Design of Portable CO_2 Infrared Detection System for Flue Gas

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Abstract. There are many interference components in boiler flue gas and the concentration of CO_2 is large. According to this characteristic, a portable CO_2 concentration detection system in flue gas is designed based on infrared absorption method. This article adopts a dual-channel detection technology with a single-wavelength dual-optical path structure. The central wavelength of the mid infrared laser diode is 4.26μm.Select the appropriate photodetector. According to the weak current signal output by the photodetector, a hardware circuit is designed to condition the signal. The hardware circuit includes preamplifier circuits, phase-locked amplifier circuits, and low-pass filter circuits. STM32 is used as the main control chip. STM32 completes the A/D sampling, display and transmission of the signal. The experimental results show that the system can achieve the purpose of detecting CO_2 concentration in flue gas.

Keywords-infrared absorption method; Portable; CO_2 detection;

1 Introduction

Climate warming is a global problem facing mankind. CO_2 is a major constituent gas of greenhouse gases. Due to the emission of CO_2 greenhouse gases, the global temperature continues to rise and resulting in disasters such as sea level rise and frequent extreme weather, which poses a great threat to human production and life[1]. China has proposed carbon peaking and carbon neutral targets, committing to no further growth in CO_2 emissions by 2030, and then slowly reducing them after reaching the peak[2] . In China, thermal power plants are the largest source of emissions, account for half of the total domestic emissions. For this reason, monitoring of thermal power plants CO_2 Emissions become the key to mitigating the greenhouse effect[3]. Due to the complicated operation and low detection accuracy of the traditional method, it is difficult to achieve the purpose of boiler flue gas CO_2 quality detection. In the field of CO_2 gas detection, infrared absorption method has a variety of advantages compared with other detection methods. Infrared absorption method is not affected by the external environment, has fast response speed , good stability and strong selectivity for gas. It is suitable for detecting CO_2 in multi-component gas. It can realize the miniaturization and field application of detection devices[4-5].

At present, thermal power plants use near-infrared spectrometer to detect the concentration of

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flue gas CO_2. The volume of the spectrometer is large, and the absorption intensity of CO_2 at the near-infrared wavelength is small, which is easily interfered by other gases. Due to the above shortcomings of near-infrared spectrometer, this article designs a portable flue gas CO_2 detection system with simple structure and reliable performance based on infrared absorption method and mid-infrared wavelength. So as to accurately and conveniently detect the CO_2 concentration in boiler flue gas.

2 Infrared absorption method

2.1 Lambert-Beer law

Gases have characteristic absorption wavelengths in the infrared wavelength range. When infrared light is directed at a gas, the gas absorbs specific wavelengths of infrared light, resulting in attenuation of the light intensity. As the concentration of the gas is different, the absorption intensity of infrared light is also different. The light intensity decreases with the increase of gas concentration. So we can determine the level of the gas concentration by the change of light intensity[6].

The Lambert-Beer Law is the fundamental theory in the field of infrared detection of gases. It elaborates the relationship between gas concentration and absorbed light energy, allowing quantitative analysis of the gas to be measured[7] . The specific expression is as follows: assuming that a beam of infrared light with frequency ω passes through the absorbing medium, due to the existence of absorption of the gas leads to the attenuation of the original output light intensity, the original output light intensity and the absorption of the gas after the light intensity to meet the Lambert-Beer law, the relationship between the equation is:

$$I_{(\omega)} = I_{0(\omega)} \exp(-KCL) \qquad (1)$$

where I(ω) is the light intensity of the gas after absorption, I0(ω) is the original output light intensity, K is a constant that represents the strength of the gas's ability to absorb light.C denotes the concentration of the gas to be measured and L represents the optical path of infrared light in the sampling gas chamber. After the light range is determined, the light intensity is determined by detecting the original output light intensity I0(ω) and the value of the light intensity I(ω) after absorption of the gas, the concentration of the gas to be measured can be calculated.

2.2 Dual channel detection model

The principle of the dual-channel detection technology is that in addition to a measurement channel, there is also an additional reference channel. The additional channel is used to measuring the gas without the gas to be measured under the same conditions. The original output light intensity of the light source cannot be measured directly. The signal of the reference channel can be used as the original output light intensity and the signal of the measurement channel as the absorbed light intensity, which can avoid the interference brought by environmental factors and improve the reliability of the detection system[8-9].

As shown in Figure 1, a schematic diagram of a single-wavelength dual-optical detection system, the light emitted from the infrared light source is divided into two signals. One signal is the reference signal that is not absorbed by the gas to be measured. The other is the detection signal absorbed by the measured gas.This article adopts a single wavelength dual-optical path measurement method, and the dual optical path is realized by beam splitter. One chamber contains the gas to be measured and the other chamber does not contain, and the concentration value of CO_2 can be calculated by comparing the signal ratio of the two channels.

