Design of High Precision Ultrasonic Flowmeter Based On TDC-GP22 and Time Difference Method

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ABSTRACT

Based on the principle of time difference method and the design concept of high precision, the measuring principle together with the improvement of the calculation method of the time difference method were investigated, aim at the problems of high complexity of the circuit and the inadequate precision of the traditional ultrasonic flowmeter that require pipeline modification. To promote the precision accuracy of the ultrasonic flowmeter to 0.5%, the function principle and its related structure of high-precision timing chip, TDC-GP22 (Time-to-Digital-Converter) were elaborated; and the design of hardware circuit and the working process of the system were introduced. The cause of signal attenuation was analyzed and the amplifying circuit for transmitting signal was designed. Finally, a flowmeter system design based on ATmega single chip and high-accuracy timing chip TDC-GP22 was proposed.

INTRODUCTION

Ultrasonic Flowmeter As a non-contact flowmeter, the fluid flow is measured by simply installing the ultrasonic transducer on the outside of the pipe without interfering with the flow of fluid in the pipe. Do not need to modify the original pipe, and can be high temperature, high pressure and other conditions to achieve the corrosive fluid flow measurement, it has been widely used [1-2]. In water, the propagation velocity of ultrasonic waves is about 1500m/s [3]. The propagation time difference between downstream and countercurrent is generally several hundred microseconds or less, and sometimes it may reach ps level, so it requires high time accuracy. With the continuous development of integrated circuits, there have been a variety of high-speed chronograph chip, making the measurement accuracy can reach tens of picoseconds. Germany ACAM company's high-precision timing chip TDC-GP22, with a clock measurement unit, the temperature measurement unit, stop signal enable, high-speed pulse generator, analog control part, programmable comparator and the first wave detection and other functions. This makes the ultrasonic flowmeter to improve the accuracy while also simplifying the design of the external circuit.
TIME DIFFERENCE METHOD ULTRASONIC FLOWMETER
MEASUREMENT PRINCIPLE

The working principle of the time difference method is to measure the time difference between the flow velocity and the propagation time of the ultrasonic wave in the fluid, and the average flow velocity $V$ of the fluid can be obtained by the relationship between the fluid flow rate and the propagation time, and the flow rate $Q$ is obtained\cite{4-6}. The schematic diagram of the measurement principle shown in Figure 1.

Ultrasonic transducer A and ultrasonic transducer B alternately transmit and receive ultrasonic signals, the angle of the two transducers relative to the velocity of the fluid flow is $\alpha$, the propagation distance of the ultrasonic wave between the two transducers is $L$, the fluid velocity is $V$, The diameter of the pipe under test $D$, the velocity of the ultrasonic wave in the fluid is the vector sum of the fluid velocity $V$ and the velocity of sound $C$ on the transmission path.

According to Figure 1, downstream, the ultrasonic wave in the liquid propagation time:

$$t_1 = \frac{L}{c + V \cos \alpha} + \tau_1 \quad (2-1)$$

In the countercurrent, the propagation time of the ultrasonic wave in the liquid is:

$$t_2 = \frac{L}{c - V \cos \alpha} + \tau_2 \quad (2-2)$$

$\tau_1$ and $\tau_2$ are the times that ultrasonic waves travel in downstream and countercurrent propagation in non-fluid media, and $\tau_1$ is equal to $\tau_2$.

According to the formulas (2-1) and (2-2), the fluid velocity $V$ can be obtained with the value of the countercurrent time minus downstream time:

$$V = \frac{(t_2 - t_1)L}{2t_1 t_2 \cos \alpha} \quad (2-3)$$

$$\Delta t = \frac{2LV \cos \alpha}{c^2 - V^2 \cos^2 \alpha} \quad (2-4)$$
As the temperature and other factors on the speed of propagation of ultrasound in the liquid have a great impact, it should be as far as possible in the ultrasonic flow calculation formula will be excluded from the ultrasonic velocity variable. According to the formula (2-3), we can see that we do not need to know the speed of sound, thus avoiding the impact of other factors on the speed of sound, thus eliminating the impact of sound velocity on the accuracy of the time $t_1$ and $t_2$ to calculate the instantaneous flow $\nu$. And then according to the size of the pipeline parameters to determine the cross-sectional area of the pipeline $S$, and then obtain the volume flow $V$, as shown in formula (2-5):

$$Q = S \cdot K \nu$$  \hspace{1cm} (2-5)

K in the formula is the correction coefficient of the fluid flow rate.

