Design of interference system for portable Fourier transform infrared gas analyzer

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Abstract

In this paper, a novel interference system for portable Fourier transform infrared gas analyzer was developed. Compared to the traditional Michelson interferometer, 4 times optical path difference can be obtained at a small swing angle by swinging a structure with double cube corner mirrors of the system. Simultaneously,the portability and vibration resistance of the system are also enhanced. A compact Fourier gas analyzer with the inversion infrared spectrum range of 1110 ~ 5000 cm^{-1} was realized with the interference system. Validated by measuring the concentrations of different gradients, the results showed that the error of inversion concentration is less than 1%, which indicates the interference system has potential to be embedded in portable Fourier infrared gas analyzer for on-line comparison and supervision.

Introduction

Continuous on-line monitoring of flue gas emission can evaluate the concentration of pollutants and the total amount of flue gas emission qualitatively and quantitatively. For a continuous monitoring system for pollutant discharge installed at the outlet of fixed pollution source, it is necessary to carry out comparative measurement regularly to check its accuracy. Fourier transform infrared (FTIR) spectroscopy has the advantages of high spectral resolution, wide spectral range and strong anti-interference ability. It is an important method for environmental monitoring. On-line environ-mental monitoring instruments can be compared and supervised through a portable FTIR spectrometer, ensuring the accuracy and reliability of online monitoring data.

Interferometer is the core component of portable FTIR spectrometerThe classical FIIR spectrometer is a time-modulated Michelson interferometer, which adopts the moving mirror in linear motion mode. The moving distance required by the resolution and the collimation of the moving mirror under fast motion are difficult to meet the requirements of a portable device, and also difficult to adapt to complex industrial sites.

In this paper, a miniaturized oscillating double cube corners interference system is designed for a portable FTIR gas analyzer. This paper introduces the portable gas analyzer and the basic condition of the interference system. The inversion effect of spectrum and concentration is verified. The stability of the gas analyzer using the interference system was verified by adding the sample gas of SO_2 and NO_x.

PORTABLE FTIR GAS ANALYZER

Analyzer system

The analyzer system mainly includes an infrared light source, an interferometer, a gas cell, an infrared detector, an intake preprocessing system, a signal control and processing circuit, and a computer. The infrared light source is directly fixed on the interferometer, and the high-temperature gas chamber is equipped with an accessory heat trace tube. The schematic diagram of portable Fourier transform infrared gas analyzer system is shown in Figure 1.

