Study of Effect of Straight Pipe Length on Ultrasonic Flowmeter Measurement during Typical Baffle Interference

Min Wei (Oil and Gas Measurement Center of Southwest Pipeline Company)
Zhu Rui (Production and Operation Department of Southwest Pipeline Company)

Abstract:

On the current domestic market, a variety of ultrasonic flowmeters, including those with four (sound) channels, six channels, and eight channels, either through-beam and retro-reflective in channel arrangement, are all claimed to be extremely adaptable to baffle interference and have shorter straight pipes than required by the national standard. To observe and study the tolerance of these gas ultrasonic flowmeters to typical baffle interference and the requirements on the length of the front straight pipe segment, our technical team, according to the process installation requirements of GB/T18604-2014 measurement of natural gas flow by gas ultrasonic flow meters, as well as the AGA NO.9 -2017 report, use the turbine working standard combination system as a flow measurement standard device to test the real flow of natural gas for representative DN100 gas ultrasonic flowmeters with A, B, C, and D channels and different arrangements. Testing process: First, basic data were obtained by testing under ideal pipeline conditions, and then a flow regulator is installed under the interference conditions of typical flow blocking parts (space elbow and manifold are located 30D, 20D and 15D upstream of ultrasonic flowmeter), and see whether the main technical indicators can meet the requirements of trade handover. The technical team of the author designed the test of the effect of different process installation conditions on the measurement accuracy of the gas ultrasonic flowmeter and put forward their own views on the basis of analyzing the test data.

Keywords: significant gas flow interference, flow regulator, measurement accuracy

1. Preface

According to the requirements in national standard *Measurement of Natural Gas Flow by Gas Ultrasonic Flow Meters* (GB/T 18604-2014), trade measurement was carried out with an ultrasonic flowmeter. When there is no flow regulator, a 50D straight pipe segment is required at upstream, and when there is a flow regulator, a 30D straight pipe segment is required at upstream, and the flow regulator is installed at 10D. However, in some domestic trade handover stations with gas ultrasonic flowmeters, due to the early construction time or limited by the site area, the process installation conditions of some stations do not meet the above technical requirements. With the progress of technology and standards, there are a large number of new ultrasonic flowmeters in the domestic market. They are advertised as having better adaptability to typical baffle interference and lower requirements for the front straight section. Meanwhile, foreign standards also specify new technical requirements for the installation conditions of the gas ultrasonic flowmeter process. For example, the report of American AGA NO.9-2017 sets forth different technical requirements for the process installation conditions of ultrasonic flowmeters, that is, the accuracy requirements of the gas ultrasonic flowmeter can be met with only a 20D straight section upstream and a flow regulator installed at the 10D. Domestic technical organizations also put forward that domestic standards should be adjusted according to the actual situation in China. In order to further discuss the effect of process installation conditions on the measurement accuracy of the current mainstream gas ultrasonic flowmeter in the market, the technical team of the author designed the test for the effect of different process installation conditions on the measurement accuracy of the gas ultrasonic flowmeter, analyzed the test data, and obtained some conclusions on this basis.

2.Test Method and Conditions

A mature and reliable turbine working standard system was selected as the standard flowmeter device to test the real natural gas flow for DN100 gas ultrasonic flowmeter distributed on different channels by four companies, A, B, C and D on the market. Flowmeters A and B are all through-beam four-channel ultrasonic flowmeters, flowmeter C is an 8-channel through-beam and retro-reflective ultrasonic flowmeters, and flowmeter D is a through-beam 6-channel ultrasonic flowmeter. The test is carried out in three stages: the ideal flow state test, the manifold (header) interference test, and then the space elbow interference test. Ideal

flow rate test refers to ideal pipeline installation condition (no elbow, transition parts, resistance parts, etc. within 120D upstream of the flowmeter), uniform flow velocity distribution, and stable flow field (without pulsating flow or vortex flow). Manifold interference and space elbow interference tests are directed at the presence of baffles (space elbow, manifold) in the upstream of the ultrasonic flowmeter and 30D, 20D, and 15D long upstream straight pipes. The flow field is unstable due to the upstream baffle interference, and there is a slight vortex flow.

