared absorption principle, the weak signal processing circuit is designed according to correlation detection technology. Under laboratory conditions, system performance of SO_2 concentration is tested, and the experimental data are analyzed and processed. Then relationship of SO_2 concentration and the measuring voltage is provided to prove that the design improves measuring sensitivity of the system.**

Key words – ***SO_2*; *infrared absorption*; *correlation detecting and filtering technology*; *weak signal processing***

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In recent years, with the rapid development of China's industry, to a great extent, a large number of coal power production, steel and non-ferrous metal smelting caused SO_2 pollution[1]. The acid rain, formed by SO_2, endangers human body health, corrodes building materials and damages ecological system, which caused huge economic losses to human society. At present, measurement methods of SO_2 are summarized mainly including laser gas, electrochemical gas, ultraviolet spectrum, online chromatography and infrared spectrum analyses[2]. Comparing with the first four analysis methods' advantages and disadvantages, infrared spectrum analysis method can not only be used for high concentration gas analysis, but also undertake low concentration gas analysis. And stability and selectivity of the method are very good.

The weak signal processing circuit of measuring SO_2 is designed, which based on 4.0 μm strong absorption lines of SO_2, combines with correlation filtering technology, and infrared absorption principle and makes use of the correlation detection technology.

1 Infrared absorption principle

Infrared radiation of different gases has different absorption spectrum, and gas infrared absorption intensity has related to the concentration of gas. That principle can measure concentration of different gases. Under conditions of linear absorption, the absorption of light accords with Lambert-Beer law.

$$I(\lambda) = I_0(\lambda)e^{-\alpha(\lambda)cl}, \tag{1}$$

where I_0 is initial value of the incident light intensity of measured gas, l is absorption optical path, α is absorption coefficient of the gas under measuring, c is gas concentration, I is the intensity of output light after SO_2 absorbing infrared radiation light[3].

2 Filter correlation technology and cross-correlation principle

Filter correlation technology is infrared absorption measuring technology that measuring gas and reference gas of high concentration which are sealed in the filter wheel system with a matched filter to detect the same measured gas in gas chamber. Filter correlation technology is spectrum comparison based on high concentration measured gas and absorption of reference gas in the filter wheel system[4].

Cross-correlation detection is based on the correlation function, which makes use of the time correlation characteristics between measured signal and the same frequency reference signal. Cross-correlation detection is a method of extracting measured signal which is submerged in noise signal[5]. If $S_i(t)$ is the measured signal, $S_r(t)$ is the reference signal with the same frequency of the measured signal, $S_r(t-\tau)$ is the signal through delay, and $f(t)=S_i(t)+n(t)$ is the signal interfered by the noise. Reference signal after delay and input signal interfered by noise are put into correlation operation to multiply. Then through the low-pass filter, the corresponding output cross-correlation signal is obtained as shown in Fig. 1.

Cross-correlation function is as follows

$$R_{fS_r}(\tau) = \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T} f(t)S_r(t-\tau)\mathrm{d}t$$

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$$= \lim_{T \to \infty} \frac{1}{2T} \left[\int_{-T}^{T} S_i(t) S_r(t-\tau) \mathrm{d}t + \int_{-T}^{T} n(t) S_r(t-\tau) \mathrm{d}t \right] = R_{S_i S_r}(\tau) + R_{n S_r}(\tau) = R_{S_i S_r}(\tau). \quad (2)$$

Because reference signal $S_r(t)$ and noise signal $n(t)$ are not related, i. e., cross-correlation function $R_{nS_r}(\tau) \approx 0$ which eliminates noise. Frequencies or cycles of input measured signal $S_i(t)$ and reference signal $S_r(t)$ have to be consistent, or else $R_{S_i S_r}(\tau)$ may become fluctuating signal whose average is zero.

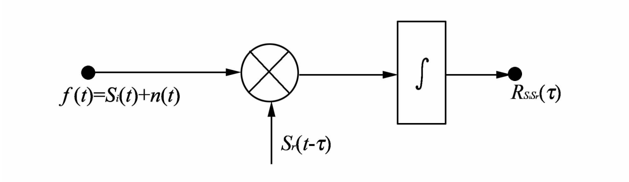

Fig. 1 Cross-correlation principle

3 Design of the circuit system

Correlation filtering technique based on non-dispersive infrared detection principle is the method which obtains measured gas concentrations through the reference chamber and measured chamber on related wheel of infrared light intensity of a differential comparator. Overall system consists of infrared light, relevant filter wheel, reflective opto, IR window, gas chamber, filters, photodetectors, brushless DC motor and signal processing circuit.

