Standard Device of Natural Gas Real-flow Detection

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Abstract

In my country's primary energy consumption structure, the proportion of natural gas is increasing. Accurate and reasonable measurement of natural gas is one of the important links in natural gas utilization, which has huge social and economic benefits. The Chongqing branch of the National Petroleum and Natural Gas Large-flow Detection Station has established a set of standard equipment for real-flow detection of natural gas. The device uses 10 critical flow venturi nozzles with different throat diameters in parallel, and uses the 1.6MPa natural gas stored in the upstream 5500m^3 spherical tank as the verification gas. One of the biggest advantages of this device is that the pressure of the upstream natural gas source is relatively stable and the gas quality is clean. There is no need to add a voltage stabilizer and a purification device, and it can realize the verification of gas flow meters such as ultrasonic, turbine, and waist wheel. The working pressure of the device is (0.1~1.2) MPa, and the standard flow q_N is (14~19000) m^3/h. The measurement uncertainty of the device is evaluated, and the uncertainty of the device is U_r=0.28%, k=2 . A SICK DN200 gas ultrasonic flowmeter was calibrated using this testing standard device and the uncertainty of the measurement results was analyzed, and U_r = 0.32%, k = 2.

1. Introduction

In energy transmission, as the lifeline of modern industry, my country's long-distance pipeline construction has made great progress since the 1990s [1,2]. In recent years, the natural gas industry has developed rapidly, especially the construction of large-scale gas pipeline networks such as "West-East Gas Transmission", "Sichuan-East Gas Transmission", and "Sea-Gas Landing"[3,4]. In my country's primary energy consumption structure, the proportion of natural gas Continuously increasing, accurate and reasonable measurement of natural gas is one of the important links in natural gas utilization, and has great social and economic benefits[5].

From the point of view of metrology, the actual flow verification or calibration of natural gas is the most traceable feature of natural gas flow value, and GB/T 18603[6] and GB/T 18604[7] both put forward corresponding requirements. The physical parameters, operating conditions, installation conditions, environmental conditions and other influences are fully considered in the real-flow verification or calibration of natural gas to ensure that the detection conditions are as consistent as possible with the actual use conditions[8]. All countries in the world have successively built natural gas flow standardization devices with a high level of accuracy, and established corresponding natural gas flow value traceability systems or transmission systems, basically realizing the real-flow verification or calibration of commonly used natural gas flow meters [9]. The main parameters of the main foreign natural gas real-flow standard devices are shown in Table 1[10].

Table 1: Main parameters of the main foreign natural gas real-flow standard devices

Device Abbreviation or Location	Unit of Use	Nation	Pressure Range /MPa	Maximum flow /m^3/h	Test Pipe diameter /mm	Uncertainty	Working Standard	Primary and Secondary Standards
Westerbork	Nim	Netherlands	6.3-6.3	40000	750	0.25	Turbine flowmeter	Bell jars, volumetric flowmeters
Pigsar	Ruhrgae	Germany	1.4-5.0	6500	300	0.25	Turbine flowmeter	Piston Flowmeter, Turbine Flowmeter
BisShop	British Gas	U.K.	2.4-7.0	20000	500	0.30	Turbine flowmeter、critical flow nozzle	At Pigsar, NEL calibration
K-lab	Statoil	Norway	2.0-15.6	1750	150	0.40	critical flow nozzle	Calibrated at NEL, CEESI
GR LMRF	SwRI	U.S.	1.0-8.0	2400	500	0.25	critical flow	mt method device

							nozzle	
Clear Lake	CEESI	U.S.	7.0-7.0	34000	600	0.40	Turbine flowmeter	pVTt method device, critical flow nozzle
Winnipeg	TCC	Canada	6.5-6.5	49000	750	0.25	Turbine flowmeter	Rotary Piston Flow Meter (calibrated in the Netherlands)
Groningen	Gasunie	Netherlands	0.9-4.0	900	100	0.30	Turbine flowmeter	Bell jars, volumetric flowmeters
Bergum	Nmi	Netherlands	0.9-5.0	2500	200	0.30	Turbine flowmeter	Bell jars, volumetric flowmeters
Alfortville	GdF	France	1.0-6.0	1200	150	0.25	critical flow nozzle	pVTt method device