2.1Standard Equipment for Testing

The instruments used in the test are shown in Table 1 below.

Table 1 Introduction of Test Instruments and Equipment

S/N	Measuring Instruments	Instrument Name	Uncertainty	Remark
1	Standard	Combined turbine operating standard	±0.25%	Within the verification period
2	Ultrasonic flowmeter pressure	High-accuracy and high-range absolute pressure transmitter is adopted.	±0.025%	Within the verification period
3	Ultrasonic flowmeter temperature	Grade AA industrial platinum resistor grading high-accuracy temperature transmitter	±0.1℃	Within the verification period
4	Time	Time acquisition module	±0.01s	Within the verification period
5	Natural gas composition	Online chromatograph	±0.1%	Within the verification period

2.2Test Conditions and Test Plan

(1) Test conditions

Use turbine working standard as a standard device, and connect it in tandem with the ultrasonic flowmeter; arrange 6 flow points between the minimum and maximum flow rates, and test each flow point repeatedly for at least three times, under the conditions of no less than 100s per data acquisition, test pressure fluctuations ≤ 0.2%, test temperature fluctuations ≤ 0.2℃, gas composition fluctuations ≤ 0.08%, and flow fluctuations ≤ 0.25% during data acquisition. The step (misalignment) of the tube inner wall and the ultrasonic flowmeter is 1mm.

(2) Testing of measurement performance of ultrasonic flowmeter under ideal pipeline conditions

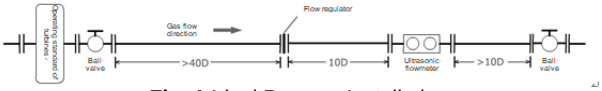


Fig. 1 Ideal Process Installation

The forward flow test was carried out on four ultrasonic flowmeters from different manufacturers at six flow points, Qmin, 0.10Qmax, 0.25Qmax, 0.4Qmax, 0.7Qmax and Qmax at 2.9MPa (under absolute pressure). The multi-point correction coefficient of the flowmeter is obtained and then included for calculation. The initial relative indication error was corrected to zero as far as possible, and the above six flow point tests were repeated to investigate the measurement performance of the flowmeter under ideal pipeline conditions and obtain the basic performance parameters of the flowmeter.

(3) The measurement performance of ultrasonic flowmeter in the presence of upstream manifold interference was tested.

①Theflowmeter is 30D from the upstream manifold, and a flow regulator is installed at 10D for performance test;

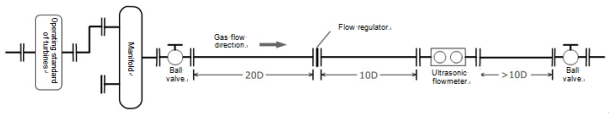


Fig. 2 Process Installation Drawing under Manifold Interference in Front 30D Straight Pipe Segment

②Theflowmeter is 20D from the upstream manifold, and a flow regulator is installed at 10D for performance test;

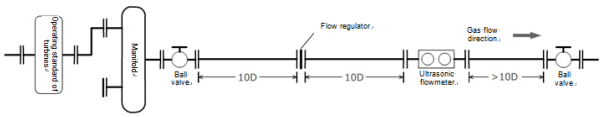


Fig. 3 Process Installation Drawing under Manifold Interference in Front 20D Straight Pipe Segment

③Theflowmeter is 15D from the upstream manifold, and a flow regulator is installed at 10D for performance test;

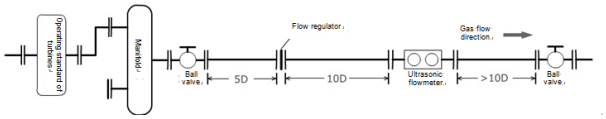


Fig. 4 Process Installation Drawing under Manifold Interference in Front 15D Straight Pipe Segment

A flowmeter is arranged at 30D, 20D and 15D of the upstream respectively, and a flow regulator shall be installed at 10D. Six flow points, including

Qmin, 0.10Qmax, 0.25Qmax, 0.4Qmax, 0.7Qmax and Qmax were distributed for the ultrasonic flowmeter to conduct the forward flow test under 2.9MPa to investigate the measurement performance of the flowmeter under the condition of manifold interference flow state.