Pyroelectric detector LIM-262 puts the gathered light signals into electrical ones that are very weak, then correlation detection and differential operation are conducted after they are amplified and filtered. The key to filter correlation technology is that it realizes correlation detection of signal and is necessary to obtain correlation signal of the same frequency and the same phase with input signal. Correlation signal of the system is obtained by reflective optocoupler ST188. The reflective optocoupler can produce a coupler signal which synchronizes with not only measured signal of SO_2, but also with reference signal. Then two groups of signals are detected by phase-sensitive circuit respectively. Correlation operation is carried out for measuring signal and reference signal through amplifier and filter with the matching correlation signal produced by reflective optocoupler. Strength of the infrared radiation can be measured at the two moments. Differential operation is put forward for the two intensity of infrared radiation, so the voltage signal related to SO_2 concentration is obtained. Signal processing circuit diagram is shown in Fig. 2.

According to Fig. 2, the signal processing circuit is designed as Fig. 3.

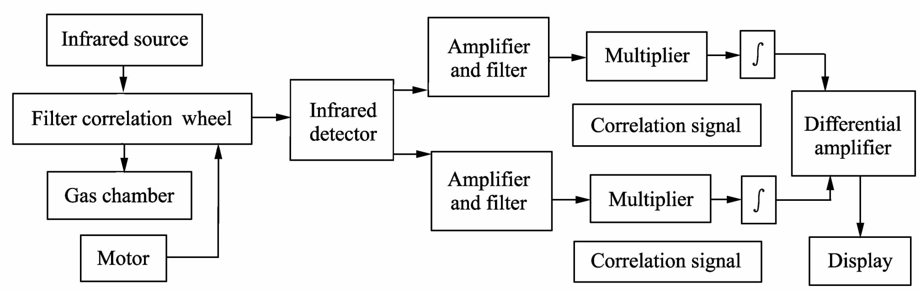

Fig. 2 Schematic diagram of detection system

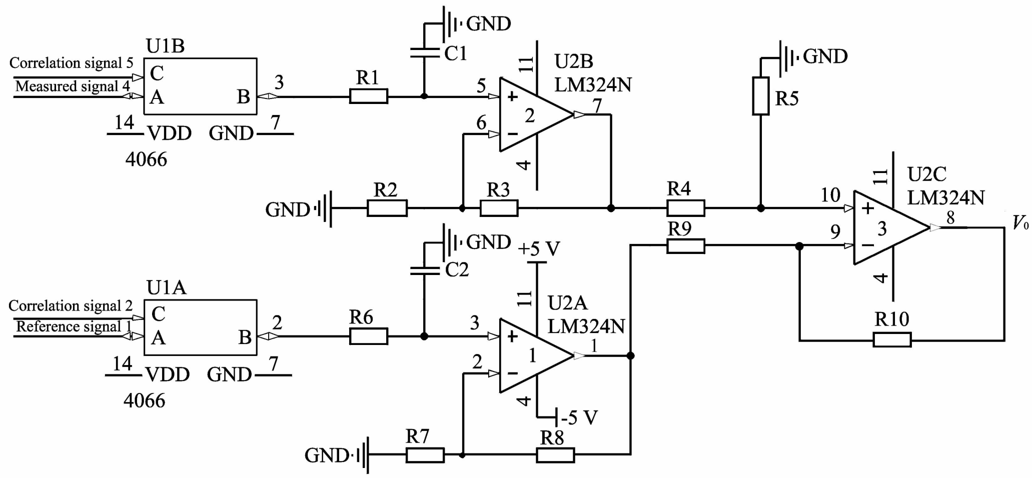

Fig. 3 Signal processing circuit diagram

3.1 Design of phase-sensitive detection circuit

Analog switch in the circuit plays the role of turning on and turning off the signal. CD4066, four-way analog switch, is used in the design. Each package has four independent analog switch internally, and each analog switch owns three terminals of control, input and output, while the input and output terminal are interchangeable. When control terminal is added to the high level, switch is turned on; when control terminal is added to the low level, switch is off. In order to further reduce the interference of noise, analog switch CD4066 circuit connects with a RC low-pass filter circuit as shown in Fig.4.