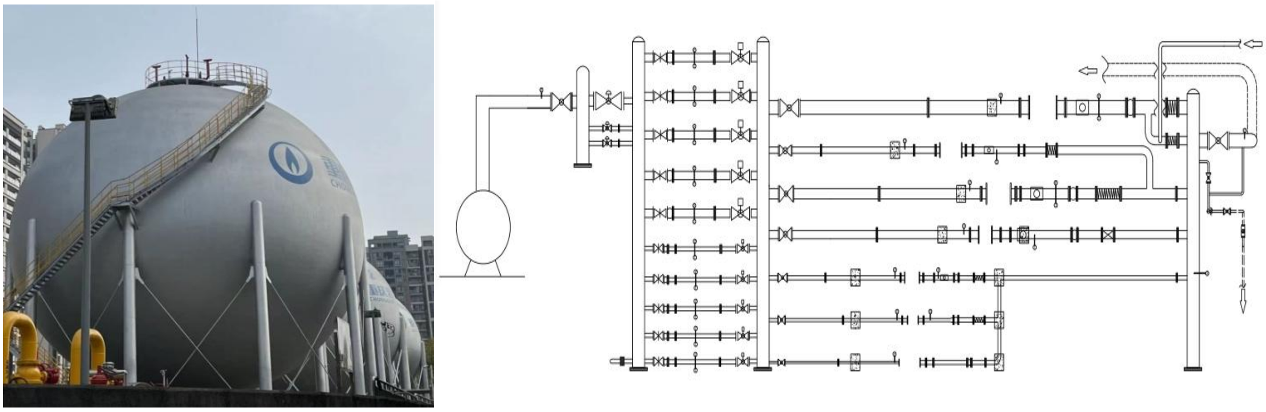
In order to be able to calibrate or verify the flowmeter under the conditions of use, improve the accuracy of natural gas on-site measurement, and maintain the economic benefits of the enterprise, my country has established a national oil and natural gas large flow measurement station in Daqing, and successively in Chongqing, Chengdu, Nanjing, Guangzhou, Urumqi, Wuhan and other cities have established measurement sub-stations. The verification capabilities of the national oil and natural gas large-flow metering stations and the standard devices of each sub-station are shown in Table 2 [11, 12].

Table 2: Verification capability of national oil and natural gas mass flow metering station and standard devices of each branch

Metering Station Name	**StandardType**	**Uncertainty (%,k=2)**	**Flow Range (m^3/h)**	**Operating Pressure （MPa）**
National Station	Bell-type primary device, mobile working standard	0.05～0.07	5～320	0.3～6.0
Chengdu Branch	mt method primary, secondary, working and mobile standards	0.23 0.21	32-8000	1.5-2.0 2.0-5.5
Nanjing Branch	mt method primary, secondary, working and mobile standards	0.29	16～8000	6.0-7.0
Wuhan Branch	HPPP Act Primary, Working and Mobile Standards	0.29	20-9600	2.5-10.0
Urumqi Branch	Secondary, working-level standards	0.29	25-10000	5.0-9.5
Guangzhou Branch	Secondary, working-level standards	0.29	8-12360	4.5-10
Shenyang Branch	Secondary, working-level standards	0.33	16-30000	4.0-9.85

The “Chongqing Branch of the National Petroleum and Natural Gas Large Flow Detection Station” built on the basis of Chongqing Academy of Metrology and Quality Inspection has a set of standard equipment for real-flow detection of natural gas. The process flow diagram of the equipment is shown in Figure 1. The Chongqing branch adopts the primary standard device of pVTt method, and takes the critical flow Venturi nozzle as the working standard. Using the parallel method of 10 critical flow venturi nozzles, under the working pressure of (0.1~1.2) MPa, the back pressure ratio is less than the critical back pressure ratio, so that the gas flow at the throat of the critical flow venturi nozzle can reach a standard of the local speed of sound device. The station provides a means for the factory verification, periodic verification, measurement arbitration verification and scientific research in the field of measurement of flowmeters.