(4) The measurement performance of ultrasonic flowmeter in the presence of upstream space elbow interference was tested.

①Theflowmeter is 30D from the upstream space elbow, and a flow regulator is installed at 10D for performance test;

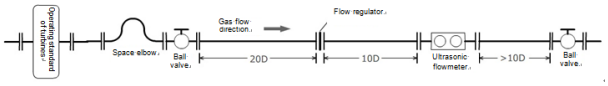


Fig. 5 Process Installation Drawing under Space Elbow Interference in Front 30D Straight Pipe Segment

②Theflowmeter is 20D from the upstream space elbow, and a flow regulator is installed at 10D for performance test;

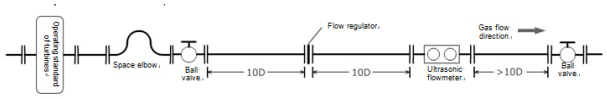


Fig. 6 Process Installation Drawing under Space Elbow Interference in Front 20D Straight Pipe Segment

③Theflowmeter is 15D from the upstream space elbow, and a flow regulator is installed at 10D for performance test;

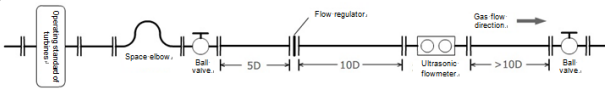


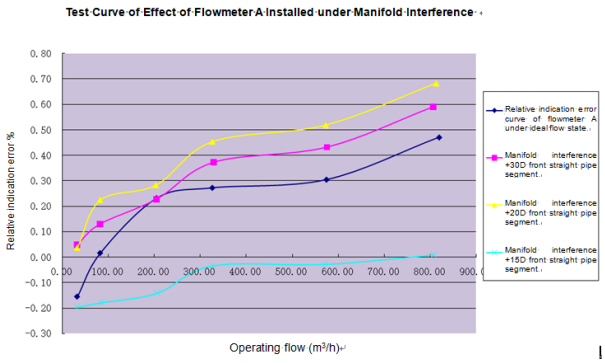
Fig. 7 Process Installation Drawing under Space Elbow Interference in Front 15D Straight Pipe Segment

A flowmeter is arranged at 30D, 20D and 15D of the upstream respectively, and a flow regulator shall be installed at 10D. Six flow points, including Qmin, 0.10Qmax, 0.25Qmax, 0.4Qmax, 0.7Qmax and Qmax were distributed for the ultrasonic flowmeter to conduct the forward flow test under 2.9MPa to investigate the measurement performance of the flowmeter under the condition of the space elbow interference flow state;

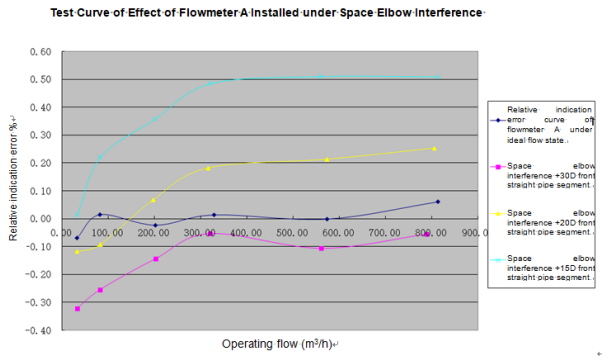
3.Analysis on Test Results

We chose four typical sets of DN100 ultrasonic flowmeters of different channels from four domestic manufacturers Chinese market. The marketing time of the four ultrasonic flowmeters is different, among which flowmeter B was marketed earlier, second by flowmeter A, and followed by flowmeters C and D which are the latest ultrasonic flowmeters in the market. The test results are as follows:

