Research on the calibration of Sonic Nozzles by HPPP

HaimingYan,Yongtao Pei

PipeChina, West East Gas Pipeline Company,Wuhan, China
E-mail (HaimingYan): 553216585@qq.com

Abstract

The mathematical model and the measurement uncertainty of the outflow coefficient for calibrating the sonic nozzle with the High Pressure Piston Prover (HPPP) primary standard device were studied. The design and modification of the existing HPPP primary flow standard device were carried out. , replace the upstream transmission turbine flowmeter with an ultrasonic flowmeter, and replace the downstream transmission turbine flowmeter with a set of inspected sonic nozzle pipe sections, optimize the uncertainty of the measurement results, and realize the function of calibrating the sonic nozzle with the HPPP primary standard device .

1. Introduction

The HPPP (High Pressure Piston Prover) original standard device (hereinafter referred to as HPPP) established by the Wuhan Branch of the National Petroleum and Natural Gas Mass Flow Metering Station is designed and manufactured by the German Eller Company[1]. The second set of HPPP method gas flow standard device has been running well since it was put into production in 2016, with stable and reliable performance. It can calibrate the working-level standard device through two DN100 transfer turbine flowmeters, which has successfully completed the value transfer. Task: At present, the actual flow verification of sonic nozzles is generally carried out on the pressure temperature volume time method (PVTt method) gas flow standard device or the mass time method (mt method) gas flow standard device. The principle is to measure stagnation pressure and stagnation pressure. The standard device measures the actual gas flow through the nozzle to calculate the outflow coefficient. There is no method to directly calibrate the secondary critical flow sonic nozzle with HPPP. Now the HPPP is designed and modified to have the ability to calibrate the critical flow sonic nozzle. , and improve the traceability system of quantity value..

2. Background

Sonic nozzles, also known as venturi nozzles, are widely used in petroleum, chemical, natural gas, energy saving, environmental protection, aviation, aerospace and other fields. In the 1970s, sonic nozzles were widely used in gas flow measurement. Because of their simple structure, good stability, high accuracy, and high pressure resistance, they were used as gas flow standard meters. At present, the sonic nozzle method gas flow standard device. It has become the mainstream standard device for gas flow measurement, and there are a large number of standard devices using the sonic nozzle method nationwide.

The formula for calculating the critical flow of a sonic nozzle under working conditions is as follows:

$$Q_m = \frac{A \cdot c_d \cdot c_* \cdot p_0}{\sqrt{(\frac{R_0}{M})\ T_0}} . \qquad (1)$$

In the formula, Qm — the mass flow through the nozzle, kg/m^3 ;

A — the throat cross-sectional area of the critical flow nozzle, m^3 ;

cd — the outflow coefficient of the critical flow nozzle;

c*—critical flow function under stagnation condition;

p0 — stagnation pressure at the upstream inlet of the critical flow nozzle, kPa;

T0 — the stagnation temperature at the upstream inlet of the critical flow nozzle, K;

R0—universal gas constant J · mol-1 · K-1;

M—the molar mass of natural gas, kg/mol;

The throat area of the sonic nozzle is calculated using the nominal throat diameter of the sonic nozzle, and the formula is:

$$. A = \frac{\pi}{4} d^2 . \qquad (2)$$

In the formula, d—nozzle throat diameter, m;

From equations (1) and (2), the calculation formula of the outflow coefficient cd of the critical flow nozzle can be deduced as follows:

$$.\,c_{\mathrm{d}}=\frac{Q_{\mathrm{m}}}{\frac{\pi}{4}d^{2}\cdot c_{*}\cdot\frac{p_{0}}{\sqrt{\frac{R_{0}}{M}\cdot T_{0}}}}. \qquad (3)$$

At present, HPPP is mainly composed of high pressure volume pipe, transfer turbine flowmeter, flow control nozzle, process pipeline, valve, pressure and temperature transmitter, data acquisition and processing system, etc. HPPP is the source of the natural gas flow and value transfer system in Wuhan substation. It adopts the principle of standard volume method to reproduce the volume flow and value of high-pressure natural gas. When working, the natural gas enters the HPPP process flow after being adjusted by pressure and temperature. The four-valve valve switch is used to push the piston to move at a constant speed in the measuring section of the volume tube. The timer installed on the section of the volume tube is used to trigger the timer to measure the movement time of the piston, and calculate Obtain the natural gas volume flow and complete the measurement. The HPPP volume tube master standard is made of stainless steel cylinder, the design pressure is 10 MPa, the length is about 6 m, the length of the measuring section is about 3 m, the diameter is about 0.25 m, and the flow range is (20-480) m3/h; expanded uncertainty U⩽0.07% (k=2).

