Validity Guarantee of Measurement Data in Application of Big-diameter Heat-meter in China's Heating System

Jiguang ZHU[1]，Huizhe CAO[2,3]*

[1]Harbin Institute of Metrology, Harbin, China
[2]School of Architecture, Harbin Institute of Technology, Harbin, China
[3]Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science and Technology, Ministry of Industry and Information Technology, Harbin Institute of Technology, Harbin, China
**E-mail (corresponding author): caohz@hit.edu.cn*

Abstract

There are many limitations for the accuracy assurance technology of large-diameter heat meters characterized by laboratory calibration mode, which is hard to adapt to the complicated situation of heating system in China. Aiming to improve the measurement data accuracy of heating system thermal quantity, this paper proposes a new technical method by installing elbow sensor in the natural heating pipe bend to obtain the exact measure reference value. The method is based on the studies of current quality control conditions of big-diameter heat-meters, the flow measuring capability of heat-meters inside the hot water pipeline, the demand of heating operation to flow measurement accuracy, the online-verification technical model of flow measure, and the comparison between external clamp-on ultrasonic heat-meter and elbow heat-meter measurement ability under the situation of heating operation. The measurement data show that the elbow sensor of heat-meter prepared by the industrial ordinary elbow has the accuracy level of 3% and the long-term stability can reach 0.3%. Compared with the clamp-on ultrasonic flowmeter, the elbow sensor can better provide a stable measurement reference value at the heating site.

Key words: Heat-meter; Big-diameter; Online-verification; Elbow sensor; Clamp-on ultrasonic flowmeter；Reference value

1. Introduction

In china, the district heating business is now in a new era of smart heating after 70 years development, the total energy consumption of nearly 15 billion m^2 heating area takes a heavy ratio in northern China. Therefore, as the standard component of smart heating measurement system, the higher measurement date quality of heating heat-meter has a profound significance to the technique improvement of energy management, intelligent decision-marking, trade settlement and security warning.

As the basic support technique of smart heating, the research of big-diameter heat-meter online-verification is just in its infancy, there are still so many bottleneck problems need to be solved. Therefore, it is quite necessary to carry discussion of flow sensor of big-diameter heat-meter on the aspects of measurement characteristics under laboratory testing, the accuracy under actual site installation and operation condition, the basic rout chart of online-verification and the selection of measurement reference devices etc. Thereby, it will settle the effective data measurement of big-diameter heat-meter application in heating system of China, and it will also push the development of online-tracing of heating measurement technique with the great potential value.

2. Status of flow sensor laboratory calibration

In China, the scale of district heating system substation is normally between 1.5-7.0MW, and the heat-meter diameter is around DN80-DN300, the big-diameter heat-meter installed at the head of heating network is above DN500 with the biggest diameter as DN1400, all them are needing the exact flow measurement to guarantee the operation qualification. Presently, the scale and quantity of standard device of big-diameter hot water flow are hard to realize the heat-meter offline calibration, and the proof ability of the intrinsic measurement characteristics and calibration result under cool water is not applying to the hot water condition. It predicates that it is hard to realize the "similar" result between the conditions of hot water operation on site and laboratory normal temperature calibration, which is unavoidably to increase the measurement uncertainty.

In district heating systems, the key points to manage and monitor the possible measurement error of heat-meter should concentrate upon the comprehension of actual accuracy of flow measurement under the operation condition in order to obtain the higher quality data of flow and heat quantity. As the main component of big-diameter heat-meters, the data quality of flow sensor

upload is normally lie on the application in heating system after the steady laboratory calibration under hot water situation, which the measurement characteristics is close to the intrinsic value.

In recent years, the durability experiment of heat-meter service life is most under DN50. Though the accelerated durability experiment technique of 2400 hours and 4000 hours continuous cycle of small-diameter heat-meters is already standardized, it is not yet to be popular and mandatory put into implementation. The durability experiment of a certain ratio heat-meters in operation is still under the level of 300 hours laboratory test, while the expected service life of big-diameter heat-meters in operation is unknown, the obvious error is non-negligible to occur. It is insufficient for the conventional monitoring and maintenance methods proposed by EN1434-6, which is suitable for he operation management and maintenance of general household heat meters and doesn't meet the refinement management of heating system. The reasons maybe related with the determination of the reasonable life period of big- diameter heat meters in operation and the identification of possible measurement stability variation.

