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Discussion on the Application of Measurement Reproducibility in Gas Flow Standard Devices by Master Meter Method

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Abstract

Based on the analysis of the test results of several gas flow standard devices by master meter method, it is found that under the same flowing conditions, the indication errors of a meter under test at the same flow rate with different master meters in a set of standard device are not consistent with each other, the deviations are 0.08% ~ 0.21%, that is, there will be a non-negligible systematic deviation in the results of the verification or calibration of the flow meter with different master meters. In the present paper, the reproducibility of test results is innovatively introduced to measure the consistency of measurement results of different master meters in a gas flow standard device, and the reproducibility application in the performance examination, uncertainty evaluation and quantity transfer of a gas flow standard device is discussed.

1. Introduction

The gas flow standard device by master meter method (hereinafter also referred to as standard device) is composed of multiple identical master meters or multiple master meters with overlapping flow ranges. Under the same operating conditions (pressure, temperature, flow rate, personnel, and meter under test), there is a certain deviation between the indication errors of the meter under test with different master meters in a standard device, and some of the deviation of the indication error even exceeds the measurement uncertainty of the standard device. Therefore, the problem with this is that using different master meters to carry out the quantity transfer can introduce a system bias. In JJF1001 [1], measurement reproducibility is defined as measurement precision under reproducibility conditions. Reproducibility conditions are a set of measurement conditions that are repeated to the same or similar measured objects in different locations, operators and measurement systems. When the operating conditions remain unchanged, the same flow meter is tested with different master meters in a standard device at the same flow point, the master meter and the temperature and pressure measuring instruments installed on the master meter run are changed. In the present paper, for the convenience of quantitative analysis, the reproducibility of test results measured by a standard device is described by the deviation of the indication errors of the meter under test with different master meters in the standard device.

2. Working principle of gas flow standard device by master meter method

2.1 Technological process

Generally, high precision turbine flow meters are used as the master in a gas flow standard device by master meter method, and the meter under test is connected in series downstream. When the natural gas flows through the standard device and the meter under test, the flow value measured by the two meters in the same time interval is compared to determine the metering performance of the meter under test. According to the test flow rate, select a single master meter or multiple master meters work in parallel. In order to monitor the performance of the master meters, the standard device is also equipped with an ultrasonic flow meter as a check standard. Generally, it is installed in series upstream of the master turbine meters to check the performance of the master turbine meter in real time. The installation forms of the check meter are divided into total check and one to one check. The process flow chart is shown in Figure 1 and Figure 2 respectively. In Figure 1, under the same operating conditions and the same flow rate, the check results of each mater meter can also be used for the evaluation of the reproducibility of the standard device.

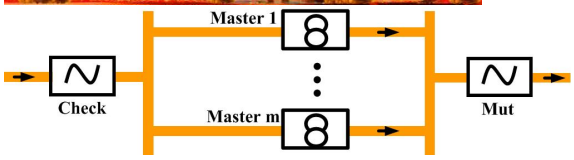

Figure 1: Process flow chart of gas flow standard device by master meter method for total check

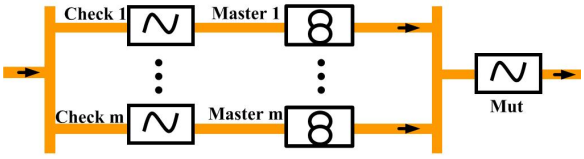

Figure 2: Process flow chart of gas flow standard device by master meter method for one to one check

2.2 Calculation formulas

When the flow meter is tested with different master meters in the gas flow standard device by master meter method, the calculation formula of the indication error is as follows:

$$E_{ij} = \frac{V_{muti} - V_{s,mi}}{V_{s,mi}} \times 100\% \qquad (1)$$

Where E_{ij} is the calculated value of the relative indication error in the *i*-th test of the *j*-th master meter, %;
V_{muti} is the cumulative flow rate measured by the meter under test, m³;
$V_{s,mi}$ is the cumulative flow rate measured by the master meter converted to the flow conditions of the meter under test, m³.

Under the same operating conditions, the repeatability of the test results of the meter under test repeated many times with the same master meter can be calculated by formula (2):

$$E_{ri} = \sqrt{\frac{\sum_{i=1}^{n} (E_{ij} - E_j)^2}{n-1}} \qquad (2)$$

Where E_{ri} is the repeatability of multiple tests on the meter under test at the *i*-th flow point with the same master meter, %;
E_j is the average relative indication error of the meter tested with the *j*-th master meter at the *i-th* flow point, %;
n is the number of repeated measurements at the *i*-th flow point of the meter under test.