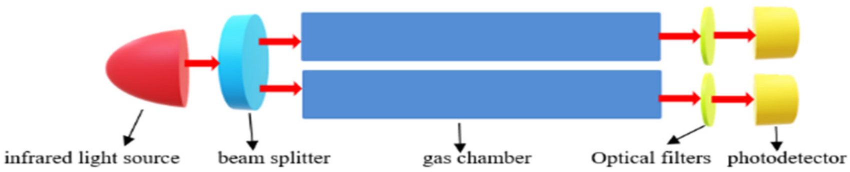


Figure 1. Schematic diagram of dual optical path single wavelength detection system

3 Overall system scheme

The system mainly includes optical system and circuit system. The optical system includes infrared light source, beam splitter, gas chamber, photodetector, etc. The circuit system includes light source driver circuit, signal conditioning circuit and STM32 based main control circuit. The system block diagram is shown in Figure 2.

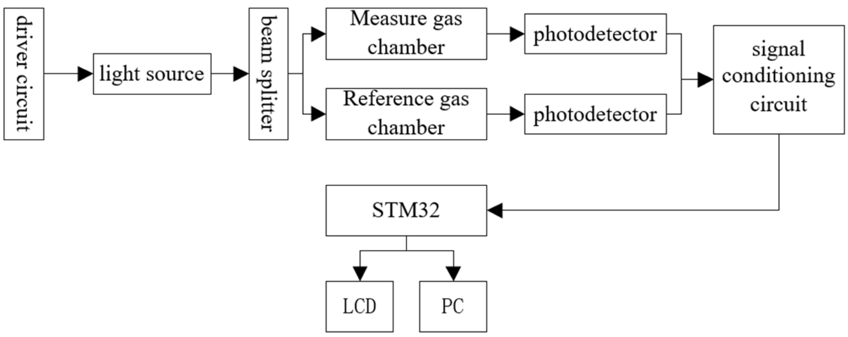


Figure 2. Block diagram of detection system

The laser diode is first driven by the light source driving circuit.The laser is divided by the beam splitter into two beams. One pass through the measure gas chamber and the other pass through the reference gas chamber. In the front of the two photodetectors placed the same center wavelength filter. The filter center wavelength is the CO_2 absorption peak.The light intensity of the two channels is detected separately. The photodetector converts the light signal into a current signal. The signal conditioning circuit amplifies and filters the signal. Then the signal is A/D sampled by the STM32, and through the calculation of the signal amplitude, transmission and display. The concentration of CO_2 can be obtained.

4 Software and hardware design

4.1 Light source and photodetector

Light sources and photodetectors are important part of the detection system. Consider-ing the specific application environment constraints performance requirements, power consumption, et, this article selects 4.26μm as the central absorption wavelength. The LMS43LED from LED Mi-crosensor-NT is chosen as the mid-infraredlaser LED light source and the LMS43PD is used as the photodetector.

4.2 STM32 Minimum System Circuit

In this system, STM32 needs to complete A/D sampling, temperature and humidity acquisition, data processing and transmission, displaying concentration data. Based on the task requirements of the STM32 module in the system, the STM32F103ZET6 model was chosen for this article. The STM32F103ZET6 can provide three 12-bit ADCs, a minimum sampling period of up to 1us, and standard and advanced communication interfaces. The STM32's minimal system consists of four parts: the chip, the reset circuit, the clock circuit, and the power supply circuit. The STM32 minimal system is shown in Figure 3.

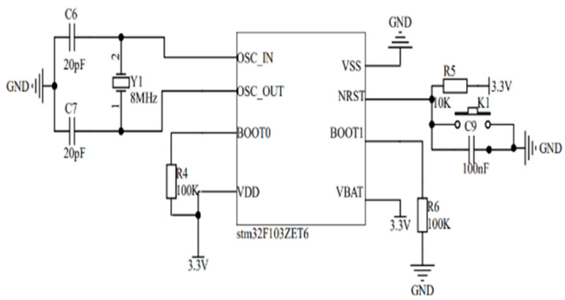


Figure 3. STM32 minimal System

4.3 Signal Conditioning Circuit

The physical diagram of the signal conditioning circuit is shown in Figure 4. The signal conditioning circuit mainly consists of a preamplifier circuit, a phase-locked amplifier circuit and a bandpass filter circuit, all of which are powered by a ±12 V power supply module.

