A large Flow Signal Processing and Measurement Method based on Ultrasonic Gas Meter

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Abstract. Ultrasonic flowmeter is extensively used in petrochemical, metallurgical and other industries for its non-contact measurement, large measuring range, stable measurement results and no pressure loss. The time difference measurement method is adopted by the ultrasonic gas meter that can reduce the error caused by the variation of sound velocity with the temperature of the fluid. But there are some problems in the large flow point and small flow point in the time difference measurement method, such as low precision, low repeatability, poor stability. According to study the influence of flow velocity on ultrasonic echo signals, a method of variable threshold and variable gain based on peak detection is proposed and the prototype of gas ultrasonic flowmeter is designed in this paper. The national standard device, 100L automatic bell cover test device, is applied to verify the design scheme proposed in this paper. The experimental results indicates that the validity of variable threshold and variable gain ultrasonic signal processing method based on peak sampling is verified, in addition, the measurement accuracy and repeatability of the ultrasonic gas meter are enhanced at the point of large flow (large flow rate).

1. Introduction

The ultrasonic flowmeter is a metering device which utilizes the propagation characteristics of ultrasonic waves in the fluid to measure the flow rate. Due to advantages of no-contact measurement, the instrument cost has basically nothing to do with the diameter of tested pipe, high precision, large measuring range, convenient installation and simple testing, the ultrasonic gas meter is considered a preferable large-diameter flow measuring meter, and are widely applied in electric power, petroleum, chemical industry, especially water supply systems. At present, there are no self-developed products in China. Although some domestic manufacturers sell the ultrasonic gas meter which core technology is provided by foreign countries. Therefore there is still a big gap between domestic and developed countries in the research of ultrasonic flowmeters. In order to narrow this gap, it is very significant to study the ultrasonic gas meters.

In the research process of ultrasonic signal processing, there are two mainly difficulties. On the one hand, the time difference value at low velocity is only a few tens of nanometers. Affected by the performance of transducers and the noise of electronic device itself, the ultrasonic receiving signal would superimpose the irregular noise with small amplitude to influence the measurement accuracy of the flowmeter. On the other hand, the energy loss during the propagation of ultrasonic signal would cause the severe amplitude fluctuation at the large flow point when using the time difference method. This could lead to inaccurately select the signal characteristic wave and influence the measurement accuracy. Therefore in this paper the method with variable threshold and variable gain based on peak
detection is proposed by studying the influence of flow velocity on ultrasonic echo signals, which can improve the measurement accuracy and repeatability of ultrasonic gas meters at large flow points.

2. Background knowledge

2.1. Measurement principle of time-difference ultrasonic flowmeter
The principle of the time difference method is: in the same channel, when the propagation direction of ultrasonic wave is the same with the fluid flow (referred to as downstream), the speed of ultrasonic signal is accelerated due to the superimposed of fluid flow velocity, and this can shorten the propagation time. While the propagation direction is the opposite with the fluid-flowing direction (referred to as countercurrent), the speed becomes slower and the propagation time is extended. The fluid velocity is calculated by measuring the difference of ultrasonic propagation time between the downstream and countercurrent, and the gas flow can be computed via combining the size of flow channel, as shown in Fig. 1.

![Fig.1 Measurement principle of time-difference ultrasonic flowmeter](image)

2.2. Effect of flow rate on the amplitude of ultrasonic signals
In the field of gas flow measurement, there are two major aspects for the influence of flow rate on ultrasonic signals: energy loss in ultrasonic signal propagation and ultrasonic propagation path offset.

From the analysis in the gas flow measurement, it can be obtained that:
1) The energy loss during ultrasonic propagation is reduced in the downstream direction, however, the propagation path exists offset.
2) The energy loss during ultrasonic propagation is increased in the countercurrent direction, and the propagation path also exists offset.

The measured data of peaks values for the ultrasonic signals at different flow velocity is obtained through experiments and shown in Tab.1, where the P-P, First, Second, Third, Fourth and Fifth represent the peak-to-peak, first peak, second peak, third peak fourth peak and fifth peak of ultrasonic signals.

It can be seen from Tab.1, with the flow rate increase the peak value of the ultrasonic echo signal in the downstream direction, namely the envelope peak of echo signal, gradually augments, meanwhile the individual wavelet peaks also increase slightly. On the contrary, the envelope peak of the ultrasonic echo signal has declined at the countercurrent direction and the individual wavelet peaks also decrease slightly. The difference of the envelope peak-to-peak value has been increased from 10mV at zero flow to 456mV at 4.0 flow point. On account of the large difference of ultrasonic signals between downstream and countercurrent, the traditional threshold and zero-crossing ultrasonic signal processing method cannot correctly locate the feature point of ultrasonic echo signal, which would inevitably affect the measurement accuracy and repeatability of gas ultrasonic flowmeter.

| Flow point (m³/h) direction | P-P (v) | First (mv) | Second (mv) | Third (mv) | Fourth (mv) | Fifth (mv) |
|-----------------------------|--------|------------|-------------|------------|-------------|------------|
| 4.0 downstream               | 1.973  | 170        | 380         | 670        | 890         | 910        |
| 4.0 countercurrent           | 1.517  | 150        | 280         | 450        | 650         | 720        |
3. Ultrasonic echo detection of vary threshold and variable gain based on peak detection

