Study on the effect of pressure on gas ultrasonic flowmeter

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Abstract

With the ultrasonic flowmeter (Ultrasonic Flowmeter) in the natural gas metering is widely used, ultrasonic flowmeter accuracy is increasingly concerned. however, by the limitations of the calibration operation conditions, there are differences between the calibration operation conditions and actual operation conditions , and operation conditions on the impact of ultrasonic flowmeter metering lack of systematic research, Wuhan branch station established a mobile natural gas metering standard device can be carried out in different pressure conditions of the gas transmission station calibration services.In this paper, we study the calibration tests carried out by the mobile natural gas metering standard device at different pressures ,and through analyzing and integrating data, we derive the metering deviation caused by ultrasonic flowmeter under different working conditions, establish the mathematical model of Reynolds number error correction to guide the use of ultrasonic flowmeter, and eliminate the deviation introduced by the different operation conditions of calibration and use, improve the accuracy of trade measurement . while the research results can be the technical support for the revision of relevant standards and norms

1. Introduction

With the rapid development of natural gas trade, people have higher requirements for the accuracy and reliability of flow metering. Gradually concerned about the legitimacy and accuracy of its metering, the role of flow metering has become increasingly important and significant. Therefore, in recent years, the typical high-pressure gas flow metering of natural gas has received unprecedented attention.

Gas flow metering is more complicated than liquid flow metering because the state of gas is easily changed by temperature and pressure. It has been shown that the mechanical performance of gas flowmeter will change greatly with different gas pressure, which will result in serious change of metering performance of gas flowmeter. Due to the differences in principle and structure of different gas flowmeters and the difference of pressure, the measurement result of the same flow may be different.

Ultrasonic flowmeter, which is based on the combination of sound field and flow field, has the advantages of non-direct contact fluid, no choke parts, no moving parts, almost no pressure loss, and almost no influence of viscosity and conductivity of fluid, bi-directional measurement, high range ratio, high accuracy, high reliability, and can measure high-temperature and high-pressure fluid comparing with other flowmeters. Ultrasonic flowmeter has become one of the most widely used gas flowmeters in the field of high pressure natural gas flow measurement. As pressure variation will affect the geometry of ultrasonic flowmeter and the density of gas under different pressure is very large, the pressure fluctuation will cause a lot of changes in the transmitted and received acoustic energy and finally the signal will be distorted because of the fluctuation of amplitude. The intensity of airborne noise interference is related to flow rate, pressure and pressure regulating device. For the moment, many countries have a long history of the research and production of gas ultrasonic flowmeter, such as the excitation mode of ultrasonic transducer, the calculation of transit time, the method of ultrasonic signal processing, the multi-channel arrangement, the channel integration algorithm, the mechanism of ultrasonic signal and the mechanism of flow field, etc. Rich theoretical and practical experiences have been accumulated. The research of ultrasonic gas flowmeter in China began in the 1950s. With the wide use of natural gas and the encouragement of government, more and more universities, enterprises and scientific research institutes devoted to the research and production of ultrasonic gas flowmeter.

2.Analysis of Test Results under Different Pressure Conditions

2.1 Test Objects

The portable natural gas metering standard device established by the Wuhan sub-station of the State Petroleum & Natural Gas Large Flow Metering Station is based on the principle of the standard method. The standard device consists of three turbine flowmeters with calibers of DN80, DN150 and DN400 which are connected in series at the downstream of the flowmeter to be detected. When the natural gas flows through the calibrator and the flowmeter, the metering performance of the flowmeter can be determined by comparing the output flow values of the two at the same time interval. In order to monitor the measurement performance of the standard indicator, the device is also equipped with a caliber DN300 ultrasonic flowmeter, which is connected in series with the upstream of the standard indicator as a verification standard for different flow ranges. It can conduct real-time verification of the measurement performance of the turbine flowmeter and ensure the accuracy and reliability of the verification/calibration data of the flowmeter. The information of DN300 verification ultrasonic is listed in table 1.

