

Remote Calibration Research of Large Flow Samplers

Wang Lei¹, Zhang Yinan², Liu Yuan¹, Meng Tao^{1*}

¹National Institute of Metrology, No. 18, East Road of North 3rd Ring Road, Chaoyang District, Beijing, China

²Nanjing Institute of Measurement and Testing Technology, Nanjing, China

E-mail (corresponding author): mengt@nim.ac.cn

Abstract

In recent years, calibration demands of automatic monitoring stations for atmospheric radiation environment in China are increasing. However, large flow samplers in monitoring stations are relatively large, so dismantling and transportation will result in significant cost. While the monitoring stations may be dozens or even hundreds of kilometers apart and the cost of field testing is too high, so the values couldn't be guaranteed. In this paper, a set of remote calibration device for large flow samplers based on master meter method is developed, which is a fully automated calibration system. Sealing test and mutual verification test of double master meters are designed. Besides, an intelligent video recognition system, a control terminal of field tests and a remote monitoring platform are built to fully guarantee authenticity and effectiveness of remote data.

Key Words: remote calibration, large flow samplers, master meter method, intelligent video recognition system, control terminal of field tests, remote monitoring platform

1. Introduction

In recent years, China has given strong support to environmental radiation monitoring and there are more and more automatic monitoring stations, which basically cover capital cities and main city-level administrative districts in China. National data center has been built to collect, process, analyze and display the data of automatic monitoring stations, forming a nationwide automatic monitoring network^[1-2].

Automatic monitoring stations are composed of one or more radiation monitoring equipments, sampling equipments, meteorological monitoring equipments, automatic data acquisition and control system, communication system, station house and infrastructure, etc.^[2]. Because large flow samplers in monitoring stations are relatively large with high failure rate, so dismantling and transportation will result in significant cost. While the monitoring stations may be dozens or even hundreds of kilometers apart and the cost of field testing is too high, so the values couldn't be guaranteed^[3]. At national conferences of radiation monitoring, technical personnel of radiation monitoring stations in various provinces have repeated requests for calibration of existing large flow samplers^[4].

The characteristics of calibration demands of radiation monitoring fields in China are clear. In addition to providing calibration service for samplers of hundreds of monitoring stations in China, it's necessary to reduce test cost and save labour. Remote calibration mode is the first choice. However, compared with traditional calibration

mode, it couldn't be confirmed whether the master meters and pipelines are in normal state after transportation and installation since metering professionals are not present. During the test, data may be disturbed. Besides, if human monitoring is also required, personnel costs are not saved. So how to ensure the authenticity and validity of the calibration tests and the accuracy of data in the whole process and save labour are key issues to be solved in this new calibration mode.

2. Design and implementation of calibration device

2.1 Overall architecture

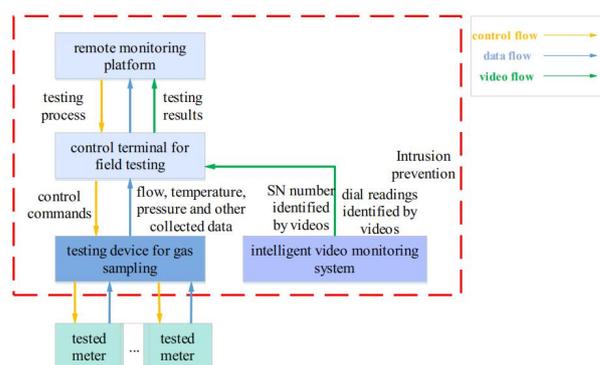


Figure 1: Overall architecture of remote calibration device for large flow samplers

As shown in Figure 1, a remote calibration device for large flow samplers is composed of a remote monitoring platform, a control terminal of field tests, an intelligent video monitoring system and testing device for gas sampling. Three kinds of data, which are control parameters, gas indicators and video streams are generated. The system should



be certified and calibrated by a testing institute before it is installed at field for remote calibration.

Firstly, tests could be automatically implemented by the testing device for gas sampling according to the process issued by the control terminal of field tests, including sealing test, mutual verification test of double master meters and calibration test. Secondly, monitoring automation is realized. In the intelligent video monitoring system, a handheld terminal is used to identify SN numbers of tested meters and a smart camera is used to identify the readings of the master meter. Besides, perimeter intrusion could be prevented to save labor. Thirdly, data processing automation is also realized. The remote monitoring platform sends calibration tasks

and related configuration parameters to the control terminal of field tests. It also receives test data and video recordings returned by the front-end testing system. Various front-end data are integrated to be analyzed in the background.

