Design and uncertainty analysis of field service gas flow standard device based on standard meter method

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Abstract. This paper introduces the composition and working principle of field service gas flow standard device based on standard meter. Through the analysis of the uncertainty of the device and the verification of the measurement results, it is confirmed that the field service standard meter method gas flow standard device can be applied to the verification of the field gas flowmeter.

1 Introduction

Flow measurement is an important parameter in energy measurement, which is closely related to the development of national economy and people's life. From the gas meters, water meters and heat meters used for metering and charging in households, to the domestic import and export of crude oil and natural gas trade settlement, all are related to flow measurement. Therefore, the detection and calibration of gas flowmeter is the most important link in the flow value transmission or traceability, which is not only related to the economic interests of both sides of the trade, but also has very important social benefits for the development of China's national economy[1].

For the detection of gas flowmeter, sonic nozzle gas flow device, standard meter gas flow calibration device and bell type gas flow calibration device are generally used. These devices are generally large in volume and very heavy in weight. They need to be used in an open environment, and there is no way to ensure the temperature and pressure specified in the national regulations. And the sonic nozzle is used at a fixed point, so it can't adjust the flow continuously, so the desired flow point can't be calibrated[2]. When the gas flowmeter is sent for inspection, it needs to be sent to the address of the designated testing unit for offline detection. After detection, it can be retrieved. It usually takes one to two days to send it back and forth. In addition, the detection time is one week at the fastest before it can be installed on the device for use again, which greatly increases the shutdown time of the enterprise and reduces the production efficiency. How to shorten the testing time of laboratory testing device, save time for testing device users, improve production efficiency, and accurately test the flow parameter testing device has become a difficult problem in the field of quality inspection.

In this paper, on the basis of learning the advanced technology at home and abroad, we design the field service gas flow standard device based on standard meter method, for solving the problem of high-precision measurement and detection of gas flow parameter test device.

2 Overall design and principle of the device

This device mainly consists of Elster's Roots meter as standard meter, Elektror's fan, ABB frequency transformer and Rosemount's temperature and pressure transmitter. The controller unit adopts Advantech's industrial control host and NI's LabWindows / CVI upper computer development software. The software system of the device provides a simple and easy-to-use program for calibration. The work orders and verification parameters entered by the software system can be stored in the MySQL database, and the traceable calibration data can be stored locally through the database and word file format. Figure 1 is the system flow chart of the device. The negative pressure standard meter method is adopted in this device, and the design and verification basis is JG 643-2003 “Standard meter method flow standard device”. The designed flow range is 0.5 ~ 270 m³/h, which can be used to verify DN8 ~ DN80 gas flowmeter.
The control unit of the device is mainly composed of Advantech's IPC-900 industrial computer, PCI series board and Adam data acquisition module. The control structure is shown in Figure 2.

As the upper computer of the whole system, industrial computer is connected with Advantech's ADAM-4117 analog acquisition module, PCI-1753 interrupt control board and PCI-1780 high-speed counter board. Among them, ADAM-4117 module realizes the data acquisition function of the tested meter and temperature and pressure transmitter. PCI-1753 interrupt control board takes the pulse of the inspected meter and the standard meter as the external interrupt source, and starts and stops the pulse counting function. PCI-1780 high-speed counter card can count the pulse output of standard meter and tested meter, and start and stop the solenoid valve.

The device is a negative pressure standard device with air as the gas source. The tested flowmeter, standard flowmeter and fan are connected by pipelines and valves. The frequency converter regulates the flow stability through PID algorithm. When the set flow rate is stable, the control system starts to receive the signals from the standard flowmeter and the tested flowmeter, and measures the temperature and pressure at the standard meter and the tested flowmeter. At the end of the test, stop receiving the signals from the standard flowmeter and the tested flowmeter. The control system converts the volume of the standard meter into the volume of the tested flowmeter temperature and pressure condition, and finally obtains the metering performance of the tested flowmeter.

