Research on Flow sensor of Ultrasonic Gas Meter

Yang You-Tao [1] Chen Hai-Lin[2]

1. Beijing Institute of Metrology, yangyt@bjjl.cn Beijing China;
2. Chongqing Central Sensing Technology Co.Ltd., Chongqing , China
E-mail (corresponding author): 13521522748@139.com

Abstract

By reviewing the development of gas meter, the application prospect of ultrasonic gas meter is forecasted, the key technology and research and development difficulties of ultrasonic flow sensor, as well as the key application technology problems to be solved are discussed.

The paper focuses on the design and selection of timing scheme of flow sensor, design of flow field characteristics of flow channel of flow sensor, electro-acoustic performance of flow sensor, linearity and repeatability of gas flow sensor.

Through the exchange of theoretical research and practical application experience, the promotion of ultrasonic sensing technology, so as to promote the batch production and application of ultrasonic gas meters.

1. Introduction

In the new Plan, China has clearly put forward the goal of achieving carbon neutral in 2060.With a focus on green, low-carbon and sustainable development plans, natural gas has been given priority as a clean energy source, and consumption continues to rise. Promoted by the good news of the rapid development of the natural gas industry, the gas metering industry has developed rapidly, and all kinds of metering instruments have been constantly updated. There are two kinds of gas meters for domestic gas metering in the current market, the traditional mechanical diaphragm gas meter and the electronic gas meter. Diaphragm gas meter has been used for more than a century since its birth. With the improvement of the demand for information technology in energy management, metering meters are developing towards the direction of electronic and network. Such as Japan, the United States and the European Union has used ultrasonic measurement technology for gas metering, developed ultrasonic gas meter. Ultrasonic gas meter as a measuring instrument used for people's livelihood and trade settlement, because of its non-contact measurement, no moving parts, small pressure loss, can be combined with more intelligent applications and other advantages, is a strong momentum in the gas meter market. At present, some countries have taken ultrasonic gas meter as the measuring instrument of trade settlement. For the Chinese market with more than 200 million gas meters, the broad development prospect of ultrasonic gas meters will bring a new development opportunity to the potential Chinese gas meter enterprises. In March 2021, national standard GB/T 39841-2021 "Ultrasonic gas Meter" was issued and implemented, from then on, ultrasonic gas meter has the technical basis for production and testing.

2. Research and application status of ultrasonic gas meter

In the mid 1970s, Europe and the United States have successfully developed ultrasonic gas flowmeters, and in the 1990s, there are more perfect and mature products. Due to the development of timing chip technology, the flow meter has been able to measure short time differences, flow rate resolution has reached 1mm/s, has been able to measure small flow and bidirectional gas flow. Subsequently, many gas companies in Britain and Germany have developed ultrasonic gas meters. However, due to the limitations of ultrasonic transducer, timing chip, electronic technology and other technical factors, the price is too expensive to compete with the traditional diaphragm gas meter. After entering the 20th century, the price of key components of ultrasonic gas meter has been reduced, ushering in the rapid development of ultrasonic gas meter. At present, the ultrasonic gas meter technology in the world mainly comes from Panasonic, Japan, etc. They have been deeply engaged in the ultrasonic field for many years, and have many patents from the flow channel structure, software algorithm, ultrasonic transducer and module to the whole machine. Although a number of domestic gas meter companies have begun to research and

development of ultrasonic gas meter, but most manufacturers are using panasonic ultrasonic sensor program, buy panasonic ultrasonic module, supporting shell and motherboard composed of ultrasonic gas meter.Such a model makes the core technology of domestic ultrasonic gas meter lack, the price is high, and the market promotion is limited.

With the adjustment of global energy structure, the development and application of natural gas energy has entered a period of rapid development, and the urban gas rate will be higher and higher. Ultrasonic gas meter will have great development prospects in the future domestic and foreign markets with its many advantages.Domestic gas meter enterprises should actively improve the overall quality of the industry and technological innovation ability, enhance the comprehensive strength, and participate in the global market competition.

3. Key technologies and difficulties of gas flow sensor

At present, ultrasonic flow measurement can be roughly divided into propagation time difference method, beam shift method, Doppler method, spatial filtering method and so on.The time difference method is widely used because it can overcome the error caused by the change of sound velocity with gas temperature and has high accuracy.The core component of ultrasonic gas meter metering is ultrasonic flow sensor (including transducer, measuring circuit and flow channel). The research and development of ultrasonic transducer is mainly limited by its bandwidth and high and low temperature characteristics. The distance between two transducers of ultrasonic gas meter is about 60 ~ 80 mm.This and high pressure pipe ultrasonic flowmeter has a larger measurement technology difference.Low pressure small flow rate (as low as 16L/h) leads to extremely low gas flow rate and small acoustic time difference (about dozens of ns), which makes it very difficult to measure and requires high requirements on circuit hardware and software. At the same time, due to low pressure gas's relatively large attenuation to ultrasonic signal, Therefore, the sensitivity and bandwidth of the sensor, temperature characteristics and medium matching, amplification and SNR of the system, and the algorithm of the software have higher technical requirements.

