Piston gas flow standard Facility

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Abstract

Some gas flowmeters such as standard wet gas meter and critical flow Venturi nozzles are often used in the main standard of standard facility, and their accuracy is high, so its value transmission is particularly important. This paper introduces an active piston gas flow standard device. This paper introduces an active piston gas flow standard facility, which is composed of three active pistons and used in series. The measuring range can reach (0.01~128) m^3/h, and the pistons can be automatically switched according to the required flow during the detection process. According to JJF 1586-2016 "Calibration Specification for Active Piston Provers", analysis the uncertainty of the active piston flow standard facility. It can be obtained that the expanded uncertainty of the device is $U_r(V)$=0.062%(k=2).Through the result of uncertainty evaluation, the standard facility can transmit the value to the gas flowmeter with higher accuracy level.

0. Preamble

The active piston flow standard facility has the advantages of high accuracy, good stability, easy flow adjustment, and fast measurement. The facility is a high-precision detection facility. It can not only measure gas meters with high accuracy levels such as critical flow venturi nozzles and standard wet gas meters, but also gas meters such as rotameters[1-2].

There are pVTt facility and piston gas flow facility in our institute, which can measure instruments with high accuracy levels. The detection flow range of the pVTt facility is wide. The smaller the gas flow rate, the longer the required experimental time and the lower the experimental efficiency. Moreover, the pVTt facility can only detect the critical flow venturi nozzles and has a single purpose. The piston gas flow facility can detect standard wet gas meters, diaphatgm gas meters, critical flow venturi nozzles, and gas displacement meters, and it has a wide range of detection purposes. However, the detection range of the existing piston device is small, and the detection flow range is (0.001~6) m^3/h. A new active piston gas flow facility is established now. The facility has a larger measurement range, a higher degree of automation, improved detection efficiency, and a higher level of accuracy. It can be directly traced to basic quantities such as length and temperature, and can be used as the original standard facility. The detected meter adopts pneumatic clamping, which is simple and easy to operate, occupies less space and convenient to use[3-5].

1. Facility introduction

The active piston flow standard facility is also called the electric driven piston flow standard facility. There are three piston facilities of 1200L, 50L and 1L in our institute. The 1L piston facility is embedded in the 50L piston, and the two share a grating ruler. Three pistons are used in series, according to the set flow rate, the suitable size piston is automatically switched.
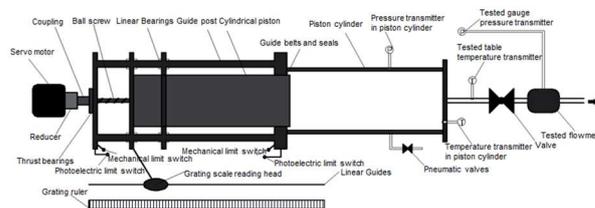
Figure 1: Basic structure diagrams of piston gas flow standard facility

It consists of servo motor, reducer, coupling, thrust bearing, ball screw, cylindrical piston, guide belts, seals, piston cylinder, grating ruler, guide mechanism and control system, etc. Its basic structure is shown in Figure 1 below. Its working principle is: when the flowmeter is detecting, the servo motor rotates at the corresponding speed, according to the preset flow value. Through the deceleration of the reducer, the motor torque is converted into a lateral force by the roller screw, which pushes the cylindrical piston to make uniform linear motion in the horizontal direction, and the cylindrical piston discharges the gas in the cylinder into the measured flowmeter.

The direct-reading flowmeter can directly read the indication value of the measured flowmeter. The flowmeter with signal output can connect pulse or current signal to PLC to realize automatic acquisition. Through the collection and conversion of the flow, temperature, pressure and other information of the device and the measured flowmeter, the detection of the flowmeter is realized. When testing the critical flow

Venturi nozzle, it is necessary to start the vacuum pump at the end of the nozzle, adjust the back-pressure ratio to make the nozzle reach the critical state, adjust the speed of the servo motor to keep the pressure in the piston cylinder in a "zero balance" state. The other detection processes are the same as the detection of the flowmeter.

The outer diameter D of the cylindrical piston is a fixed value. The horizontal movement distance L of the piston is measured by a grating ruler, and the volume V discharged by the cylindrical piston can be obtained. The temperature T, pressure p, time t and other parameters of the piston cylinder and the measured flowmeter are measured. Convert the flow rate q_s of the piston facility to the flow rate in the state of the measured flowmeter, and compare it with the measured flowmeter to obtain the indication error E of the measured flowmeter.