3.1The DN100 through-beam four-channel ultrasonic flowmeter from manufacturer A was tested, and the results are as follows:



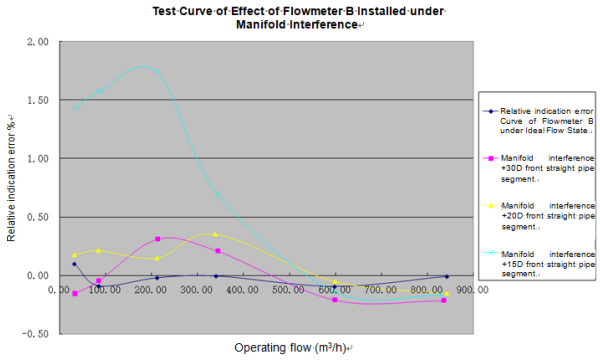
According to the above figure: ① Under the condition of manifold interference, the relative indication error curve trends of flowmeter A in the ideal flow state and at 30D and 20D of the upstream straight pipe segment are basically the same. ②The maximum change of relative indication value error is not more than 0.20% at 30D and 20D of the upstream straight pipe segment and in the ideal flow state. ③ However, the relative indication errors of the upstream 15D straight pipe segment are obviously different. The relative indication error changes to the negative error direction, and the maximum change is 0.46%. The larger the flow rate, the more obvious the relative indication error gap is. ④Under manifold interference, flowmeter A can be used for trade handover at 30D and 20D of the straight pipe segment in the upstream, while at 15D in the upstream, it should be used carefully during trade handover.



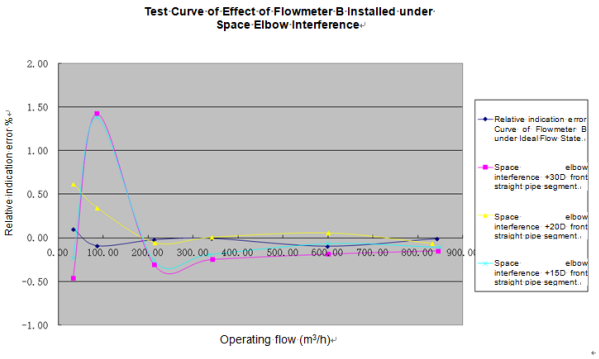
According to the above figure: ① Under the condition of space elbow interference, the relative indication error curve trends of flowmeter A in the ideal flow state and at 30D and 20D of the

upstream straight pipe segment are basically the same. The maximum change is not more than 0.20%. ②The relative indication errors of the upstream 15D straight pipe segment are obviously different, and the maximum relative indication error under the ideal flow state is 0.50%. ③When the front straight pipe segment is less than 20D, the relative indication error changes to the positive error direction. The larger the flow rate, the more obvious the relative indication error gap is. ④Under space elbow interference, flowmeter A can be used for trade handover at 30D and 20D of the straight pipe segment in the upstream, while at 15D in the upstream, it should be used carefully during trade handover.

