Development and uncertainty evaluation of gas flow standard facility with adjustable working temperature

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Abstract

To study a gas standard facility by master meter method, a master meter flow range is 10 to 250 m³/h, DN80. With one large-capacity temperature chamber, and the meter under test (MUT) places in the temperature chamber. The temperature chamber can be adjusted to a temperature range of -25 to 55 °C, and the temperature is stable when the test flow reaches a maximum of 250 m³/h. The master meter is placed in a room temperature environment, and a heat exchange is installed between the master meter and the MUT.The facility can be used to calibrate increasingly growing gas flow meters such as gas turbine meters, gas rotary meters, gas ultrasonic meters, and the like. In particular, it is possible to carry out research on the measurement performance change of a gas flow meter under different temperature environments. The facility adopts a Duo-rotary meter as master meter, and uses a non-fixed point method to correct the error of the master meter by the polyline method. To carry out the temperature stability test and measurement uncertainty evaluation on the facility. The facility was evaluated for uncertainty using the *ISO/IEC GUIDE 83-3:2008 GUM* method and the result was *Urel* = 0.29% (*k* = 2). Tested with an actual working flow meter, the facility meets the requirements of the relative extended uncertainty of the design, and as an innovation, it will promote the temperature performance test level of gas flow standard facility technology.

- **Keywords:** Master meter method, Gas flow standard facility, Meter under test (MUT), Adjustable temperature, Evaluation of measurement uncertainty

1. Introduction

The gas flow standard facility is used for the verification or calibration of the gas flow meter, and is an important device for the transmission and traceability of the quantity.

In 2018, global natural gas consumption was about 3.86 trillion cubic meters, a growth rate of 5.3%. Natural gas development has led to a significant increase in the use of gas flow meters. In general, the natural gas station requires an accuracy class of 0.5, and the accuracy class of the flow meter commonly used by urban natural gas industrial and commercial users is 1.0, and the usage is several hundred times that of the station. The gas flow facility device bears the periodic verification or calibration of the gas flow meter, and its resource allocation and the importance of technical performance indicators are self-evident.

At present, the gas flow standard facilities, in addition to a small number of primary standard facilities, the widely used gas flow standard facilities expanded uncertainty is usually 0.2% to 0.33% (k=2), used to verify accuracy class 1.0 gas flow meter[1]. Usually, the facility is placed in a laboratory room temperature environment, so that it is impossible to evaluate the metering performance of the MUT at different work temperatures. Based on this, the gas flow standard facilities with adjustable ambient temperature of the study can provide a new idea.

2. facility composition and workflow

The gas flow standard facility of this study is mainly composed of temperature chamber system, MUT workbench and straight pipe section, heat exchanger, master meter, gas source, timer, computer control and data acquisition and processing system (see Figure 1 and Figure 2). The facility in this study adopts the

negative pressure method, and the flow range is (10-250) m^3/h. For economic considerations, one MUT workbench and the straight pipe section is DN80, which can be used for the flow meter of DN80 and below to perform verification or calibration. The device has an expanded uncertainty of 0.29% and can be used to calibrate or calibrate accuracy class 1.0 meter with pulse output type or a field read type gas meter such as gas turbine meter, gas rotary meter, a gas swirling vortex meter, a gas ultrasonic meter, etc. .

Build an temperature chamber to place MUT inside it, to adjust the work temperature of the meter. According to the OIML R137[2], EN 12261[3] and EN 12480[4] standards, The work temperature of meter is in common use -25 °C ~ 55 °C, and there is sufficient temperature control ability to ensure that the temperature does not exceed ± 0.5 °C in each test of the test maximum flow. The downstream pipeline of the MUT is wrapped with insulation material and connected to the heat exchanger. The heat exchanger is connected to the master meter through the pipeline. The test flow is controlled by the variable-frequency drive to control the blower speed and the ball valve opening. The PLC collects the temperature and the pressure signal of the MUT and the master meter. Through the comparison of the flow rate of the MUT and the master meter, the indication error and repeatability of the MUT are obtained. The following two types of MUT are available for this study:

1) A flow meter that only displays the mechanical counter to display the volume;

2) The output pulse frequency is related to the flow rate of the rotating part.

