

# Mobile Flow Working Standard of Ultrasonic Meter for Natural Gas

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**abstract:** The components and testing results of working standard equipment for natural gas flow meter used multi-path ultrasonic meters in this paper. The testing results in different conditions by NMI of Netherlands, PTB of Germany and CVB of China showed that the uncertainties of the DN100 and DN300 meters for the standard equipment could meet the requirement of 0.5% and 0.35% respectively.

**Keywords:** Standard equipment; testing; uncertainty; repeatability

## 1 Introduction

Normally, the verification or calibration of flow meter for natural gas is offline. In this way, the user would bear an additional error of the meter due to the differences of the installation, pressure and natural gas between calibrating and metering. In addition, it is hard to uninstall and transport the large meters. To solve the problem of the offline verification or calibration, Chengdu Verification Branch for Natural Gas Flow Meter of National Crude Oil Large Flow Measurement Station (hereafter referred to as CVB) imported a set of mobile ultrasonic gas flow rate calibration equipment. The equipment will be used as a working standard equipment to verify and calibrate the meter of natural gas online.

## 2 Brief of the standard equipment

The main technical indexes of the standard equipment are.

- Volume flow rate range at flow condition: (40~8000) m<sup>3</sup>/h.
- Uncertainty of volume flow rate at flow condition: 0.35~0.5%.
- Working pressure range: (0.3~6.4) MPa.
- Pipeline diameter for MUT: DN50~DN400.

### 2.1 Measurement instrument

The standard equipment consists of following instrument:

- gas multi-path ultrasonic gas flow meter:
  - DN300 Q.Sonic-5S: (400~8000) m<sup>3</sup>/h, 0.35%
  - DN100 Q.Sonic-3S: (40~800) m<sup>3</sup>/h, 0.5%
- Pressure transmitter : Rosemount 3051TA, 0.075%.
- Difference pressure transmitter : Rosemount 3051CD, 0.075%.
- Temperature transmitter +Pt100 : Rosemount 3144, 0.3%.
- Online GC: Encal 2000, for C<sub>6</sub><sup>+</sup> analysis.

### 2.2 Data acquisition and processing

Data acquisition and processing of the standard equipment are carried out with a special software based on Windows 2000. Communication for data acquisition from the instruments mentioned in 2.1 and MUT of Instrumet ultrasonic flow meter are digital. To calibrate other kinds of flow meter, there are frequency and analog signals input channel. The calculations of flow rate and physical properties are used the ISO relevant Standard.

### 2.3 Installation

The ultrasonic flow meter, upstream and downstream pipeline, and the skid of pressure, difference pressure and temperature transmitters,

diameter-changing adapter are unloaded from goods cabin of truck by a crane equipped with the truck. The ultrasonic flow meter, upstream and downstream pipeline with diameter-changing adapter are installed in series the measurement route between the MUT and its' upstream or

downstream header or elbow. There are different diameter-changing adapters for different pipe diameter and pressure class. The minimum installation distances for different size and pressure class and pressure class MUT are listed in table 1.

Table 1 The minimum installation distances of standard equipment for MUT

Standard Meter	MUT pipe diameter	Minimum installation distances, mm		Standard Meter	MUT pipe diameter	Minimum installation distances, mm	
		PN4.0MPa	PN6.4MPa			PN4.0MPa	PN6.4MPa
DN100	DN50	3080	3124	DN300	DN150	6862	6934
	DN80	3100	3134		DN200	6894	6950
	DN100	3220	2620		DN300	6840	6040
	DN150	3204	3276		DN400	7308	7364

### 3 Test of standard equipment

This is the first time to use ultrasonic flow meter as mobile working standard. It is needed large numbers of testing data to prove the measurement performance of the meters meet the requirement as standard equipment. Up to now, there are following tests on the equipment:

- a. May, 2001, ultrasonic flow meters were tested in Instromet calibration station in Utrecht of Netherlands, which is authorized by NMI (hereafter referred to as NMI), the testing pressure is 0.8MPa.
- b. July, 2001, ultrasonic flow meters were

tested in PigSar calibration station in Germany, which is authorized by PTB (hereafter referred to as PTB), the testing pressure is 5.0MPa.

- c. August, 2003, ultrasonic flow meters were tested in CVB in Chengdu of China, the testing pressure is (0.8~1.5) MPa.

