Study on the Comparison of Three Typical Gas Flow Standards for Calibrating Low Gas Flowmeter

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Abstract

A gas flowmeter for measuring low flow rate has been widely used in the field of medical, health, environmental protection, energy industry, aerospace, etc. To against Covid-2019, the requirement on the low flow rate has been increasing dramatically. At present, the typical standard devices for calibrating low gas flowmeter mainly include standard bell provers of gas flow, standard piston provers of low gas flow and standard laminar of low gas flow. Different measuring principles are adopted among these typical standard devices. To ensure the consistency of these typical standard devices, a comparison test is performed. The standard devices used in the comparison are of the same accuracy grade, with an extended uncertainty of 0.2%(k=2). The piston-type gas flow calibrator of grade 1.0 is selected as the transfer standard, and three flow points with high flow rate, medium flow rate and low flow rate are selected for test. The consistency of measurement results is evaluated by normalized deviation E_n. The comparison results are acceptable which show that three typical standard devices are accurate and reliable.

1. Introduction

In recent years, with the national policy of energy conservation and environmental protection and the needs of sustainable development strategy, more and more indicators need to be controlled in industrial production. Accurate and quantitative analysis are required in every step of industrial production. A gas flowmeter for measuring low flow rate has been widely used in the field of medical, health, environmental protection, energy industry, aerospace, etc. To against Covid-2019, the requirement on the low flow rate has been increasing dramatically.

At present, the typical standard devices for calibrating low gas flowmeter mainly include standard bell provers of gas flow, standard piston provers of low gas flow and standard laminar of low gas flow. Different measuring principles are adopted among these typical standard devices. To ensure the consistency of these typical standard devices, a comparison test among these typical standard devices is important.

First, the structure and principle of three typical standard devices are introduced. Then a comparison test is performed. The standard devices used in the comparison are of the same accuracy grade, with an extended uncertainty of 0.2%(k=2). The piston-type gas flow calibrator of grade 1.0 is selected as the transfer standard. Last, the consistency of measurement results is evaluated by normalized deviation E_n.

2. Three typical gas flow standards

2.1 Standard bell provers of gas flow

The structure of standard bell provers of gas flow is shown in Figure 1. Standard bell provers is made up of bell, ruler, balancing weight, buoyancy compensation mechanism, oil tank, etc.

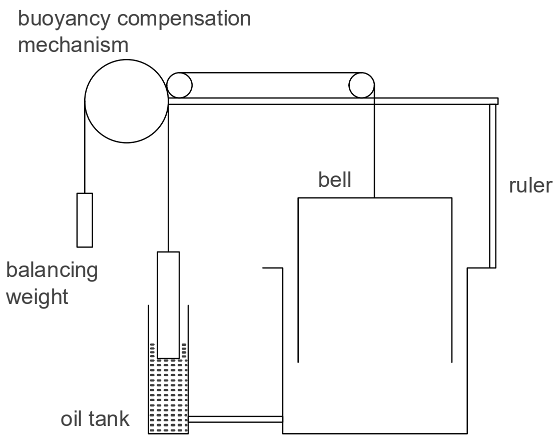

Figure 1: Structure of standard bell provers of gas flow.

The bell is inverted in the oil tank. The upper end of the bell is closed and the lower end is open. The oil between the bell and the oil tank is used as the sealing medium, so that the bell is airtight to the atmosphere. There are two baffles, one is above the ruler and the other is below the ruler. The volume between the two baffles is given and invariant. The flow value can be calculated by measuring the time difference between the two baffles passing through the photoelectric signal generator respectively. Thermometers and pressure gauges are installed in the bell and at the flowmeter which is calibrated, to compensate and correct the flow value. The internal pressure of the bell will change as it rises and descends. In order to keep the internal pressure constant, a buoyancy compensation mechanism is used to compensate for changes in buoyancy. The balancing weight acts as a balance.

Standard bell provers of gas flow consists of three measuring sections with different flow ranges. The flow value which can be calculated covers (0.005~45)m³/h, with an extended uncertainty of 0.2%(k=2).