3.2The DN100 through-beam four-channel ultrasonic flowmeter from manufacturer B was tested and the results are as follows:

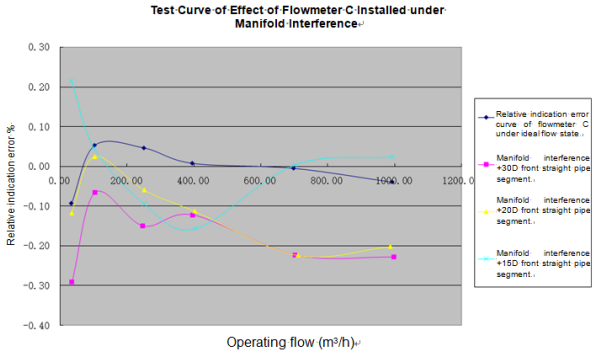


According to the above figure: ① Under the condition of manifold interference, the relative indication error curve trends of flowmeter B in the ideal flow state and at 30D and 20D of the upstream straight pipe segment are basically the same. The maximum change is not more than 0.36%. ②The relative errors of the upstream 15D straight pipe segment are obviously different. The relative indication error changes greatly to the positive error direction, and the maximum change is 1.63%. ③Whenflowmeter B at 15D of the straight pipe segment in the upstream and the operating flow rate is small, the relative indication error curve gap is more obvious. ④Under manifold interference, flowmeter B can be used for trade handover at 30D and 20D of the straight pipe segment in the upstream, while at 15D in the upstream, it shall not be used carefully during trade handover.



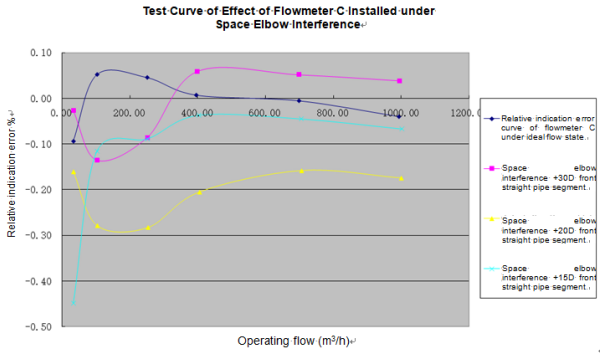
According to the above figure: ① Under the condition of space elbow interference, the relative indication error curve trends of flowmeter B in the ideal flow state and at 20D of the upstream straight pipe segment are basically the same. The maximum change is not more than 0.42%. ②The relative error curve trends at 30D and 15D of the upstream straight pipe segment are basically the same. When the operating flow is small, the relative indication error sharply changes to the positive error direction, with the maximum change up to 1.42%. ③Under the space elbow interference, the measurement accuracy of flowmeter B is greatly affected when it is below 0.1Qmax, so it is not suitable for use in trade handover. When it is greater than 0.1Qmax, it can be used.

3. 3The DN100 through-beam and retro-reflective eight-channel ultrasonic flowmeter from manufacturer C was tested and the results are as follows:



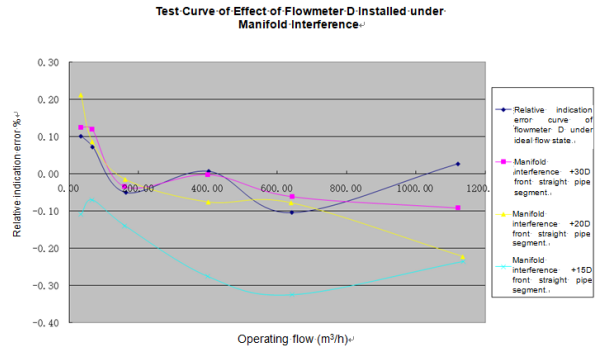
According to the above figure: ① Under the condition of manifold interference, the relative indication error curve trends of flowmeter C in the ideal flow state and at 30D and 20D of the upstream straight pipe segment are basically the same. The maximum change is not more than 0.21%. ②The relative error curve has different trends at 15D of the upstream straight pipe segment, with the maximum change up to 0.32%. ③Under manifold interference, when the operating

flow of flowmeter B is at the minimum, the relative indication error gap is obvious, while it is small in other operating flows. Within the maximum change is within 0.18%, it can be used in the trade handover.