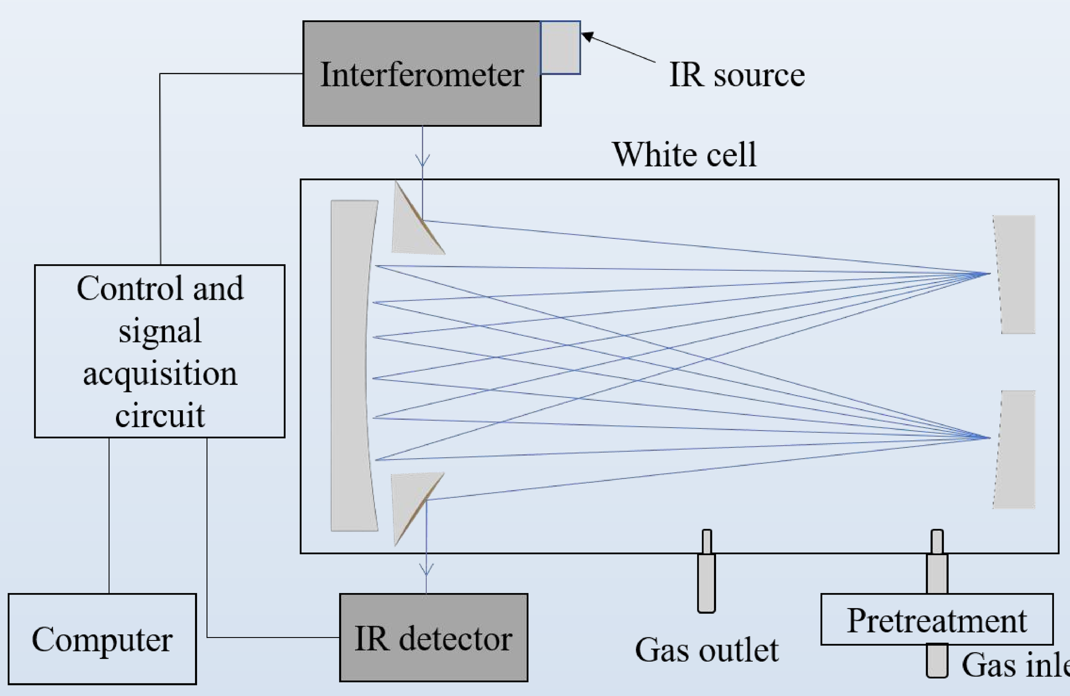

Figure 1. Portable FTIR gas analyzer system

Infrared light emitted by an infrared source is modulated by the interferometer and launched into the gas cell in parallel. The gas cell is a multi-reflection White cell cavity, which is composed of three spherical mirrors with the same radius of curvature. The sensitivity is improved by extending the optical path reflection in the gas cell cavity. The design length of the cavity is 0.3 m, the number of reflection is 16, and the optical path is 4.8 m.

There is a pre-treatment system at the gas inlet of the gas cell to filter the dust and particulate matter of the sample gas to prevent dust accumulation by the reflection mirror inside the gas cell, especially the particulate matter with a similar diameter with the infrared wavelength, which has a strong scattering effect and will cause the decline of infrared light intensity. At the same time, the temperature of the heat tracer tube is controlled at 180℃, and the sample gas is directly measured on the wet basis under the heat tracer, so as to avoid corrosion of the system during the condensation sampling process and prevent the condensation of high humidity flue gas from affecting the accuracy of the test results.

Interference system

The core component of the analyzer is Michelson interferometer (Figure 2). Different from the traditional Michelson interferometer with linear motion, the designed interferometer uses two cube corners fixed on both ends of the same swing arm to produce optical path difference.