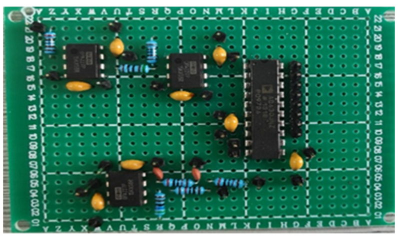


Figure 4. Hardware physical diagram of the signal conditioning circuit

4.3.1 Pre-amplifier circuit

The photodiode output converts the light signal into a weak current signal. The weak current signal is firstly adjusted into a voltage signal by preamplification circuit. Using a two-stage amplification structure, and using an integrated op-amp OPA227P as the op-amp chip. The chip features low noise, low detuning voltage, etc.It is suitable for portable systems. The OPA227P chip and its peripheral circuitry are used to transfer the I_0 converted to a weak voltage signal U_0.The preamplifier circuit is shown in Figure 5.

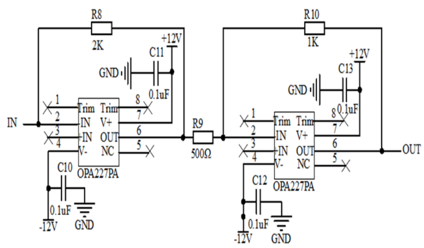


Figure 5. Preamplifier circuit

4.3.2 Phase-locked amplifier circuit

Since the preamplifier circuit can amplify the noise signal and the signal to be measured together[10] .Resulting in noise interference in the signal to be measured. This article adopts the lock-in amplifier method to eliminate the interference brought by noise. The lock-in amplifier is a weak signal detection means based on the interdependent method. Extracting the signal within the bandwidth centered on the frequency of the reference signal and effectively filtering the signal of other frequencies. Thus being able to extract the amplitude information of the weak signal with the same frequency as the reference signal in the strong noise environment [11] . In this article, we use AD630 chip as phase sensitive detector to realize the correlation operation of input signal and reference signal, which can recover the small signal from 100dB interference noise to improve the anti-interference of the system. The specific circuit is shown in Figure 6.

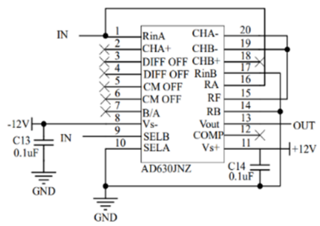


Figure 6. Phase-locked amplifier circuit

4.3.3 Low-pass filter circuit

After the multiplier output waveform graph there are many high frequency components and noise signals unrelated to the useful signal. After low-pass filtering to get the measurement signal we need. In this article, the second-order active low-pass filter structure is selected, using an integrated op-amp OPA227P, and the resonant frequency of the low-pass filter circuit is adjusted by adjusting the resistance and capacitance of the external circuit, as shown in Figure 7 for the low-pass filter circuit schematic.

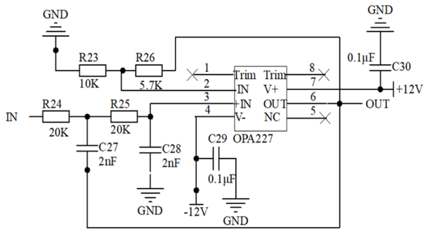


Figure 7. Low-pass filter circuit

4.4 System program

After the STM32 module is powered on, it firstly completes the initial configuration of the system. After the initial configuration, it starts the A/D conversion function to convert the analog signal to digital signal. Then the STM32 calculates the actual value of the signal amplitude and uploads the actual value to the host computer; The equation and coefficients for the relationship between the concentration value and the signal amplitude are brought into the STM32 program, and then the STM32 calculates the CO_2 concentration value is displayed by LCD. The main system program flow is shown in Figure 8.

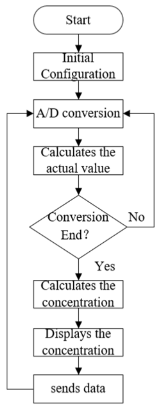


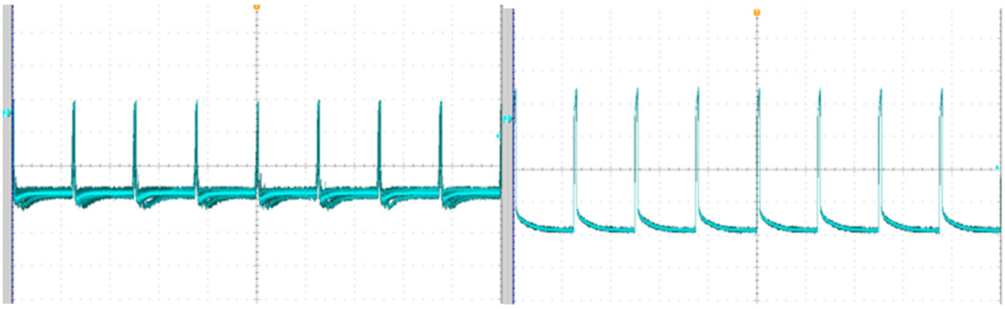
Figure 8. System main program flow chart

