Calibration Design and Test of Photoionization Gas Sensor

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Abstract. A dynamic gas-mixing system and PID measurement system were designed. Three VOCs of series concentration were obtained through the controlling on-off of the three-way solenoid valve, and the corresponding circuit design and test were completed. The result shows that the output voltage of the system has a good linearity with the concentration of the gas in the concentration range from 0 to 20ppm, which indicates that it is effective to the dynamic mixing of the gas by the controlling on-off of the solenoid valve. The response sensitivities of the system to three VOCs are different, the sensitivity to butane is the highest, and the sensitivity to xylene is the lowest. The dynamic gas-mixing system can be used in gas sensor calibration.

Introduction

With the increasingly serious environmental pollution, volatile organic compounds (VOCs) are easily accumulated in many places. Before operating in such a place, besides the corresponding ventilation, it is necessary to carry out the necessary detection of environmental gases [1]. Simply judging the danger of gas by human sense of smell is prone to be misjudged by factors such as olfactory fatigue. There are many sensors for gas detection, such as gas chromatograph [2], spectrophotometer and electrochemical sensor. After nearly 20 years of development, photoionized gas sensor has become a kind of gas sensor with high sensitivity and low selectivity [3]. In recent years, the research and development of new sensors [4, 5] and electronic nose [6, 7] which is made of sensor array has become a research hotspot in the field of sensors. The most famous commercial photoionized VOCs sensors are produced by Alpha and Baseline. Before making practical instruments with these sensors, corresponding circuit design and calibration are needed. The power supply circuit and a calibration gas circuit were designed for Alpha photoionization sensor, and the calibration test was carried out.

Design of Detection Gas Path

The detection gas circuit is mainly composed of filter, miniature three-way solenoid valve, three-way joint, miniature diaphragm pump, photoionization sensor, gas chamber, sample gas bag, pipeline and pipeline interface (Figure 1).

![Figure 1. The diagram of detection Gas Path.](image-url)

Adjust the pumping rate of the diaphragm pump to keep the pressure of the buffer chamber (a barometer is equipped on the buffer chamber, which is not shown in Figure 1) 50 mmHg lower than atmospheric pressure. When the voltage of solenoid valve is at low level, clean air enters the pipeline system through solenoid valve under the pressure, and while the voltage of the solenoid...
valve is at high level, sample gas enters the system through the solenoid valve. Driven by a square wave voltage with a specific duty ratio, the corresponding ratio of sample gas enters the system through the solenoid valve. Different duty ratios correspond to different concentrations of the sample gases.

**Design of the Circuits**

The driving voltage of solenoid valve and amplifier chips is 5V, which is consistent with the supply voltage of the PID sensor. Therefore, a 5V DC power supply is needed. The power supply module uses a high-power transformer to convert 220V AC to 12V AC. A rectifier bridge is used to complete the rectification. The circuit diagram of the power module is shown in Figure 2.

![Figure 2. Schematic diagram of power supply module.](image)

The schematic diagram of duty ratio regulating circuit is shown in figure 3. The input signal is a stable triangular wave voltage from a signal generator with a frequency of 1Hz and amplitude of 4V. The output signal is a stable square wave voltage signal with amplitude of 5V, whose duty ratio can be adjusted with the change of R2 (R2_{max} = 4 \times R1), and the duty ratio can be readout using an oscilloscope.

![Figure 3. Schematic diagram of square wave circuit.](image)

The sample gas is diluted by clean air, and the concentration of sample gas is very low, so the output signal of the PID is very weak. The output signal of PID is amplified 10 times by the common instrument amplifier circuit.

**Test and Results**

Gas samples with known concentrations should be allocated before the experiment. A certain volume of sample gas is extracted by a syringe and injected into the air bag, and then clean air with known volume is injected into the air bag. In this way, three sample gases (ethanol gas, butane and xylene) with a concentration of 20 ppm are allocated. The potential of the negative input terminal of
the amplifier Q1 (U-) can be adjusted with the change of the resistance of R2 in Figure 3 as the equation (1). The input and output signals in Figure 3 are shown in Figure 4.

\[ U = 5V \cdot \frac{R_2}{R_1 + R_2} \]  

Figure 4. Schematic diagram of solenoid valve drive voltage.

The experimental steps are as follows:

(1) After the sample gas is connected, the diaphragm pump is opened and the flow rate of the diaphragm pump is adjusted till the pressure of the buffer chamber is about 50 mmHg lower than the ambient pressure.

(2) The output voltage is monitored by an oscilloscope while the resistance R2 is adjusted, till the duty ratio of the driving voltage of the solenoid valve reaches the presupposed value.

(3) Switch on the power supply of PID. The output signal of the PID is basically stable after 15 minutes. Then the output signal of the PID is recorded in every subsequent minute. 10 minutes later, the power supply of the PID and the solenoid valve is closed, and the solenoid valve is only connected to the clean air.

(4) Turn off the power supply of the diaphragm pump after 20 minutes.

(5) Repeat steps (1) to (4) for different sample gases.

The experimental data are shown in Table 1, and the response curves are shown in Figure 5.

<table>
<thead>
<tr>
<th>Duty Ratio</th>
<th>Concentration (ppm)</th>
<th>Ethanol gas</th>
<th>Xylene</th>
<th>Butane</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>61</td>
<td>64</td>
<td>68</td>
</tr>
<tr>
<td>0.1</td>
<td>2</td>
<td>279</td>
<td>225</td>
<td>293</td>
</tr>
<tr>
<td>0.2</td>
<td>4</td>
<td>511</td>
<td>422</td>
<td>518</td>
</tr>
<tr>
<td>0.3</td>
<td>6</td>
<td>681</td>
<td>599</td>
<td>749</td>
</tr>
<tr>
<td>0.4</td>
<td>8</td>
<td>885</td>
<td>783</td>
<td>974</td>
</tr>
<tr>
<td>0.5</td>
<td>10</td>
<td>1076</td>
<td>946</td>
<td>1185</td>
</tr>
<tr>
<td>0.6</td>
<td>12</td>
<td>1294</td>
<td>1109</td>
<td>1389</td>
</tr>
<tr>
<td>0.7</td>
<td>14</td>
<td>1512</td>
<td>1238</td>
<td>1648</td>
</tr>
<tr>
<td>0.8</td>
<td>16</td>
<td>1702</td>
<td>1409</td>
<td>1900</td>
</tr>
<tr>
<td>0.9</td>
<td>18</td>
<td>1906</td>
<td>1606</td>
<td>2150</td>
</tr>
</tbody>
</table>
It can be seen from Fig. 5 that the output voltage of the system has a good linearity with the concentration of the gas to be measured in a certain range, which also shows that it is effective to control the dynamic mixing of the gas by the on-off of the solenoid valve. The response sensitivity of the system to three VOCs is different, the sensitivity to butane is the highest, and the sensitivity to xylene is the lowest.

Summary

A dynamic gas-mixing system and PID measurement system were designed. VOCs of series concentration were obtained through the controlling on-off of the three-way solenoid valve, and the corresponding circuit design and test were completed. The result shows that the output voltage of the system has a good linearity with the concentration of the gas in a range from 0 to 20ppm, which indicates that it is effective to control the dynamic mixing process of the gas by controlling on-off of the solenoid valve. The response sensitivities of the system to three VOCs are different, the sensitivity to butane is the highest, and the sensitivity to xylene is the lowest.

References