The intrinsic precision level of heat-meter represents the optimal uncertainty could be achieved under the ideal site condition. However, the actual site situation is not good enough with the additional uncertainty hard to be identified by disturbance, such as the environment temperature, humidity, hydraulic pulsation of closed circulation pipe network, the random gas mixed within pipe network, equipment vibration, complicated electromagnetic environment and so on. All the factors mentioned could lead to the rough and large systematically measurement error tending to the truth value of flow. The hydraulic condition of closed heating system and open laboratory is quite different which could impact on the measurement characteristics, the service life and the flow data quality, for example, the installation post near to the pump, the high work pressure, the hydraulic shock and so on.

Though there is already high accuracy requirement of heat-meter installed in heating resource and substation inside the heating design standard as CJJ/34-2022 (The Design Normal of Urban Heating Network), it only requires the accuracy but no insuring methods on the pipeline design, installation environment of heat-meters. Hence, it results in the insufficiency of guarantee ability during design phase with only small description as "the systematic accuracy of hot water flow is not less than 1% for the heat-meters of heating supply and heating resource companies with the demand of trade." However, the demand is already higher than the intrinsic accuracy level of certain heat-meter, it serves to show that the importance of flow measurement accuracy in heating system operation.

Figure1: Heat-metering online verification experiment device

3. Accuracy under actual installation condition

The heat-meter product standard GB/T32224-2020 specifies the flow disturbance test for heat-meters, but so far, this test has not been fully carried out. The structure of the flow measurement cavity of the big-diameter heat-meter is mostly different from that of the small-diameter, and its turbulence characteristics are mostly unclear. For this reason, we carried out the error comparison of flow interference experiment of common front resistance parts under installation conditions, and measured the flow of the big-diameter heat-meter flow sensor in the baseline pipeline with straight pipe length of 50D upstream to 10D downstream, and in the general installation pipeline with straight pipe length of 10D upstream to 5D. The types of upstream pre-resistance parts are: horizontal single elbow, vertical single elbow, the double elbow under the same plane, double elbow under different planes, concentric reducer, and fully open butterfly valve, fully open ball valve, etc. When the flow measurement error of any type of resistance element exceeds the control limit, it is regarded as unqualified.
It is randomly selected 27 sets of 9 brands and 3 types of big-diameter heat-meters between the range from DN80 to DN150. As shown in Figure 2, the 1MPE pass rate of the baseline test is 88%, and under the actual installation condition, the 2MPE pass rate is 72%. In the baseline pipeline test, 12% of the heat-meters failed to pass the 1MPE. In addition to the quality problem, the obvious error caused by the difference between the straight pipe section of baseline test and the factory inspection cannot be ruled out.

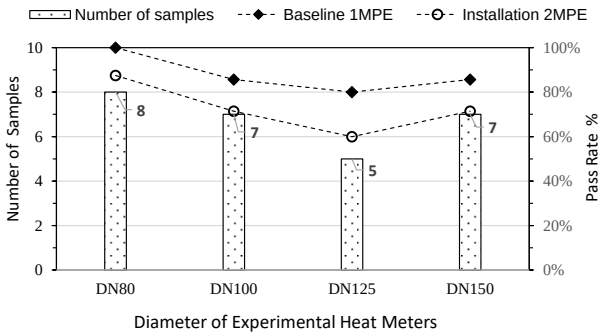

Figure 2: Experiment under different installation conditions

The water quality of heating system in different area in China is quite comprehensive, it is still short of enough experiment data of accuracy influence of heat-meter in use. Figure 3 shows the experiment result of water quality

influence to 9 groups small size heat-meters. It is found that the influence is obvious to the qualification rate of heat-meter, and there is already found the unacceptable significant error during a certain service life. Likewise, the influence of water quality to big-diameter heat-meter should be more focused.