**HIGH PRECISION CHRONOGRAPH CHIP TDC-GP22**

TDC-GP22 is a new generation of TDC-GP21 products, TDC-GP22 chip through two timing methods for high-precision timing, one is the use of pulse counting the value of the counter, by recording the number of reference clock pulses to calculate the time interval ; The other is a high-speed timing unit, which is through the internal logic gate delay to the time interval of high-precision measurement, measurement accuracy depends mainly on the signal through the chip internal logic gate propagation time. TDC-GP22 chip measurement time schematic diagram shown in Figure 2.
The system uses TDC-GP22 chip measurement mode 2, the measurement range of 500ns ~ 4ms, the timing unit triggered by the start signal, stop signal end, the chip is not the entire time interval measurement, but the measurement from the start signal and stop Signal to the rising edge of the adjacent reference clock, and the TDC-GP22 chip will record the number of pulses of the reference clock between the two precision measurements, and the measurement range can reach 26 bits.

TDU-GP22 chip ALU calculation time interval is calculated as:

\[
T = T_{\text{ref}} \times \left( n + \frac{t_1 - t_2}{cal_2 - cal_1} \right)
\]  

(3-1)

In the above formula, \( T_{\text{ref}} \) -- The period of the reference clock;
\( T \) -- Measure time;
\( cal_2, cal_1 \) -- Calibration clock cycle.

**HARDWARE CIRCUIT DESIGN**

**TDC-GP22 peripheral circuit**

TDC-GP22 peripheral circuit shown in Figure 3-1, the entire peripheral system, the need to use two crystal to ensure its normal work, one is shown in Figure Y2 (4MHz) shown high-speed calibration clock unit, the other One is the 32.768KHz reference clock for clock calibration and to control the start of the high-speed clock.
Ultrasonic emission signal amplification circuit

TDC-GP22 chip pulse generator can produce excitation wave amplitude of 3.3V, ultrasonic transducer cannot be fully excited, and the launch of the ultrasonic signal in the flight process, due to pipeline and liquid flow and other factors, the signal will appear in the media attenuation phenomenon, the signal becomes weak, and will bring the media inside the noise and electronic circuit noise, etc., so that the detection unit within the chip cannot accurately obtain the ultrasonic signal, which cannot be on the ultrasonic flight time of the accurate calculation, so it needs more energy excitation signal, so the chip TDC-GP22 in the peripheral circuit designed a signal amplifier circuit.

Figure 3-2 shows the ultrasonic signal amplifier circuit. The circuit input signal is from the FIRE_UP / FIRE_DOWN pin of the chip TDC-GP22 and the output signal pin is FIRE_OUT. Select the appropriate resistance R1 and R2, through the in-phase proportional amplification circuit to achieve the amplification of the excitation signal. AD8065 has a frequency characteristic of 145MHz, has a high enough switching speed, to ensure that the frequency of 1MHz input signal is not distorted.

Figure 3-3 for the ultrasonic excitation pulse and excitation output signal, in which the lower side of the square wave excitation signal from the TDC-GP22 chip pulse generator, that is, interface FIRE_UP / FIRE_DOWN, 3.3V before amplification; the top of the square wave is amplified The circuit is amplified after the output signal, that is, FIRE_OUT, the amplitude increased to about 13V, and the output signal is no significant distortion, to meet the excitation requirements of the transducer.
CONNECT WITH ATMega MICROCONTROLLER

Microcontroller and TDC-GP22 communication connection shown in Figure 4.
The whole circuit system uses ATmega MCU produced by ATMEL company, which is 8-bit low-power, high-performance single-chip microcomputer, rich interface, can be directly connected with the TDC-GP22 chip SPI interface for data
communication, to achieve the ultrasonic signal transmission time Measurement and flow calculation.