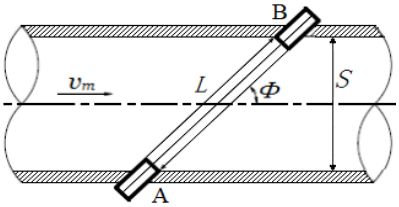

Figure 1. Schematic diagram of ultrasonic time difference method

Gas meter ultrasonic downstream and counter-current propagation time and the relationship between each quantity:

$$t_{\text{down}} = t_{\text{AB}} = \frac{L}{c_{\text{f}} + v_{\text{m}} \cos\phi} \qquad (1)$$

$$t_{up} = t_{BA} = \frac{L}{c_f - v_m \cos\phi} \qquad (2)$$

In the formula:

$t_{\text{down}}(t_{\text{AB}})$ -- the downstream propagation time of ultrasonic wave in gas, s;

$t_{\text{up}}(t_{\text{BA}})$ -- the countercurrent propagation time of ultrasonic wave in gas, s;

L -- vocal tract length, m;

c_{f} -- Velocity of sound wave propagation in gas, m/s;

v_{m} -- Axial average velocity of gas, m/s;

ϕ -- Channel Angle, °.

According to formula (1) and (2), the average speed of gas can be calculated as:

$$v_{\text{m}} = \frac{L}{2\cos\phi}\left(\frac{1}{t_{\text{down}}} - \frac{1}{t_{\text{up}}}\right) \qquad (3)$$

According to the relationship between the average gas velocity and the cross section area of the closed pipe, the instantaneous flow rate can be obtained. v_{m} S

$$q = 3600 \times v_{\text{m}} \times S \qquad (4)$$

In the formula:

S -- Pipeline cross section area, m^2;

q -- Instantaneous flow, m^3/ h.

3.1 Design and selection of timing scheme for flow sensor

The timing scheme design and selection of flow sensor in ultrasonic time difference measurement is the core technology.Based on the current timing hardware circuit technology level, flow sensor pipeline length, and gas

meter low flow precision control conditions, the timing circuit measurement accuracy requirements to ps level.Timing scheme design: the first is to use the gate circuit to separate components to obtain the time difference, the other is to choose integrated circuit.Many integrated timing chips integrate sensor drive and echo signal processing, including A/D and D/A conversion, band pass filtering, trigger delay, signal amplification, etc.Due to the attenuation of ultrasonic signal in different gas, it is necessary to add high gain and low noise operational amplifier in the circuit, and at the same time, it is necessary to consider the matching circuit with ultrasonic transducer to improve driving performance and reduce temperature drift.

At present, TDC (time digital conversion) and ADC (analog digital conversion) are two ways to obtain the time of flight through timing circuit.

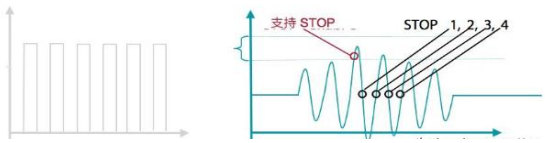

Figure 2 SCHEMATIC diagram of TDC based on zero-crossing detection

The TDC scheme detects the amplitude of the signal at the ultrasonic receiver. When the received signal exceeds the set threshold, the zero-crossing detection circuit is turned on. By detecting the zero-crossing time after the threshold is exceeded, the ultrasonic time of flight is obtained, and then the time difference between the upstream and downstream is obtained.The TDC of zero crossing detection can usually obtain high precision time of flight, but the key algorithms such as signal interference, dynamic gain and cross period need to be solved.

ADC time difference scheme is used for echo signal of high-speed ADC sampling, usually for more than four times the measured signal frequency up and down two ultrasonic echo signals for sampling, again to do the sample into two discrete signals line related operations, line related calculation results peaks abscissa (or monitoring) is the phase difference between the two signal circuits.Then the abscissa is obtained by high-precision interpolation algorithm to obtain the time of flight and time difference between the two signals.ADC sampling can obtain accurate time difference, but due to envelope changes, sensor characteristics and measurement medium changes, the accuracy of time of flight will be affected to a certain extent.

TDC and ADC time sampling have their own characteristics and advantages. How to choose these two schemes depends on the hardware and software processing of the chip and the accumulation of professional skills of the developer.It is believed that with the development of technology, more time sampling methods will appear, and the integration of chip to sensor drive, echo signal processing will be further improved.