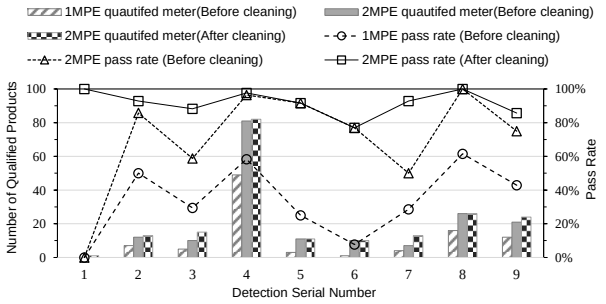

Figure 3: Experiment of water quality influence to heat-meter

Smart heating has high requirements on the accuracy of load forecasting to achieve accurate and comparable historical working condition data, otherwise, problems existing in operation will be covered up. While most heat-meters could guarantee the quality, it is inevitable to occur that the occasional failures or a drop in accuracy due to unforeseen factors. In addition, the error brought by the replacement of instruments will cause obvious deviations from the historical data model, which may be unacceptable. In order to realize the online verification with the purpose that to avoid disassembly during operation, in some trade settlement occasions, orifice flowmeter is also being used in the heating system, although its pressure loss could bring a certain amount of operating energy consumption. In the case of bulk heating measurement and settlement, in order to ensure accuracy and reliability and to reduce the economic risks, it is necessary to evaluate its absolute accuracy online, and the importance of online-verification is self-evident.

4. Basic technical route of online-verification

For big-diameter heat-meter of heating systems, low data quality means that the measurement error is too large, while the system error includes the flow sensor and the operating environment. Excessive error may mask the error in heating operation process. We regard the site application of big-diameter heat-meter as a collection of flow sensor, temperature sensor, measuring pipe section, installation, environment, transmission, software and maintenance for the entire process to obtain the heat measurement results.

The essence of the online-verification is to analyze whether the errors caused by various factors are small enough. Through the regular online-verification, it could find the measurement characteristics change and to take relative corrective actions, so that the flow measurement in operation could be continuously controlled in long-term condition. Before determining the method of obtaining the reference value for online-verification, the accuracy requirements required for the flow measurement of the heating system should be practically evaluated.

For heating load prediction and operation regulation, it generally does not require high accuracy of the flow sensor. As long as it has good stability of measurement characteristics in long-term operation, it can also meet the accurate and comparable requirements of historical data. If the stability of the flow sensor does not meet the required level, it means that the heat-meter may be faulty and needs to be replaced or repaired offline.

The accuracy requirements of heating energy consumption measurement and settlement not only emphasize the good long-term operation repeatability and linearity, but also require the traceability of heat-meter flow measurement results.

Current optional methods of obtaining the reference value of online-verification standard for heating flow measurement mainly include the following methods:

a) In order to achieve the required uncertainty, it connects the tested flowmeter and the reference flowmeter in series on the same pipeline, which is difficult to be widely used due to the safety problems of the heating system and cost constraints.

b) It is normally to adapt the external clamp-on flow measuring instrument as the standard meter to take comparison. But in practice, the uncertainty of measuring the reference value is difficult to control.

c) At the natural bend of the heating system pipeline, it has carried out in-depth experimental research by using the flow measurement characteristics of standard ordinary elbows to provide a stable measurement reference value.

d) The relationship between the pressure loss and flow characteristics of a section of pipeline, the resistance is always changing due to the heating pipe network regulation, the uncertainty of this method is relatively large.

e) For the method using the intelligent algorithm of the heating mechanism model, such as the identification of the characteristics of pump, while there is no case where traceability can be achieved so far.

The most economical and more general method is to provide the measurement reference value through the reference flowmeter in series, and to realize the online-verification by technical comparison with the flow indication value of the heat-meter. The reference flow sensor should have the required performance in terms of long-term stability and accuracy, and the reference value

provided by the reference flow meter is traceable. In the following, we will focus on the feasibility of clamp-on ultrasonic flowmeters and elbow flow sensors as verification criteria.

5. Reference apparatus for online-verification

In district heating sites nowadays, the use of a non-intrusive in-line flow meter method is the preferred operating path for flow measurement reference value. To this end, we carried out a series of experiment analysis, taking the external clamp-on ultrasonic flowmeter with movable operation and the measurement characteristics of the elbow at the existing bend of the heating pipeline as the research of the online flow measurement reference value for this topic.