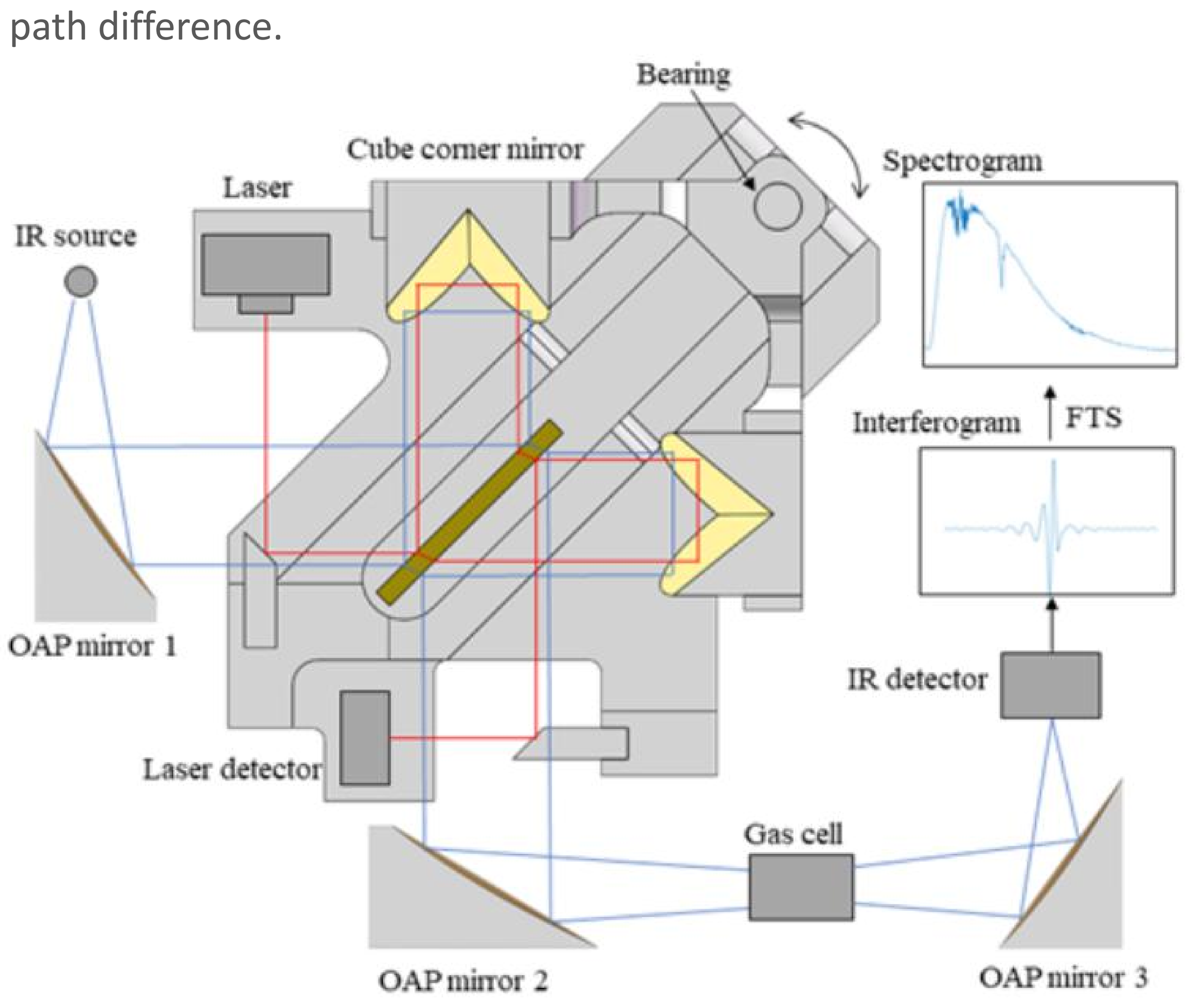

Figure 2. Swing double cube corners interference system

The infrared parallel light is emitted to the beam splitter through the off-axis parabolic (OAP) mirror 1, and is divided into two beams by transmission and reflection respectively on the beam splitter. The two beams of light are reflected to the beam splitter again through the cube corner and combined into one beam. The modulated infrared light is incident into the gas cell by the OAP mirror 2 and interacts with the measured gas molecules, then the OAP mirror 3 converges to the mercury cadmium telluride (MCT) detector or the deuterium triglyceride sulfate detector (DTGS). The optical signal detected by the detector over time is the infrared optical interference signal, while the laser detector synchronously detects the laser interference signal. The laser interference signal samples the equal optical path difference of the infrared interference signal, and then Fourier transform is carried out to get Fourier transform infrared spectrum.

SWING ARM STRUCTURE

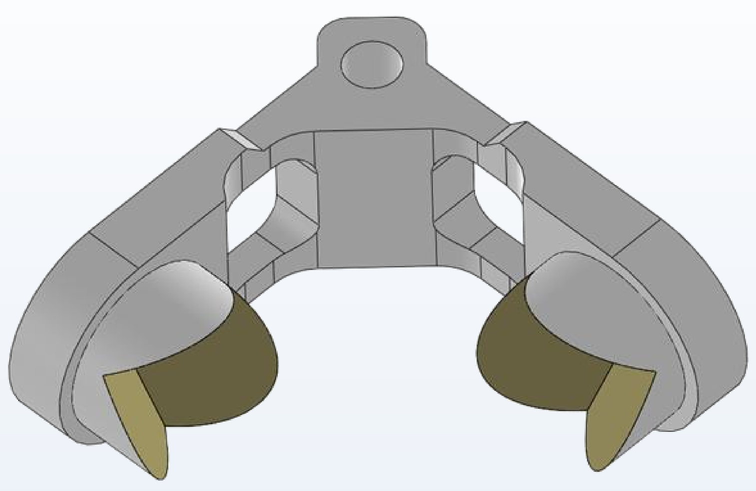

Figure 3. (a)Swing arm structure

The signal is obtained by integrating all the wave numbers from 0~∞ cm^{-1}, the sum of the intensities of all the different wavelengths of light. Because the optical path difference is continuous, the complete interferogram is obtained. By Fourier transform one can theoretically get a spectrum of 0~∞ cm^{-1} with infinite resolution. In reality, due to the limited scanning distance of the moving mirror of the interferometer and the limited interval of data acquisition, it is obviously impossible to obtain such a spectrum.

The designed angle of the swing arm is 90°, and two cube corners are fixed on both ends of the swing arm (Figure 3). The optical path difference caused by the swing:

$$\delta = 4d\tan(\theta)$$

δ is the optical path difference, d is the length of the swing arm, and θ is the rotation angle of the swing arm.