Table 1 Information of DN300 checking ultrasonic flowmeter

The name of flowmeter	manufacturer	specifications	Factory number	Flow range
DN300 checking ultrasonic flowmeter	Elster	Q.Sonic-5c	4810	80～8000

2.2 Calculation of the indication error

The flow velocity qc measured by ultrasonic flowmeters is obtained by summing the flow velocities [2] on each channel after weighting and is calculated as shown in Formula (1):

$$q_c = R\sum_{i=1}^{n} w_i v_i l_i = \frac{D}{2}\sum_{i=1}^{n} w_i v_i L_{wi} \sin\varphi \qquad (1)$$

D-Inside diameter of pipeline，m；

W_i-Weighting coefficient;

v_iMeasured velocities in each channel，m/s;

L_{wi}Length of sound track,m;

l_iProjection of Length of Vocal Tract on Section，m;

φAngle between the acoustic channel line and the pipeline axis（°）;

N Number of channels

The mobile standard installation system shall calculate the flow value of the flow meter by collecting the accumulated pulses within the sampling time as per the formula (2):

$$Q = \frac{N}{K \cdot t} \times 3600 \qquad (2)$$

Q—the flow value of the flowmeter, m³/h；

N—The number of flowmeter pulses collected by the system,

K—K coefficient of flow meter，1/m³；

t—System sampling time，s。

The checking flowmeter is taken as the standard meter and the standard turbine flowmeter as the inspected meter. The error of relative value for check shall be calculated according to the formulas (2) and (3):

$$E_{ij} = \frac{(Q_{MUT})_{ij} - (Q_{actul})_{ij}}{(Q_{actual})_{ij}} \times 100\% \qquad (3)$$

$$E_i = \frac{1}{n}\sum_{j=1}^{n} E_{ij} \qquad (4)$$

E_{ij}—Verification of Relative Indication error at Time j of ith Flow Point, %；

$(Q_{MUT})_{ij}$ —The indication of the standard turbine flowmeter flow at the ith flow point at the jth calibration, m³/h；

$(Q_{actual})_{ij}$ —Verification of Conversion of Flow Value at ith Flow Point at the jth measurement of Ultrasonic Flowmeter to Flow Value at Standard Turbine Flowmeter Operating Conditions, m³ /h；

E_i—Average Relative Indication Error of the ith Flow Point of the Calibrated Flowmeter, %;

n—Number of measurements for the ith calibration point.

2.2 Test results under different pressures

It is required to conduct measurement traceability once a year for the mobile standard in-house standard turbine flowmeters, verification ultrasonic flowmeters and supporting metering equipment, and modify the metering equipment according to the calibration results. After the measurement traceability in 2020, verification services shall be provided at 2.5MPa and 5MPa at natural gas transmission stations respectively. The statistics of the examination results of inspection ultrasonics and standard turbine flowmeters are as the following table:

Table 2 Verification of Ultrasonic Test Results at 2.5 MPa and 5 MPa

Pressure	Flow point（m³/h）	Error (%)					Average (%)
2.5 MPa	2300	-0.58	-0.58	-0.55	-0.60	-0.43	-0.55
	1700	-0.60	-0.86	-0.68	-0.66	-0.65	-0.69
	1000	-0.97	-0.96	-0.70	-0.80	-0.84	-0.85
	800	-0.85	-0.90	-0.89	-0.85	-0.84	-0.87
5.0 MPa	2300	-0.28	-0.24	-0.34	-0.35	-0.30	-0.30
	1700	-0.30	-0.42	-0.27	-0.34	-0.32	-0.33
	1000	-0.54	-0.58	-0.67	-0.83	-0.45	-0.61
	800	-0.61	-0.64	-0.66	-0.6	-0.6	-0.62

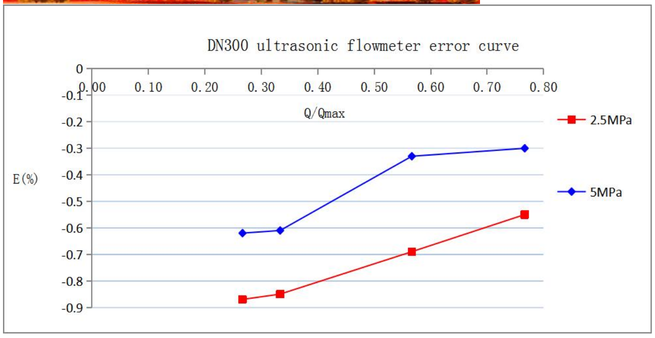

Diagram 1 Verification of ultrasound test results at 2.5 MPa and 5 MPa

As can be seen from Table 1 and Diagram 1, when the DN300 verification ultrasonic flowmeter increases with the increase of the flow velocity, the verification error becomes larger, indicating that the low flow velocity will cause the measurement value of the verification ultrasonic flowmeter to be larger, and the maximum deviation above Qt is 0.32%. When the pressure is at 2.5 MPa, the verification error is larger than the pressure at 5 MPa, indicating that as the pressure increases, the verified ultrasonic flowmeter measurements become smaller. The average deviation of four flow points is 0.25%.

After the traceability of the values in 2021, verification services were carried out at the 5MPa and 7MPa at natural gas transmission stations respectively. Verification results of ultrasonic and standard turbine flowmeters are as Table 3.

