The uncertainty analysis and capability verification for the high pressure pVTt gas flow facility of NIM

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Abstract

The high pressure pVTt gas flow facility was built in NIM in 2014. The stagnation pressure can be changed within (100~2500) kPa. At 1000 kPa, the maximum flow rate can be 87 m^3/h, while the maximum flow rate can be 47 m^3/h at 2500 kPa. With the improvement on the pressure, temperature and time measurement, the mass cancellation was achieved for the inventory volume. So, the uncertainty of the pVTt facility was 0.06% (k=2), while the uncertainty of the discharge coefficient of sonic nozzle was 0.08% (k=2). The capabilities of the pVTt gas flow facility were verified by two bilateral comparisons between NIM and PTB, and NIM and NIST with sonic nozzles as transfer meters in 2015.

1. Introduction

In the fields of energy, environment, medicine, and so on, the gas meters are widely used. Due to high accuracy, no moving parts and ease of use, sonic nozzles frequently used as master meters to calibrate other kinds of gas meters.

When the working fluid is ideal gas and the flow can be treated as one dimensional and isentropic, the ideal maximum mass flow rate through the sonic nozzle, q_{mi} can be calculated in theoretical equation. In practice, the flow is not isentropic due to the viscous losses of the real gas and the three dimensional flow due to the nozzle geometry. Thus, the real mass flow rate, q_{mr}, is not equal to the ideal mass flow rate. The discharge coefficient, C_d is defined to relate the real mass flow rate to the ideal mass flow rate, which is the most important parameter for sonic nozzle.

$$C_d = \frac{q_m}{q_{mi}} \quad (1)$$

In China, the sonic nozzles are usually traceable to the pVTt primary standard facility of NIM. There were two sets of pVTt facilities with nominal volume of 2 m^3 and 20 m^3 respectively built in 1986. With the reference of pVTt facilities of NMIJ [2] and NIST [3], the 100 L and 2 m^3 pVTt facilities were built in NIM [4] in 2010. On the base of the new pVTt facility, the high pressure pVTt gas flow facility was finished the updating in NIM in 2014.

The pressure of high pressure pVTt facility can be changed within (100~2500) kPa. At 1000 kPa, the maximum flow rate can be 87 m^3/h, while the maximum flow rate canbe 47 m^3/h at 2500 kPa. With the improvement of pressure, temperature and time measurement, the mass cancellation was achieved for the inventory volume. The uncertainty of the pVTt facility is 0.06% (k=2), while the uncertainty of the discharge coefficient of sonic nozzle was 0.08% (k=2).

The uncertainty analyses and the experimental verification will be presented in this paper.

2. The uncertainty analyses

The systematic diagram of the pVTt facility is shown in Figure.1.

There are two compressors with dryer and filter to produce the high pressure dry air. The dry air from the compressors is saved in the buffer tank. There are two stages of buffer tank. The first stage buffer tank is consisted with 2 tanks with the volume of 10 m^3 individually, and the second stage buffer tank is consisted with 2 tanks with the volume of 7.5 m^3 individually. The maximum pressure in the first stage buffer tank is 10 MPa, while it is 5 MPa in the second stage.

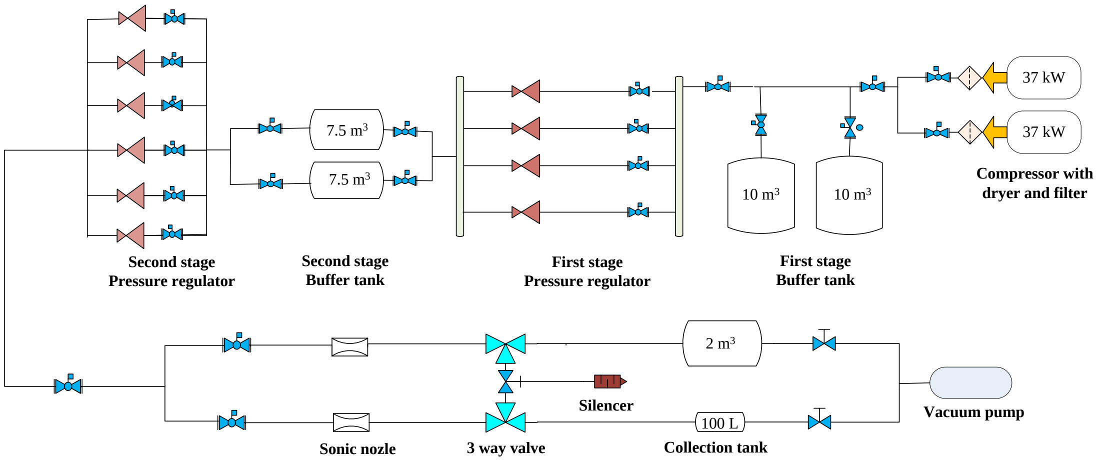


Figure 1 the systemic drawing of the pVTt facility

On the base the old pVTt system, the pressure, the temperature and time measurement improvements are achieved to guarantee the uncertainty from 0.08% to 0.06% for pVTt facility, and from 0.10% to 0.09% for discharge coefficient of sonic nozzle.