Figure 3(a) shows the structure of the swing arm, and Figure 3(b) shows the swing diagram. The swing arm rotates an angle counterclockwise from the initial position.

With such structure, large optical path difference can be obtained with a small swing angle. The length of the designed swing arm is 4.7 cm, and the optical path difference can reach 1.6448 cm at the swing angle of 5°, and the theoretical resolution can reach 0.6 cm^{-1}.

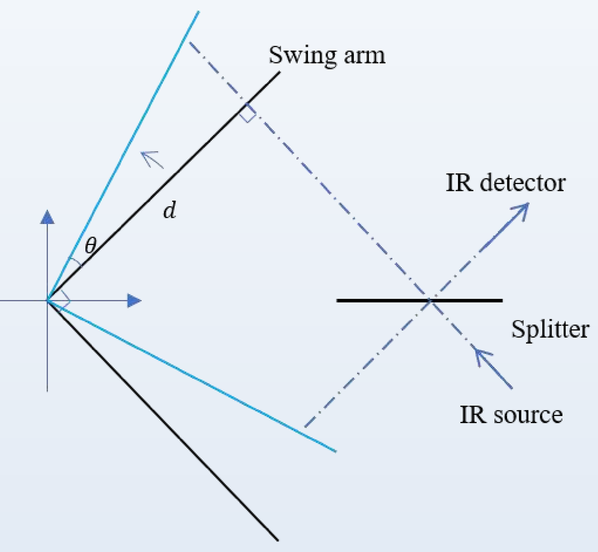

Figure 3. (b) Swing process

EXPERIMENTAL AND DISCUSSION

Calibrating gas	Initial value	Measured value	Absolute deviation	Stability
SO_2	157	157.03	0.4525	0.29%
		157.11	0.3725	
		157.87	0.3857	
		157.92	0.4375	
NO	238	235.31	2.515	1.06%
		238.54	0.715	
		238.85	1.025	
		238.6	0.775	
NO_2	238.5	239.07	0.425	022%
		238.66	0.015	
		238.13	0.515	
		238.72	0.075	

TABLE I. RESULTS OF STABILITY EXPERIMENTS

The swing double cube corners structure interference system does not need to collimate the moving mirror, which can improve the stability of the portable FTIR gas analyzer. When the gas analyzer runs stably, SO_2, NO and NO_2 gases with 80% full-scale concentration are passed into the gas chamber, the concentration value c_0 estimated by the analyzer as the initial value. The analyzer runs continuously for 1h, with injecting sample gas every 15min,and the estimated concentration value c_i was recorded at the same time. The maximum deviation from the initial value is taken to calculate the stability.

$$\eta = \frac{max|c_i - c_0|}{c_0} \times 100\%$$

η is the stability index of gas analyzer,c_iis the concentration measurement value of the i-th gas standard material.c_0 is the initial concentration of gas reference material.

The experimental results are shown in Table 1. The maximum absolute deviation of SO_2 is 0.4525, and the stability is 0.29%. The maximum absolute deviation of NO is 2.515 and the stability is 1.06%. The maximum absolute deviation of NO_2 is 0.515 and the stability is 0.22%. The three stability results of the test were all less than 2%. The experimental results show that the interference system has good stability and meets the technical requirements.

