Design of an anti-interference multi parameter sensor

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Abstract. Aiming at the shortcomings of single function, easy to be affected by underground background gas and weak anti-interference of current mining environment parameter sensor, an environment multi parameter sensor is designed, which can simultaneously detect three parameters of methane, carbon monoxide and temperature in the environment. The interference of background gas is eliminated by optical identification method, and the reliability of temperature detection is realized by thermal resistance isolation module. At the same time, the filter circuit of the sensor is optimized, the interference suppression frequency band of the filter is expanded, the anti electromagnetic interference ability of the sensor is improved, and the problem of false alarm caused by the interference of large-scale frequency conversion equipment on the sensor is solved. The experimental results show that the sensor has strong anti-interference and high reliability.

1. Introduction

Underground environmental parameter detection is the top priority of mine safety production. With the help of environmental parameter sensors, coal mine safety monitoring system can realize real-time online monitoring of underground methane, carbon monoxide, temperature and other environmental parameters. However, at present, the common mining sensors have single function, and most of them are single parameter sensors, with low degree of intelligence. In terms of electromagnetic compatibility of sensors, although the latest industry standard aq6201-2019 "general technical requirements for coal mine safety monitoring system" has put forward clear requirements for the anti electromagnetic interference ability of products, and the new generation of safety monitoring system does have a certain anti electromagnetic interference ability after upgrading. But in practical application, especially the sensors arranged near the large-scale frequency conversion equipment, there will still be false alarms such as "big number". According to the measurement and analysis of electromagnetic environment on site by technicians, the emission interference of frequency conversion equipment is mainly concentrated below 80MHz \cite{1-8}, while the measurement frequency band of RF electromagnetic radiation immunity test specified in aq6201-2019 is 80mhz-1ghz, which does not cover the frequency range below 80MHz. Therefore, the anti-interference ability of sensor in low frequency band needs to be strengthened.

The detection of gas sensors in the environment mainly includes spectral absorption principle, catalytic principle, thermal conductivity principle and electrochemical principle. For methane detection, quantitative detection based on spectral absorption principle has the problem of complex process and...
high price, so the catalytic principle is still mainly used in the underground methane detection in the coal industry; for carbon monoxide detection, limited by the measurement resolution (1ppm) and price factors in the industry, the electrochemical principle is mainly used in the underground carbon monoxide detection at present. The catalytic methane detection method and electrochemical carbon monoxide detection method will be affected by the background gas in the environment to produce false alarms. At the same time, because the output signal of the sensitive element is small, especially the output signal of the electrochemical sensitive element is a low current signal of NAA level, it is easy to be affected by the underground electromagnetic interference to produce the phenomenon of "big number"\(^9\)\(^{-13}\). The underground temperature detection mainly adopts the thermal detection principle, and realizes the real-time temperature detection with the help of digital single bus transmission mechanism, with limited range and weak anti-interference.

In this paper, an environmental multi parameter sensor is designed, which can detect methane, carbon monoxide and temperature at the same time. Optical qualitative identification method and anti electromagnetic interference design are used to eliminate the influence of background gas and frequency conversion equipment on the sensor, and improve the reliability of detection.

2. Detection principle

2.1. Methane detection design

Mjc4 / 3.0L methane probe of 718 Institute of Shipbuilding Heavy Industry is used as methane sensor. Its measuring range is 0-4%, and its working voltage is 3V. The internal resistance can be equivalent to fixed resistance (white part) and variable resistance (black part). When there is methane gas outside, the resistance value of variable resistance increases linearly with the increase of methane concentration, and the sensitivity is about 25mV/1% CH4. The acquisition circuit is shown in Figure 1. The output voltage of the bridge is amplified by the amplifier AD623 and then enters the AD entrance of the single chip microcomputer for data acquisition.