The verification gas of the Chongqing substation mainly relies on the natural gas of 1.6 MPa stored in a 5500m^3 spherical tank upstream. One of the biggest advantages of this device is that the pressure of the upstream natural gas source is relatively stable and the gas quality is clean. It can realize the verification of ultrasonic, turbine, waist wheel and other gas flow meters.



(a) (b)

Figure 1: Natural gas storage tank (a), Structure diagram of the standard device for natural gas real-flow detection (b)

2. Device Uncertainty Assessment

2.1 Measurement methods

The mass flow through the critical flow Venturi nozzle is q_Z. According to the principle that the mass flow is equal everywhere, that is, the mass flow qmi flowing through each instrument to be inspected is equal to q_Z, and the pressure p_{mi} and temperature of each instrument to be inspected are measured. T_{mi}, its density ρ_{mi} and volume flow q_{vi} can be calculated, and the cumulative flow through each meter to be inspected within the time Δt can be calculated.

The measurement uncertainty of the actual volume V_{ms} that flows through each meter to be inspected, that is, the cumulative amount V_{ms} given by the device is the measurement uncertainty U of the device.

When calibrating gas flowmeters such as gas waist wheel, B-type velocity flowmeter, etc. that display the cumulative amount on the meter, the actual volume V_{ms} at the meter to be inspected is compared with its indicated value V_m to obtain the indication error E, and the measurement of the indication error E is not valid. The degree of certainty is the uncertainty U_E of the device measuring this type of flowmeter.

When calibrating a class A velocity flowmeter (output pulse) such as precession vortex, vortex street, turbine, etc., the ratio of the actual volume V_{ms} at the tested meter to the output pulse volume N within the time Δt is the meter coefficient K, the measurement of the meter coefficient K Uncertainty is the uncertainty U_k of the device measuring this type of flowmeter.

2.2 Digital model

2.2.1 The calculation formula of the actual volume V_{ref} at the inspected meter

$$V_{ref} = \frac{\sum_{i=1}^{m} q_{m,atmos}}{\rho_{m,atmos}} t = \frac{\sum_{i=1}^{m} \frac{\pi}{4} d^2 c c_* \frac{p_s}{\sqrt{RT_s}}}{\frac{p_m}{RT_m} k_\phi} = \sum_{t=0}^{n} \frac{\pi}{4} d^2 c c_* \sqrt{R} \frac{p_s}{p_m} \frac{T_m}{\sqrt{T_s}} t \tag{1}$$

In the formula:
C, C_*, d—Respectively the nozzle outflow coefficient, critical flow function, and nozzle throat diameter (m);
R— is the gas constant of natural gas;
P_s, T_s—Stagnation pressure and stagnation temperature, respectively;
P_m, T_m—Respectively the absolute pressure and temperature of the instrument under test.

2.2.2 Calculation formula of indication error E

$$E = \frac{V_m - V_{ref}}{V_{ref}} \times 100\% \tag{2}$$

In the formula:
V_m—the detected value.

2.2.3 Calculation formula of meter coefficient K

$$K = \frac{N}{V_{ref}} \tag{3}$$

In the formula:
N—the number of output pulses of the meter to be inspected.

According to the standard meter method standard device verification procedure, after the standard meter is connected in parallel, the flow rate is not lower than the accuracy of a single standard meter, so the accuracy of a single nozzle can be taken for analysis, and the measurement uncertainty U and U_E of the device can be obtained. U_K.

2.3 Evaluation of Measurement Uncertainty of Cumulative V_{ref}.

2.3.1 Measurement standard uncertainty u_1, u_2 caused by stagnation pressure P_s and pressure P_m at the instrument under test

The accuracy of the absolute pressure transmitter is 0.1, taking the inclusion factor k=2

$$u_1 = u_2 = \frac{0.1\%}{2} = 0.05\% \quad (4)$$

2.3.2 Measurement standard uncertainty u_3, u_4 caused by stagnation temperature T_s and temperature T_m at the instrument under test.