SYSTEM WORK PROCESS

Transmission time measurement process

After the system is powered on, the internal registers of the TDC-GP22 chip are configured accordingly. Single-chip to the TDC-GP22 chip issued ST signal, TDC-GP22 output two in-phase pulse signal, all the way to start timing circuit, the other way to drive the transmitter to launch ultrasound. As the received echo signal through the pipeline and the fluid will produce attenuation, the receiving transducer in the ultrasonic echo signal, you need to receive the signal amplification, filtering and shaping to stop signal, the last TDC-GP22 internal the arithmetic unit ALU calculates the interval between the start signal and the stop signal. After 10 ms, the two ultrasonic transducers are switched and transmitted and received. After repeating the above-mentioned transceiving process, the ultrasonic downstream flow Countercurrent propagation time and.

TDC-GP22 first wave detection function measurement process

In the actual measurement of the pipeline, the pipe section and the transducer if there are too many precipitates or pipes containing bubbles, spoiler and other interference, the measurement results will be a considerable error, in order to reduce the measurement error, TDC-GP22 The first wave detection function of the chip will give the user a message of the received signal strength before the STOP signal. This message will be used to determine the quality of the received ultrasonic signal and to filter out the normal signal [7-8]. TDC-GP22 first wave detection function measurement process shown in Figure 5.

![Figure 5. First wave detection mode.](image)
TABLE 1. THE ERROR OF THE FLOWMETER UNDER DIFFERENT FLOW RATES.

| velocity of flow \((m^3/h)\) | Set the flow value \(L\) | Measured flow value \(L\) | Measured flow average \(L\) | Relative error % | Maximum relative error % | Repeatability error % |
|-------------------------------|--------------------------|--------------------------|---------------------------|-----------------|------------------------|-----------------------|
| 50                            | 5000                     | 4992.3440                | 5007.8968                 | 0.15            | 0.39                   | 0.2780                |
|                               |                          | 5019.5710                | 5001.7755                 | 0.24            |                        |                       |
|                               |                          | 4986.0351                | 5015.1620                 | 0.28            |                        |                       |
| 100                           | 5000                     | 5014.9650                | 5005.3874                 | 0.30            | 0.30                   | 0.3348                |
|                               |                          | 10008.1894               | 9988.6206                 | 0.08            |                        |                       |
|                               |                          | 10003.0753               | 10007.2274               | 0.03            |                        |                       |
| 200                           | 1000                     | 20000                   | 9999.9618                 | 0.11            | 0.11                   | 0.1015                |
|                               |                          | 10003.0753               | 10007.2274               | 0.07            |                        |                       |
|                               |                          | 10013.2654               | 10003.8058               | 0.13            | 0.13                   | 0.1155                |
| 300                           | 1000                     | 20000                   | 9990.9246                 | 0.09            |                        |                       |
|                               |                          | 10002.0374               | 9994.0006                 | 0.20            |                        |                       |
|                               |                          | 10001.1512               | 10008.3964               | 0.06            |                        |                       |
|                               |                          |                          |                          | 0.11            |                        |                       |

In the first wave detection mode, the offset value (offset value) of the comparator is set, for example, to +30 mV. If the amplitude of the first wave received is less than the offset value, the second Wave as the first wave, GP22 will measure the pulse width of pulse 1, will automatically offset the offset level back to 0mV, TDC-GP22 will automatically calculate the three stop pulse relative to the start pulse time interval, and calculate the average value, and then stored in the register 4, in this way, the measurement results can be read out once, and greatly simplifies the communication with the microcontroller [9].

CONCLUSION

In this paper, by improving the time difference method and the emission signal amplification circuit, the design of the peripheral circuit of the ultrasonic flowmeter is simplified by using the high precision chronograph chip TDC-GP22 for the complicated and accurate accuracy of the existing flowmeter circuit. At the same time, the design of the ultrasonic signal amplification circuit is designed, and finally a flowmeter system design based on ATmega single chip microcomputer and TDC-GP22 high precision time measuring chip is proposed. It can be seen that when the flow rate of the fluid (water) is between 50 and 400, the relative error of the ultrasonic flowmeter is small, the repeatability error is relatively small, and the precision is guaranteed to be within ± 0.5%.

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