2. Uncertainty analysis of the facility

According to JJF 1586-2016 "Calibration Specification for Active Piston Provers", the working principle of the active piston flow standard facility. The volume value provided by the device under constant temperature and constant pressure is the product of the inner diameter of cylinder or the outer diameter of cylindrical piston and the displacement of piston. The piston facility needs precise measurement of cylinder or piston. Combined with the technical parameters of screw rod, the pulse equivalent or piston coefficient is calculated, and its uncertainty component is evaluated to determine the expanded uncertainty of the facility[6-10].

Assuming the average inner diameter of the cylinder or the outer diameter of the cylindrical piston is D, the pitch of screw rod is P_L, the natural step angle of two-phase stepping motor is 1.8° at room temperature T_0, and the standard volume V_{20} is calculated according to equation (1).

$$V_{20} = \frac{\pi}{4} \times D^2 \times P_L$$
$$= \frac{\pi}{4} \times P_L \times \left\{ \frac{1}{m} \frac{1}{n} \sum_{j=1}^{m} \sum_{i=1}^{n} \left[D_{ij} \left(1 + (\alpha - \beta_p)(T_0 - 20) \right) \right] \right\}^2 \quad (1)$$

The pulse equivalent k is calculated according to equation (2).

$$k = \frac{\pi}{4f} \times D^2 \times P_L$$
$$= \frac{\pi}{4f} \times P_L \times \left\{ \frac{1}{m} \frac{1}{n} \sum_{j=1}^{m} \sum_{i=1}^{n} \left[D_{ij} \left(1 + (\alpha - \beta_p)(T_0 - 20) \right) \right] \right\}^2 \quad (2)$$

Where D_{ij} denotes the i-th measurement of the j-th measurement section of the cylinder inner diameter or cylindrical piston outer diameter(mm); P_L denotes the pitch of screw rod(mm); α, β_P denotes linear expansion coefficient of gauge, cylinder or cylindrical piston

material(℃⁻¹); f denotes Pulses per P_L of the rotary encoder or stepper motor(pul).

From the equations (1) and (2), the calculation of the composite relative standard uncertainty of the standard volume V_{20} and the pulse equivalent k is shown in equations (3) and (4).

$$u_r(V_{20}) = \sqrt{u_r^2(D) + u_r^2(T) + u_r^2(P_L)} \quad (3)$$

$$u_r(k) = \sqrt{u_r^2(D) + u_r^2(T) + u_r^2(P_L) + u_r^2(f)} \quad (4)$$

Where $u_r(D)$ denotes the relative standard uncertainty of the average diameter of the cylinder or piston of the facility(%); $u_r(T)$ denotes the relative standard uncertainty of ambient temperature at the time of measurement(%); $u_r(P_L)$ denotes the standard uncertainty of the grating ruler(%); $u_r(f)$ denotes the relative standard measurement uncertainty of the pulse(%).

For the 1200L piston gas flow standard facility, the measurement uncertainty of the cylinder is $U = 0.04$ mm(k=2), and the ambient temperature is 20.02 °C. The measurement uncertainty of the grating ruler is U=0.002mm(k=2), the relative measurement uncertainty of the crystal oscillator is U_r=1×10⁻⁶(k=2), and the relative standard uncertainty is:

$$u_{r1200}(V_s) = \sqrt{\left(\frac{0.040}{1099.809}\right)^2 + \left(\frac{20.02-20}{293.52 \times \sqrt{3}}\right)^2 + \left(\frac{0.002}{200}\right)^2 + \left(1 \times 10^{-6}\right)^2} \times 100\%$$

$$= 0.0055\%$$

For the 50L+1L piston gas flow standard facility, the measurement uncertainty of the cylinder is $U = 0.004$ mm(k=2), and the ambient temperature is 20.02 °C. The measurement uncertainty of the grating ruler is U=0.002mm(k=2), the relative measurement uncertainty of the crystal oscillator is U_r=1×10⁻⁶(k=2), and the relative standard uncertainty is:

$$u_{r50}(V_s) = \sqrt{\left(\frac{0.004}{350.013}\right)^2 + \left(\frac{20.02-20}{293.52 \times \sqrt{3}}\right)^2 + \left(\frac{0.002}{100}\right)^2 + \left(1 \times 10^{-6}\right)^2} \times 100\%$$

$$= 0.0046\%$$

$$u_{r1}(V_s) = \sqrt{\left(\frac{0.004}{49.979}\right)^2 + \left(\frac{20.02-20}{293.52 \times \sqrt{3}}\right)^2 + \left(\frac{0.002}{100}\right)^2 + \left(1 \times 10^{-6}\right)^2} \times 100\%$$

$$= 0.0091\%$$

Among the measurement uncertainties given by piston cylinder and grating ruler, the uncertainty has been included the expansion coefficient of gauge and piston material.