2.2 Standard piston provers of low gas flow

The structure of standard piston provers of low gas flow is shown in Figure 2. Standard piston provers is made up of photoelectric emitter, temperature and pressure sensor, cylinder, piston, base, etc.

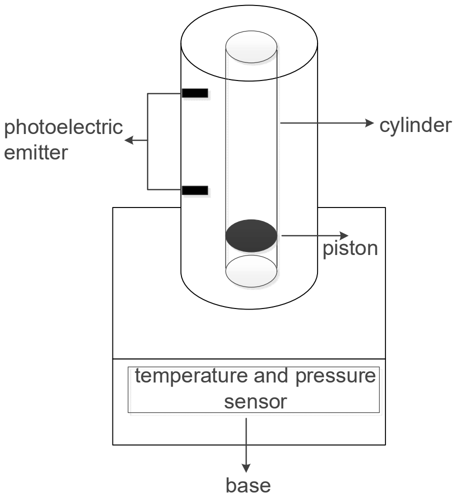

Figure 2: Structure of standard piston provers of low gas flow.

Temperature and pressure sensor are placed in the base, which make temperature and pressure corrections for flow value. A display screen and many buttons are on the base.The measuring unit consists of a cylinder and a piston. The inner wall of the cylinder is equipped with a circuit board and two photoelectric emitters. As the gas flows through the measuring unit, the piston is pushed up, and the time it takes to pass the two photoelectric emitters can be given. According to the geometry of the cylinder, the current flow can be calculated.

Standard piston provers of low gas flow consists of three measuring sections with different flow ranges. The flow value which can be calculated covers (5~50000)mL/min, with an extended uncertainty of 0.2%(k=2).

2.3 Standard laminar of low gas flow

The structure of standard laminar of low gas flow is shown in Figure 3. Standard laminar is made up of pressure connection, flow measurement host, laminar flow element, etc.

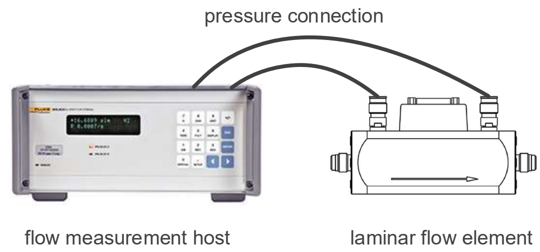

Figure 3: Structure of standard laminar of low gas flow.

A host machine can be equipped with multiple laminar flow elements, covering different flow ranges. The flow measurement host has the functions of setting the type of gas, adjusting the conversion coefficient, displaying the flow value of the laminar flow element, and connecting the computer terminal. The laminar flow element is connected to the flow measurement host by two pressure connections and a data cable. The host machine reads the calibration data from the laminar element, and measures the upstream and downstream pressure of the laminar element with its built-in high-precision pressure sensor. At the same time, the system reads the resistance of the laminar element platinum resistance thermometer, then calculates the temperature of laminar element, and finally calculates the flow through the laminar element.

Standard laminar of low gas flow is equipped with several laminar flow elements in different flow ranges. The flow value which can be calculated covers (5~50000)mL/min, with an extended uncertainty of 0.2%(k=2).

3. A comparison test

The standard devices used in the comparison are of the same accuracy grade, with an extended uncertainty of 0.2%(k=2). Standard piston provers of low gas flow and standard laminar of low gas flow are easy to carry with their portability. Three standard devices are placed in the same laboratory, so that the impact of the transfer standard during transportation will be reduced. The transfer standard should be stable and reliable with good repeatability. The piston-type gas flow calibrator of grade 1.0 is selected as the transfer standard, and three flow points with high flow rate, medium flow rate and low flow rate are selected for test.

The test system structure is shown in Figure 4. It is made up of nitrogen, pressure reducing valve, pressure regulator valve, flow control valve, transfer standard and low gas flow standard devices. These devices are connected in series.