If the acquisition voltage at the AD entrance of the single chip microcomputer is set as \(V_{CH4}\), there are:

\[
V_{CH4} = (V_{+} - V_{-}) \times \left(\frac{100k}{R22} + 1\right)
\]

The magnification of AD623 can be changed by adjusting R22. In this paper, R22 is selected as 10K. The output range is about 0.1V to 1.5V.
In practical application, acetylene and other gases in the environment will cause black part reaction of the sensor, which leads to the sensor can not effectively identify methane in the air. In view of this situation, a methane recognition module is designed. Methane gas has strong absorption to the spectrum of 1650nm, while other gases have almost no absorption. When there is methane gas in the optical path, the optical signal will be attenuated. If it is other gas, it will not be attenuated. It can be effectively identified by the receiving photodiode. When the module outputs high level, it thinks that there is methane in the air, otherwise it outputs low level. When the MCU receives the high-level signal from the methane identification module and the signal voltage is changed, the methane data will be updated. Otherwise, the methane data will not be updated.

![Figure 2. Principle block diagram of methane recognition module.](image)

### 2.2. Detection design

The carbon monoxide sensor is a 4cm carbon monoxide probe from city, UK, with a range of 0-2000ppm and a sensitivity of 70nA / 1ppmCO. The acquisition circuit is shown in Figure 3. The current signal output by the probe is amplified by the operational amplifier, converted into voltage signal, and then enters the AD entrance of the single chip microcomputer for data acquisition.

If the acquisition voltage at the ad entrance of the single chip microcomputer is set as $V_{CO}$, there are:

$$V_{CO} = \frac{V_I}{R_{13}} + V_0$$

Among them, $V_0 = 0.2V$, $R_{13} = 14.3k$, so when the carbon monoxide in the environment is 2000ppm, $V_{CO} = 14.3 \times 1000 \times 70 \times 10^{-9} \times 2000 \times 0.2 \approx 2.2V$.

The output range of $V_{CO}$ is 0.2~2.2V.

![Figure 3. Principle diagram of carbon monoxide detection.](image)

In practical application, acetylene, nitric oxide and other gases in the environment will cause the reaction of sensitive elements, which leads to the sensor can not effectively identify carbon monoxide in the air. In view of this situation, a carbon monoxide recognition module is designed. Carbon monoxide...
gas has strong absorption to the spectrum of 2330nm, while other gases have almost no absorption. When there is carbon monoxide gas in the optical path, the optical signal will be attenuated. If it is other background gas, it will not be attenuated. It can be effectively identified by the receiving photodiode. When the module is designed, it outputs high level and thinks that there is carbon monoxide in the air, otherwise it outputs low level. When the MCU receives the high-level signal from the carbon monoxide identification module and the signal voltage change is collected by the ad port of the MCU, the carbon monoxide data will be updated, otherwise the carbon monoxide data will not be updated.

**Figure 4. Principle block diagram of carbon monoxide recognition module.**

2.3. Temperature detection design

The temperature sensitive element is PT100 thermal resistance. The temperature signal can be converted into standard 4-20mA current signal through trp16150p. The isolation module is a hybrid integrated circuit which transforms the thermal resistance signal into linear standard signal according to the temperature isolation. The circuit integrates two groups of isolated power supply on the same chip to supply power to internal input amplifier circuit, modulation circuit and output demodulation circuit, conversion circuit and filter circuit respectively; power supply, signal input and signal output are isolated from each other, and have strong anti-interference performance. The protection capability of electrostatic ±4KV, impulse group immunity ±2KV and surge immunity ±1kV can be achieved.

Fig. 5 is the schematic diagram of temperature detection, and the range is designed as 0-200 ℃. When using, the zero point is set by adjusting R35, and R36 is adjusted to set the gain coefficient. The final module outputs the standard 4-20mA current signal. The signal is converted to voltage signal after 100 ohm precision resistor, and then enters the AD entrance of MCU to collect data.

Set the entrance voltage of the MCU AD, and the output range is 0.4-2V.