The expanded uncertainty of the temperature sensor measurement is 0.05°C. When the gas temperature is taken as 20°C during measurement, the standard uncertainty of the temperature part of the measurement

$$u_3 = u_4 = \frac{0.025}{293.15} \times 100\% = 0.0085\% \quad (5)$$

2.3.4 Measurement standard uncertainty u_5 caused by nozzle outflow coefficient C.

The 10 nozzles of the device have been verified, and the accuracy level of the outflow coefficient C is 0.2, including the factor k=2. The accuracy of the nozzle group used in combination after parallel connection is not lower than the accuracy of a single nozzle, so a single nozzle can be used for analyze.

$$u_5 = \frac{U_C}{K} = \frac{0.20\%}{2} = 0.10\% \quad (6)$$

2.3.5 Standard uncertainty of measurement caused by gas critical flow function C_*

According to the verification regulations and international standards of critical flow flowmeters (sonic nozzles), there is a 0.1% error in directly citing the calculation formula of C_* or the value-checking table, and it is estimated according to the uniform distribution.

$$u_6 = \frac{0.1\%}{\sqrt{3}} = 0.058\% \quad (7)$$

2.3.6 Measurement standard uncertainty u_7 caused by nozzle throat diameter d

During verification and use, take the theoretical diameter d of the actual flow of the nozzle as a constant, so u_7=0.

2.3.7 Measurement standard uncertainty u_8 caused by time Δt.

The device uses the counter hardware in the acquisition card to measure the time, the clock pulse source is 8MHz, and the measurement uncertainty is 1×10^{-5}. Therefore, the time measurement error of this device is mainly the error of the time interval collected by the computer in the device and the measurement of the external start-up. The error of the stop button signal, and the error of measuring the external start and stop button signal is caused by the cyclic acquisition error of the start and stop button signal, and the inconsistency of manually pressing the start and end buttons.

The program design of the device is as follows: the acquisition error of the time interval is 5ms, the error of measuring the external start-stop button signal, that is, the cyclic acquisition error of the external start-stop button signal and the inconsistency of manually pressing the start and end buttons are measured as 6ms. The square root of the two is 7.8ms, which is the time Δt measurement error of the device. Take the shortest measurement error of the device as 60s, and take the uniform distribution.

$$u_8 = \frac{0.0078}{60\sqrt{3}} \times 100\% = 0.0075\% \quad (8)$$

Assuming that the influences are independent of each other, they are synthesized.

$$u_c = \sqrt{\sum_{i=1}^{11} (c_i u_i)^2} = 0.14\% \quad (9)$$

Assuming that each influence quantity is not correlated with each other, the standard uncertainty of the device is obtained by synthesizing each influence quantity. The measurement uncertainty of the actual accumulated volume Vms at the meter isU_{Vms}=0.28(k=2), and the measurement uncertainty of the accumulated volume Vms is defined as the measurement uncertainty U of this device.

3. Use the device to verify the gas ultrasonic flowmeter

The number of critical flow venturi nozzles in parallel can be selected according to the flow rate of the meter to be inspected. Install the meter to be tested on the calibration pipeline of the corresponding diameter, open or close the pneumatic valve and ventilate. Ventilation runs for a period of time, adjust the opening of the upstream pneumatic control valve to adjust the flow, and adjust according to the flow value displayed in the computer until it is close to the verified flow value (within the range of ±2.5%). Control the downstream regulating valve to adjust the actual test pressure, enter the test module, the computer automatically measures the pressure P_m and temperature T_m at the test meter, the critical flow Venturi nozzle, the number of input pulses and the start and stop time of the test meter. The computer automatically calculates and processes the inspected representation value E, instrument coefficient K, etc. according to the instrument type of the inspected table. A SICK DN200 gas ultrasonic flowmeter was calibrated using a natural gas real-flow detection standard device, and the typical results are shown in Table 3.