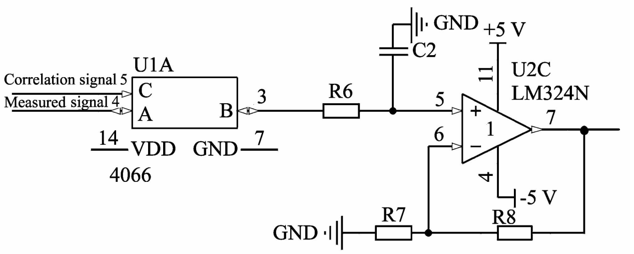

Fig. 4 Phase-sensitive detection circuit

3.2 Design of differential amplifier circuit

A special purpose of differential amplifier circuit is to act as a subtracter[6], which can not only restrain zero drift effectively, but also possess high CMRR, to replace instrumentation amplifier with impedance matching as a prercquisite, or else the advantages of using the differential circuit cannot function effectively. Quad-operational amplifier LM324 of low power consumption is used to construct the differential circuit in the design.

Impedance matching of differential circuit has to be realized, that is, $R_1 = R_2$, $R_3 = R_4$. Output voltage is obtained as follows

$$V_0 = \frac{R_2}{R_1}\left(\frac{1+\dfrac{R_1}{R_3}}{1+\dfrac{R_2}{R_4}}V_2 - V_1\right) = \frac{R_2}{R_1}(V_2 - V_1). \quad (3)$$

According to the principle and impedance matching conditions of differential circuit, differential circuit is designed as Fig.5.

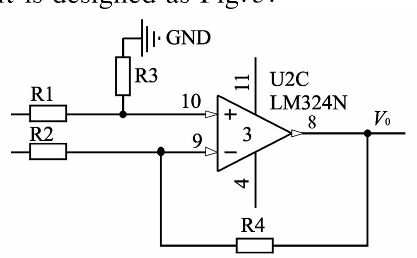

Fig. 5 Schematic diagram of differential amplifier circuit

4 Results and discussion

At room temperature and standard atmospheric pressure, infrared source is preheated for 5 minutes. After intensity of light is stable, a variety of different SO_2 gas concentrations are made respectively. Then SO_2 is put into the gas chamber respectively for experiment. Different SO_2 concentration measuring experiment data is shown in Tab.1.

Tab.1 Measurement voltage of different sulfur dioxide concentration

sulfur dioxide concentration (%)	Measuring voltage(mV)				average (mV)
	1	2	3	4	
0.00	396	398	396	395	396.25
0.02	375	372	377	374	374.50
0.04	361	362	358	364	361.25
0.06	351	351	355	352	352.00
0.08	340	341	338	345	341.00
0.10	327	324	326	329	326.50
0.12	321	322	321	323	321.75
0.14	315	315	319	315	316.00
0.16	310	309	313	310	310.50
0.18	306	305	304	307	305.50

According to the experimental data in Tab.1, the experimental data is quadratic fitting by using data processing software, the relationship equation for the SO_2 gas concentration and output voltage value is obtained as

$$c = 2E - 0.5v^2 - 0.012\,7v + 2.613\,4, \quad (4)$$

where c is the SO_2 gas concentration, v is output voltage value.

Fig.6 is the fitling curve of measured SO_2 concentration.

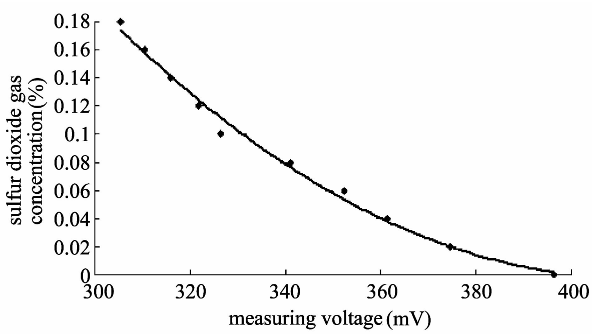

Fig. 6 Fitting curve of measured SO_2 concentration

System error is caused by characteristics of the frequency spectrum of light and instability of infrared source transmitting power. System of SO_2 gas concentration measuring is affected by changing environment temperature, limitation of experimental data and the refraction of gas cell interior wall.

5 Conclusions

The signal processing circuit designed in this paper adopts phase-sensitive detection and differential amplifier circuit, which improves the sensitivity of detection. At the same time, analysis of experimental results shows that system error is small. But on the whole, its sensitivity is low. In order to improve sensitivity of the system, temperature compensation problem has to be considered, and optical path length of the gas chamber should also be increased.

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