**Figure 5. Principle of temperature detection.**

2.4. Electromagnetic protection design

The author found that the interference frequency band produced by large-scale frequency conversion equipment is less than 80MHz, which can easily cause the sensor to produce "large number" in a short
time and give false alarm. In order to solve this problem, it is necessary to adjust the filter parameters of existing sensors. In this paper, ADS (Advanced Design System) simulation software is used to design the parameters of the filter.

Firstly, the existing sensor filter circuit is simulated and its insertion loss is tested. Draw the filter circuit and set the device parameters in ADS software, add S parameter simulation control, and set the simulation frequency band to 10kHz-1GHz, as shown in Figure 6. The simulation calculation is shown in Figure 7.

![Figure 6. Simulation of filter insertion loss circuit before optimization.](image1)

![Figure 7. Simulation results of pre filter insertion loss.](image2)

It can be seen from the simulation results that the insertion loss of the existing filter circuit of the sensor can reach 30dB above 100MHz (the actual insertion loss will be less than the simulation value due to the influence of parasitic parameters in the process of use), while the insertion loss is smaller for the frequency band below 100MHz. This filter has obvious filtering effect for the interference above 80MHz, but it is not suitable for the interference below 80MHz. The results are consistent with the field and laboratory test results. Therefore, it is necessary to design and adjust the filter to meet the actual
field filtering needs. Adjust the structure of the filter circuit, optimize the parameters of related devices, and simulate the optimized filter circuit, as shown in Figure 8.

![Simulation of insertion loss circuit of filter after optimization.](image1)

Figure 8. Simulation of insertion loss circuit of filter after optimization.

After simulation, the result is shown in Figure 9.

![Simulation results of filter insertion loss after optimization.](image2)

Figure 9. Simulation results of filter insertion loss after optimization.

From the simulation results, it can be seen that the insertion loss of the optimized filter circuit is significantly improved in the frequency band below 80MHz, and it has obvious filtering effect on the interference above 5MHz. Table 1 shows the comparison of the parameters before and after the filter...
optimization. The filtering effect of the optimized filter in wide band is significantly improved. Finally, the optimized filter is applied to the actual test verification.

Table 1. Comparison of filter parameters before and after optimization.

| Filter parameters                  | 10MHz insertion loss (dB) | 100MHz insertion loss (dB) | 500MHz insertion loss (dB) | 1GHz insertion loss (dB) |
|------------------------------------|---------------------------|-----------------------------|-----------------------------|--------------------------|
| Filter capacitor C = 100pF;       | -1.301                    | -30.956                     | -49.950                     | -56.279                  |
| common mode inductance LP = 1uh;  |                           |                             |                             |                          |
| capacitor filter is in the second  |                           |                             |                             |                          |
| stage                               |                           |                             |                             |                          |
| Filter capacitor C = 2200pf;       | -37.774                   | -63.128                     | -77.211                     | -83.235                  |
| common mode inductance LP = 10uh;  |                           |                             |                             |                          |
| capacitor filter is in the first   |                           |                             |                             |                          |
| stage                               |                           |                             |                             |                          |

3. Hardware design

The hardware block diagram of the sensor is shown in Figure 10. The MCU of the sensor is C8051F040. The 21vdc intrinsically safe power supply is converted into three power supplies through power filter and voltage conversion circuit. One 3.3V power supply is used to supply power for MCU, peripheral display module, storage module and remote control module; one 3VDC power supply is used to supply power for methane detection module and carbon monoxide detection module; one 12VDC power supply is used to supply power for temperature detection module.

Methane detection module, carbon monoxide detection module and temperature detection module output a voltage signal to single-chip microcomputer ad module respectively, through AD acquisition, the values of methane, carbon monoxide and temperature in the environment can be obtained in real time; methane identification module and carbon monoxide identification module output a level signal respectively, through single-chip microcomputer IO port, the level change can be detected in real time. At the same time, the MCU drives the display module to display data through the serial communication, the I2C communication drives the storage module to store data, and the SPI communication drives the remote control module to conduct remote control calibration.
4. Software design

After the system is powered on, the power on initialization is carried out first, and the MCU starts to configure the internal clock and related peripherals. After the configuration is completed, the detection mode is turned on, the timer 0 starts to work, and the acquisition flag is set every 1 second. After setting, the MCU starts to detect the level state of P3.0 and P3.1, so as to determine whether there is interference gas outside. If P3.0 is low level, the methane channel data will not be collected. If P3.1 is low level, the carbon monoxide channel data will not be collected.