The following describes the second type of flowmeter to be tested, and defines the number of pulses per unit volume as the meter factor *K*.
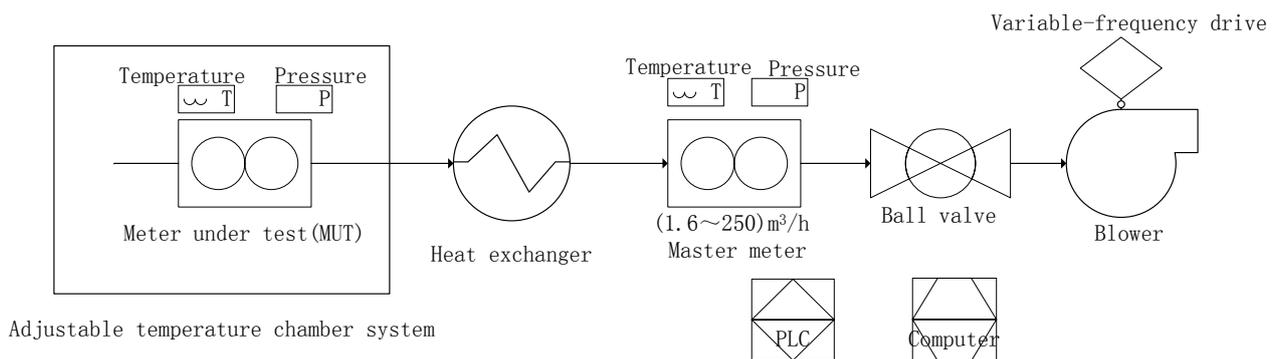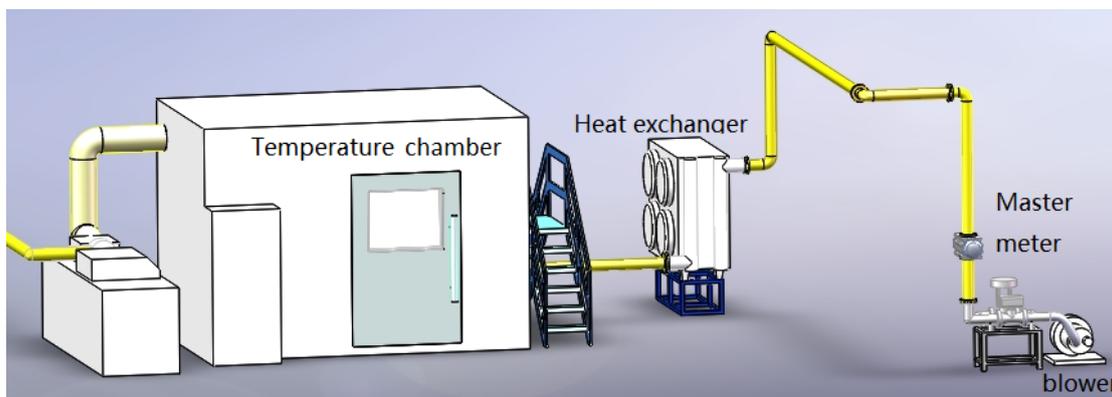

Figure 1: Device block diagram

Figure 2: Device schematic

The computer system controls the temperature of the temperature chamber to be stable and maintains the flow of the blower through the variable-frequency drive and the adjustment of the opening degree of the ball valve. At the same time, the PLC in the system collects the temperature and pressure signals of the master

meter and the MUT and transmits them to the computer system for processing. The computer system completes the verification process and saves, outputs the verification or calibration results. The process is shown in Figure 3.
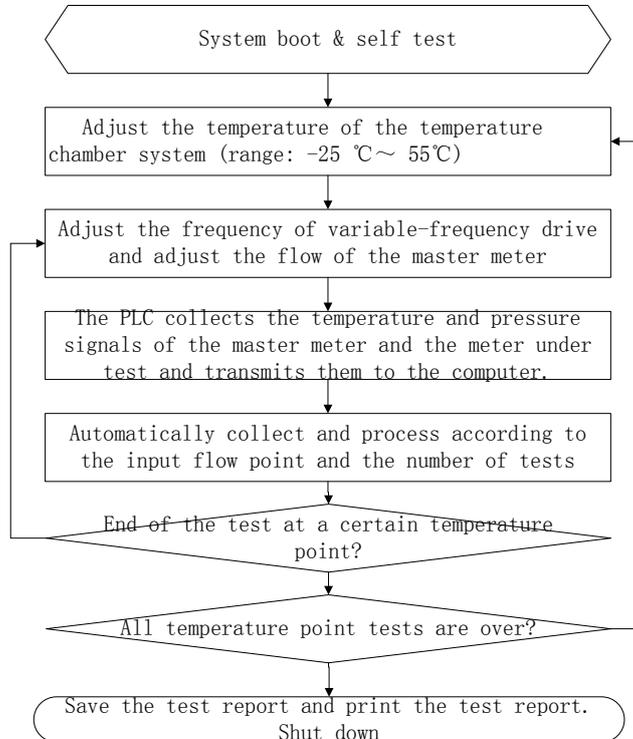
Figure 3: workflow chart