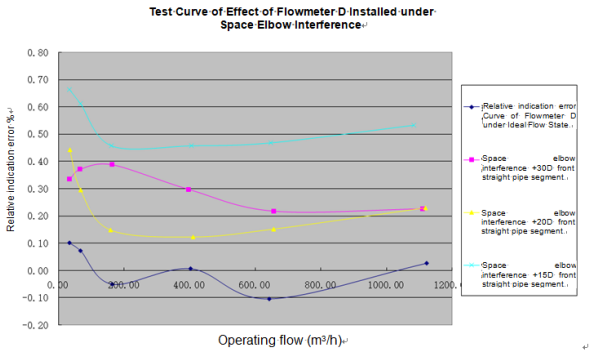


According to the above figure: ① Under the condition of space elbow interference, the maximum change of the relative indication error curve trends of flowmeter C in the ideal flow state and at 30D and 20D of the upstream straight pipe segment is not more than 0.31%. ②The relative error curve has different trends at 15D of the upstream straight pipe segment when the operating flow is minimum, with the maximum change up to 0.35%. ③Under space elbow interference, when the operating flow of flowmeter C is at the minimum, the relative indication error gap is obvious, while it is small in other operating flows. Within the maximum change is within 0.31%, it can be used in the trade handover.

3.4The DN100 through-beam six-channel ultrasonic flowmeter from manufacturer D was tested and the results are as follows:



According to the above figure: ① Under the condition of manifold interference, the relative indication error curve trends of flowmeter D in the ideal flow state and at 30D and 20D of the upstream straight pipe segment are basically the same. The maximum change is not more than 0.23%. ②The relative errors of the upstream 15D straight pipe segment are obviously different. The relative indication error changes greatly to the negative error direction, and the maximum change is 0.28%. ③Under manifold interference, when the operating flow of flowmeter D is at the 0.5Qmax operating flow, the relative indication error gap is obvious. Within the maximum change is within 0.22%, it can be used in the trade handover.



According to the above figure: ① Under the condition of space elbow interference, the relative indication error curve trends of flowmeter D in the ideal flow state and at 30D and 20D of the upstream straight pipe segment are basically the same. The maximum change is not more than 0.38%. ②The maximum change of the relative error reaches 0.58% at 15D of the upstream straight pipe segment. ③Under space elbow interference, flowmeter D can be used for trade handover at 30D and 20D of the straight pipe segment in the upstream, while at 15D in the upstream, it shall be considered carefully before use in trade handover.

3.5Test Summary

After multi-point linear correction, the measurement accuracy of the four tested ultrasonic flowmeters meets the requirements of trade handover under ideal flow conditions. If the upstream straight pipe segment is 30D long, with a flow regulator installed at 10D, and four ultrasonic flowmeters have manifold interference and space elbow interference, the relative indication error change is small, and basically can meet the measurement accuracy requirements of trade handover. If the upstream straight pipe segment is 20D long, with a flow regulator installed at 10D, and four ultrasonic flowmeters have manifold interference and space elbow interference, the relative indication error change is larger than when the front straight pipe segment is 30D, and still can basically meet the measurement accuracy requirements of trade handover. If the upstream straight pipe segment is only 15D long, with a flow regulator installed at 10D, and four ultrasonic flowmeters have manifold interference and space elbow interference, the relative indication error

change is large, and basically cannot meet the measurement accuracy requirements of trade handover. When the flowmeters that have been early put into the market have the typical baffle interference and the small operating flow, the test result of the relative indication error is large, so it should be fully considered before use. For new flowmeters that have been put into the market at the latest have the typical baffle interference, the relative indication error is small in the testing range of all operating flow conditions, which proved that both the adaptability of the new ultrasonic flowmeters to the baffles and its comprehensive measurement technology level are improved.

4.Conclusions

4.1Under the typical baffle interference, the upstream conforming to the requirements of GB/T 18604-2014 requires a 30D straight pipe segment, and when the flow regulator is installed at 10D, the relative indication error has increased compared with that in the ideal state except for the indication of the four-channel ultrasonic flowmeters earlier on the market below the inflection point. But it can still be used for trade handover measurement.