#### 3.1 Error of flow rate indicated value

Errors of flow rate indicated value ( $E_i$ ) of two ultrasonic flow meters tested in NMI, PTB and CVB are shown in Fig.1 and Fig. 2.

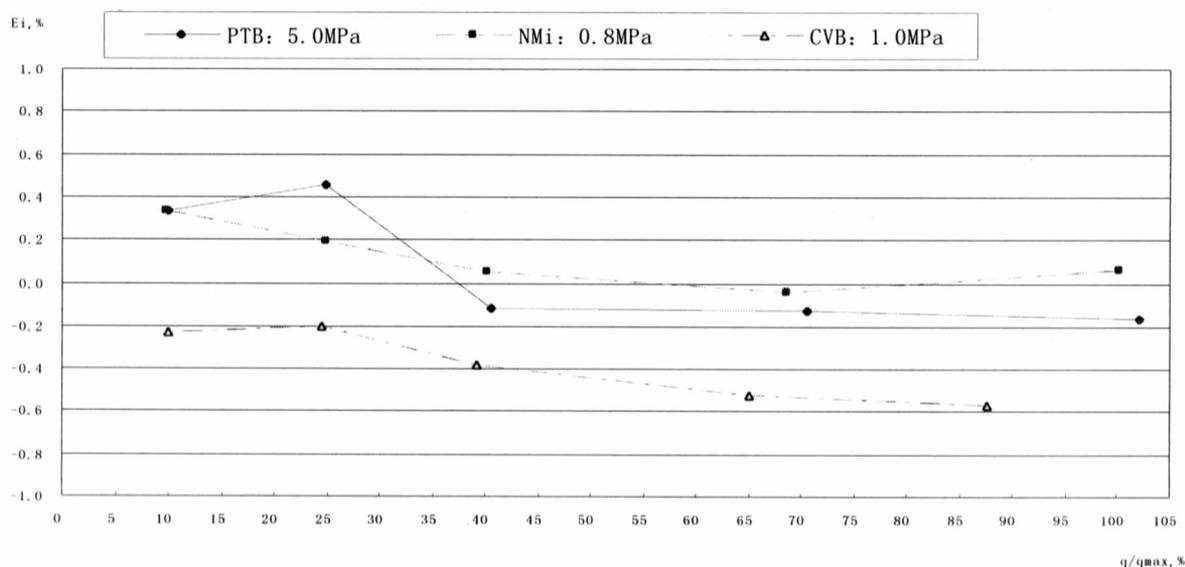


Fig.1 Error of flow rate indicated value of DN100 Q.Sonic-3S

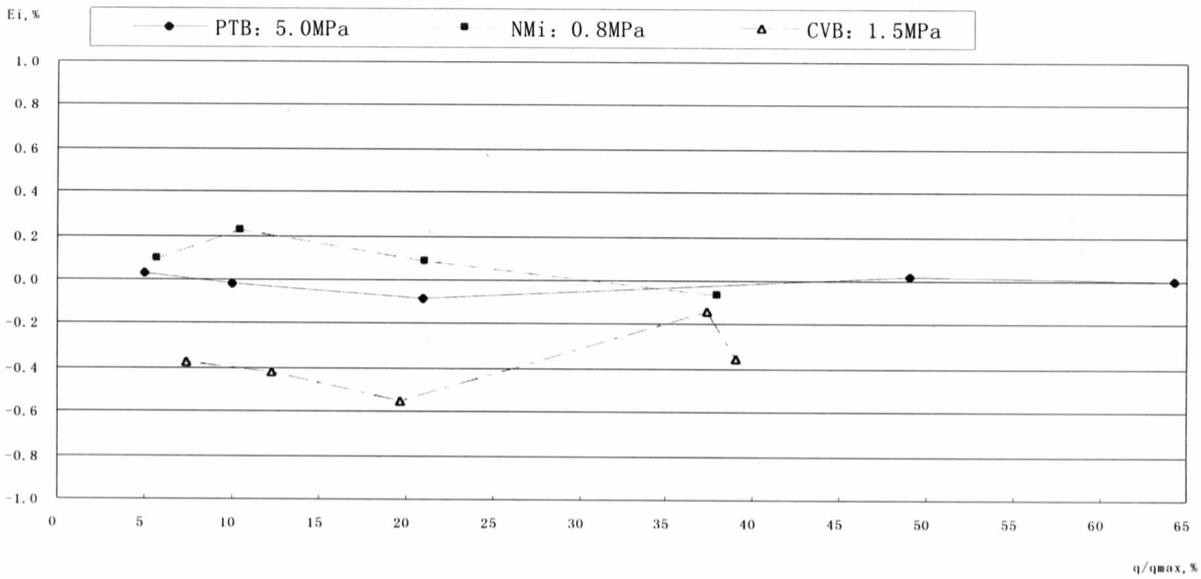


Fig.2 Error of flow rate indicated value of DN300 Q.Sonic-5S

From Fig.1 and Fig.2, the results could be reached:

