The Designed MEMS Methane Sensor Based on Pulse Power Supply

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Abstract. As the power too high, the traditional catalytic methane sensor has high wiring cost and quantitative restriction in single circuit. In this paper, a new intelligent methane sensor aimed at low power consumption is designed by using low power MEMS catalytic methane cell, pulse supply mechanism and low power waste circuit. It is observed from the test that the new sensor has low power consumption and well performance.

Key words: Catalytic methane; MEMS; low power consumption; pulse power.

1. Introduction
Gas disaster has always been the main threat to coal production safety in China [1]. The main component of gas is methane which detection is very important for personal and production safety. With the progress of science and technology, the detection of methane concentration has been greatly developed both in principle and technology[2-4]. For example, new infrared and laser methane sensors have great performance on accuracy detection and anti-interference, while traditional catalytic methane sensors still occupy the majority of the market due to their high reliability and low cost although they need high power consumption, more wiring cost and regular calibration [5]. The newly upgraded safety system of coal mining requires the sensor layer to realize bus communication and carry as many load sensors as possible on a single bus, which puts forward a serious test for the power consumption of traditional catalytic methane sensors [6]. As a result, a new type of intelligent bus catalytic methane sensor was designed in this paper. Choosing low power catalytic beads with MEMS process as a sensitive element and then using pulse power supply to further reduce the power consumption, the new sensor power consumption as a whole machine is far less than the traditional catalytic methane sensor.

2. Bus Type Intelligent Sensor Design

2.1. New Methane Sensor Design
The new methane sensor is composed of core processor, catalytic methane components, signal-processing circuit, zero circuit, bus communication module, display, remote control, sound and light alarm circuit. A Block diagram of the new methane sensor is given in figure 1. After comparison, amplification, filtering and other processing, the voltage analog signal output from the catalytic methane
element is sent to the AD port of stm32f103rbt6 MCU for sampling. The MCU converts the collected signal into the corresponding methane concentration, displays it in real time through the display circuit and sends it to the monitoring system through the CAN bus. All circuit components of the sensor are selected with low power consumption to ensure sufficient accuracy, and the single-chip microcomputer will sleep periodically after completing the task to reduce power consumption.

![Figure 1. System block diagram](image1)

As the main energy consuming unit of methane catalytic sensor, traditional catalytic elements are usually designed in the form of cantilever that the sensitive beads and compensation beads are suspended on the support, which are easy to be affected by vibration. Although this way can make the catalyst fully contact with the measured gas, but it is sensitive to the gas flow velocity and has rapid heat loss, therefore maintaining the heat balance is uneasy and it consumes a lot of power. The MEMS catalytic methane element [7-8] is first fabricated by etching snake-like grooves into silicon wafers, precious metal is precipitated in the grooves by precipitation to form heating beads, printing catalyst on heating bead to form catalyst bead. Finally, the catalyst bead and the compensation bead without printed on catalyst are encapsulated in the explosion-proof shell. The crystal structure is shown in figure 2 [9-10].The catalytic elements made by MEMS technology are not only small in size, consistent, high in reliability, shock and vibration resistance, but also be able to rapidly heat up and achieve thermal balance under electric heating.

MEMS components have good heating performance and thermal equilibrium performance that make it less power consumption than that of traditional catalytic components when heating and maintaining the temperature required by the catalyst [11-12]. In this paper, SGX company's VQ548MP MEMS catalytic methane element (as shown in figure 3) was selected, which average current was as low as about 40mA at rated working voltage 3.0v, and the power consumption was much less than that of traditional catalytic element (440mW).

![Figure 2. Schematic diagram of crystal element structure](image2)

![Figure 3. VQ548MP element](image3)

### 2.2. High Efficiency Power Circuit Design

The MEMS methane element normally operates at 3.0v and the operating current is about 40mA. In order to reduce the power consumption, the LDO power supply chip TPS77601 with high conversion
efficiency is selected in this paper to supply power. TPS77601 chip has low IQ voltage difference, low output noise, adjustable output voltage, low static current to 85μA, high conversion efficiency, cost performance and is suitable for MEMS components power supply. The circuit shown in figure 4 indicates that TPS77601 is equipped with enabling pin EN, which can output 3.0v when EN is low and 0V when EN is high.

![Power supply circuit of element](image)

**Figure 4.** Power supply circuit of element

### 2.3. Intelligent Zeroing and Signal Processing Circuit Design

Wheatstone bridge is used when collect the output voltage of elements which principle is given in figure 5. The MEMS catalytic element selected has a sensitivity of 13mV/1%CH4, a measurement range of 0 to 100%LEL, and a total deviation of the output signal of about 65mV. For the sake of improving resolution of the sensor, high-precision operational amplifier LM4562 is selected to amplify the signal, and the circuit is shown in figure 6. Where, \( V_f \) is the improved Wheatstone bridge zero voltage regulation, \( V_s \) is the component output signal, \( R_7, R_8, R_9, R_{10} \) take the same resistance value, then the circuit output \( V_{out} \) can be calculated by formula (1). When the catalytic element works for a long time, the zero point has a slow drift and needs to be adjusted regularly. The traditional sensor adopts potentiometer for zero adjustment, and the sensor shell needs to be removed for adjustment, which is very inconvenient.