4.2 Under the typical baffle interference, the upstream conforming to the requirements of AGA NO.9-2017 requires a 20D straight pipe segment, and when the flow regulator is installed at 10D, the relative indication error has increased compared with that at 30D of the upstream straight pipe segment, and it shows that the shortening of the upstream straight pipe has an effect on the measurement performance of the ultrasonic flowmeter. However, the relative indication error increases slightly, and can still be used for trade handover measurement.

4.3 Under the typical baffle interference, if the upstream is just a 15D straight pipe segment, and the flow regulator is installed at 10D, the relative indication error has obviously increased compared with that at 30D and 20D of the upstream straight pipe segment, and it shows that when the length of the upstream straight pipe is shorter than 20D, the measurement performance is greatly affected and the relative indication error changes greatly. Therefore, even if the upstream flow regulator is installed at 10D, the upstream straight pipe length should not be less than 20D;

4.4 The test shows that the relative indication error of the ultrasonic flowmeter is generally large under low flow, small flow rate and the typical baffle interference, and the shorter the straight pipe segment, the relative indication error changes greatly.

4.5 For the four-channel ultrasonic flowmeters that have been early put on the market, the relative indication error is large under typical baffle interference and the small operating flow according to the test. For the latest ultrasonic flowmeters on the market, their measurement accuracy is better than that of earlier products in the whole flow range under typical baffle interference, showing the technical progress of ultrasonic flowmeter performance.

5.Deficiencies in the Research

5.1As the number of ultrasonic flowmeters used in tests was too small, a sufficient statistical scale was not formed. For some random incidence or unusualness, the estimation may not be accurate.

5.2 Due to the limitation of test installation conditions, no further test was carried out for shorter upstream straight pipe segments less than 15D, and the effect of the upstream straight pipe segment shortening was not further studied.

5.3 It should be further studied for the extent of changes in relative indication errors that would seriously affect measurement performance and the relation between the relative indication error change and the operating flow range;

5.4 The test data on the resistance of ultrasonic flowmeters from different manufacturers and models to the typical baffle interference is insufficient, and there is not enough data to demonstrate the change of performance parameters and the change extent.

6.Suggestions for Next Step

The author's team carried out the test and study on the effect of front straight pipe length on the measurement of the ultrasonic flowmeter under the typical baffle interference in a short period of time and obtained some preliminary data and conclusions. However, the current research is rather incomplete due to the limitations of installation conditions, development time and the number of tests. According to the current experience, when the upstream conforming to the requirements of GB/T 18604-2014 requires a 30D straight pipe segment, and the flow regulator is installed at 10D, the use of field trade handover measurement will not be affected even if there are typical baffles in the upstream. When the upstream conforming to the requirements of AGA NO.9-2017 requires a 20D straight pipe segment and has typical baffles, and the flow regulator is installed at 10D, the relative indication error increases but the measurement performance still can basically meet the requirements of field trade handover

measurement. However, if the typical baffle interference exists, the measurement performance of the ultrasonic flowmeter may be greatly affected even when the flow regulator is installed at an area shorter than 20D, even if at 10D, in the upstream straight pipe segment. For the mainstream ultrasonic flowmeters currently on the market, the front straight section requires at least 20D, and it is safer to install the flow regulator at 10D. However, due to the small number of ultrasonic flowmeters involved in the test, there are only two typical baffle interferences (manifold interference and space elbow interference), and the length of the front straight pipe segment changes little, the test conclusion is not solid, and it is suggested to carry out the following tests:

6.1 More types of ultrasonic flowmeters, the front straight pipe segments of different lengths, and other types of front baffles will be selected for the test, so as to obtain more extensive and convincing test data.

6.2. In the next test, the self-diagnosis of ultrasonic flowmeters should be considered to strengthen the research on the effect of different flow fields formed by typical baffles on the measurement performance of ultrasonic flowmeters.

References

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