3 Uncertainty analysis

It can be seen from the composition and principle of the device that the combined uncertainty of the whole set of device mainly includes[3-4]: the uncertainty of the device which calibrate the standard flowmeter. The uncertainty of standard flowmeter. The uncertainty of temperature and pressure measurement, and the uncertainty of device timer. Table 1 is a list of measurement uncertainty of the whole set of devices.
Table 1. List of uncertainty of the whole set of device.

| Serial | Symbol | Source of uncertainty                      | Uncertainty |
|--------|--------|-------------------------------------------|-------------|
| 1      | Qs     | The device of calibrating the standard flowmeter | 0.08%       |
| 2      | Cf     | Fitting curve of standard flowmeter        | 0.086%      |
| 3      | Ts     | Standard flowmeter temperature transmitter | 0.03%       |
| 4      | Tm     | Tested flowmeter temperature transmitter   | 0.03%       |
| 5      | Ps     | Standard flowmeter pressure transmitter    | 0.043%      |
| 6      | Pm     | Tested flowmeter pressure transmitter      | 0.043%      |
| 7      | T      | Timer                                      | Ignore      |
| 8      | M      | Data acquisition and processing             | Ignore      |
| 9      | h      | Matching instrument                        | 0           |

Combined standard uncertainty $U_{cr} = 0.14\%$, Expanded uncertainty $U_{rel} = 0.28\%$ ($k=2$)

3.1 Uncertainty of the device of calibrating the standard flowmeter

The verification devices of calibrating the two standard flowmeters are bell type gas flow standard device $U_{rel}=0.06\%$, $K=2$, and critical flow Venturi nozzle method gas flow standard device $U_{rel}=0.16\%$, $K=2$ in Shanghai Institute of Metrology and testing technology. Therefore, the standard uncertainty of calibration standard device is $U_r(QS)=0.08\%$.

3.2 Uncertainty caused by fitting curve

The standard meter of the device is Roots flowmeter, which is not used at fixed point, and instrument coefficient is not used. According to the calibration certificate issued by Shanghai Institute of Metrology and testing technology, the measured flow qi and flow correction value $\Delta q_i$ are fitted to obtain the flow-flow correction value curve. The fitting curve data of the two standard tables are shown in Figure 3 and Figure 4 below.

Fig. 3. Fitting curve of DN50 standard flowmeter.

Fig. 4. Fitting curve of DN100 standard flowmeter.

For $n$ test points of the standard flowmeter, the flow indication value of the $i$ test point is $q_i$, and the indication error is $\Delta q_i$, $v_i = \Delta q_i-\bar{q}(q_i)$. The standard uncertainty caused by fitting curve is calculated as $u$ according to formula (1) $U_r(cf)$ were 0.0069% and 0.086% respectively. So the uncertainty caused by fitting curve is $U_r(cf)=0.086\%$.

\[
U_r(cf) = \frac{1}{\bar{q}_i} \sqrt{\frac{\sum (q_i - \bar{q})^2}{n-2}} * 100\% \quad (1)
\]

Where: $(q_i)$ is the mean value of the flow point of the standard flowmeter, m$^3$/h.

3.3 Uncertainty of temperature measurement at standard flowmeter and tested flowmeter

The maximum allowable error of the temperature transmitter used in the temperature measurement at the standard flowmeter and the tested flowmeter is $\pm 0.15\ ^\circ C$. According to the uniform distribution, if the gas temperature is $20\ ^\circ C$, the standard uncertainty of the temperature measurement of the standard flowmeter and the tested flowmeter is:

\[
U_r(Ts) = U_r(Tm) = \frac{0.15}{\sqrt{3} \cdot (273.15+20)} = 0.03\% \quad (2)
\]

3.4 Uncertainty of pressure measurement at standard flowmeter and tested flowmeter

The maximum allowable error of the pressure transmitter used for the pressure measurement at the standard flowmeter and the tested flowmeter is $\pm 0.075\%$. According to the uniform distribution, the uncertainty of the pressure measurement at the standard flowmeter and the tested flowmeter is:

\[
U_r(Ps) = U_r(Pm) = \frac{0.075}{\sqrt{3}} = 0.043\% \quad (3)
\]

3.5 Combined standard uncertainty of device

When the synchronous pulse counting method is used for pulse counting and verification timing, the error depends on the timer. If the verification time is 30 seconds, the timing accuracy can reach $10^{-4}\%$, so the uncertainty of the timer can be ignored, then $U_r(t)=0$. 
Because the standard flowmeter is calibrated together with the supporting instrument, the uncertainty of the supporting instrument is $U_r(\beta) = 0$.

In the standard device, data acquisition, signal processing, data processing and communication are all completed by computer and controller, which can achieve very high resolution. The main uncertainty is caused by digital to analog signal conversion, and the class B uncertainty is less than 0.01%, $U_r(m) = 0$.