2.2 Testing device for gas sampling

The testing device for gas sampling, which is mainly composed of a master meter, a pressure transmitter, a temperature transmitter, quick connected flanges and pipelines, is used to collect test data. The schematic diagram of the device structure is shown in Figure 2.

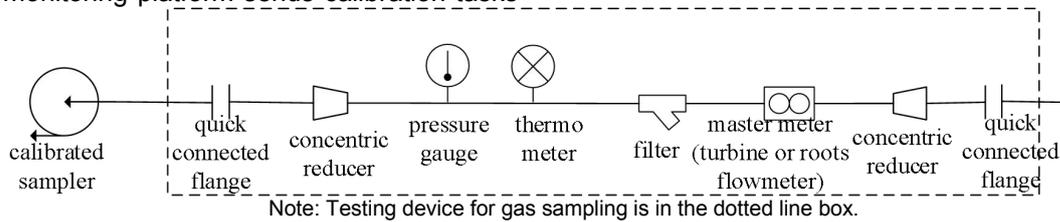


Figure 2: Schematic diagram of testing device for gas sampling

Table 1: equipments of testing device.

Equipments	Purpose	Measurement Range	Accuracy
turbine flowmeter	master meter 1	(80~1600) m ³ /h	1%
roots flowmeter	master meter 2	(0.5~25) m ³ /h	1%
roots flowmeter	verification meter	(1.6~250) m ³ /h	1%
digital pressure gauge	pressure gauge calibration test	5kPa full scale	0.2% FS
pressure transmitter	pressure gauge sealing test	(-100~100) kPa	0.1% FS
temperature transmitter	tube thermometer	(0-50) °C	0.1%

Generally, sampling devices of automatic monitoring stations for atmospheric radiation environment are mainly composed of ultra-large flow samplers and iodine gas flow samplers, whose diameters are DN150 and DN50, and measuring ranges are (480~1200) m³/h and (1.2~12) m³/h respectively. According to their flow ranges, DN150 and DN50 pipelines are designed. A turbine flowmeter and a roots flowmeter are chosen as master meters. Pipelines are composed of stainless steel pipe, flanges and quick clamps which are all made of 304 stainless steel. The connecting pipelines could be flexibly combined, meeting fast installation requirements of sealing test and mutual verification test of double master meters. The socket joint hose is used to connect the system and the tested sampler, which is not only easy to install and interfaces at different positions could be flexibly matched. According to the parameters of the tested sampler and test requirements, measurement range and accuracy of chosen equipments are shown in Table 1.

Testing pipeline for ultra-large flow samplers is shown in Figure 3 and the structure of testing pipeline for iodine gas flow sampler is similar.

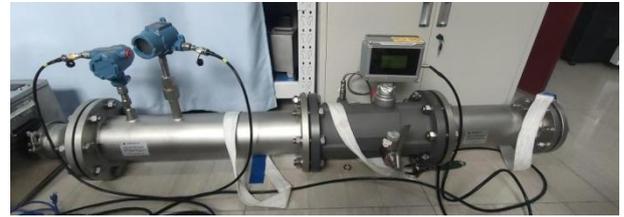


Figure 3: Testing device for gas sampling (Testing pipeline for ultra-large flow sampler)

Calibration tests are based on master meter method. The value of the master meter is used as reference. When the fluid passes through the master meter and the tested meter continuously in the same time interval, whose output flow values are compared to determine metrological performance of the tested flowmeter^[5-6]. The mathematical model of the standard flow is expressed as follows.

$$Q_{sm} = Q_s \cdot \frac{p_s}{p_m} \cdot \frac{T_m}{T_s} \quad (1)$$

Where, Q_s is flow rate of the master meter in the working condition, m³/h. When Q_s is converted to flow rate in the working condition of the tested meter, Q_{sm} is obtained, m³/h. p_m is the pressure of the tested meter, kPa. p_s is the pressure of the master meter, kPa. T_m is the temperature of the tested meter, K. T_s is the temperature of the master meter, K.

$$E = \frac{Q_m - Q_{sm}}{Q_{sm}} \times 100\% \quad (2)$$



Where, E is the relative indication error of the flow point, %. Q_m is the flow rate of the tested meter, m^3/h .