Table 3 Verification of Ultrasonic Test Results at 5 MPa and 7 MPa

Pressure	Flow Point (m^3/h)	Error (%)					Average (%)
5.0 MPa	1700	0.04	0.09	0.04	0.08	0.12	0.07
	1000	0.15	0.13	0.13	0.17	0.11	0.14
	800	-0.25	-0.17	-0.23	-0.16	-0.27	-0.22
7.0 MPa	1700	0.01	0.13	0.10	0.12	0.16	0.10
	1000	-0.09	0.13	0.03	0.11	-0.02	0.03
	800	-0.36	-0.21	-0.47	-0.32	-0.33	-0.34

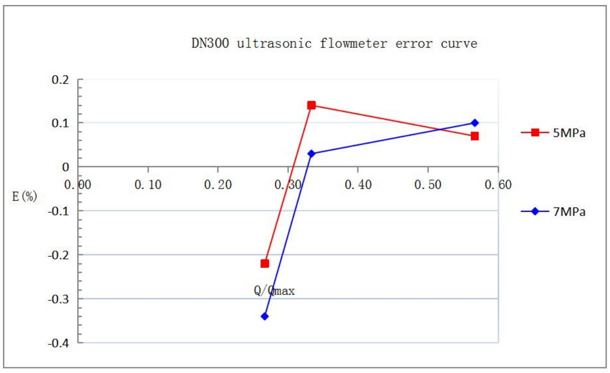

Diagram 2 Verification of ultrasound test results at 5 MPa and 7 MPa

It can be known from Table 2 and Diagram 2 that, when the DN300 verification ultrasonic flowmeter increases with the increase of the flow velocity, the verification error becomes larger, indicating that the measurement value of the verification ultrasonic flowmeter will be larger if the flow velocity is lower, the maximum deviation at the three flow points above Qt is 0.44%, and the verification errors are almost the same when the pressure is 5MPa and the pressure is 7MPa, and the maximum average deviation of the three flow points is 0.12%.

2.3Structure Analysis of Ultrasonic Flowmeter

Diagram 3 shows the structure of the probe in the pipe diameter of the ultrasonic flowmeter. It can be seen that the probe goes deep into the pipe and forms a small bulge. According to the structure, a simplified two-dimensional pipe model with the probe going deep into the pipe and forming a bulge is constructed. The simulation is carried out in FLUENT to observe the change of the internal flow field.

Diagram 3 Probe Structure of Ultrasonic Flowmeter in Pipe Diameter

Diagram 4 shows the velocity cloud formed by the fluid flowing through the ultrasonic flowmeter at a velocity of 20 m/s, from which it can be seen that due to the presence of the protuberance formed by the probe, the fluid in the boundary region forms a small tangent plane when flowing through the protuberance, which then forms a corresponding low velocity region, and the low velocity region formed by the upstream probe overlaps the downstream probe, resulting in a lower flow velocity measured on the acoustic line.

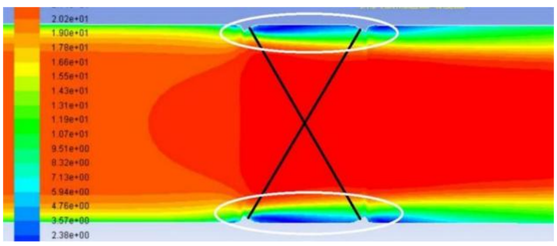

Diagram 4 Variation of Flow Field in Pipeline after Probe Goes Deep Into Pipeline and Forms Bulge

At the same time, with the increase of flow rate, the Reynolds number and the error of indication value increases gradually at the same pressure. The reason for this result is also related to the protrusion formed on the probe, the larger the flow velocity and the larger the slope of the tangent plane formed after the protrusion of the probe, the more the downstream probe is covered by the low velocity region, resulting in the lower measured flow velocity.

To be more accurate, probe protrusion is one of the reasons resulting in the negative error of the integral calculation result of the flowmeter. But it is not the whole reason. The flowmeter will generally correct this part of the error in the process of data processing. At this time, the ultrasonic flowmeter needs to obtain the pressure and temperature values of the medium for correcting the geometry of the measuring body and calculating the current Reynolds number.

3.Conclusionvs and Suggestions

According to the test results, there is a linear relationship between indication error and Reynolds number. With the increase of pressure, flow velocity and Reynolds number, the measurement value of ultrasonic flowmeter is larger.

Measurement traceability of ultrasonic flowmeters shall be conducted regularly, so as to judge whether their performance meets requirements; the verification pressure shall be no more than 2 times the pressure used in gas transportation station.

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