3. Working principle mathematical model

The master meter and the MUT are operated in series. At this time, the meter factor of a single verification for each flow point is calculated as follows [5][6]:

$$Q_s = N_s / K_s \tag{1}$$

$$Q_m = N_m / K_m \tag{2}$$

$$Q_m = Q_s \times \frac{273.15 + t_m}{273.15 + t_s} \times \frac{p_s}{p_m} \times \frac{z_m}{z_s} \tag{3}$$

$$K_m = \frac{N_m}{Q_m} = \frac{N_m}{Q_s} \times \frac{273.15 + t_s}{273.15 + t_m} \times \frac{p_m}{p_s} \times \frac{z_s}{z_m} \tag{4}$$

where
K_s, K_m — respectively, the meter factor of the master meter and the MUT, $(m^3)^{-1}$ or L^{-1};
N_s, N_m - respectively, the number of pulses of the master meter and the MUT;
Q_s, Q_m - respectively, the cumulative flow of the master meter and the MUT, m^3 or L.
T_s , t_m — respectively, the temperature of the gas at the master meter and the MUT, °C;
P_s , p_m — respectively, the absolute pressure of the gas at the master meter and the MUT, Pa or kPa;
Z_s , Z_m — respectively, the gas compression factor at the master meter and the MUT.

Because the master meter is not-fixed use, the curve is corrected by the polyline method, and the instantaneous flow rate flowing through the master meter is q, which has the following relationship:

$$K_s = K_{s,i} + \frac{q - q_i}{q_{i+1} - q_i} \times \left(K_{s,i+1} - K_i\right)$$

(5)

4. Measurement uncertainty evaluation [7][8][9][10]

The uncertainty of the facility is shown in Table 1.

Table 1: Uncertainty analysis of gas flow standard device

No.	Symbol	Source	Standard uncertainty of input quantity $u_r(x_i)$/%	Sensitivity coefficient $c_r(x_i)$	$|c_r(x_i)|u_r(x_i)$/%
1	Vs	calibration master meter device	0.1	-1	0.1
2	K1	master meter meter factor repeatability	0.010	1	0.010
3	K2	master meter interpolated meter factor	0.001	1	0.001
4	Ts	master meter temperature measurement	0.039	1	0.039
5	Tm	Checked table temperature measurement	0.046	-1	0.046
6	Ps	master meter pressure measurement	0.058	-1	0.058
7	pm	Pressure measurement at the checklist	0.058	1	0.058
8	t	timer	0.003	1	0.003
The combined standard uncertainty is 0.143%; the expanded uncertainty is 0.29%, k=2					

4.1 Calibration Master meter Device Standard Uncertainty

The expanded uncertainty of the flow standard facility used to calibrate the master meter, therefore

$$u_r(V_s) = U_r(V_s) / k = 0.1\%$$

(6)

4.2 Master meter Standard Uncertainty

Considering that the master meter factor of the master meter is 5820.74, the indication error of 10 m^3/h or less in the calibration data is large, so (10 -250) m^3/h is used. The calibration results are shown in Table 2,and the Bessel equation is used to calculate the repeatability. The standard uncertainty calculation formula of the inter polation algorithm is

$$u_{r2}(K) = \frac{1}{\sqrt{3}} \times \left| \frac{K_{i+1} - k_i}{K_{i+1} + k_i} \right|$$

(7)

Table 2: Master meter Meter Coefficient Calculation and Uncertainty Analysis

flow/ m^{3}h^{-1}	Average meter factor/ m^{-1}	Repeatability $u_{r1}(K)$ /%	Interpolation $u_{r2}(K)$ /%
250	5836.65	0.006	0.0005
160	5826.17	0.006	0.0002
100	5822.68	0.006	0.0002
65	5819.38	0.006	0.0003
40	5825.01	0.006	0.0008
25	5809.87	0.006	0.0002
16	5806.19	0.010	0.0008
10	5821.52	0.006	0.0014