Eq. (1) is substituted into Eq. (2), expressed by Eq. (3).

$$E = \frac{Q_m}{Q_s} \cdot \frac{p_m}{p_s} \cdot \frac{T_s}{T_m} - 1 \quad (3)$$

2.3 Communication, measurement and control system

The network communication architecture is shown in Figure 4. A complete test process is started by the remote monitoring platform and executed by the control terminal of field test. Data such as gas flow, temperature and pressure are collected automatically by the flow test unit. The intelligent video monitoring system is used to guarantee the whole test process and give the test results to the remote monitoring platform. The results are analysed comprehensively and judged by the remote monitoring platform.

Data acquisition and control system is shown in Figure 5. Signal outputs are all connected to the control box, such as the temperature transmitter, the pressure transmitter, the master meter, the

verification meter and so on. Two-circuit digital meter MIK-2200-JDH is used to collect and process the current signals of the temperature transmitter and the pressure transmitter. The processed data are transferred to the serial server MOXA Nport5650-8. One control system is shared by two pipelines.

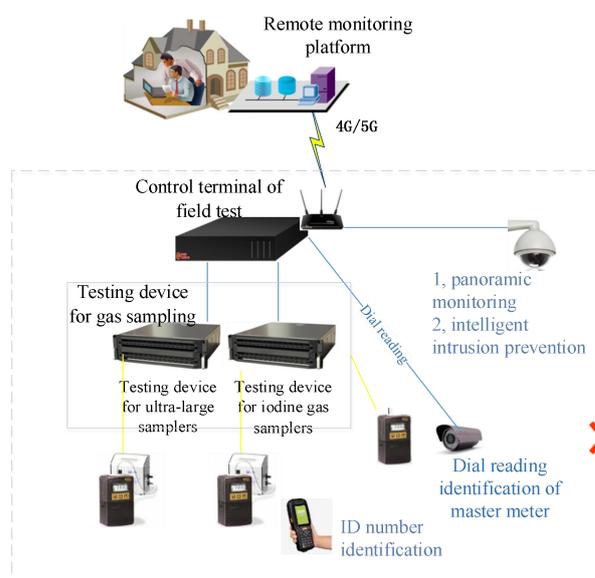


Figure 4: Network communication architecture

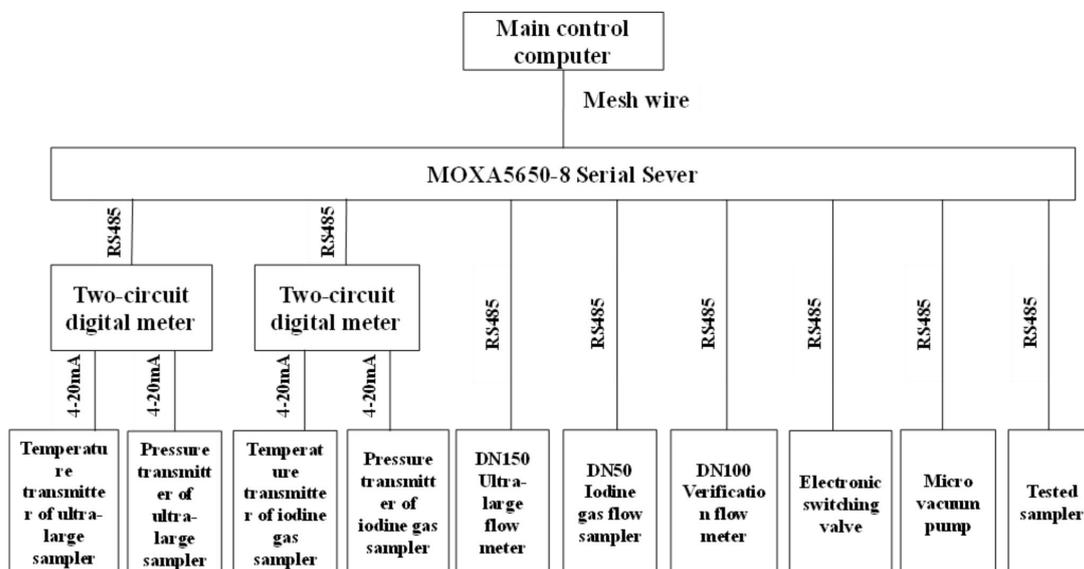


Figure 5: Electrical wiring diagram

3. Intelligent automation technology

There are no metering professionals on the site, leading to some difficulties. Firstly, it couldn't be confirmed whether there is air leakage in the pipeline and whether the master meters are damaged after transportation and installation, resulting in unreliable displayed data. During the test, it couldn't be confirmed whether there is

human intervention on the device on the site and transferred data, so that the validity of data couldn't be guaranteed.