5 Experiment

5.1 Circuit Analysis Testing

5.1.1 Phase-locked amplifier circuit analysis

This part uses a 2KHz rectangular wave signal to test the phase-locked amplifier circuit. The Figure 9 (a) shows the waveform of the signal after preamplification. There is noise interference in the signal and spikes at the rising edge. After passing the signal into the phase-locked filter circuit, the obtained signal waveform is shown in Figure 9 (b). Although the shape of the square wave signal changes, the signal amplitude data can still be extracted from the signal. The comparison of the signal before the phase-locked amplification shows that the noise interference is significantly we- akened and the antiinterference capability of the signal is enhanced.

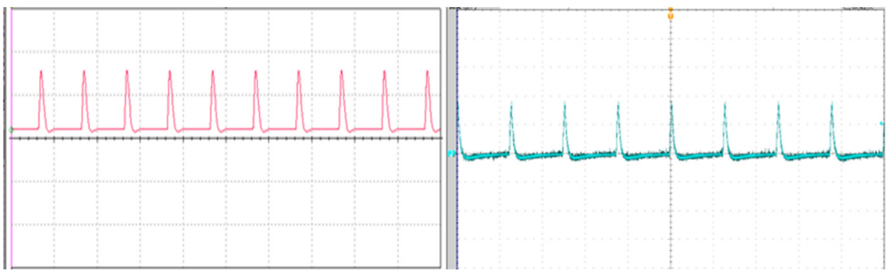


(a) Waveform after signal pre-amplification (b) Waveform after phase locking and amplification

Figure 9. Circuit test analysis signal waveform diagram

5.1.2 Signal Conditioning Circuit Analysis

In order to ensure that the circuit can work properly, this part connects the signal conditioning circuit to the system. Through the oscilloscope to observe the signal after conditioning, pay attention to the signal amplitude, frequency, noise and other information, the actual measured signal and circuit simulation results compared to the signal conditioning circuit analysis test. Multisim 14.0 software is used to simulate the signal conditioning circuit including three parts: preamplifier circuit, phase-locked amplifier circuit and low-pass filter circuit. According to the actual output signal of the photodetector, the signal source of the simulation circuit is set to a rectangular wave signal with a frequency of 2KHz, an amplitude of 1mA and a duty cycle of 4%. The simulation results are shown in Figure 10(a). The circuit is plugged into the system and the signal obtained by the oscilloscope is shown in Figure 10 (b). The comparison between the simulation results and the actual signal shows that the actual measured signal parameters are in good agreement with the simulation results, and the designed circuit can realize the conditioning of the signal.



(a) Multisim simulation signal (b) Oscilloscope measured signal

Figure 10. Comparison of simulated signal and measured signal

5.2 System Testing

After the system is built, the standard gas mixed by N_2 and CO_2 is used to test the system. According to the characteristics of high CO_2 concentration in flue gas, 0% and 10% of CO_2 were selected for testing. The gas was passed into the reference gas chamber and the measure gas chamber, and the signal amplitudes of the two channels were measured separately as shown in Figure 11. Due to the presence of the measurement channel of CO_2,the gas absorbs the infrared light, resulting in an attenuation of the light intensity, which in turn leads to a significant decrease in the signal amplitude.

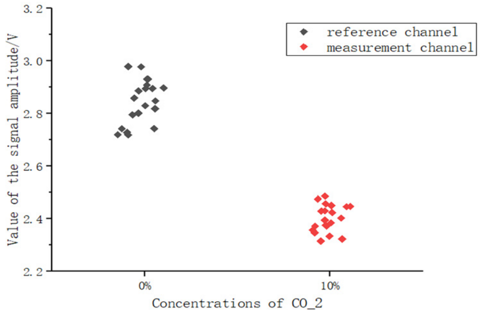


Figure 11. Scatter plot of signal amplitude data of two channels

6 Conclusions

Based on the background of CO_2 concentration detection in flue gas, a portable CO_2 detection system in flue gas is designed based on infrared absorption method. In order to simplify the system structure, the system design is realized by using middle infrared devices. A dual-channel structure is used in the system structure, and the important devices of the optical part are selected and designed. The signal conditioning circuit is designed to convert the sensor's weak current signal into a voltage signal that can be easily sampled by the main control chip. The performance of the signal conditioning circuit is tested to meet the design purpose. The drivers required for the system were written, and finally the circuit and the whole system were tested and experimented. The experiment shows that the system can be applied to the measurement of CO_2 concentration in flue gas. The system has certain application value.

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