Experiment and Simulation of Coriolis Mass Flowmeter with Multi-Medium and Multi-Working Conditions

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Abstract. Coriolis mass flowmeter can directly measure mass flow, high measurement accuracy, which can be used for gas, liquid, high viscosity media and other fluids. Thus it is one of the most important directions of flow measurement. Coriolis mass flowmeters currently used in natural gas pipeline networks are usually calibrated using water. The effects of differences in the detection medium and pressure on the results are lacking in relevant studies. This article analyzes the influence of fluid pressure on the test results by statics simulation, and different pressure was carried out on the DN80 flow meter to simulate different calibration media. Then real flow calibration on several brands and models of flowmeters to compare the influence of water and natural gas respectively. The experimental results show that the error of water is less than ±0.2%, and the error of natural gas is less than ±0.1%. The influence brought by pressure is close to the simulation analysis, and the results of different media have good consistency.

1. Overview
The most prominent feature of the Coriolis mass flow meter is its ability to directly measure the fluid quality. It is not only accurate, repeatable and stable, but also has no choke or movable elements in the fluid passageway, making it reliable, lasting and capable of measuring the flow rate of high-viscosity fluid and high-pressure gas [1-3].

The Coriolis mass flow meter consists of two parts, namely, the mechanical sensor through which the fluid flows and the flow meter transmitter. The sensor consists of a shell, a micro-vibration measuring tube, a vibrator, a signal detector, and a temperature compensating element. When the fluid passes through the measuring tube, the measuring tube is slightly distorted due to the Coriolis force; as a result, the phase difference at the time of vibration is converted into a linear electrical signal output. The transmitter receives and processes the signals to show the mass of the metered fluid.

Since the Coriolis mass flow meter can directly measure the flow mass of natural gas, it is becoming more widely used in metering the company's internal compressor fuel gas and self-use gas. But problems still exist. For example, no conclusion has been made in the domestic research in the aspect of natural gas flow meter application and performance evaluation. In addition, there are few academic reference for the performance test of natural gas mass flow meter in the aspects of whether water or air can be used as medium instead of natural gas, whether the measurement results of mass flow meter is reliable under different pressure conditions, whether the flow meter is stable during use, and whether drift and other influencing factors will occur [4, 5].

It is necessary to analyze and evaluate the results of tests in which water and natural gas are used as
the medium under different pressures, and verify the feasibility of using water instead of natural gas to calibrate the mass flow meter based on the performance indicators and measurement results [6].

This paper uses three Coriolis flow meters of different models and different calibers to obtained the test results according to the verification procedure. Since the flow meters are different in age, the test results cannot fully characterize the corresponding brand performance. To avoid misunderstanding, the serial numbers of the flow meters are replaced by letters.

2. Water flow test
This paper uses the static mass method water flow standard device according to the verification procedure, and conducts the test in the Institute of Metrology, Zhejiang Province. The test flow range of the device is (0.2~220) t/h, and the relative expansion uncertainty is 0.05% (k=2). After connecting the device, the supporting instrument and the circuit of the flow meter, select the pulse output mode, manually start the water flow device so that the pipe is full of static water medium; then close the valves at both ends, and set the instrument to zero. The test is performed according to the flow point order of $Q_{\text{max}}$, $0.5 Q_{\text{max}}$, $0.2 Q_{\text{max}}$, $Q_{\text{min}}$, and $Q_{\text{max}}$ and the data is recorded respectively. In addition, a total of three tests are carried out in different seasons so as to verify the repeatability of the flow meter and compare the metering performance of flow meters under different temperatures.

![Figure 1. Water flow test results of A flow meter](image)

The range ratio of A flow meter is approximately 10:1. It can be seen that the results of the three tests have good repeatability, with the single point repeatability higher than 0.05% and the majority higher than 0.02%. The single point errors of the first two tests are all less than 0.1%, indicating high accuracy; the average single point error of the third test is about 0.1%.

For B flow meter, its diameter is DN=80mm, its test flow range is (6~60) t/h, and the maximum-minimum flow ratio is about 10:1. From the test data, it can be seen that the results of B water flow have good repeatability, with single point repeatability higher than 0.1% and the majority higher than 0.05%. Relatively speaking, the accuracy of the first test is poorer, with its single point error of about (0.10~0.15) %, while the accuracy of the second and third tests is higher, with the single point error of about 0.05%.
The maximum-minimum flow ratio of C flow meter is approximately 5:1. The repeatability of each flow point is higher than 0.05% and the single point error of all flow points is less than 0.1% except for the minimum flow point. In addition, in the third test, the error also shows a significant trend of turning from negative to positive. The error of the second test is generally 0.1% smaller than that of the third one.

3. Natural gas test

The natural gas tests are carried out at the Guangzhou Sub-station of the National Oil and Gas Large Flow Metering Station. The tests adopt standard method and the gas flow device, with the test flow range set as (8~15000) m³/h, the relative expansion uncertainty, 0.29% (k=2), and the gas pressure, 7MPa. The test procedure is the same as above after turning off the pressure compensation function of the flow meter. The test results of the three flow meters are shown in Figures 4~6.