2.1 The pressure uncertainty

On the base of the calibration results, the error Δp can be calculated,

$$\Delta p = p_{ind} - p_{st} \tag{2}$$

p_{ind} the indication of the pressure instrument, p_{st} the standard valve from the standard pressure gauge. The curve fitting between the error and the indication of pressure instrument was developed to compensate the error of the indication. On the other hand, two pressure instruments at the same position are used, and the average of two pressure instruments are used in the evaluation procedure.

There is challenge for the stagnation pressure measurement due to wide range (100~2500) kPa. The pressure instrument with two sensors is chosen finally, the relative uncertainty can be 0.017%, which is the relative uncertainty of reading.

For different stagnation pressure, the different pressure (DP, in the diagram) between two pressure instruments is shown in Figure. 1.

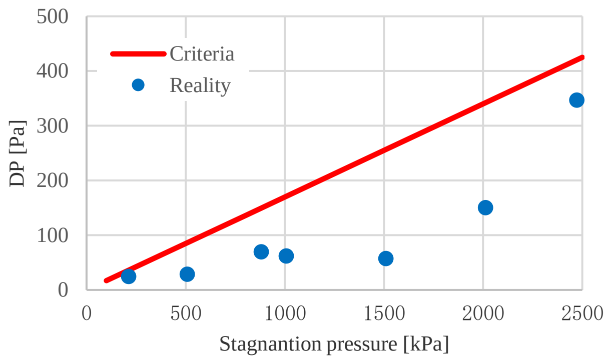


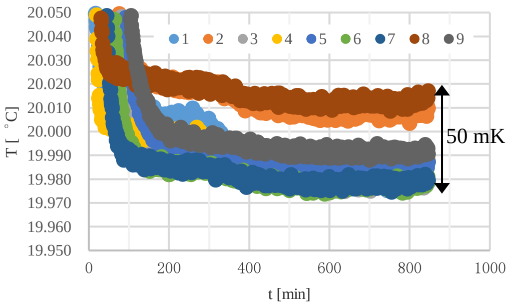
Figure 2 the systemic drawing of the pVTt facility

The criteria is the limit of the uncertainty. The DP value is always smaller than the criteria, which means that the uncertainty can be guaranteed very well.

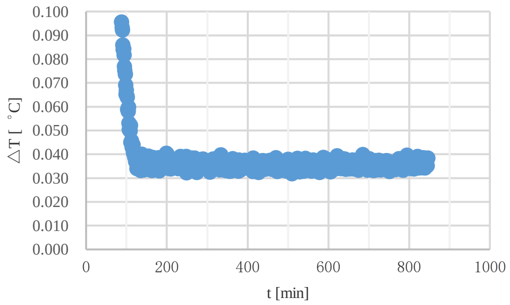
2.2 The temperature uncertainty

The uncertainty of the temperature is updated from 89 mK (k=2) to 50 mK (k=2).

There are 9 PT 100 temperature sensors with 4 wires in the 2 m^3 pVTt facility. After filling, the temperature changes with time is shown in Figure.3 (a), the maximum temperature difference among 9 sensors, ΔT is shown in Figure.3 (b).



(a)



(b)

Figure 3 the temperature change after filling

According to the results, the stability time after filling time is 100 min, after ΔT is smaller than the temperature uncertainty of 50 mK.

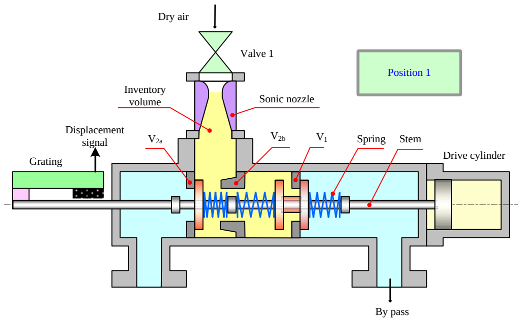
2.3 The time uncertainty

The most important part for pVTt facility is the 3 way valve, which is directly related with the time measurement and uncertainty. There were many designing on the valve [2,3,5].