Discussion

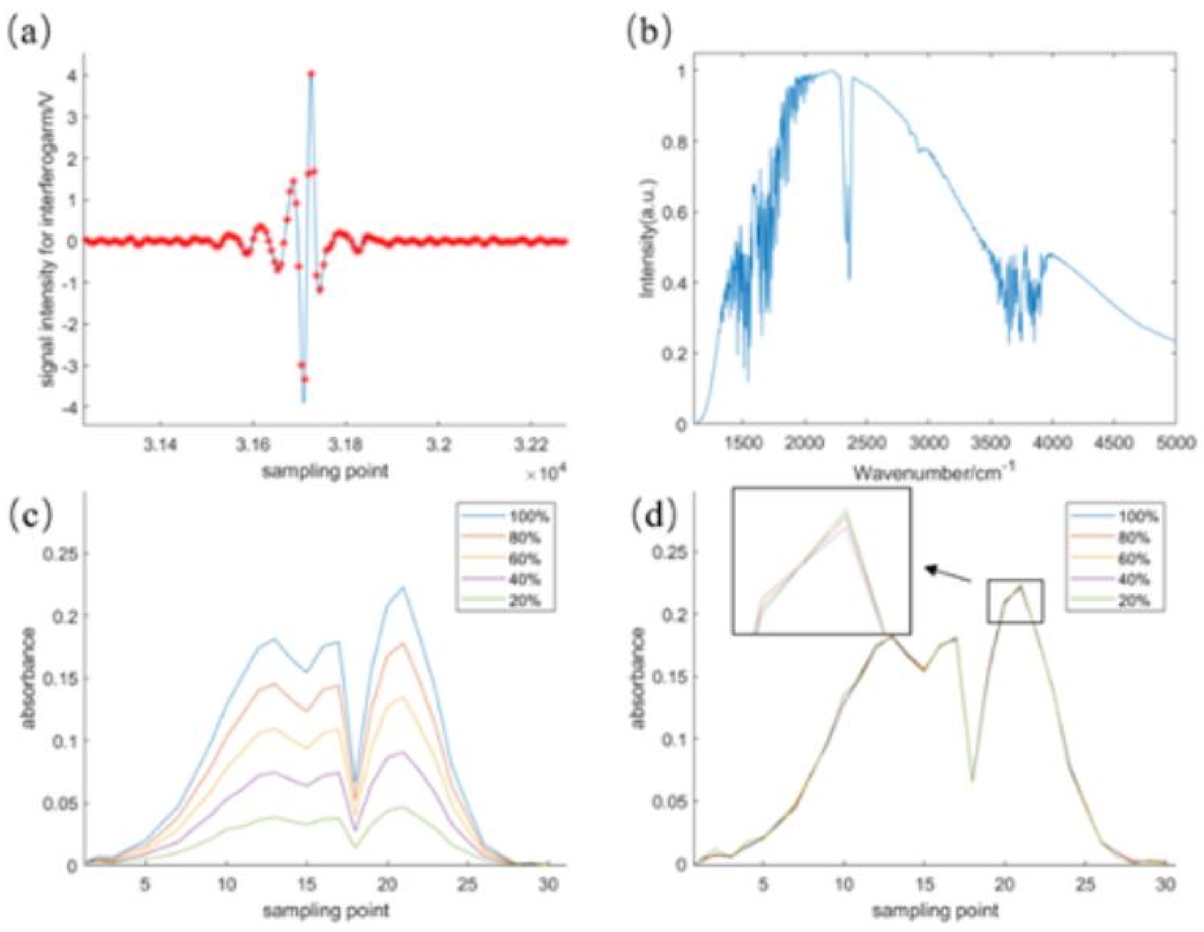

Figure 4. (a)original interferogram. (b) original retrieve spectrum. (c) Absorbance of different gradients.(d) Fitting effect of nonlinear least square

The designed interference system uses a laser at 1512nm. The laser beam and the infrared beam pass through the beam splitter (Figure 2) and incident to the laser detector via a planar mirror. The interference signals were detected by the laser detector and the infrared detector synchronously and uploaded to the computer. The optical path difference between the data points was 0.756 µm. After the data points with equal optical path difference were located and screened out, the sidelobe oscillation was suppressed by the apodization, and then the phase correction was carried out. Finally, the infrared spectrum was inverted by the fast Fourier transform. As shown in Figure 4(a) and Figure 4(b)

Figure 4(a) is the original interferogram, and the red dots are the sampling points with equal optical path difference. Figure 4(b) shows the original retrieve spectrum obtained by fast Fourier transform. Figure 4(c) shows the infrared absorption peaks of SO2 with different concentration gradients at 7.45 µm. Figure 4(d) shows the absorbance curve of different gradients fitted by nonlinear least square method, and the error between the fitted concentration value and the actual value is less than 1%.

Conclusion

In summary, we designed a small-scale swing double cube corners structure interference system. The error of concentration fitting is less than 1%, and the stability is less than 2%. Compared with the traditional interferometer, the interferometer system has better repeatability and stability. It can be applied to the portable FTIR analyzer for the comparison and supervision of online instruments

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