A New Ultrasonic Gas Meter for Household Application

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Abstract. This paper proposes a new ultrasonic gas meter based on the time difference method. The gas flow measurement model is derived to reduce the environmental impact. A fluid pipeline structure is designed to reduce the impact of the flow field on the measurement. The max35104 time measurement chip is selected and the corresponding transmit and receive circuits are designed. Finally, the ultrasonic gas meter is tested in a standard device. The experimental results show that the designed household ultrasonic gas meter has an accuracy rating of 1.5 level.

1. Introduction
Gas is an important source of energy for people's lives and factories. Gas supply is an important part of national and urban infrastructure. As an important tool for measuring gas flow, gas meters are an important instrument for measuring the total gas consumption and an indispensable part of the entire gas supply industry chain. At present, the mainstream gas meters on the market are traditional mechanical diaphragm gas meter. The mechanical diaphragm gas meter has the advantages of reliable measurement, stable quality, and the disadvantages of low intelligent level, with movable parts, large pressure loss, complex production and assembly, and large labor cost. Ultrasonic gas meter is a new type of measuring instrument that works with acoustic principle. Compared with the mechanical diaphragm gas meter, it has non-contact measurement and no moving parts. At the same time, it has the advantages of small pressure loss, large flow measurement range, high measurement accuracy and simple assembly. Moreover, with the rapid development of computers, network information technology and microelectronics technology, as well as the continuous decline in the price of sensors and chips, the production cost of ultrasonic gas meters has been greatly reduced, making it possible to make ultrasonic gas meters a new generation of gas meters [1-5].

2. Flow measurement model and physical design
2.1. Measurement Principle
Ultrasonic measurement can be roughly classified into Doppler method, beam offset method, correlation method and time difference method according to the measurement principle. Because the measurement principle of the time difference method is simple, the error caused by the change of the sound speed with the temperature of the fluid is reduced, and the measurement accuracy is high. Therefore, we finally choose the time difference method as the flow metering method of the gas meter.

The basis of the time difference method is the principle of speed superposition. When ultrasonic waves are transmitted in a flowing medium, the transmission speed is affected by the flow velocity of
the medium. When the medium flows and the ultrasonic wave propagates in the forward direction, the ultrasonic wave propagation speed increases with the medium flow velocity; when the medium flow and the ultrasonic wave propagate in the opposite direction, the ultrasonic wave propagation velocity decreases as the medium flow velocity increases. Further, according to the time difference of the upstream and the countercurrent flow through the fluid pipeline, as shown in figure 1, the flow rate information of the fluid can be obtained [6].

From the figure1. The acoustic path distance can be expressed as

\[ L = D / \sin \theta \]  

(1)

Where \( L \) = acoustic path distance

\( D \) = diameter of pipe

\( \theta \) = transmission angle

The key to the measurement of the time difference method is the downstream time \( T_{AB} \) and the upstream time \( T_{BA} \) measured between the sensors A and B. And the downstream time \( T_{AB} \) and the upstream time \( T_{BA} \) are respectively:

\[ T_{AB} = \frac{L}{C + V \cos \theta} \]  

(2)

\[ T_{BA} = \frac{L}{C - V \cos \theta} \]  

(3)

Where \( T_{AB} \) = pulse transit time in downstream direction

\( T_{BA} \) = pulse transit time in upstream direction

\( C \) = gas velocity of sound

\( V \) = flow velocity

The flow velocity \( V \) can be calculated in (4). According to (2) and (3).

\[ V = \frac{L(T_{BA} - T_{AB})}{2 \cos \theta \times T_{AB} \times T_{BA}} \]  

(4)

Then the volume flow rate \( Q \) is obtained in (5).

\[ Q = \frac{\pi D^3(T_{BA} - T_{AB})}{4 \sin 2\theta \times T_{BA} \times T_{AB}} \]  

(5)

It can be concluded from (5) that volume flow rate \( Q \) is only related to flight time \( T_{AB} (T_{BA}) \) and has nothing to do with sound velocity \( C \).

2.2. Pipeline design

The measuring gas continuously enters the cavity from the air inlet. As the gas in the cavity increases, the pressure gradually increases, and enters the flow measuring tube section from the air inlet of the fluid pipe, and finally discharges from the air outlet. As shown in figure2.

The pipeline structure of ultrasonic gas meter is shown in figure 3. A rectifier is installed in the pipe to balance the flow field in the gas flow state and reduce the impact on the measurement [7].
3. Circuit Design

The whole household ultrasonic gas meter overall hardware system is composed of MSP430F448 and its peripheral circuits, time measuring chip, transmitting circuit, receiving circuit, LCD display circuit, 485 communication circuit, storage circuit and keying circuit. As shown in figure 4.