Under the same operating conditions, the reproducibility of the test results of the meter under test with each master meter in the standard device can be calculated by Formula (3):

$$E_{Ri} = \sqrt{\frac{\sum_{j=1}^{m} (E_j - \overline{E_j})^2}{m-1}} \qquad (3)$$

Where E_{Ri} is the repeatability of the test results at the *i*-th flow point of the meter under test with *m* master meters, %;
$\overline{E_j}$ is the average indication error of the meter under test with *m* master meters, %;
m is the number of master meters with the same flow rate in a standard device.

Under the same operating conditions and flow point, the indication error deviation of the meter under test with different master meters is calculated by formula (4):

$$\Delta E = E_{max} - E_{min} \qquad (4)$$

Where ΔE is the deviation of indication error of the meter under test with different master meter runs in the standard device, %;
E_{max} is the maximum indication error of the meter under test with *m* master meters in the standard device, %;
E_{min} is the maximum indication error of the meter under test with *m* master meters in the standard device, %.

3. Problems found in test results

Table 1 shows the test results of 7 sets gas flow standard devices by master meter method in different laboratories. Each laboratory should test the flow meter selected by itself and repeat the measurement no less than 6 times. The volumetric flow measurement uncertainty of these standard devices ranges from 0.16% to 0.29%.

Table 1: Test results of seven gas flow standard devices by master meter method

Standard Device Number	Deviation of Indication Error (%)	Measurement Reproducibility (%)	Measurement Repeatability (%)	Uncertainty of Standard Device (%)
1	0.14	0.05	0.01	0.16~ 0.29
2	0.21	0.08	0.02	
3	0.08	0.03	0.01	
4	0.19	0.05	0.01	
5	0.12	0.04	0.01	
6	0.13	0.07	0.03	
7	0.19	0.05	0.02	

It can be seen from the data in Table 1 that the deviation of indication error of test results with different master meters in the same flow standard device is 0.08% ~ 0.21%, which indicates that using different master meters to carry out the dissemination of the value of quantity will bring a great deviation. The reproducibility of the test results is 0.03% ~ 0.08%, the repeatability of the test results is 0.01% ~ 0.03%, and the reproducibility of the measurement results is 2~3 times of the repeatability. The core requirement of measurement is to ensure the accuracy and consistency of measurement results. The measurement standard device is the source of the

quantity transfer; therefore, ensuring the accuracy and consistency of measurement results of the measurement standard device is the prerequisite to ensure the accuracy and consistency of measurement results. In JJG643 [2], there is no mention of reproducibility requirement for flow standard devices by master meter method. Therefore, it is necessary to analyze and discuss the reproducibility of standard devices to ensure accuracy and consistency of the values measured by these standard facilities.

4. Reproducibility verification test results and analysis

In order to certify and analyze the reproducibility of the standard device, two ultrasonic flow meters and one turbine flow meter were selected for testing at the flow rate of 800 m³/h by the seven master meters in the standard device (extended uncertainty is 0.29%) under the same flowing conditions. These tests were repeated six times for each master meter. The second test was performed after a time interval of three weeks. The test results are summarized in Table 2, and the test results of each flow meter are shown in Fig. 3~ Fig. 5. The results of this reproducibility test are better than those in Table 1

Table 2: Summary of reproducibility test results

Meter Under Test	Testing Time	Deviation of Indication Error (%)	Measurement Reproducibility (%)	Measurement Repeatability (%)
Ultrasonic meter A	The First time	0.12	0.05	0.09
	The second time	0.13	0.06	0.09
Ultrasonic meter B	The first time (a)	0.16	0.06	0.04
	The first time (b)	0.12	0.04	0.07
	The second time (a)	0.11	0.04	0.04
	The second time (b)	0.14	0.05	0.05
Turbine meter	The first time	0.12	0.05	0.02
	The second time	0.12	0.05	0.01

It can be seen from Table 2 that these deviations of the relative indication error tested with different master meters in the same standard device are all greater than 0.1%, and the maximum deviation is 0.16%, which verifies that using different master meters in the same standard device to carry out the quantity transfer will bring a certain deviation. The reproducibility of the test results of the ultrasonic flow meters is 0.04% ~ 0.06%, and the repeatability is 0.04% ~ 0.09%, the difference between the reproducibility and repeatability is not very obvious. For the turbine flow meter, the reproducibility is 0.05%, and the repeatability is 0.01% ~ 0.02%. The reproducibility is 2~3 times of repeatability. Apparently, the reproducibility and repeatability of the turbine flow meter test are better than that of the ultrasonic flow meters.

