Technical Reformation of Gas Flow Primary Standard with pVTt Method

Wang Dongwei
(National Institute of Metrology, Beijing, 100013,China)

Abstract

This paper introduced gas flow primary standard with pVTt method in NIM which is carrying on technical reformation. After improvement, the primary standard can enhance the ability of measurement and calibration and the reliability of measurement. The reformation can also be as the basis of doing experiment research and unifying the flow value all over the country in future.

Keywords pVTt;; gas flow; primary standard; reformation

Introduction

The gas flow primary standard with pVTt method in NIM was set up in 1986 which include $20m^3$ rig and $2m^3$ rig, covered flowrate from 10 to 1300 m^3/h, the small one, $0.2m^3$rig was established in 1999. The total flow range is from 0.1 to 1300 m^3/h. In the past twenty years, the facility can not meet the needs of flow value dissemination gradually, because the instruments and devices of the facility has became aging and reliability of measurement has declined. From the beginning of 2003, we started the project reforming the facility which will finish at the end of 2004.

1.Specification

The specification of the facility before and after reformation is shown as table 1.

Table 1

	Before	After
Flow range (m^3/h)	0.1~1300	0.1~1300
Pressure upstream the critical nozzle (MPa,a)	0.1	0.1~0.5（small rig ）
Temperature range	Ambient	Ambient
Uncertainty (%)	0.05	0.05

2.Main contents

1)Renew the vacuum pump. The vacuum pumps before are two pump produced by domestic company whose rate for sucking is 70L/s each pump. The disadvantage of the pumps which have run almost 20 years are that they suck slowly, can not work for a long time continuously and can not filtrate the gas which contain some oil. For the sake of decreasing the pollution to the environment and other reasons, we chose a vacuum pump from Leybold company. It is able to not only work continuously, but also filtrate sucking gas very well. Its rate is 120L/s.

2)Renew transducers of temperature and pressure. Due to the amount of temperature measurement points, and the limit of the outlay, we had to chose industrial platinum resistance as temperature transducer. We selected part of them which can meet our requirement. The temperature transducers before have been used for about 20 years. Some of them can not work, the others have hardly kept high quality feature. The new transducers have

better stabilization and use 4-line system. The pressure gauge before is quartz Bodeng gauge from Texas company in U.S.A. which is traditional instrument, no electric signal output and 0.02% of accuracy. The new one is from Druck company. Its accuracy is 0.01%. We can input the signals of temperature and pressure to computer. So we can easily realize the automatic collection for all data.

3)Adding positive pressure resource. This is the main work of the project. As being known, the discharge coefficient of critical nozzle is affected by some factors, for example, pressure. The facility before can only be use at zero of pressure gauge. So we can not do any research for the relationship between the pressure and discharge coefficient of critical nozzle and can not calibrate critical nozzle at real using condition. The facility after reformation can be used to calibrate critical nozzle at pressure from 0 to 0.4 MPa,g at certain flow rate. It will get great improvement.

4)Adding the function of automatic collection and dealing with for all data. After that, we can automatically collect 55 of temperature points, 5 of pressure value and time. We can also control part of the devices automatically.

5)Improving the condition of temperature measurement upstream the critical nozzle. This is to prevent from the disturb by ambient.

3.Principle and structure of the facility

1) Principle of measurement

Air flows into the container whose volume is V through critical nozzle in a certain time. We can get practical gas mass flowrate by means of absolute pressure and temperature in the container. We can calculate discharge coefficient of the critical nozzle using practical gas mass flowrate divided by theoretical gas mass flowrate through the critical nozzle. This kind of facility is mainly used to calibrate critical nozzle.

The structure of the facility is shown as figure 1. It is combined with standard container, pressure gauge, temperature device, timer, vacuum pump, gas-control valve, critical nozzle, signal conversion device and control desk.