3.1. String of wave phenomenon of ultrasonic echo signal

Because of the influence of flow velocity, the amplitudes of ultrasonic echo signals between the downstream and countercurrent would have big difference when the flow velocity is increased. When the method with fixed threshold and zero-crossing comparison is employed to locate the ultrasonic echo feature points, it would inevitably lead to misjudgment of the arrival time of ultrasonic wave and the "cross-wave" phenomenon would be occurred introducing a measurement error (namely, the feature points of ultrasonic signal would offset an integral multiple the period of signal), as shown in Fig.2. When the flow velocity is large and the airflow is extremely unstable, the "cross-wave" situation is more irregular and the echolocation is more difficult. In Fig.2, the solid line represents perfect waveform and the dashed line denotes the waveform of the ultrasonic echo signal affected by the downstream and countercurrent. In the downstream direction, with increase of ultrasonic amplitude, the threshold comparator may be triggered in advance and the ultrasonic echo feature point is advanced from the timing point b to a. While in the countercurrent direction, due to the decrease of ultrasonic amplitude, the threshold comparator would have a lag trigger, and the ultrasonic echo feature point is advanced from the timing point c to d. Based on the above analysis it is very difficult to correctly distinguish the "string" occurring or not for the influence of circuit components, environmental noise and airflow interference.

![Fig.2 A schematic diagram of ultrasonic signal detection of “string”](image)

3.2. Ultrasonic echo detection based on vary threshold and variable gain method

To improve the measurement accuracy and repeatability of the ultrasonic gas meter at the large flow point, the method adopting variable threshold and variable gain based on peak detection is proposed. By collecting the peak value of the ultrasonic echo envelope, the comparison threshold and the amplification gain of the ultrasonic signal processing circuit are adjusted, which can realize the accurate positioning of the ultrasonic echo signal feature points and improve the accuracy of the time difference measurement. The principle is shown in Fig.3.
In the method of fixed threshold zero-crossing comparison, the ultrasonic signal attenuates and the spacing between each peak diminishes with the augment of flow velocity. The waveform of the measured ultrasonic signal is shown in Fig.4, which would readily cause the measurement error.

The variable threshold and variable gain of proposed method are based on the peak sampling to know the attenuation degree of the ultrasonic echo signal, so that the amplification gain parameter is confirmed. Furthermore, the comparison threshold is adjusted to enable at the optimal position, which can greatly refrain the "String problem" caused by airflow fluctuations.

The ultrasonic gas flowmeter prototype based on the variable threshold and variable gain ultrasonic signal processing method in large flow points is designed, and the structure of prototype is shown in Fig.5.

As shown in Fig.5, beyond adopting two-stage amplifier circuit, the receiver part of designed gas ultrasonic prototype has also been added the programmable gain amplifier (PGA) and a programmable threshold comparator. The microcontroller can real-time monitor the PGA output signal through the peak detection circuit which adjusts the gain of PGA and sets the threshold of threshold comparator to...
avoid the “string” phenomenon of ultrasonic signal caused by the velocity fluctuation and improve the measurement accuracy and repeatability of the ultrasonic gas meter at large flow points.

4. Experimental verification

In order to verify the designed prototype shown in Fig. 5, the national standard device, 100L automatic bell tester shown in Fig. 6, is applied to detect the ultrasonic gas meter. For the reliability and accuracy of experiment, the experimental process is implemented in accordance with the national standard verification procedures which the experimental environment is closed with relatively stable temperature and humidity.

![Fig.6 100L automatic bell cover test device](image)

The requirements of class 1.5 instrument in CJ/T 477-2015 ultrasonic gas industry standard is: the relative error in 0.4 (demarcation flow) - 4.0m³/h flow point is -1.5% - +1.5%, while in 0.025-0.4m³/h flow point the relative error is -3%+3%. The requirement of repeatability error is following: with continuous measurement 3 times, the difference between the maximum value and minimum value of the indication error is demanded to less than 0.6% in 0.4-4.0m³/h flow point and not more than 1% in 0.025-0.4m³/h flow point. The relevant experimental calibration results is shown in Tab. 2.

As shown in Tab.2, the experimental result demonstrates that the prototype fulfills the relevant demand of the national standard 1.5-level instrument at the large flow point, which could verify the validity of proposed ultrasonic signal processing method with variable threshold and variable gain based on the peak sampling.

| Flow Rate (m³/h) | Measurement error (%) | Repeatability (%) |
|------------------|------------------------|-------------------|
| 4.0              | 0.156                  | 0.332             |
| 2.8              | 0.303                  | 0.412             |
| 1.6              | 0.721                  | 0.109             |
| 0.8              | -0.774                 | 0.366             |
| 0.4              | -0.845                 | 0.094             |
| 0.25             | -0.419                 | 0.173             |
| 0.125            | 0.291                  | 0.131             |
| 0.075            | -0.833                 | 0.817             |
| 0.025            | -0.48                  | 0.653             |

5. Conclusion

In this paper the ultrasonic signal processing method of ultrasonic gas meter at large flow point is studied and the main contents are as follows:

1) According to analyzing the influence of variational flow velocity on the amplitude of ultrasonic echo signal, the method of variable threshold and variable gain based on peak detection is proposed.

2) Based on the proposed method of variable threshold and variable gain based on peak detection, the prototype of gas ultrasonic flowmeter is designed.
3) The national standard device, 100L automatic bell cover test device, is applied to verify the prototype of gas ultrasonic flowmeter. The experimental results indicate that the validity of variable threshold and variable gain ultrasonic signal processing method based on peak sampling is verified, in addition, the measurement accuracy and repeatability of the ultrasonic gas meter are enhanced at the point of large flow (large flow rate).

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