The absolute pressure p_s of the standard facility is measured directly by the pressure sensor, the maximum range of the pressure sensor is 120kPa, the measurement uncertainty result is U=0. 01% F.S (k=2), the absolute pressure of the standard facility at the flow point of 15 m³/h is 97960 Pa, and the absolute pressure of the facility at the flow point of 0.8 m³/h is 97810 Pa. The relative standard uncertainty component of the absolute pressure of the standard facility is:

$$u_{r1200}\left(p_s\right)=\frac{120000\,/\,2\times0.01\%}{97960}\times100\%=0.006\ \%$$

The measurement uncertainty of the temperature inspection instrument is U=0.15 °C(k=2), and the standard uncertainty introduced by the medium temperature of the standard facility is:

$$u_{r1200}\left(T_s\right)=u_{r50+1}\left(T_s\right)=\frac{0.15}{2\times292.95}\times100\%=0.026\ \%$$

Using wet gas meter to measure the repeatability of the facility, it can be seen from the experimental results that the repeatability of the1200L piston facility is0.013%, the repeatability of the 50L+1L piston facility is0.006%.

Assuming the influences are independent of each other, we can get:

$$u_{r1200}\left(V\right)=\sqrt{\left(0.0055\right)^2+\left(0.006\right)^2+\left(0.026\right)^2+\left(0.013\right)^2}=0.031\%$$
$$u_{r50}\left(V\right)=\sqrt{\left(0.0046\right)^2+\left(0.006\right)^2+\left(0.026\right)^2+\left(0.006\right)^2}=0.030\%$$
$$u_{r1}\left(V\right)=\sqrt{\left(0.0091\right)^2+\left(0.006\right)^2+\left(0.026\right)^2+\left(0.006\right)^2}=0.031\%$$

The expanded measurement uncertainty of the actual cumulative volume V of the meter measured by the standard facility is:

$$U_{r1200}(V)=0.062\%,\ k=2$$
$$U_{r50}(V)=0.060\%,\ k=2$$
$$U_{r1}(V)=0.062\%,\ k=2$$

The expanded measurement uncertainty of the standard facility (1200L piston, 50L + 1L pistons) is $U_r(V)$ = 0.062%(k=2).

3. Uncertainty analysis of the wet gas meter

The measurement of the wet gas meter refers to JJF1357-2012 " Calibration Specification for Wet Gas Meters ". Piston gas flow standard facility is used as a measuring standard facility(called standard facilityin this assessment). Under the working pressure and set flow rate of the facility, the gas is discharged from the facility and flows through the measured wet gas meter. The cumulative volume of the facility is compared with the cumulative volume of the measured wet gas meter,

and the correction factor of the measured wet gas meter is obtained through mathematical calculation[11-14].

The calibration environmental conditions meet the requirements of 6.1.1. During the calibration process, the pressure and temperature of the gas in the pipeline from the standard facility to the wet gas meter will change to a certain extent, so temperature and pressure compensation is required. Since the gas is at normal temperature and pressure, the ideal gas equation of state can be used for volume conversion. According to the definition of correction factor, the calculation equation(5) of the correction factor of calibrated wet gas meter is :

$$k=\frac{V_{ref}}{V}=\frac{p_s V_s T_m}{p_m V T_s} \tag{5}$$

Where k denotes the correction factor of the standard wet gas meter; V_{ref} denotes the actual value of gas volume through the standard wet gas meter(L); V_s denotes the exhaust volume value of the standard facility(L);V denotes the indication value of the standard wet gas meter(L); p_s denotes the absolute pressure in the standard facility(Pa); p_m denotes the absolutes pressure in standard wet gas meter(Pa); T_s denotes the thermodynamic temperature in the standard facility(K); T_m denotes the thermodynamic temperature in the standard wet gas meter(K).