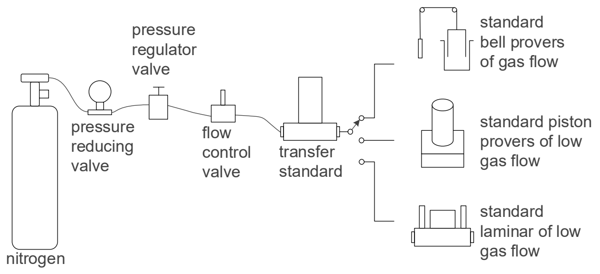

Figure 4: Test system structure.

The magnitude values of the three standard devices involved in comparison are independent of each other, and the uncertainty of magnitude values is the same, so that the arithmetic mean of the three measurement results is selected as the reference value of this comparison. In the comparison test, the reference value of the *i*th measurement point is denoted as Y_{ri}, with the equation as

$$Y_{ri} = \frac{1}{3}\sum_{j=1}^{3} Y_{ji} \tag{1}$$

j is the serial number of the standard device;
i is the serial number of the measuring point in the test;
Y_{ji} is the measurement result of the *j*th standard device at the *i*th measuring point.

The uncertainty of the three standard devices is not correlated with each other, and the influence of the uncertainty introduced by the transfer standard can also be ignored. Then the uncertainty of Y_{ri} follows as

$$u_{ri} = \frac{1}{3}\sqrt{\sum_{j=1}^{3} u_{ji}^2} \tag{2}$$

u_{ji} is the standard uncertainty of the measurement result of the *j*th standard device at the *i*th measuring point;
u_{ri} is the standard uncertainty of the reference value of the *i*th measuring point.

The consistency of measurement results is evaluated by normalized deviation E_n, which is the ratio of the difference between the measurement result of each standard device and reference value and the extended uncertainty of this difference. E_n results as

$$E_n = \frac{Y_{ji} - Y_{ri}}{ku_i} \tag{3}$$

k is the coverage factor, *k*=2 in general;
u_i is the standard uncertainty of (Y_{ji}-Y_{ri}) at the *i*th measuring point.

The comparison result is less affected by the transmission standard, then the uncertainty introduced by transfer standard at the *i*th measurement point in the comparison can be ignored. The magnitude value of the standard device is involved in the calculation of reference value, as the equation (2). So that u_{ri} and u_{ji} are strongly correlated. u_i can be written as

$$u_i = u_{ji} + u_{ri} \tag{4}$$

4. Analysis and discussion of comparison results

The transfer standard is tested on three standard devices in turn. The flow rate of the transfer standard is adjusted respectively to 50L/min, 5L/min and 0.5L/min, and the flow rate of three standard devices are measured. After multiple measurements, the arithmetic mean of a standard device at a flow point is shown in Table 1.

Table 1: Measurement results of standard devices (unit is L/min).

Flow Rate	Standard Bell Provers	Standard Piston Provers	Standard Laminar
50	49.875	49.862	49.784
5	4.9927	4.9906	4.9853
0.5	0.49826	0.49799	0.49715

The experimental data are analyzed and processed, and the results are shown in Table 2, Table 3 and Table 4.

Table 2: The result on the flow rate of 50L/min.

Reference Value and Uncertainty	Y_{r1}=49.840 L/min	u_{r1}=0.0365 L/min	
	(Y_{j1}-Y_{r1})/ L/min	**u_{j1}/ L/min**	**E_n**
Standard Bell Provers	0.0347	0.060	0.18
Standard Piston Provers	0.0217	0.065	0.11
Standard Laminar	-0.0563	0.065	-0.28

Table 3: The result on the flow rate of 5L/min.

Reference Value and Uncertainty	Y_{r2}=4.9895 L/min	u_{r2}=0.00373 L/min	
	(Y_{j2}-Y_{r2})/ L/min	**u_{j2}/ L/min**	**E_n**
Standard Bell Provers	0.00317	0.0063	0.16
Standard Piston Provers	0.00107	0.0066	0.05
Standard Laminar	-0.00423	0.0065	-0.21

Table 4: The result on the flow rate of 0.5L/min.