- In NMi, the testing  $E_i$  of DN100 meter is in the range of -0.04% ~0.33%, the average is 0.12%; and DN 300 meter is -0.07%~0.22%, the average is 0.08%.
- In PTB, the testing  $E_i$  of DN100 meter is in the range of -0.12% ~0.46%, the average is 0.08%; and DN 300 meter is -0.08%~0.03%, the average is -0.01%.
- In CVB, the testing  $E_i$  of DN100 meter is in the range of -0.20% ~-0.57%, the

average is -0.38%; and DN 300 meter is -0.14%~0.55%, the average is -0.37%.

### 3.2 Repeatability

In CVB testing, the repeatability ( $E_R$ ) for both meters is calculated, it show in the Fig3.

Fig.3 shows that the repeatability of DN100 meter is in the range of 0.06%~0.10%, and DN300 meter is 0.01%~0.05%.

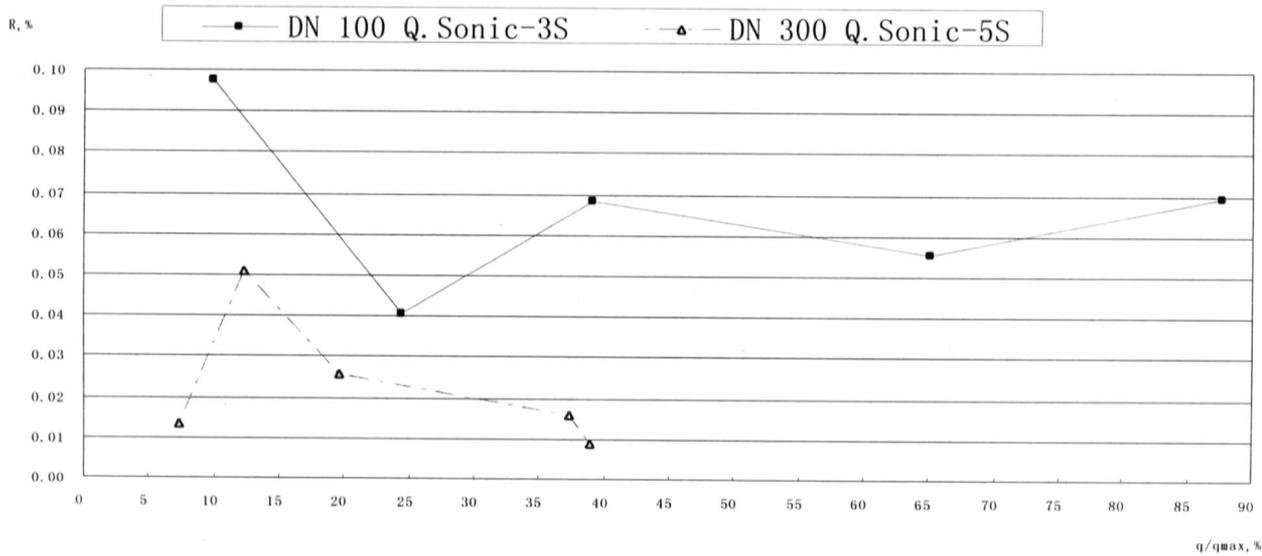


Fig.3 Testing repeatability of Ultrasonic flow meters

## 4 Measurement uncertainty

### 4.1 Formula for uncertainty calculation

The volume indicated value of the meter ( $q_i$ ) is calculated with:

$$q_i = \frac{\pi}{8} D^2 \frac{L}{\cos \phi} \left( \frac{1}{t_{ab}} - \frac{1}{t_{ba}} \right) \quad (1)$$