Table 3: Verification results of gas ultrasonic flowmeter

Serial number / Flow Point	Flow (m^3/h)	Device V_s(L)	Device T_s(°C)	Device P_s(Pa)	Instrumentation Ni	Instrumentation T_m(°C)	Instrumentation P_m(Pa)	Actual Value V_{ref}(L)	Meter Factor F_{ij}	Average Coefficient/F_i / Indication Error E_i(%)	Repeat Ability (%)
1	2500	47448.08	13.59	948986	136149	12.79	688886	47448.08	2869.43	2870.16	0.03
q_{max}		47491.43	13.19	948914	136339	12.57	688982	47491.43	2870.81	0.29	
		47491.67	13.94	948894	136312	12.08	688975	47491.67	2870.23		
2	1000	17471.87	13.96	997389	49993	13.86	857412	17471.87	2861.34	2861.27	0.01
0.4 q_{max}		17317.24	13.85	997410	49548	13.11	857519	17317.24	2861.19	-0.02	
		17304.15	13.21	997349	49512	13.49	857486	17304.15	2861.28		
3	250	5895.81	14.29	1030683	16828	13.19	777137	5895.81	2854.23	2853.63	0.02
q_t		5893.17	14.01	1030765	16815	13.37	777273	5893.17	2853.30	-0.29	
		5874.82	13.96	1030633	16763	12.93	777217	5874.82	2853.36		
4	32	1118.74	13.78	962481	3204	13.09	835748	1118.74	2863.94	2864.22	0.04
q_{min}		1113.05	13.69	962351	3187	13.16	835977	1113.05	2863.30	0.08	
		1142.94	13.21	962411	3275	13.51	835833	1142.94	2865.42		
Flow meter coefficient F_0 before adjustment: 2880 (P/m3), after adjustment, flow meter coefficient F: 2861.90 (P/m3); F/F_0: 0.9937.											

According to the formula (3), the measurement uncertainty U_K of the instrument coefficient K is composed of two parts: V_{ms} and N.

3.1 Uncertainty u1 caused by V_{ms}

$$u_1 = \frac{U_{Vms}}{k} = 0.14\%$$

3.2 Uncertainty u_2 caused by instrument pulse N

During verification, the instrument pulse input N ⩾ 1000 pulses (this can be achieved by controlling the length of the verification time), and the pulse quantity measurement error △N= ±1, which is uniformly distributed.

$$u_2 = \frac{\Delta N}{kV} = \frac{1}{1000\sqrt{3}} \times 100\% = 0.058\%$$

$$u_k = \sqrt{u_1^2 + u_2^2} = 0.16\%$$

The measurement uncertainty of the instrument coefficient K is U_K=0.32% (k=2).

Through the uncertainty analysis of the measurement results, Ur = 0.32% (k = 2) can be finally obtained.

4. Conclusion

This paper summarizes the main parameters of the main natural gas flow standard devices at home and abroad, and introduces in detail the critical flow Venturi nozzle method gas flow standard device established at the Chongqing Branch of the National Petroleum and Natural Gas Large Flow Detection Station. The device adopts 10 critical flow venturi nozzles with different throat diameters in parallel, and uses the 1.6MPa natural gas stored in the upstream 5500m^3 spherical tank as the verification gas. One of its biggest advantages is that the upstream natural gas source pressure is relatively stable and the quality is clean. Evaluate the measurement uncertainty of the device. The measurement uncertainty of the device is caused by the influence of absolute pressure transmitter, temperature sensor, nozzle outflow coefficient C, gas critical flow function C_*, nozzle throat diameter d, time Δt, etc., assuming that the influencing quantities are not correlated with each other, the uncertainty of the device is obtained as =0.28%, k=2. The working pressure of the device is (0.1~1.2) MPa, and the standard flow rate q_N is (14~19000) m^3/h, which can realize the verification of ultrasonic, turbine, waist wheel and other gas flow meters. A SICK DN200 gas ultrasonic flowmeter was calibrated using this testing standard device and the uncertainty of the measurement results was analyzed, and U_r= 0.32% (k = 2).

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