The measured natural gas flow range of A flow meter is about (2~20) t/h. Despite the obvious differences in temperature and pressure of the three tests, the overall repeatability is higher than 0.1%, and most test errors are close to 0.2%.
Figure 4. Natural gas flow test results of A flow meter

The measured natural gas flow range of B flow meter is about (2~20) t/h. C flow meter shows a certain fluctuation in three tests, with the error mean being -0.1%, 0% and -0.5%, respectively. The error of the third test is relatively larger, with the minimum flow point of -0.94%, and the single point repeatability fluctuating significantly from 0.01% to 0.32%.

Figure 5. Natural gas flow test results of B flow meter

For C flow meter, its natural gas flow range is about (2~20) t/h, the overall repeatability is good, with the majority higher than 0.05%, and its errors are mainly negative.

Figure 6. Natural gas flow test results of C flow meter
It can be seen from the comparison results that when the medium is water, the error curve is smoother with less fluctuation; when the medium is natural gas, the error curve shows stronger fluctuations. This phenomenon is related to the lower density of the gas (which is 1/20 or so that of the water). In addition, the uncertainty of the natural gas flow standard device itself is relatively low, which will also affect the results. The error curves of actual gas tests are generally below that of the water flow tests, and the average offset amplitude of natural gas tests is (-0.5~0.3) %. Since pressure compensation is turned off before the test, the phenomenon is supposed to be related to the influence of the medium pressure. Therefore, this paper intends to carry out the corresponding analysis.

4. Simulation analysis

In order to analyze the influence of medium pressure on the metering characteristics, this paper establishes a simulation model of the Coriolis mass flow meter in SolidWorks. The structure and size are set according to the actual flow meter, and the non-flow pipeline section is ignored. The author selects the stress analysis in the Simulation plug-in, sets the material to stainless steel, fixes the pipe section, and generates the mesh for calculation and analysis [7, 8].

In the stimulation test of the DN80 flow meter, 0.1 MPa, 0.5 MPa, and 6 MPa are applied respectively to simulate the case where the medium is air, water, and natural gas. From the simulation results in Fig. 10, it can be seen that under the medium pressure, the maximum deformation is concentrated at the center of the U-tube since the interfaces at both ends are fixed. When the pressure is 0.1 MPa, 0.5 MPa, and 6 MPa, the maximum deformation in the diameter direction is 7.634×10^-3 mm, 7.108×10^-3 mm, and 6.356×10^-2 mm, respectively, which indicates that greater pressure has a greater influence on the deformation of the U-shaped tube.

![Simulation results under different pressures](image)

The expansion coefficient is a physical quantity that characterizes the expansion property of an object, that is, a physical quantity that characterizes the expansion degree of length, area, and volume. Its calculation formula is as follows:

\[ K = \frac{R_1^2}{R_0^2} \]

Where: \( R_0 \) is the size before expansion and \( R_1 \) is the size after expansion.

According to the above formula, K1, the variation of the cross-sectional area of the pipeline during the natural gas test of the three Coriolis mass flow meters, and K2, the average value of the ratio of the actual flow rate to the detected flow rate can be calculated. It is known that K2 approximates the pressure compensation coefficient of the flow meter. The simulation coefficient K1 and experimental coefficient K2 are shown in Table 1. It can be seen that there is good consistency between K1 and K2 in terms of the numerical value and the variation direction. However, since K2 is calculated from the error detection, which is greatly affected by the performance of the flow meter and the detection process, it provides limited reference in quantitative evaluation [9, 10].
Table 1. Comparison of simulation and experimental results

| No. | Simulation coefficient $K_1$ | Experimental coefficient $K_2$ |
|-----|-----------------------------|-------------------------------|
| A   | 1.0089                      | 1.00610                       |
| B   | 1.0089                      | 1.00416                       |
| C   | 1.0038                      | 1.00058                       |

5. Conclusion

Based on the experimental comparison of three Coriolis mass flow meters, it can be seen that the detection results of tests in which water and natural gas are respectively used as medium are generally consistent. When the medium is water, the error is between -0.25% and 0.2%. When the medium is natural gas, the error is slightly larger because of low device uncertainty and the lower density of natural gas. Errors of two flow meters exceed -0.5%. Since the pressure compensation is turned off, the natural gas detection result has a significant negative deviation. Static simulation is carried out targeting the influence of test pressure on the flow meter, and the result shows that the pressure increase will cause the expansion of the metering tube, resulting in negative deviation, which is more consistent than the experimental data.

It is preliminarily determined that water can be used to replace natural gas in the Coriolis mass flow meter, but pressure compensation should be applied to the medium in its application. The author will conduct further tests to compare Coriolis mass flow meters.

Acknowledgements

This work was supported by the Zhejiang Provincial Natural Science Foundation of China (No.LY18E050009) and the research project of West-east Gas Transmission Branch of China Petroleum Pipeline Co., LTD. (No. XQDSPO123).

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