After calibrating, the volume flow rate of the meter at flow condition ( $q_f$ ) is calculated with:

$$q_f = F_m q_i \quad (2)$$

After calibrating, the flow meter factor ( $F_m$ ) is

calculated with:

$$F_m = \frac{q_s P_s T_s Z_s}{q_i P_i T_i Z_i} \quad (3)$$

After calibrating, the systematic error (tape A uncertainty) can be expressed as repeatability, the uncertainty of the volume flow rate of the meter at flow condition is calculated with:

$$u_{q_f} = \sqrt{E_R^2 + u_s^2 + u_{P_s}^2 + u_{T_s}^2 + u_{Z_s}^2 + u_{P_i}^2 + u_{T_i}^2 + u_{Z_i}^2} \quad (4)$$

The parameters expressed with the symbols in the above formulas and their influences to the uncertainty of the volume flow rate of the meter at flow condition are listed in table 2.

Table2 The parameters influenced the uncertainty of the volume flow rate of the meter

symbol	parameter	value
$t_{ab}(t_b)$	Time of the ultrasonic travel from transducer A (B) to transducer B (A).	The quantity of $t_{ab}$ and $t_{ba}$ is in the level of 0.1ms, the time measurement uncertainty of ultrasonic flow meter is in the level of 1ns. Machining uncertainty is in the level of 0.1mm. After calibrating, influenced to flow rate uncertainty by those parameters can be expressed with $E_R$ .
$L$	Distance between transducer A and B	
$\Phi$	Angle of the line of transducer A and B with the center line of pipeline.	
$D$	Pipeline diameter	
$q_s, u_{q_s}$	Volume flow and uncertainty .at the condition of $P_s$ and $T_s$ .	CVB secondary standard equipment, $U=0.25\%$
$P_s, u_{P_s}$	Pressure and uncertainty of the standard equipment	Using Rosemount 3051 series smart transducer, $U=0.075\%$
$P_f, u_{P_f}$	Pressure and uncertainty of the MUT	
$T_s, u_{T_s}$	Temperature and uncertainty of the standard equipment	Use Rosemount transducer and class A Pt100, $U=0.3\%$
$T_f, u_{T_f}$	Temperature and uncertainty of the MUT	
$Z_s, u_{Z_s}$	Compressibility factor and uncertainty of the standard equipment	Calculated with ISO 12213, natural gas composition, pressure and temperature are in the range of pipeline quality, $U=0.1\%$
$Z_f, u_{Z_f}$	Compressibility factor and uncertainty of the MUT	
$E_R$	Repeatability at calibrating	Express with experimental standard deviation

### 4.2 Uncertainty calculation

The results of uncertainty calculation of the volume flow rate of the meter at flow condition with CVB calibrated Data of DN100 Q.Sonic-3S and DN300 Q.Sonic-5S meter are listed in Table 3.

## 5 Conclusion

Testing results in NMI, PTB and CVB show that the uncertainties of the standard equipment in the range of  $5\% q_{max} \sim 100\% q_{max}$  are 0.37% for the

DN 100 meter of the flow rate in the range of (40~800)  $m^3/h$  and 0.35% for the DN 300 meter of the flow rate in the range of (400~80000)  $m^3/h$  at flow condition. The results also show that the difference of errors between PTB and NMI is within 0.1% (their reference values had harmonized within 0.2%); and the difference between CVB and PTB or NMI is around -0.4% which is acceptable because the measuring uncertainty of PTB is 0.15%, CVB is 0.25% and the meter is 0.37%. However, CVB is going to join the international comparisons to make its reference value harmonize with others.

Before the standard equipment put into use, it stall

has some tests to do for the measurement performance.

- a. Repeatability and stability testing in CVB regularly.
- b. Research on the influence to stability of the standard equipment by different road condition, and necessary measure to reduce the influence.
- c. Research on the influence to calibration result by installation distance between the standard equipment and different kinds of MUT, and necessary measure to reduce the influence.

- d. Research on the influence to calibration result by different pressure between the standard equipment and MUT calibrated, and necessary calibration to reduce the influence.