It can be seen from the above equation that the uncertainty sources of correction factor k of the wet gas meter mainly include:

(1)The uncertainty component of the standard facility $u_r(V_s)$;

(2)The standard uncertainty of the indicated value that obtained by repeated measurement of the calibrated wet gas flowmeter is the standard uncertainty component of the correction factor;

(3)The uncertainty component of pressure in the standard facility $u_r(p_s)$;

(4)The uncertainty component of temperature in the standard facility $u_r(T_s)$;

 (1)~(4) are the uncertainty of the standard facility, and $U_r(V)$=0.062%(k=2) can be obtained from the above analysis.

(5)The uncertainty components of pressure in standard wet gas meter $u_r(p_m)$;

The uncertainty analysis of the pressure in the standard wet gas meter is the same as the uncertainty analysis in the standard facility. When the 1200L piston facility is used, the absolute pressure in the standard wet gas meter is 97910 Pa. When the 50L+1L piston facility is used,

the absolute pressure in the standard wet gas meter is 97880Pa.The relative standard uncertainty component introduced by the pressure is :

$$u_{r1200}\left(p_m\right)=u_{r50+1}\left(p_m\right)=0.06\ \%$$

(6)The uncertainty components of temperature in standard wet gas meter $u_r(T_m)$;

$$u_{r1200}\left(T_m\right)=u_{r50+1}\left(T_m\right)=\frac{0.15}{292.95\times2}\times100\%=0.026\ \%$$

(7)The uncertainty components due to environmental changes and inaccurate attachments $u_r(F)$;
The uncertainty components introduced by level, reference liquid level, and temperature difference of the calibrated wet gas meter.

1)The uncertainty component introduced by temperature difference u_y:
The maximum allowable variation of the standard wet gas meter(accuracy class of 0.2) during a calibration process is 0.2 °C, assuming follow a uniform distribution:

$$u_y=\frac{0.2}{292.95\times\sqrt{3}}=0.039\%$$

2)The uncertainty components introduced by spirit levels:
Assuming it follow a uniform distribution:

$$u_b=\frac{0.03\%}{\sqrt{3}}=0.017\%$$

3)The uncertainty component introduced by level indicator:
The uncertainty introduced by the tip reflective level indicator, assuming follow a uniform distribution:

$$u_p=\frac{0.02\%}{\sqrt{3}}=0.011\%$$

(Note: The uncertainty introduced by spirit levels and level indicator is based on experimental data.)

$$u_{r1200}\left(F\right)=u_{r50+1}\left(F\right)=\sqrt{0.039\%^2+0.017\%^2+0.011\%^2}$$

$$=0.044\%$$

List of relative standard uncertainty is shown in Table 1.

Table 1: List of relative standard uncertainty

Serial Number	1	2	3	4	Combined Standard Uncertainty $u_r(k)$
Symbol	$u_r(V)$	$u_r(p_m)$	$u_r(T_m)$	$u_r(F)$	
Relative Sensitivity Coefficient C_r	1	-1	1	1	
Relative Standard Uncertainty Components of 1200L Piston Facility /%	0.031	0.006	0.026	0.044	0.061
Relative Standard Uncertainty Components of 50L Piston Facility /%	0.030	0.006	0.026	0.044	0.060
Relative Standard Uncertainty Components of 1L Piston Facility /%	0.031	0.006	0.026	0.044	0.061

If the relative standard uncertainty is independent of each component, the combined standard uncertainty $u_r(k)$ of k is:

$$u_{r1200}(k)=\sqrt{0.031\%^2+0.006\%^2+0.026\%^2+0.044\%^2}=0.061\%$$
$$u_{r50+1}(k)=\sqrt{0.030\%^2+0.006\%^2+0.026\%^2+0.044\%^2}=0.061\%$$

Taking the coverage factor k=2, the expanded uncertainty is:

$$U_{r1200}=2\times0.061\%=0.13\%$$
$$U_{r50+1}=2\times0.061\%=0.13\%$$

4. Conclusion

This paper introduces an active piston gas flow standard facility, which uses three pistons in series to expand the measuring range of the facility. At the same time, different flow rates are automatically switched, which improves the detection efficiency. It has high accuracy, easy operation and strong reliability. According to the uncertainty evaluation, the flow range of the facility can cover (0.01 ~ 128) m³/h, and the extended uncertainty is $U_r(V)$ = 0.062%(k=2). The test proves that the facility can transmit the value of the standard wet gas meter with accuracy class of 0.2.

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