The standard volume of the measuring section of the volume tube is calculated by accurately measuring the length and diameter of the standard volume tube. During the measurement, the piston passes through the measuring section of the volume tube at a constant speed, and pushes out the gas in the measuring section at a constant speed. By recording the time when the piston passes through the measuring section, the volume flow of natural gas is calculated.

$$q_{v}=\frac{V}{\Delta t}\times\frac{T_{m}}{T_{s}}\times\frac{p_{s}}{p_{m}}\times\frac{Z_{m}}{Z_{s}}. \qquad (4)$$

where:

V——HPPP volume tube volume measurement, m3;

- the time required for the piston to pass through V, s.

Ts, Tm — the measured value of the medium temperature at the HPPP volume pipe and the transfer turbine flowmeter, K;

ps, pm—medium pressure measurement value at the HPPP volume pipe and at the transfer turbine flowmeter, MPa;

Zs, Zm — the medium compression factor at the HPPP volume pipe and the transfer turbine flowmeter, dimensionless.

It can be seen from equation (3) that calculating the outflow coefficient cd of the sonic nozzle needs to measure the mass flow Qm passing through the sonic nozzle, and according to equation (4), the volume flow qv is measured when calibrating the turbine flowmeter with HPPP. The equation of state can get the gas density calculation formula as follows:

$$\rho_{0}=\frac{p_{0}}{Z\cdot\frac{R_{0}}{M}\cdot T_{0}} \qquad (5)$$

In the formula, ρ 0—the density of the gas under actual conditions, kg/m³;

Z—compression factor of gas;

According to ISO9300, the measured pressure and temperature values at the nozzle are corrected to obtain the stagnant pressure p 0 and stagnation temperature T0 at the upstream inlet of the critical flow nozzle, which can be obtained by entering the above formula:

$$c_{\mathrm{d}}=\frac{Q_{\mathrm{V,0}}}{\frac{\pi}{4}d^{2}\cdot c^{*}\cdot Z\cdot\sqrt{\frac{R_{0}}{M}\cdot T_{0}}} \qquad (6)$$

2 Implementation of HPPP standard device to detect sonic nozzles

Replace a turbine flowmeter with a secondary transmission standard with the sonic nozzle to be inspected, and use the existing temperature and pressure transmitters of the original turbine flowmeter. Through the data acquisition system, the mass flow rate of the inspected meter can be obtained, according to the standard The flow rate of the nozzle, the temperature and pressure values at the nozzle are brought into formula (6) for calculation to realize the verification of the sonic nozzle. As shown in Figure 1, the original HPPP system is simply modified to initially realize the verification of the sonic nozzle.

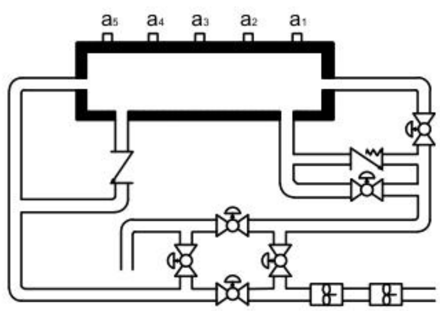

Figure 1 Flow chart of the HPPP method sonic nozzle verification device

2.1 System Transformation

2.1.1 Design of Molar Mass M Correction Scheme

The molar mass M of natural gas is mainly obtained by the composition measurement of the gas chromatographic analyzer at the station. It is very difficult to correct the gas chromatographic analyzer in practical applications, and the actual installation position of the gas chromatographic analyzer from the nozzle It is far away. In the case of lower flow rate, the molar mass of the gas at the gas chromatograph and the actual value at the nozzle are quite different. To sum up, a new model needs to be established to correct the molar mass M, as shown in the figure As shown in 2, the measurement of the outflow coefficient cd with low uncertainty is realized, and the molar mass is corrected through the sound velocity measurement unit SoS-unit, thereby improving the measurement accuracy of the entire system, and the sound velocity is measured by means of an ultrasonic flow rate. count to achieve. The implementation method of this solution in the software is shown in Figure 3. The gas components in the outbound yard can be measured by the existing gas chromatographic analyzer (the HPPP data acquisition system can read the relevant data), and the gas components can be measured by the ultrasonic flowmeter. A correction factor can be obtained by comparing the sound speed calculated by the chromatograph and the temperature and pressure transmitter with the sound speed calculated by the chromatograph and the temperature and pressure transmitter. Using this correction factor, the real gas composition information at the nozzle can be derived.