3.2 Flow field characteristic design of flow channel of flow sensor

The characteristics of flow field in flow channel not only affect the accuracy and stability of gas flow sensor, but also affect the consistency of flow state in different media.The design of the flow channel is usually based on flow field simulation software and 3D printing to further verify its acoustic and metering performance.Because monophonic ultrasonic flow sensor modeling uses the detection velocity profile and average velocity correction factor, in order to adapt to different gas, the design should be considered to reduce the influence of fluid viscosity change on velocity profile.

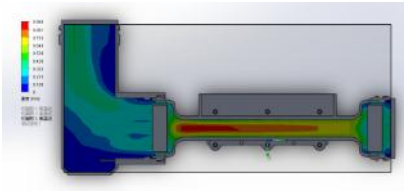

Figure 3 Air 0.4m^3/h flow simulation

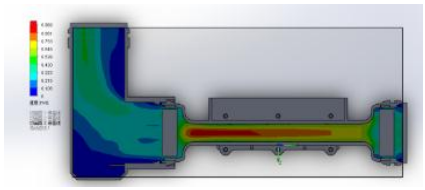

Figure 4 CH4 0.4m^3/h flow simulation

The height and width of the runner have important influence on the design characteristics of a given pipeline.Reducing the channel width can speed up the flow of gas through the pipe, thereby increasing the sensitivity, but it also reduces the strength of the ultrasonic signal.Increasing the height of the channel can also improve sensitivity at the expense of ultrasonic signal strength.

The reflector design is usually used to enhance the ultrasonic signal, modify the length of the sound channel at different flow rates, and focus the flow pattern of the edge flow field so that the detected flow rate is closer to the average flow rate.

The Angle between ultrasonic signal and gas flow direction also has a significant influence on the sensitivity of small flow rate.The larger the projection of ultrasonic propagation path on the flow rate, the higher the sensitivity.

Obviously, the maximum sensitivity can be obtained by ultrasound in the same direction as the flow velocity. However, the flow field detected by ultrasound is the flow field at the center, which may cause serious precision decline when the disturbance and component change occur. Rectifiers are often used to reduce fluid disturbances and equalize the flow field, which can provide more accurate measurements at wider flow rates. Rectifiers often cause increased pressure losses, while internal rectifiers may cause attenuation of ultrasonic signals.External rectifiers can also reduce the impact of noise.

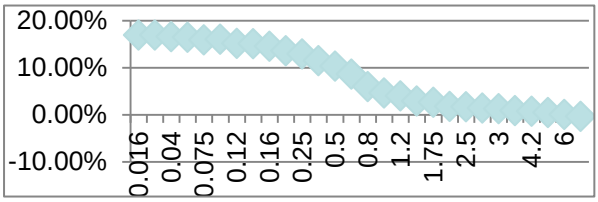

FIG. 5 Correction factor between flow velocity profile and average velocity

4. Design and selection of ultrasonic transducer in flow sensor

4.1 The electroacoustic performance of the flow sensor

The electro-acoustic performance of flow sensor mainly depends on ultrasonic transducer and transceiver circuit.In sensor designs, the piezoelectric layer thickness is usually cut to 1/2 of the desired wavelength.In order to maximize the energy of the sensor, an impedance matching layer is usually placed in front of the piezoelectric element.When the thickness of the matching layer is 1/4 of the required wavelength, the optimal impedance matching can be achieved.Such a design allows the wave to be reflected within the matching layer, and when the ultrasonic wave leaves the layer its phase is consistent with that of the subsequent wave. The acoustic impedance of the matching layer is equal to the square of the product of the acoustic impedance of the piezoelectric element and the impedance of the medium.The bandwidth of ultrasonic transducer is an important index that affects the temperature characteristics of flow sensor. It should not be less than 10% of the nominal frequency.For narrowband sensors, the consistency of the frequency response of a production batch of sensors over the operating temperature range is critical, and depends on the driving mode of the sensor (including single-frequency drive, dual-frequency drive or variable frequency drive, the number of driving signals, etc.).