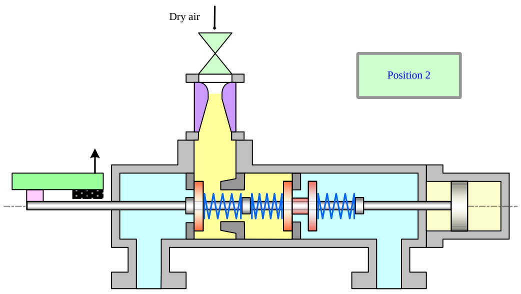
For this pVTt facility, the special 3 way valve with high speed pressure measurement and data acquisition was developed to achieve the mass cancellation in the inventory volume and the accurate measurement of colleting time.

The basic structure of the 3 way valve is show in Figure.1. Unlike the traditional 3 way valve, the vale core is separated two parts. There are three independent sealing positions to avoid the leak during the valve and achieve the mass cancellation.

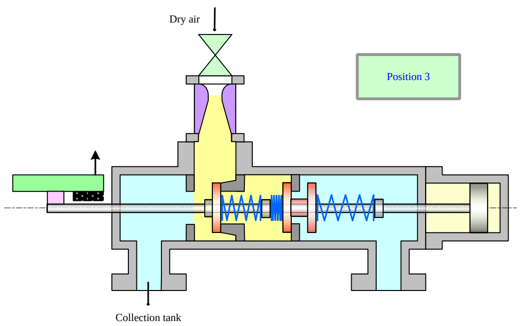
- Position 1: the sealing is in the position V_{2a}, and the dry air flow through by pass;
- Position 2: the sealing is in the position V_{2a} and the positon V_1, and the dry air flow in the inventory volume;
- Position 3: the sealing is in the position V_1, and the dry air flow through the collection tank.



(a)



(b)



(c)

Figure 4 the systemic drawing of the pVTt facility

During the opening and closing of the 3 way valve, the position of the stem was measured by the displacement signal from the grating with the resolution of 20 μm. At the same time, the pressure with high speed in the inventory volume was measured and recorded with frequency above 5000 Hz.

The timer of start and stop is triggered at the position 2. Near to and during the dead-end time, the pressure change in the inventory volume is shown in Figure. 5.

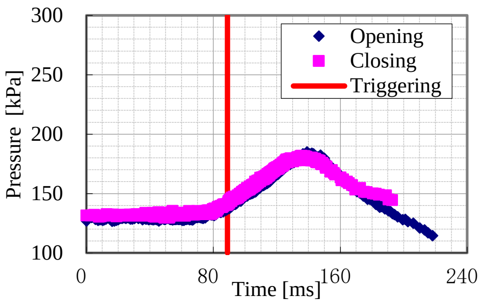


Figure 5 the systemic drawing of the pVTt facility

The point of (80~90)% maximum overlap is chosen as the match pressure. Here, the initial pressure is 166.875 kPa, while the final pressure is 166.125 kPa, the inventory volume influence is smaller than 0.003%, so the mass cancellation is achieved and the inventory volume influence can be neglected.

With the mass cancellation, the time correction is smaller than 10 ms with uncertainty of 10 μm (*k*=2). For the smallest collection time 10 s, the time measurement uncertainty can be neglected.

3. The verification on the capability of the facility

After the high pressure pVTt facility was constructed. There were two bilateral comparisons conducted. One was between NIM and PTB, another was between NIM and NIST. 4 sonic nozzles were chosen as the transfer meters. The parameters of the comparison were shown in Table. 1.

The calibration results at the atmospherical pressure was conducted in the old pVTt facility with uncertainty 0.10% (*k*=2), while the high pressure calibration was conducted in the new pVTt facility with uncertainty of 0.08% (*k*=2).

Because that the comparison results were not the exactly same, the NIM-2016 model was presented to get the curve fitting of the NIM's results on the base of Ishibashi's results [6].

$$C_{d,NIM-2016} = (a + \frac{b}{\sqrt{Re}}) + \frac{c + \frac{d}{\sqrt{\mathrm{Re}}}}{1 + \exp(e - \frac{\mathrm{Re}}{12000})} \quad (3)$$

Due to the curve fitting, the additional curve fitting uncertainty, u_{CF}, will be added in the final uncertainty, $U(C_{d,CF,NIM})$, besides the original calibration uncertainty, $U(C_{d,NIM})$,

$$U(C_{d,CF,NIM}) = \sqrt{U(C_{d,NIM})^2 + 4 \times u_{CF}^{\ 2}} \quad (4)$$

The final uncertainty was presented in Table. 1.