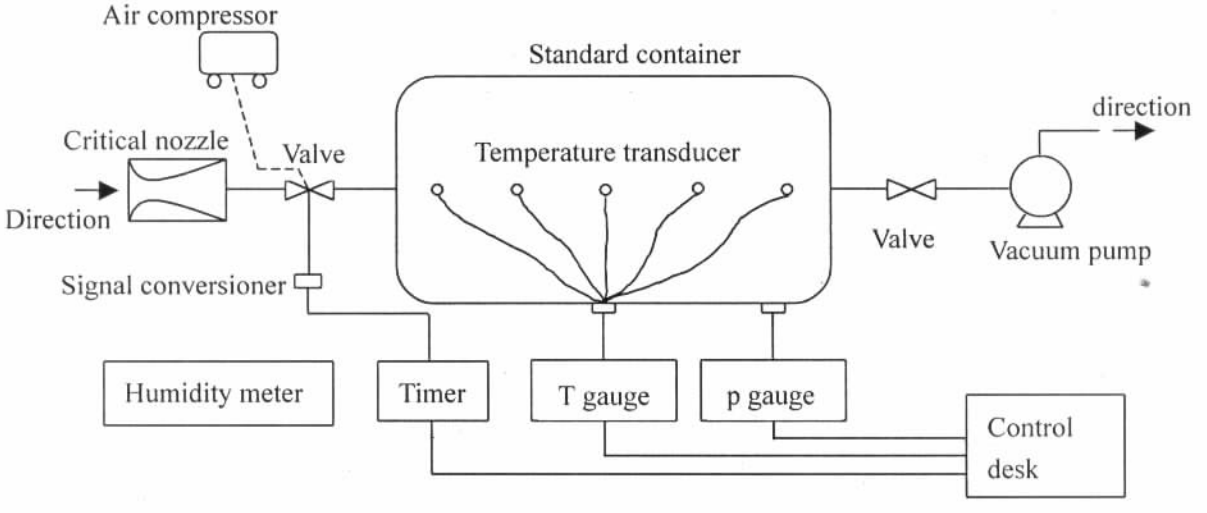

Figure 1 Structure of gas flow primary standard with pVTt method

2)Structure of the facility after reformation

At this reformation, we did a more improvement for the small rig. We kept its function of calibration at negative pressure. Besides, we added positive gas resource. So we can change the pressure upstream the critical nozzle to 0.4MPa,g in maximum. We also change the ordinarily butterfly valve to 3-way valve. As a result, the additory mass can be reduced. The structure is shown as follow (figure 2).

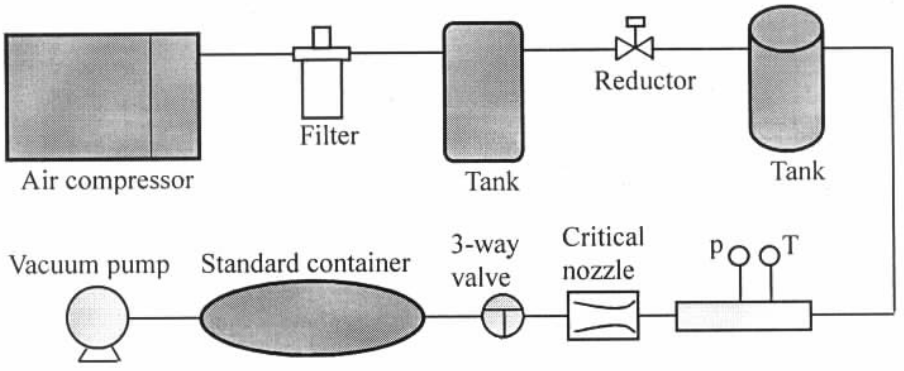

Figure 2 Structure of the facility at positive pressure

4.Technical difficulty

The main difficulties of reformation are calibration of volume of container, dryness and pressure stabilization of positive pressure gas resource, selection and calibration of temperature transducers. We will introduce calibration of volume of container below.

There are 2 method to calibrate the volume of container. First is by nitrogen, the other is by water. We use first method which is better.

Program of calibration:

1) Cleaning the air up.

2) Sucking the nitrogen with vacuum pump until pressure lower than 1kPa in it.

3) Measure pressure p_E and even temperature T_E after the state is stable in the container.

4) Measure mass m_1 of nitrogen bottle with weighing device.

5) Fill the nitrogen into the container until pressure about 50kPa in it.

6) Measure mass m_2 of nitrogen bottle with weighing device.

7) Measure pressure p_F and even temperature T_F after the state is stable in the container.

8)Repeat the program above, the times should be more than 6.

The formula of volume calculation is:

$$V_T = \frac{m_1 - m_2}{\frac{p_F}{T_F Z_F} - \frac{p_E}{T_E Z_E}} \times \frac{p_N}{T_N Z_N \rho_N} \quad (1)$$

among the formula,

V_T——volume of container at temperature T;

Z_E、Z_F——compress coefficient of nitrogen in container before and after filling;

p_N——standard pressure, p_N=101325Pa;

T_N——standard temperature, T_N=293.15K;

Z_N——compress coefficient of nitrogen at standard state(p_N, T_N), Z_N=0.99978;

ρ_N——density of nitrogen at standard state(p_N, T_N), ρ_N=1.1648kg/m^3.

Volume of container at standard temperature is:

$$V = V_T\left[1 - 3\alpha(T - 293.15)\right] \quad (2)$$

among the formula,

V——Volume of container at standard temperature;

α——line expand coefficient of the material of container;

T——even temperature of nitrogen in the container.

5.Analysis of uncertainty to facility

Formula of gas mass flow rate of facility is:

$$q_m = \frac{\frac{V \times T_n \times Z_n \times \rho_n}{p_n} \times \left(\frac{p_b}{T_b \times Z_b} - \frac{p_f}{T_f \times Z_f}\right) \times [1 + 3\alpha(\theta - 20)] - \Delta m}{t - \Delta t} \quad (3)$$

among the formula,

V——volume of container at 20℃;

t——measurement time;

p_f、p_b、p_n——pressure of air in the container

before and after filling, at standard state;

T_f、T_b、T_n —— temperature of air in the container before and after filling, at standard state;

z_f、z_b、z_n ——compress coefficient of air in the container before and after filling, at standard state;

ρ_n ——density of air at standard state;

Δm ——additory mass;

Δt ——valve open/close time;

α ——line expand coefficient of the material of container;

θ ——wall temperature of container.