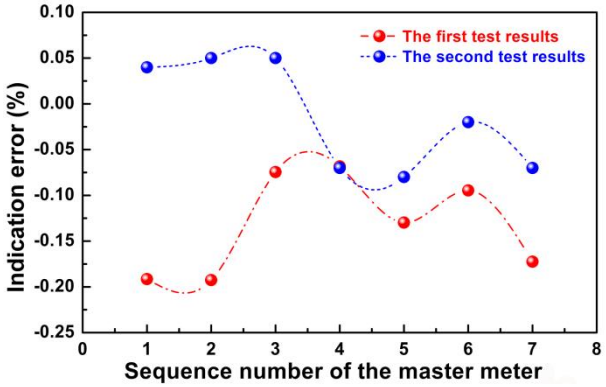

Figure 3: Test results of the ultrasonic flow meter A

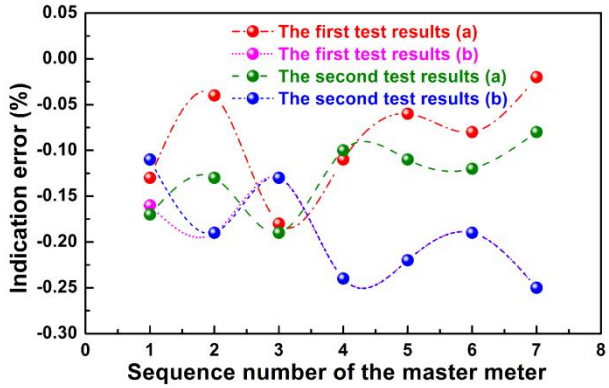

Figure 4: Test results of the ultrasonic flow meter B

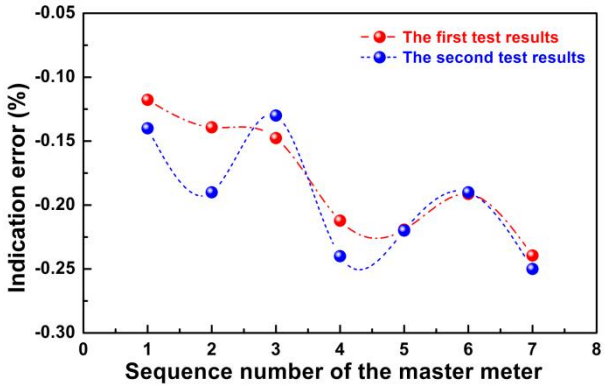

Figure 5: Test results of the turbine flow meter

The ultrasonic flow meter A in Figure 3 is installed on a test bench of the standard device. The results of the two tests were basically the same with the fourth run mater meter, and the deviation between the two results was about 0.25% when the first and the second run master meter were used. The ultrasonic flow meter B in Figure 4 is used for checking the total amount of the standard device (as shown in Figure 1). The first test results (a) and (b) are recorded during the first test of the ultrasonic meter A and the turbine meter, the second test results (a) and (b) are recorded during the second test of the ultrasonic meter A and the

turbine meter. The results of the four tests are rather close with the first and the third runs of the mater meter, and the deviation between the four results is about 0.25% with the seventh run master meter. In Figure 5, the consistency of the two test results of the turbine flow meter is good, and the deviation of the test results with different master meters shows a strong system deviation.

It can be seen from Figure 3 to Figure 5 that the test results with different master meter runs are greatly affected by the performance of the flow meter being tested.The test results are also greatly affected by the accuracy of temperature and pressure measurement, line pack capacity and operating conditions [3], which should be strictly controlled during the reproducibility test. When the performance of the flow meter under test is not stable, the deviation (reproducibility) of the test results with different master meter runs shows randomness. However, when the performance of the flow meter under test is stable, that is, it is less affected by the performance of the flow meter under test, the deviation (reproducibility) of the test results with different standard meter runs appears systematic, that is, the reproducibility of the standard device is the characteristic of the standard device itself.