3.1. The transmitting module
The MAX35104 chip has the transmitting module, including DC-DC booster module, high voltage regulator module and high voltage pulse transmission module, as shown in figure 5. After the chip is powered on, the voltage boost module will raise the voltage, and then the high-voltage voltage stabilizer module will stabilize the voltage to the set value. After stabilizing for a period of time, it will serve as a high-voltage power supply to the high-voltage pulse transmission module. Finally, the high-voltage pulse transmitting module transmits the upstream high-voltage pulse through TX_UPP and TX_UPN pin, TX_DNP and TX_DNN pins are used to transmit downstream high-voltage pulses to excite ultrasonic transducers [9].
3.2. Signal receiving and processing module

The chip has a programmable analog front end for adjusting the echo signal. The weak echo signal enters from the TX_UPP, TX_UPN and TX_DNP, TX_DNN pins, and enters the first stage amplification, the second stage amplification and the band pass filter. The echo signal comes out of the latter and finally enters the comparator, as shown in figure 6. By setting different values to the registers, the receive chain is less susceptible to noise injection applied to the common mode, providing an extra level of system accuracy and robustness.

The first stage is a fixed 20 dB gain amplifier. An internal analog switch automatically connects the input of this amplifier to the appropriate receiving sensor. When enabled, the input is pulled to VBIAS ~ 0.7 V through a 2 kΩ input resistor.

The second stage is the programmable gain amplifier (PGA). The programmable range of the PGA is 10 dB to 30 dB in steps of 1.33 dB, and the required magnification can be set directly through the registers.

The bandpass filter is a 2-pole bandpass filter with programmable Q and center frequency. The Q value of the filter can be adjusted through register settings, four programmable options in the range of 4.2 to 12 (Hz / Hz). The center frequency can be programmed from 125 KHz to 500 KHz in steps of 3 kHz. The MAX35104 provides an integrated, automatic center frequency calibration routine that can be used to select and set the appropriate center frequency [9].

4. Software Design

The software system of the ultrasonic gas meter in this paper is written in C language. By programming each function module in blocks, it is possible to effectively manage each module independently, which is convenient for updating and modifying the whole software.

The system software consists of main function program and interrupt handler. After system initialization, the time of 0.5s will be enabled. When the timeout occurs, the system calculates the flow and displays it on the LCD. The flow chart of main software block of system is shown in figure 7.

Time difference measurement is completed in timer ISR (interrupt service routine). After a complete transit time measurement of upstream and downstream, the time difference will be calculated. The measurement will be done 10 times to improve the accuracy. The flowchart of the interrupt service routine is shown in figure 8.
5. Experimental Tests

5.1. Gas flow verification device
The verification device consists of bell prover system and verification instrument, and the accuracy class of bell prover system and verification instrument is 0.5 level. The device diagram is shown in figure 9. The ultrasonic gas meter is shown in figure 10.

The gas tested in this experiment was air. The experiment was carried out under normal temperature and pressure. The flow points of this experimental test were 0.05 m³/h, 0.04 m³/h, 0.08 m³/h, 0.15 m³/h, and 0.25 m³/h, respectively. The average errors are shown in the figure 11 and the repeatability errors are shown in the figure 12.

Figure 7. Main program flowchart.
Figure 8. ISR program flowchart.
Between 0.025 and 0.04 m$^3$/h, the average error of each flow point is less than 3%; the repeatability error of each flow point is less than 1%. Between 0.04 and 0.25 m$^3$/h, the average error of each flow point is less than 1.5%; the repeatability error of each flow point is less than 0.5%. The transition flow rate is 0.04 m$^3$/h. The reason for the repeatability error deterioration at a smaller flow rate becomes more serious as follows: First, the upstream and downstream flight times are very short, and the time difference between the upstream and downstream is short, especially at small flows, the time difference is difficult to accurately measure. Secondly, at low flow rates, the measurement of flight time is more susceptible to environmental influences, such as temperature and humidity, pressure, etc., and environmental changes are more likely to lead to amplification of errors.

6. Conclusions

This paper designs a household ultrasonic gas meter based on time difference method. The measurement model and pipeline structure are deduced and designed to reduce the influence of external measurement on experimental measurement. The signal transmitting circuit and the receiving circuit and the processing circuit realized by the MAX35104 time measuring chip realize accurate measurement of the upstream and downstream time. Based on the software program of the MSP430F448 master chip, accurate measurement of instantaneous flow and cumulative flow is realized. After experimental verification, the measurement accuracy of the household ultrasonic gas meter designed in this paper is 1.5 level.

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