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Table 3 Uncertainties calculation of ultrasonic flow meter parameters

Parameter	DN100 Q.Sonic-3S	DN300 Q.Sonic-5
$u_{qs}$	$u_{qs} = 0.25\%/2 = 0.125\%$	
$u_{ps}, u_{pf}$	Average calibrated pressure: 1075kPa Allowable error of pressure transducer: $\Delta P_1 = \pm 0.075\% \times 1075\text{kPa} = 806\text{Pa}$ Estimated as rectangle distributing: $u_{p1} = 806 / \sqrt{3} \text{ Pa} = 465\text{Pa}$ A/D conversion is 12 bits, so: $\Delta P_2 = \pm 0.025\% \times 1075\text{kPa} = 269\text{Pa}$ Estimated as rectangle distributing: $u_{p2} = 269 / \sqrt{3} \text{ Pa} = 155\text{Pa}$ Measurement uncertainty of pressure: $u_p = (365^2 + 155^2)^{0.5} \text{ Pa} = 491\text{Pa}$ Expressed in relative value: $u_{ps}, u_{pf} = 491\text{Pa} / 1075\text{kPa} = 0.046\%$	Average calibrated pressure: 1392kPa Allowable error of pressure transducer: $\Delta P_1 = \pm 0.075\% \times 1392\text{kPa} = 1044\text{Pa}$ Estimated as rectangle distributing: $u_{p1} = 1044 / \sqrt{3} \text{ Pa} = 603\text{Pa}$ A/D conversion is 12 bits, so: $\Delta P_2 = \pm 0.025\% \times 1392\text{kPa} = 348\text{Pa}$ Estimated as rectangle distributing: $u_{p2} = 348 / \sqrt{3} \text{ Pa} = 201\text{Pa}$ Measurement uncertainty of pressure: $u_p = (603^2 + 348^2)^{0.5} \text{ Pa} = 635\text{Pa}$ Expressed in relative value: $u_{ps}, u_{pf} = 635\text{Pa} / 1392\text{kPa} = 0.046\%$
$u_{Ts}, u_{Tf}$	Average calibrated temperature: 25.66 °C Allowable error of class A Pt100: $\Delta t_1 = \pm (0.15 + 0.002 \times 25.66) \text{ °C} = \pm 0.201 \text{ °C}$ Estimated as rectangle distributing: $u_{t1} = 0.201 / \sqrt{3} \text{ °C} = 0.116 \text{ °C}$ Allowable error of resistance measurement and signal converting is $\pm 0.1 \text{ °C}$ , estimated as rectangle distributing: $u_{t2} = 0.1 / \sqrt{3} \text{ °C} = 0.058 \sqrt{3} \text{ °C}$ Measurement uncertainty of temperature: $u_t = (0.116^2 + (0.058^2)^{0.5}) = 0.130 \text{ °C}$ Expressed in relative value: $u_{Ts}, u_{Tf} = 0.130 / (273.15 + 25.66) = 0.043\%$	Average calibrated temperature: 23.65 °C Allowable error of class A Pt100: $\Delta t_1 = \pm (0.15 + 0.002 \times 23.66) \text{ °C} = \pm 0.197 \text{ °C}$ Estimated as rectangle distributing: $u_{t1} = 0.201 / \sqrt{3} \text{ °C} = 0.114 \text{ °C}$ Allowable error of resistance measurement and signal converting is $\pm 0.1 \text{ °C}$ , estimated as rectangle distributing: $u_{t2} = 0.1 / \sqrt{3} \text{ °C} = 0.058 \sqrt{3} \text{ °C}$ Measurement uncertainty of temperature: $u_t = (0.114^2 + 0.058^2)^{0.5} \text{ °C} = 0.128 \text{ °C}$ Expressed in relative value: $u_{Ts}, u_{Tf} = 0.128 / (273.15 + 23.65) = 0.043\%$
$u_{zs}, u_{zf}$	$u_{zs}, u_{zf} = 0.1\% / \sqrt{3} = 0.058\%$	
$E_R$	$E_R = 0.1\% / \sqrt{3} = 0.058\%$	$E_R = 0.05\% / \sqrt{3} = 0.029$
$u_{qf}$	Standard uncertainty calculated with (4): $u_{qf} = (0.125^2 + 2 \times (0.046^2 + 0.043^2 + 0.058^2) + 0.058^2)^{0.5} \% = 0.183\% = 0.18\%$	Standard uncertainty calculated with (4): $u_{qf} = (0.125^2 + 2 \times (0.046^2 + 0.043^2 + 0.058^2) + 0.029^2)^{0.5} \% = 0.176\% = 0.18\%$
$U_{qf}$	Expanded uncertainty (k=2): $U_{qf} = 2 \times 0.183\% = 0.366\% = 0.37\%$	Expanded uncertainty (k=2): $U_{qf} = 2 \times 0.176\% = 0.352\% = 0.35\%$