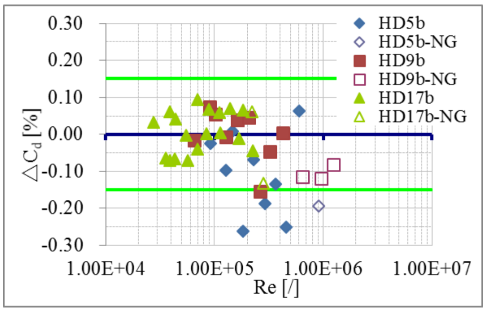
Table 1: the comparison parameters

SN	d	q_v	NIM		PTB		NIST	
[/]	[mm]	[m³/h]	p_0 [kPa]	$U(C_{d,CF,NIM})$ [%]	p_0 [kPa]	$U(C_{d,PTB})$ [%]	p_0 [kPa]	$U(C_{d,NIST})$ [%]
HD17b	2.156	2.64	100~2500	0.08~0.10	70~5000	0.06~0.15	/	
/	2.4384	3.35	100~2500	0.08~0.10	/		200~670	0.06
HD9b	4.9452	13.86	100~2500	0.09~0.11	100~5000	0.04~0.07	/	
HD5b	6.98819	27.69	100~2500	0.09~0.11	100~5000	0.08~0.22	/	

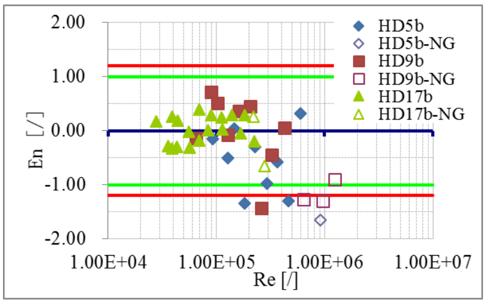
The comparison results was analysed with En value[7-8]

4.1 The bilateral comparison between NIM and PTB

The bilateral comparison between NIM and PTB was conducted in May 2015. 3 sonic nozzles were chosen as the transfer meters. Besides the dry air, the comparison was also conducted by natural gas. The results were shown in Figure 6.



(a)



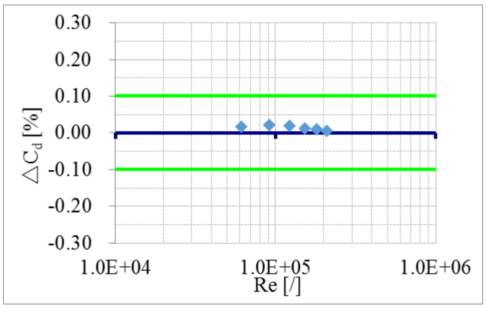
(b)

Figure 6 the comparison results between NIM and PTB

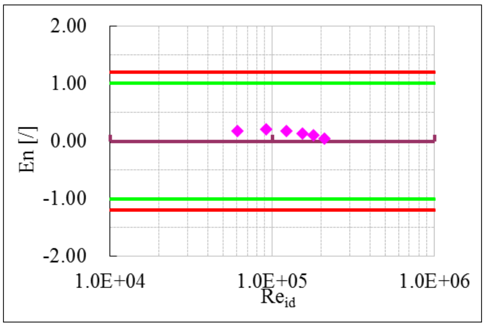
There are 42 sets of comparison results. The En value is smaller than 1 for 36 sets of results, while En is larger than 1.2 for 6 sets of results which will be checked in the future.

4.2 The bilateral comparison between NIM and NIST

The bilateral comparison between NIM and NIST was conducted in Nov. 2015. 1 sonic nozzles was chosen as the transfer meter. The results were shown in Figure 7.



(a)



(b)

Figure 7 the comparison results between NIM and NIST

The maximum difference of discharge coefficient, ΔC_d between NIM and NIST is 0.05%, while the maximum En value is smaller than 0.5.

5. Conclusions

The high pressure pVTt gas flow facility was built in NIM in 2014. The pressure could be changed within (100~2500) kPa.

- With the improvement on the measurement of pressure, temperature, and time, the uncertainty of the pVTt facility was 0.06% (k=2), while the uncertainty of the discharge coefficient of sonic nozzle was 0.08% (k=2).
- The capabilities of the pVTt gas flow facility were verified by the bilateral comparisons between NIM and PTB, and between NIM and NIST with sonic nozzles in 2015.

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