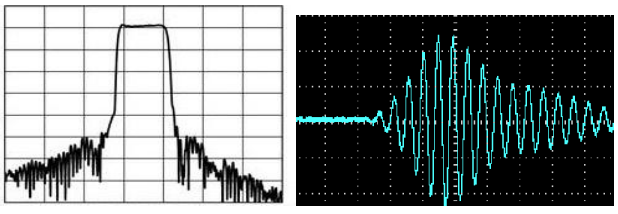

Figure 6 Bandwidth of an ultrasonic transducer

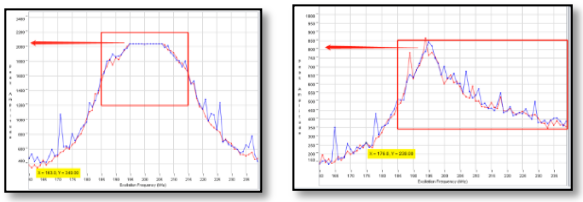

Figure 7 bandwidth and sensitivity of an ultrasonic transducer

4.2 Durability and stability of the flow sensor

Ultrasonic gas meter because of no mechanical parts, the theoretical stability is higher than the membrane table, but the membrane table has been widely accepted by gas meter companies and customers in the use of many years.How to meet the needs of gas companies in the stability of ultrasonic gas meter, to dispel the concerns of gas companies.Industry in the long ago air adaptability research was carried out by ultrasonic gas meter, one of the earliest foreign products in the domestic real gas insert has been more than 10 years, the domestic ultrasonic table insert has more than 6 years, the biggest impact of the matching layer transducer material and matching layer viscose fabric and rayon and potting process also gradually improve.

4.3 the pollution resistance of the flow sensor

As with the diaphragm gas meter, dust or impurities in the gas will adhere to the ultrasonic transducer due to the perennial operation of the ultrasonic gas meter, affecting the signal reception sensitivity of the transducer, thus affecting the measurement accuracy of the gas meter.Therefore, it is very important to use proper installation and structural design to reduce the influence of dust or impurities in gas, and to use signal detection and automatic gain control circuit to compensate the influence of sensor aging.

4.4 Air source adaptability of flow sensor

Ultrasonic signal transmission will be affected by the transmission medium, environment (temperature, humidity, pressure) and reflection in the pipeline and other factors, the received ultrasonic signal usually has waveform and amplitude changes.Therefore, in order to be widely used, the adaptability of ultrasonic gas meter to gas source is an important step to overcome. In addition to the gain compensation on the circuit, the acoustic matching of transducer to a wide range of gas, and the adaptive software algorithm are particularly important.

5 Gas flow sensor key indicators

5.1 Linearity

The linearity of ultrasonic flow sensors should generally not exceed ±1.5%.The design of flow sensors requires a linear correction, which needs to be verified by a large number of tests.

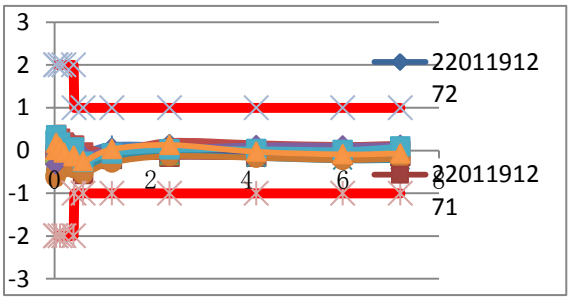

FIG. 8 Linearity measurement value of a batch of domestic gas flow sensor

5.2 Repeatability

The repeatability of flow sensors under reference conditions should generally not exceed ±0.3%.The following table is the actual measurement data for a flow sensor.

number		2201191272	2201191271	2201191270
q_{max}	1	0.00	0.10	0.03
	2	0.05	0.08	0.09
	3	0.05	0.13	0.08
	Average (%)	0.03	0.10	0.07
	Repeatability (%)	0.05	0.05	0.06
q_t	1	0.25	0.56	0.33
	2	0.24	0.54	0.39
	3	0.26	0.56	0.34
	Average (%)	0.25	0.55	0.35
	Repeatability (%)	0.02	0.02	0.06
q_{min}	1	0.09	0.08	0.19
	2	0.05	0.01	0.19
	3	0.05	0.09	0.31
	Average (%)	0.03	0.01	0.23
	Repeatability (%)	0.14	0.17	0.12

Repeatability measurement value of a batch of domestic gas flow sensor

5.3 other indicators of the gas flow sensor

Gas flow sensor also has zero flow, stability, electroacoustic sensitivity, response time, zero drift, noise interference, temperature adaptability, overload flow, environmental impact and other important indicators, due to space constraints, here is not a list.

6 Conclusion

At present, to promote the progress of state-owned metering foundation and sensing technology and the development of new products is a powerful measure to serve the international and domestic double cycle. In March 2022, the Government decided to increase financial subsidies and investment in the construction of new digital gas pipeline facilities and the renovation and renewal of old pipelines.Ultrasonic measurement has digital, real-time and some security aspects of the extended application, can better serve the people's livelihood.With the maturity and market promotion of products, the corresponding technical standards and specifications of flow sensors will be gradually improved, and the ultrasonic flow sensor will play its due role in the accurate measurement of low-carbon environmental protection and clean energy.

[References]

[1] Standardization Administration GB/T 39841-2021 "Ultrasonic Gas Meter" national standard

[2] Yang Youtao , Gas Flowmeter. China Metrology Press, 2007