In conclusion, the combined uncertainty of the standard device is as follows:

\[
U_{cr} = \sqrt{U_r(q_b)^2 + U_r(cf)^2 + U_r(Ts)^2 + U_r(Tm)^2 + U_r(Ps)^2 + U_r(Pm)^2} = 0.14\% \tag{4}
\]

If $k = 2$, the expanded uncertainty is as follows:

\[
U_{rel} = 2 \times U_{cr} = 2 \times 0.14\% = 0.28\%
\]

4 Repeatability test

A gas vortex flowmeter is selected as the measured object, the measurement range is 30 ~ 300 m$^3$/h, and the accuracy level is 1.5. Under the condition of repeatability, the device is used to repeatedly measure different measuring points for 10 times to obtain a group of data, and then the measurement repeatability is calculated by Bessel formula. The results are shown in Table 2.

Table 2. Repeatability test of gas flow standard device with standard meter method.

| Serial | Flow point m$^3$/h | Verification results of the device | Verification results of sonic nozzle | $y_{lab} - y_{ref}$ |
|--------|-------------------|-----------------------------------|-------------------------------------|---------------------|
| 1      | 30                | 29.59 100.22 199.98 269.69        | 31.988                              | 0.195               |
| 2      | 30                | 29.53 100.25 199.84 270.02        | 31.793                              | 0.297               |
| 3      | 30                | 29.50 100.17 199.75 270.10        | 266.190                             | 0.271               |
| 4      | 30                | 29.55 100.23 199.71 270.11        | 266.461                             |                     |
| 5      | 30                | 29.63 100.18 199.52 270.33        | 268.96                              |                     |
| 6      | 30                | 29.50 100.44 199.78 270.24        | 269.96                              |                     |
| 7      | 30                | 29.61 100.10 199.70 269.96        | 269.61                              |                     |
| 8      | 30                | 29.55 100.34 199.91 270.48        | 270.18                              |                     |
| 9      | 30                | 29.44 100.16 199.83 270.18        | 270.18                              |                     |
| 10     | 30                | 29.64 100.16 200.08 270.11        | 270.11                              |                     |
| average | 29.56 100.23 199.81 270.12 |                     |                     |                     |

Using the repeatability calculation formula, the repeatability data of the above 10 points were obtained as follows: 0.06; 0.10; 0.16; 0.21. Take the maximum value $S(y_i) = 0.21$ as the repeatability of the standard device, according to JJF 1033-2016 “measurement standard assessment specification”, the repeatability should be less than the combined standard uncertainty, the standard uncertainty of the device $U_{rel} = 0.28\%$, $S(y_i) < U_{rel}$, repeatability meet the requirements.

5 Verification of measurement results

The transfer comparison method is used to verify the measurement results [5]. A gas vortex flowmeter is selected as the measured object, the measurement range is 30 ~ 300m$^3$/h, and the accuracy level is 1.5. The tested measurement standard and the higher level measurement standard: This device, the measurement range is 0.5 ~ 270 m$^3$/h, the uncertainty of the device standard is $U_{lab} = 0.28\%$ (k=2); The sonic nozzle gas flow standard device of Zhejiang Diyuan Instrument Co., Ltd. has a measurement range of 5-4000 m$^3$/h, and the uncertainty of the device is $U_{ref} = 0.25\%$ (k=2). The results are shown in Table 3.

Table 3. List of uncertainty of the whole set of device.

| Flow point m$^3$/h | Verification results of the device | Verification results of sonic nozzle | $y_{lab} - y_{ref}$ |
|--------------------|-----------------------------------|-------------------------------------|---------------------|
| 30                 | 31.988                            | 31.793                              | 0.195               |
| 62.5               | 62.225                            | 61.928                              | 0.297               |
| 300                | 266.190                           | 266.461                             | 0.271               |

It can be seen from table 3 that $|y_{lab} - y_{ref}| \leq \sqrt{U_{lab}^2 + U_{ref}^2}$. Therefore, the verification result is satisfactory.

6 Conclusion

The occupied space of the device is reduced, but its performance can still meet the test requirements. All the main standards, supporting equipment and the whole set of devices on the device are traced by the national legal technical institutions, and the traceability results meet the design requirements of the test bench. By analyzing the uncertainty of the whole set of device and verifying the measurement results, it is proved that the device can be used for the verification of membrane gas meter, gas waist wheel flowmeter, gas turbine flowmeter and gas ultrasonic flowmeter. At the same time, due to the design of the roller, it can realize the on-site calibration service, save the standby time of the flow parameter test device, improve the use efficiency of enterprise laboratory equipment, and bring a significant increase in economic benefits; promote the development of China's flow measurement industry, improve the detection means of the flow parameter test device, promote the upgrading of the manufacturing industry, and produce positive social benefits.

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