5. The application of reproducibility

As mentioned above, the problem of inconsistent quantity will occur when different master meters are used for quantity transfer. Therefore, it is necessary to put forward requirements for the reproducibility of standard devices and apply them in practical work.

5.1 The application of reproducibility in measurement standard device examination

Because the reproducibility of the standard device is the characteristic of the standard device itself, it is suggested to evaluate the reproducibility as a technical index of the standard device in the assessment process of the gas flow standard device by master meter method. Currently, the assessment of the standard device is based on JJF1033 [4], which only considers the stability of standard device and the repeatability of verification or calibration results, without considering the reproducibility of test results.

After considering the reproducibility, the following problem is how to calculate the reproducibility and determine the reasonable limit of reproducibility. When using Formula (3) to calculate the reproducibility, Bessel formula can be used for calculation only after the flow meter under test is tested by all of the master meters, which is quite troublesome. In order to simplify the calculation and easy to use it, it is suggested to use the deviation ΔE that is calculated by Formula (4) to represent the degree of consistency of measurement results, namely, the reproducibility. In addition, considering that the flow meter and temperature and pressure measuring instrument installed on each run of master meter in the standard device are generally traceable to measurement standards of one lab, some system factors will cancel each other in the process of calculating the deviation of indicated error. Therefore, it is suggested that the deviation of test results with different master meter should not exceed the extended uncertainty of standard devices, namely:

$$\Delta E \leq U \tag{5}$$

Where U is the expanded uncertainty of the gas flow standard device by master meter method, %.

In the process of measurement standard examination, if formula (5) is satisfied, the reproducibility of the measurement standard is qualified, and also naturally meets the requirements of normalized deviation E_n evaluation and Z score evaluation used in measurement comparison given in JJF1117 [5].

5.2 The application in uncertainty evaluation of verification or calibration results

It can be seen from the above description that the reproducibility has a direct influence on the measurement results of the standard device. However, this component is not introduced in the evaluation of the uncertainty of verification or calibration results based on JJF1033, and only the uncertainty of the standard device and the repeatability of verification or calibration results are considered. If the reproducibility component is introduced, the uncertainty of verification or calibration results will become larger. Therefore, whether to introduce this component into the uncertainty assessment of verification or calibration results needs to be further studied. In addition, for the reproducibility caused by the stability of the measuring instrument, if the measuring instrument in the standard device is certified, the influence of the stability has been taken into account. However, for flow master meters, the current traceability is through calibration, without considering the problem of stability. Therefore, in order to ensure the accuracy and reliability of the measurement results, it is worth studying whether the reproducibility or the stability of the standard table should be considered in the process of uncertainty assessment.

5.3 The application of reproducibility in the process of quantity transfer

The influence of reproducibility should be considered in the process of carrying out quantity

transfer with one single master meter. Each time after all the master meters have been calibrated or tested, it is suggested to use the master meter whose measurement results are close to the average of the measurement results of all the master meters to carry out the quantity transfer. When multiple master meters are put into operation, the influence of reproducibility will be smaller, and the reproducibility can be ignored when all master meters are put into operation.

6. Conclusions

1) Reproducibility is the characteristic of the gas flow standard device by master meter method itself. When a single master meter in the standard device is used for quantity transfer, the reproducibility has a great influence on the measurement results. The concept of reproducibility is introduced into the gas flow standard device by master meter method, which can effectively ensure the accuracy and consistency of measurement results.

2) The flow meter with good stability and repeatability should be selected for the reproducibility test to reflect the performance of the standard device more effectively. In comparison, the performance of the turbine flow meter is relatively stable.

3) In view of the characteristics of flow measurement, it is suggested to do further research on the application of reproducibility.

References

[1] JJF1001-2011《General Terms in Metrology and Their Definitions》.

[2] JJG643-2003《Flow Standard Facilities by Master Meter Method》.

[3] Mingchang Guo、Qingqiang Hou、Xiran Zhang etc. The Application of Check Techniques in Gas Flowmeter's Calibration[C]. IMEKO International Seminar on Measurement. Hangzhou: 2017: 180～183.

[4] JJF1033-2016《Rule for Examination of Measurement Standard》.

[5] JJF1117-2010《Measurement Comparison》.