In figure6, analog single-chip microcomputer port output is used for zero setting. The reference voltage can be calculated by formula (2), where \( V_d \) is the output voltage of analog port. While incremental PID algorithm of formula (3) is adopted for zeroing, in which \( K_p, K_i \) and \( K_d \) are proportional integral and differential factors respectively, and the values are estimated by formula (1) and formula (2). \( U(k) \) is the DA value of analog port, and \( e(k) \) is the voltage difference between acquisition voltage and target voltage of AD port. This circuit can realize automatic and remote zero adjustment of sensor.

\[
V_{out} = (V_5 - V_f)(R_4 + R_5 + R_6)/R_5
\]  
\[
V_f = -\frac{3R_5R_6 - R_6V_d}{R_5}  
\]  
\[
\begin{align*}
\Delta u(k) &= K_i[e(k) - e(k-1)] + K_p[e(k) + K_d[e(k) - 2e(k-1) + e(k-2)] \\
u(k) &= u(k-1) + \Delta u(k)
\end{align*}
\]
2.4. Bus Communication Circuit and Communication Mechanism Design

The sensor and monitoring system designed in this paper adopts CAN bus for digital communication which interface circuit is given in figure 7 and figure 8. TI SN65HVD251 chip is selected as the transceiver with a communication rate of 25k, and TVS is used for electrostatic protection. Figure 9 illustrates the communication mechanism.

After the sensor is powered on, it first listens to the bus to see if there is a node with the same ID as itself. If there is, it sends out a sensor address conflict frame to the bus and waits for the monitoring system or manual processing. If the monitoring device on the bus agrees to access, the response frame will be replied. When receiving the response frame, the sensor broadcasts the measurement data to the bus in a fixed period, and then receives the heartbeat frame sent by the monitoring device on a regular basis. The data will be stopped if the received heartbeat frame timeout [13].
3. Pulse Power Supply Design

Using pulse power supply to power the MEMS catalytic element can reduce power consumption as is shown in figure 4 [14], the EN pin of the power chip TPS77601 is controlled by pulse signal to realize the pulse power supply of the catalytic element. A pulse with a frequency of 1Hz and a duty cycle of 50% was selected, and the analog signal was sampled between 485ms and 495ms at the pulse high level. In the laboratory environment, choosing basic error, zero temperature characteristics and sensitivity temperature characteristics as the test data. Four new sensors were selected, respectively no.1, no.2, no.3 and no.4, the results are shown in table 1, figure 10 and figure 11. It is can be seen from the results, the
sensor error is less than 5% with 20 °C for reference, the sensors in -20 °C to 60 °C temperature range
is less than 0.04, the zero drift sensitivity drift is less than 5%, and both drift strong regularity.

Table 1. Basic error

| Sample gas concentration | No. 1 | No. 2 | No. 3 | No. 4 |
|--------------------------|-------|-------|-------|-------|
| 0.49(%)                  | 0.50  | 0.51  | 0.50  | 0.52  |
| 0.99(%)                  | 1.01  | 1.00  | 0.98  | 1.02  |
| 2.01(%)                  | 2.02  | 1.98  | 1.97  | 2.03  |
| 3.51(%)                  | 3.46  | 3.44  | 3.43  | 3.53  |

Figure 10. Zero temperature characteristic

Figure 11. Sensitivity temperature characteristic

4. Power Consumption Analysis
Based on the hardware platform designed in this paper, the sensor adopts the MENS catalytic element
and the traditional catalytic element respectively that all powered by constant voltage. Table 2 shows
the average operating current (mA) of the whole machine at 24V, the results imply that energy
consumption of the methane sensor using MEMS components is greatly reduced. The pulse mode was further used to power MEMS components, and the machine current (mA) at 24V was tested. The results are given in table 3 shown that the average operating current of the machine is as low as 5mA.

### Table 2. Prototype circuit with constant voltage power supply

| Element type       | No. 1 | No. 2 | No. 3 | No. 4 |
|--------------------|-------|-------|-------|-------|
| MEMS elements      | 8.03  | 7.92  | 7.89  | 8.21  |
| Traditional elements | 21.75 | 22.06 | 20.96 | 22.16 |

### Table 3. Prototype circuit with constant voltage and pulse power supply

| Power supply        | No. 1 | No. 2 | No. 3 | No. 4 |
|---------------------|-------|-------|-------|-------|
| Constant voltage    | 8.05  | 7.91  | 7.96  | 8.19  |
| Pulse power         | 5.21  | 5.46  | 5.33  | 5.51  |

### 5. Conclusion

After the analysis and comparison of traditional catalytic components with the catalytic methane of MEMS components, low power consumption catalytic methane sensor based on pulse power supply is designed. New sensor not only has good performance and power consumption is much lower than traditional catalytic methane sensor. To a certain extent, it solves the problem of high power consumption of traditional catalytic sensor and small loads with single circuit power supply. It can be used for long distance bus communication monitoring system.

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