5.1 Laboratory experimental study on hot water flow measurement characteristics of external clamp-on ultrasonic flowmeter

Using the hot water flow standard device, the "Experimental Research on the Hot Water Flow Measurement Capability of the Portable Ultrasonic Flowmeter under the Actual Installation Conditions of Heating Pipeline" was carried out. Table 1 shows some experimental results of 9 sets of portable ultrasonic flowmeters of 6 brands.

Table 1: Effect experiment of single-channel external clamp-on ultrasonic flowmeter installation under hot water condition

Upstream Resistance Parts	Measurement Error (%) of Different Upstream Straight Pipe Section (Water temp. 50-80 ℃)	
	10D	20D
Butterfly valve (50%-100% open)	3～－5	3～－3
Gate valve (50%-100% open)	3～－4	2～－2.5
Ball valve (50%-100% open)	5～－6	3.5～－3
Double bend under isoplanar	3～－5	2～－4
Double bend under vertical plane	5～－8	4～－6
Diameter shrinking and off-centre	3～－5	3～－4

The experimental results show that for the flow measurement of hot water pipelines on site, when the straight pipe section is long enough, the measurement accuracy level of the monophonic portable ultrasonic flowmeter is 3%-4%. Three external mono clamp-on ultrasonic flowmeters were randomly selected to carry out 9 groups of error experiments under repeated installation conditions. Each group was tested 6 times to obtain the error average value. The experimental flow rate was 0.5 m/s, and additional factors were exposed as possible. Figure 4 shows that the flow measurement stability range under the repeated installation conditions is approaching 2%, which means that the repeatability of measurement reference value is not ideal and the uncertainty of the online-verification results of the flow measurement is relatively large.

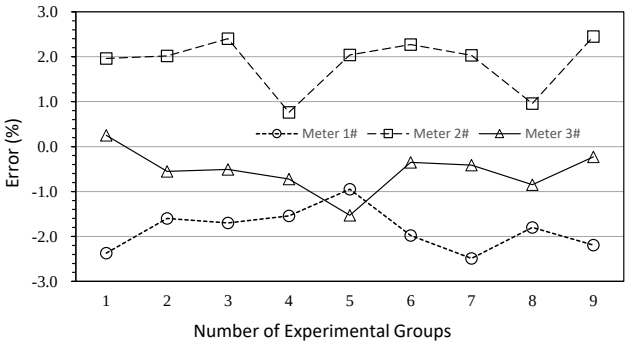

Figure 4: Stability experiment under repeated installation conditions of the external clamp-on ultrasonic flowmeter

At the same time, the layout of the existing process pipelines from the heat source to the heating pipe network should be viewed objectively. It is often difficult to support the portable ultrasonic flowmeter to find an ideal operable straight pipe section that meets the above requirements. This is one of the unfavorable conditions that affect the reliable acquisition of measurement reference values.

5.2 Experimental research on using the flow measurement characteristics of standard ordinary elbows to provide measurement reference values

As a differential pressure flowmeter, elbow flowmeter has a large number of mature applications in the industrial field. The flow measurement can be achieved without adding any moving parts and without additional pressure loss by utilizing the characteristics of the elbow at the natural bend of the heating pipe. A large number of studies have shown that the elbow flowmeter has excellent repeatability and long-term stability of measurement characteristics. The geometric structure of the elbow sensor body and its dimensional accuracy are the main factors affecting the system error of the elbow flowmeter. By reasonably controlling the geometric parameters, which can improve the measurement accuracy.

Using the hot water flow standard device, a number of DN100-DN200 standard ordinary elbows were randomly selected to prepare a flow sensor. Under the actual heating pipeline installation conditions, the error characteristics test experiment under hot water conditions was carried out. The test results are shown in Figure 5.

The results in Figure 5 shows that when the flow sensor made of standard ordinary elbow is used in combination with the mobile test instrument, the accuracy level of 2%-3% of hot water flow measurement can be achieved. Figure 6 shows the average variability results of 3 random selected bend sensors after 9 sets of tests, each of which is tested 6 times, and its long-term stability range

is 0.3%. Obviously, the hot water flow measurement characteristics of the elbow sensor are better than the clamp-on ultrasonic flowmeter.