4.3 Master meter Temperature Measurement Standard Uncertainty

The standard temperature transmitter is -10 °C to 50 °C, the MPE is ± 0.2 °C, the master meter temperature is about 20 °C, according to the rectangular distribution, the standard uncertainty brought by the temperature transmitter is

$$u_r(T_s) = \frac{1}{\sqrt{3}} \times \frac{0.2}{273.15 + 20} = 0.039\%$$

(8)

4.4 Uncertainty of temperature measurement standard at the MUT

The temperature transmitter at the meter is -50 °C to 100 °C, the MPE is ± 0.2 °C, the temperature range of the MUT is -25 °C to 55 °C, according to the rectangular distribution, the temperature transmitter with The maximum standard uncertainty is

$$u_r(T_s) = \frac{1}{\sqrt{3}} \times \frac{0.2}{273.15 - 25} = 0.046\%$$

(9)

4.5 Uncertainty of pressure measurement standard at master meter and checklist

The pressure transmitter has an accuracy rating of 0.1, distributed in a rectangular shape.

$$u_r(p_s) = \frac{0.1\%}{\sqrt{3}} = 0.058\%$$

(10)

$$u_r(p_m) = \frac{0.1\%}{\sqrt{3}} = 0.058\%$$

(11)

4.6 Timer Standard Uncertainty

The crystal oscillator adopts 12MHz, considering the crystal oscillator 8 hour stability, crystal resolution, timer interval, timer resolution, etc. The standard uncertainty is

$$u_r(t) = 0.003\%$$.

5 Test and test data analysis

5.1 Temperature stability test at the MUT workbench in the temperature chamber and master meter

According to JJG 1037-2008 *Verification regulation for turbine flowmeter*, the gas temperature change shall not exceed 0.5 °C at each flow point. In the temperature chamber, 6 temperature sensors are distributed for temperature measurement (see Figure 3), and the master meter is measured by temperature transmitter. The performance test data is shown in Table 3, Table 4, Table 5.
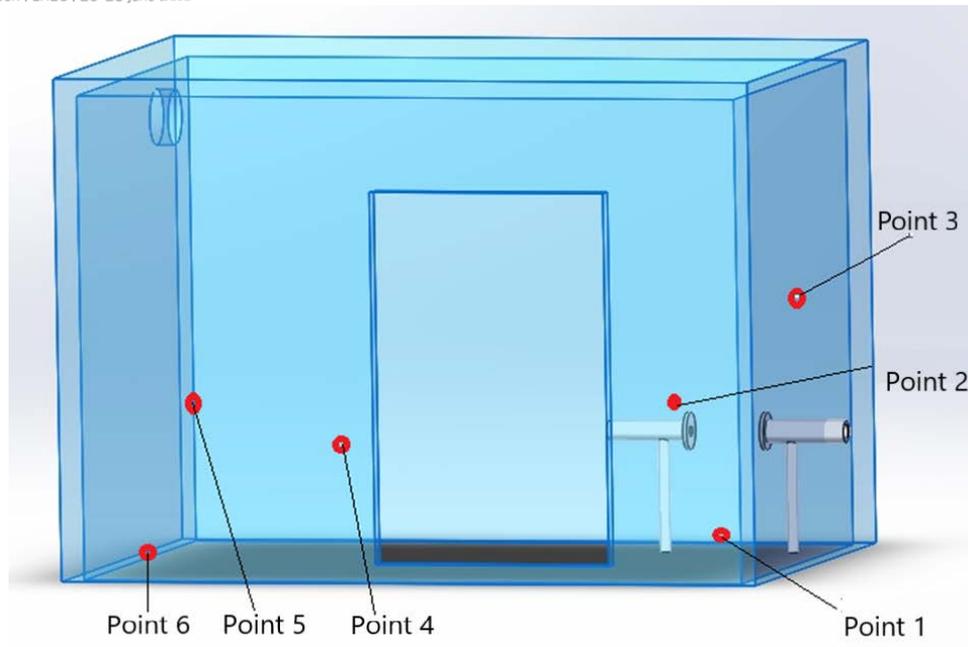
Figure 3: Distribution of 6 temperature sensors in the temperature compartment to measure temperature

Table 3: The temperature value of each test point when set the temperature chamber temperature is 55 °C