After the level state detection of P3.0 and P3.1 ports is completed, the data of temperature channel is collected through ad channel 0, and whether to collect the data of methane channel and carbon monoxide channel is determined according to the status of IO port. After data collection, the data of methane, carbon monoxide and temperature in the actual environment are obtained and displayed by numerical calculation.

After the display is completed, check whether the remote control flag is set. If it is set, it means that it is in the state of remote control calibration. Start to set the relevant parameters. After setting, return to the main interface to start the next round of data acquisition. If the remote control flag is not set, it will immediately enter the next round of data acquisition.
5. Experiment

In order to verify the influence of background gas on the sensor, 48ppm nitric oxide and 400ppm acetylene are used respectively. The experimental results show that the optical recognition module can effectively remove the interference of background gas in the environment.

| Interference gas       | Output voltage of methane module V\_CH4 (V) | Output voltage of carbon monoxide module V\_CO (V) | Methane display value (%) | Carbon monoxide display value (ppm) |
|------------------------|--------------------------------------------|-----------------------------------------------|----------------------------|-----------------------------------|
| No interference        | 0.151                                      | 0.231                                         | 0.00                       | 0                                 |
| 48ppm Nitric oxide     | 0.151                                      | 0.248                                         | 0.00                       | 0                                 |
| 400ppm Acetylene       | 0.158                                      | 0.590                                         | 0.00                       | 0                                 |

To verify the anti-interference ability of the sensor, in addition to the original pulse group, surge, radio frequency electromagnetic field radiation immunity test, the radio frequency electromagnetic field radiation immunity test is added. Table 3 and table 4 show the test results before and after the optimization of the filter respectively. The experimental results show that the optimized filter circuit also has good filtering effect on the interference below 80MHz.

| Test items               | Methane display value (%) | Carbon monoxide value (ppm) | Temperature value (°C) |
|-------------------------|----------------------------|-----------------------------|------------------------|

Figure 11. Sensor software flow chart.
| Test environment data | 0.00 | 0 | 25.6 |
|-----------------------|------|---|------|
| Surge                 | 0.00 | 0 | 25.6 |
| Burst                 | 0.00 | 0 | 25.6 |
| Radiofrequency        | 0.00 | 0 | 25.6 |
| electromagnetic radiation |     |   |      |
| Radiofrequency conduction | 2.03@20MHz | 1.52@70MHz | 25.6 |
|                       | 120@20MHz |   |      |

| Test items                      | Methane display value (%) | Carbon monoxide value (ppm) | Temperature value (℃) |
|--------------------------------|----------------------------|-----------------------------|-----------------------|
| Test environment data          | 0.00                       | 0                           | 25.6                  |
| Surge                          | 0.00                       | 0                           | 25.6                  |
| Burst                          | 0.00                       | 0                           | 25.6                  |
| Radiofrequency electromagnetic radiation | 0.00           | 0                           | 25.6                  |
| Radiofrequency conduction      | 0.00                       | 0                           | 25.6                  |

6. Conclusion
The design of multi parameter sensor adopts the method of optical identification to avoid the influence of background gas on the measurement. At the same time, according to the actual situation, the filter circuit of the sensor is redesigned and optimized to improve the anti-interference performance of the sensor and ensure the accurate and reliable measurement of the sensor data. This design has the following advantages:
- The problem of sensor false alarm caused by background gas interference in the environment is avoided.
- The interference suppression of 5mhz-1ghz broadband is realized, and the false alarm problem caused by the interference of frequency conversion equipment is solved.

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