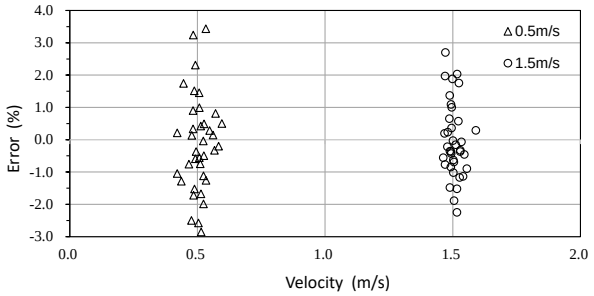

Figure 5: Accuracy experiment of elbow sensors

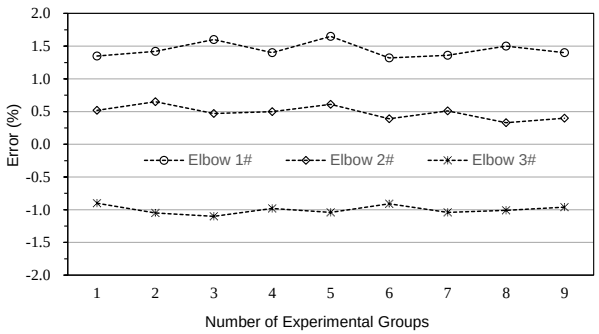

Figure 6: Stability experiment of elbow sensors

5.3 Significance of applying elbow sensors

a) For the verification sensor prepared by the standard ordinary elbow, the geometric method is used to determine its measurement characteristics, usually after a large number of real-flow calibration practices. Knowing and fully grasped, the accuracy level of the meter can be determined based on statistics and experience, and is widely recognized.

b) Based on the long-term stability of the measurement characteristics of the elbow flow sensor, a stable and reliable measurement reference value can be obtained in the online-verification operation of the big-diameter heat-meter flow measurement. Deterioration of flow measurement is undoubtedly a good technical route with low cost and strong operability.

c) In some occasions where there is a requirement for online traceability of flow measurement, the use of precision-machined, real-flow calibrated elbow sensors as a permanent verification end can achieve a smaller flow calibration uncertainty.

d) Based on the characteristics of simple structure and permanent fixed installation, the elbow flow sensor has extremely low repeatability and long-term stability, which is obviously superior to the external clamp-on ultrasonic flowmeter.

6. Conclusion

For the big-diameter heat-meter flow sensor, in order to get the more accurate measurement value, the all heating meter devices quality should be guaranteed, and the measurement during operation also needs to be monitored and controlled. It is becoming increasingly important to evaluate how well its long-term measurement performance meets the expected requirements by implementing the online-verification of flow under the actual operation site for the purpose to confirm its ability approaching to the inherent characteristics.

By the technique of using standard ordinary elbow sensor to obtain the flow measurement reference value, it could get the effect of reducing the cost of online calibration and improving the measurement data quality. In years of application practices, the effect is good with online-verification technology in heating system on-site. Use high-precision elbow sensor as the measurement reference devices, it could further improve the uncertainty of flow online calibration and to satisfy the traceability of heating measurement for trade settlement.

As an “engine” for the traceability of the heat thermal measurement, development of online-verification could bring a new change of the online calibration method, as well as the promotion to improve the date quality of online measurement of smart heating energy consumption.

References

[1] JJG643-2003 [S]*: Flow Standard Facilities by Faster Meter Method (in Chinese)*. Beijing, China Quality Inspection Publishing Company, 2003

[2] JJG225-2001 [S]*:Heat Meters (in Chinese)*, China Standard Publishing Company, 2001

[3] GB/T32224-2020 [S]*:Heat Meter (in Chinese)*. Beijing, China Standard Publishing Company, 2020

[4] Wang Chi etc., *Flow Measurement Technique Handbook (in Chinese) [M]*. Beijing, Chemical Industry Press, 2012

[5] Roger C. Baker, *Flow Measurement Handbook: Industrial Designs, Operating Principles, Performance, and Applications (Second Edition) [M]*. Cambridge University Press, 2016