The volume of container is determined with nitrogen method, its formula is:

$$V=\frac{m\times[1-3\alpha\times(\theta-20)]}{(\frac{p_b}{T_b\times z_{b0}}-\frac{p_f}{T_f\times z_{f0}})\times\rho_{n0}\times z_{n0}}\times\frac{p_n}{T_n} \quad (4)$$

among the formula,

m —— nitrogen mass filled into the container;

z_{f0}、z_{b0}、z_{n0} ——compress coefficient of nitrogen in container before and after filling, at standard state;

ρ_{n0} ——density of nitrogen at standard state.

Components of uncertainty is shown as table 2.

Table 2 outline of uncertainty of gas flow primary standard with pVTt method

number	symbol	source	Standard uncertainty of input value $u_r(x_i)$/%	Sensitive coefficient $c_r(x_i)$	$c_r(x_i)\cdot u_r(x_i)$ /%
1	V	volume	0.019	1	0.019
2	t	time	0.002	1	0.002
3	Δt	valve open/close time	0.010	1.7×10^{-4}	0.000
4	z_n	compress coefficient of air at standard state	0.006	1	0.006
5	ρ_n	density of air at standard state	0.006	1	0.006
6	p_b	pressure of air in the container after filling	0.007	1	0.007
7	T_b	temperature of air in the container after filling	0.01	1	0.01
8	z_b	compress coefficient of air after filling	0.006	1	0.006
9	p_f	pressure of air in the container before filling	0.3	0.006	0.002
10	T_f	temperature of air in the container before filling	0.009	0.006	0.000
11	z_f	compress coefficient of air before filling	0.006	0.006	0.000
12	Δm	additory mass	0.58	0.0001	0.000
Compositive standard uncertainty u_c=0.025%, expanded uncertainty U=0.05%, k=2					

Explanation of table 2:

1) Uncertainty of volume $u_r(V)$

We must measure some parameter when we calibrate the volume of container: m, θ, p_f, T_f, p_b and T_b; we can get z_{b0} from physical feature table according to p_b and T_b; we can get z_{f0} from physical feature table according to p_f and T_f; we can get α from table also.

Components of uncertainty of volume is shown as table 3.

Table 3 Analysis of uncertainty of volume

number	symbol	source	Standard uncertainty of input value $u_r(x_i)$/%	Sensitive coefficient $c_r(x_i)$	$c_r(x_i)\cdot u_r(x_i)$ /%
1	V_s	Repeatability of volume	0.011	1	0.011
2	m	mass	0.008	1	0.008
3	ρ_{n0}	density	0.0006	1	0.001
4	z_{n0}	compress coefficient of nitrogen at standard state	0.0006	1	0.001
5	p_b	pressure of nitrogen in the container after filling	0.007	1	0.007
6	T_b	temperature of nitrogen in the container after filling	0.01	1	0.01
7	z_{b0}	compress coefficient of nitrogen after filling	0.006	1	0.000
8	P_f	pressure of nitrogen in the container before filling	0.3	0.006	0.002
9	T_f	temperature of nitrogen in the container before filling	0.009	0.006	0.000
10	z_{f0}	compress coefficient of nitrogen before filling	0.006	0.006	0.000
11	θ	wall temperature of container	5.8	6.6×10^{-4}	0.004
12	α	line expand coefficient	5.8	6.6×10^{-4}	0.004
Compositive standard uncertainty u_c=0.019%, expanded uncertainty U=0.038%, k=2					

2) Uncertainty of valve open/close time

The valve open/close time is determined by calculate even value after several times measurement. The range of valve open/close time for the same critical nozzle will less than $\pm$5ms, the minimum measurement time is 30s, so,

$$u_r(\Delta t) = \frac{5 \times 0.001}{\sqrt{3} \times 30} = 0.010\% \quad ,$$

$$c_r(\Delta t) = \frac{\Delta t}{t - \Delta t} = 1.7 \times 10^{-4}$$

3）Uncertainty of additory mass

Formula of calculation of Δm :

$$\Delta m = \frac{\Delta V}{R}\left(\frac{p_a}{T_a} - \frac{p_b}{T_b}\right) \quad (5)$$

among the formula,

ΔV——volume between critical nozzle and valve;

P_a ——atmosphere;

T_a ——ambient temperature.

u_c =0.58%, expanded uncertainty U=1.2%, k=2。

6.Conclusion

1）This reformation did a lot of change since the facility established. We not only renew main instruments and devices, but also add the function of measurement at positive pressure which enhance our ability to measurement and calibration. We can do some experiment research at the basis in future.

2）After improvement, the uncertainty of the facility can still reach 0.05%(k=2).