Time	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	MUT temperature	Mater meter temperature
	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation
5 min	55.1/0.4	55.2/0.4	55.3/0.5	55.2/0.4	55.3/0.4	54.9/0.4	55.0/0.4	20.8/0.2
5 min	55.2/0.4	55.3/0.4	55.5/0.4	55.2/0.5	55.4/0.4	54.8/0.4	55.1/0.4	20.8/0.1
5 min	55.3/0.4	55.5/0.5	55.4/0.5	55.3/0.4	55.3/0.4	55.0/0.4	55.0/0.4	20.8/0.2

Table 4: The temperature value of each test point when set the temperature chamber temperature is 20 °C

Time	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	MUT temperature	Mater meter temperature
	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation
5min	20.1/0.2	20.3/0.2	20.4/0.2	20.5/0.2	20.2/0.2	19.8/0.2	20.1/0.2	20.8/0.2
5min	20.2/0.3	20.4/0.3	20.3/0.3	20.5/0.3	20.1/0.4	19.9/0.2	20.1/0.3	20.7/0.2
5min	20.2/0.2	20.5/0.3	20.5/0.2	20.4/0.2	20.2/0.3	19.8/0.3	20.1/0.3	20.7/0.2

Table 5: The temperature value of each test point when set the temperature chamber temperature is -25 °C

time	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	MUT temperature	Mater meter temperature
	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation	Average/max. deviation
5min	-24.8/0.3	-24.6/0.3	-24.5/0.4	-24.5/0.4	-24.3/0.4	-24.8/0.4	-24.8/0.3	20.6/0.3
5min	-24.7/0.4	-24.7/0.4	-24.6/0.4	-24.5/0.2	-24.4/0.4	-24.5/0.3	-24.6/0.4	20.7/0.3
5min	-24.8/0.4	-24.5/0.4	-24.7/0.3	-24.6/0.3	-24.2/0.3	-24.8/0.2	-24.7/0.3	20.6/0.3

From the experimental data, the temperature stability requirements are met.

5.2 Calibration test on the tested form

A gas rotary meter was selected for testing, and the test was carried out according to JJG 633-2005 *Verification regulation for gas displacement meters*. The test results are as Table 6, Table 7,Table 8. The test results show that the facility design meets the expected technical indicators [11].

Table 6: Test data for the MUT when the temperature of the temperature chamber is 55 °C

Flow point (m³/h)	Flowrate (m³/h)	Vs (m³)	t (s)	MUT Pulses	MUT p_m(kPa)	MUT T_m(℃)	Master meter p_s(kPa)	Master meter T_s(℃)	K (1/m³)	Ave. K (1/m³)	Error %	Repeatability %
250	252.21	4.523	60.00	123984	99.27	56.31	96.76	25.79	27414.65	27400.52	0.32	0.20
	252.25	4.516	60.00	123943	99.14	56.22	96.71	25.79	27448.04			
	252.26	4.532	60.00	123888	99.18	56.66	96.79	26.02	27338.87			
62.5	62.28	1.145	60.00	31177	99.84	56.09	99.78	25.53	27233.05	27227.93	−0.32	0.02
	62.27	1.145	60.00	31179	99.90	56.60	99.71	25.58	27222.80			
	62.25	1.145	60.00	31173	99.91	56.30	99.73	25.46	27227.94			
25	25.26	0.466	60.00	12800	100.01	56.67	99.95	24.94	27448.52	27448.74	0.49	0.14
	25.26	0.467	60.00	12804	99.95	56.74	99.89	24.87	27411.55			
	25.25	0.466	60.00	12807	100.07	56.51	99.95	24.71	27486.15			
20	19.94	0.370	60.00	10130	99.81	56.31	100.02	24.31	27392.91	27434.14	0.44	0.14
	19.92	0.368	60.00	10118	100.05	56.61	99.96	24.49	27464.98			
	19.90	0.368	60.00	10113	99.95	56.57	99.93	24.28	27444.53			
12.5	12.32	0.228	60.00	6260	99.83	56.83	99.90	24.04	27413.06	27381.39	0.25	0.10
	12.29	0.228	60.00	6245	99.84	56.62	99.98	24.08	27361.20			
	12.31	0.228	60.00	6248	99.84	56.73	99.96	24.14	27369.91			

Table 7: Test data for the MUT when the temperature of the temperature chamber is 21.5 °C