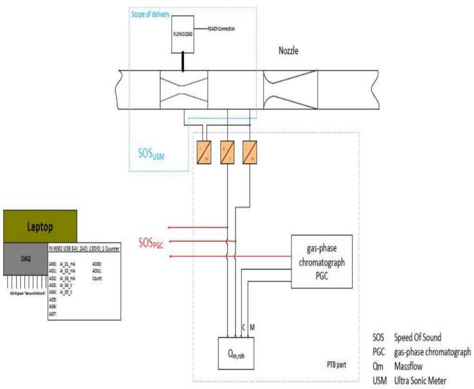

Figure 2 Molar mass M correction model

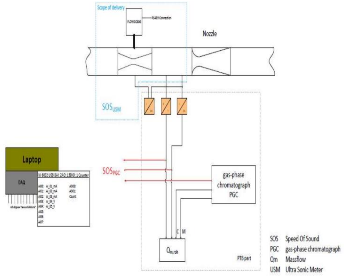

Figure 3 Software implementation method of molar mass M correction

2.1.2 Optimizing and transforming main equipment

Select a four-channel DN100 ultrasonic flowmeter to measure the speed of sound, the measurement range of the speed of sound is (200~1200) m/s, the pressure level is ANSI 600, the uncertainty should be better than 0.5%, and the flow measurement repeatability: ≤0.1% (qt< qi≤qmax); DN100 sonic nozzle, meeting the requirements of GB/T21188 and ISO9300; ultrasonic flowmeter connecting pipe section and nozzle clamping pipe section; flowmeter signal acquisition junction box and HPPP data acquisition system upgrade.

2.2 Uncertainty of critical flow outflow coefficient

From the mathematical model of formula (6), it can be known that the uncertainty composition of the critical flow outflow coefficient cd is shown in Table 1:

Table 1: uncertainty evaluation

Symbol	Input	Urel in% of input	Sens.coeff $C_r(x_i)$	$C_r(x_i)^2 u_i(x_i)^2$
$Q_{V,0}$	Q_V by HPPP	0.04%	1	0.0004
T_0	stagnation temperature	0.05%	0.5	0.00015625
M	Molar mass	0.1%	0.5	0.000625
$c*$	critical flow function	0.1%	1	0.0025
Z	compressibility factor	0.1%	1	0.0025

The expanded uncertainty of the critical flow outflow coefficient cd is obtained from Table 1:

$$U(cd)=2\sum(Cr(xi)2ui(xi)2)0.5=0.16\%$$

From the analysis of the uncertainty composition of c d, if all parameters are not corrected, the uncertainty of the critical flow outflow coefficient is large, which is mainly caused by the large uncertainty of the critical flow function c* and the compression factor Z , and the critical flow function c* and the compression factor Z are related in the actual physical sense. The experimental data are shown in Figure 4, so the synthetic expanded uncertainty of the critical flow outflow coefficient cd is:

$$U(cd)=2\sum(Cr(xi)2ui(xi)2-2cov(c*, Z))0.5=0.07\%$$

p_1 = 5,1 MPa		5,1		
T_1 = 15,5 °C		288,65		
Table 1: examples of gas compositions measured at pigsar usi				
Date/time of composition measurement	c^*	z_1	M	CH4
01.10.2010 13:51	0,7095	0,90489	18,575	0,8295
04.10.2010 08:43	0,7097	0,9034	18,536	0,8349
04.10.2010 16:38	0,7102	0,90142	18,452	0,8441
05.10.2010 09:13	0,7092	0,90611	18,587	0,8268
05.10.2010 16:15	0,7092	0,90603	18,577	0,8275
06.10.2010 09:03	0,7091	0,90635	18,577	0,827
06.10.2010 15:47	0,7102	0,90137	18,447	0,8453
07.10.2010 09:54	0,7098	0,90337	18,504	0,8372
07.10.2010 15:51	0,7098	0,90347	18,496	0,8372
Average	**0,7096**	**0,90405**	**18,528**	**0,8344**
2*StandDev [%]	2,0579	***0,425***	***0,597***	

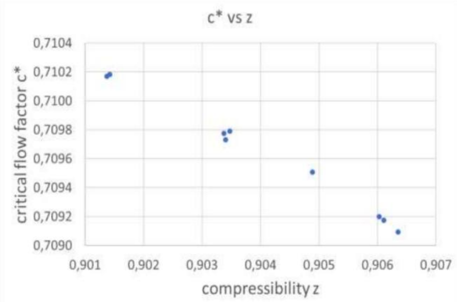

Figure 4 Experimental data of critical flow function c* and compression factor Z

3. Conclusion

The design and research of HPPP verification sonic nozzle fills the gap in the field of sonic nozzle verification, and further improves the transmission and traceability system of China's natural gas flow value, which is conducive to promoting the technological progress of China's natural gas measurement science and meeting the development needs of China's natural gas industry.

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