Reference Value and Uncertainty	Y_{r3}=0.49780 L/min	u_{r3}=0.000383 L/min	
	(Y_{j3}-Y_{r3})/ L/min	**u_{j3}/ L/min**	**E_n**
Standard Bell Provers	0.000460	0.00066	0.22
Standard Piston Provers	0.000190	0.00065	0.09
Standard Laminar	-0.000650	0.00068	-0.31

According to the above table, the normalized deviation E_n meets the formula as

$$\left|E_n\right| \le 1 \qquad (5)$$

So, the ratio of the difference between the measurement result of each standard device and reference value and the extended uncertainty of this difference is within reasonable expectations. The consistency of the comparison results is acceptable.

In order to display the comparison results more intuitively, the evaluation diagrams of the comparison results are shown in Figure 5, Figure 6 and Figure 7.

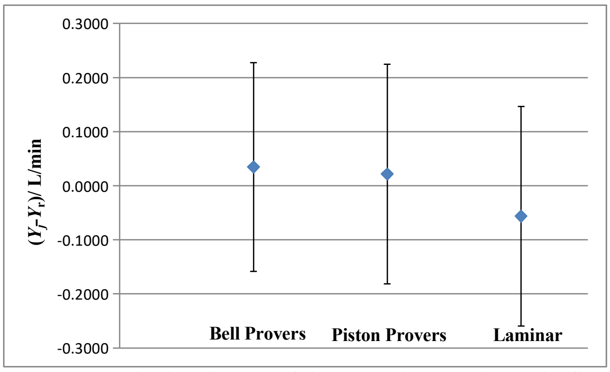

Figure 5: Evaluation diagram of the comparison results on the flow rate of 50L/min.

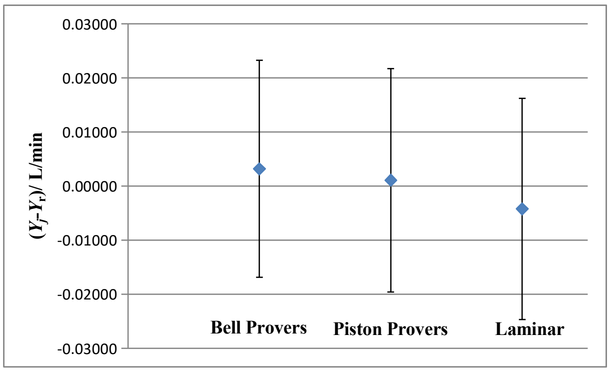

Figure 6: Evaluation diagram of the comparison results on the flow rate of 5L/min.

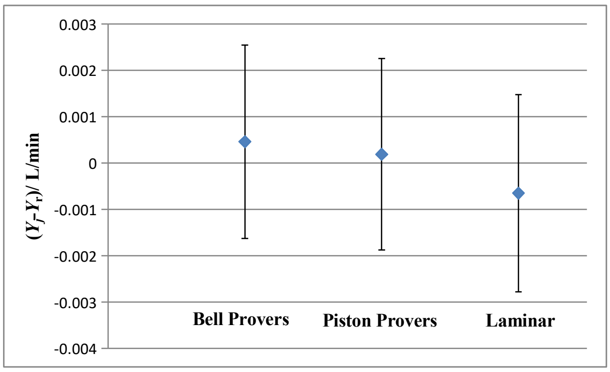

Figure 7: Evaluation diagram of the comparison results on the flow rate of 0.5L/min.

In the figure, the half-width of the error line of the numerical point is the extended uncertainty of the ordinate value, and the intersection of the error line and the horizontal line with ordinate 0 indicates that the consistency of the comparison result is acceptable.

5. Conclusion

Above all, this paper introduces three typical gas flow standards, and carries out comparative tests on three standard devices with the same accuracy grade. The consistency of measurement results is evaluated by normalized deviation E_n. The comparison results are acceptable which show that three typical standard devices are accurate and reliable. The accuracy of traceability of low flow gas flowmeter is guaranteed.

References

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