Flow point (m³/h)	Flowrate (m³/h)	Vs (m³)	t (s)	MUT Pulses	MUT p_m(kPa)	MUT T_m(℃)	Master meter p_s(kPa)	Master meter T_s(℃)	K (1/m³)	Ave. K (1/m³)	Error %	Repeatability %
250	247.11	4.056	60.00	111838	99.27	22.33	97.07	19.28	27575.28	27513.52	0.37	0.26
	247.12	4.072	60.00	112092	99.04	22.35	96.95	19.28	27529.97			
	247.11	4.087	60.00	112124	98.99	22.36	97.11	19.19	27435.30			
62.5	62.47	1.048	60.00	28637	99.85	22.03	99.69	19.65	27333.32	27308.98	−0.37	0.19
	62.48	1.051	60.00	28637	99.76	21.79	99.85	19.49	27248.51			
	62.45	1.046	60.00	28616	99.93	22.24	99.71	19.65	27345.10			
25	25.27	0.425	60.00	11681	99.91	21.82	99.90	19.53	27501.47	27495.30	0.31	0.13
	25.27	0.425	60.00	11680	99.79	21.76	99.91	19.50	27458.19			
	25.26	0.424	60.00	11674	100.05	21.86	99.96	19.70	27526.24			
20	20.10	0.338	60.00	9291	100.08	21.74	99.91	19.68	27521.02	27497.11	0.31	0.10
	20.10	0.338	60.00	9288	99.77	21.50	99.91	19.56	27467.13			
	20.08	0.338	60.00	9283	100.07	21.40	99.97	19.65	27503.19			
12.5	12.35	0.208	60.00	5700	100.10	21.50	100.09	19.86	27437.25	27439.11	0.10	0.13
	12.34	0.208	60.00	5693	99.99	21.73	99.96	19.73	27403.99			
	12.34	0.207	60.00	5695	100.08	21.48	100.03	19.62	27476.09			

Table 8: Test data for the UMT when the temperature of the temperature chamber is -25 °C

Flow point (m³/h)	Flowrate (m³/h)	Vs (m³)	t (s)	MUT Pulses	MUT p_m(kPa)	MUT T_m(℃)	Master meter p_s(kPa)	Master meter T_s(℃)	K (1/m³)	Ave. K (1/m³)	Error %	Repeatability %
250	247.90	3.424	60.00	94049	99.17	−22.56	97.22	23.83	27469.23	27464.41	0.14	0.29
	247.85	3.414	60.00	94038	99.29	−22.52	97.07	23.80	27542.04			
	247.85	3.434	60.00	94033	99.40	−22.60	97.36	23.95	27381.95			
62.5	62.33	0.873	60.00	23884	99.99	−23.53	99.84	23.73	27355.22	27387.05	−0.14	0.13
	62.37	0.871	60.00	23895	100.02	−22.77	99.73	23.95	27427.04			
	62.32	0.872	60.00	23877	100.06	−22.94	99.73	23.95	27378.90			
25	25.27	0.355	60.00	9744	100.08	−23.03	99.94	23.85	27472.89	27438.47	0.05	0.11
	25.26	0.355	60.00	9736	99.88	−23.07	100.00	23.77	27423.54			
	25.24	0.355	60.00	9726	100.00	−23.40	100.05	23.77	27418.98			
20	19.96	0.280	60.00	7692	99.98	−23.88	99.90	23.70	27481.05	27446.90	0.08	0.18
	19.94	0.281	60.00	7685	99.74	−23.64	99.97	23.75	27391.65			
	19.94	0.280	60.00	7685	99.98	−23.42	99.93	23.82	27468.00			
12.5	12.54	0.176	60.01	4807	100.06	−23.71	100.06	23.89	27264.71	27270.49	−0.57	0.03
	12.54	0.176	59.99	4807	100.00	−23.36	99.92	23.88	27281.22			
	12.53	0.176	60.00	4802	99.88	−23.53	99.94	23.79	27265.53			

6 conclusion

Through the system mechanical design, electrical design, software design and test verification, the technical indicators meet the extended uncertainty of 0.29% (k=2) standard surface gas flow standard device, which can be used for the 1.0-level gas flow with pulse frequency output. The test is performed and calibrated, and the flowmeter to be tested can be placed at different temperatures to verify its temperature adaptability. In view of the large investment required to build the temperature compartment, the device is an attempt, the maximum flow rate only reaches 250m3/h, and the verification or calibration caliber is not more than DN80. At the same time, it provides a new idea for gas flow metering test equipment.

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