In order to solve above problems, sealing test, mutual verification test of double master meters and the intelligent video monitoring system are added. As shown in Figure 6, technical process is set in the testing device for gas sampling and the relevant tests could be finished automatically. During the process, except for connecting the



mechanical pump with quick connected clamps and connecting the verification meter, the rest is fully automatic. If there is any abnormal situation, the remote monitoring platform will receive the alarm and metering professionals could view real-

time videos or video files with abnormal situations. Finally, data are analysed and the test results are judged.

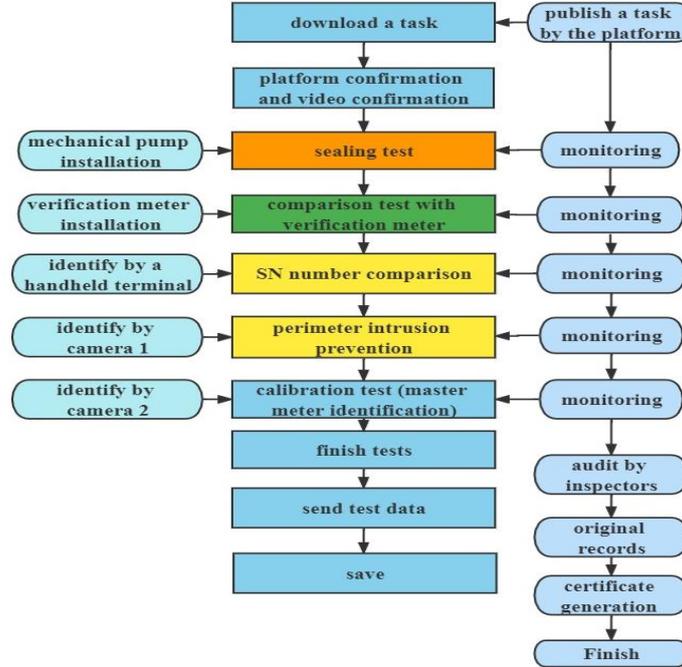


Figure 6: Task flow diagram of remote calibration

3.1 Sealing test

In order to solve air leakage during transportation and installation, it is necessary to do sealing test before calibrating. The quick connected blind plate at the upstream is pre-installed with the quick

connected clamp. The blind plate at the downstream is welded with a fast joint, directly connected to the electric switching ball valve. A micro brushless vacuum pump is installed after the ball valve. Quick connection could be realized for sealing test and the schematic diagram is shown in Figure 7.

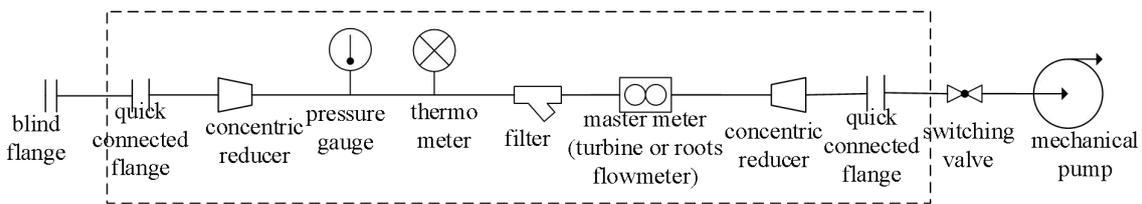


Figure 7: Sealing test status

According to the pumping speed and device condition, the pipeline pressure could be pumped to (-60~-65) kPa in one minute. According to Bernoulli's equation, the greater the differential pressure, the greater the leak rate. In the actual calibration test, the pipeline pressure is within -1kPa. In order to calculate the limit, the pressure is taken as -65 kPa. Besides, the temperature difference in the pipeline is much less than 2°C and 2°C is taken for calculation. Minimum flow point 3m³/h is taken as the calibrated point for limit calculation. The relative error δ could be calculated by Eq. (4).

$$\delta = \frac{q_{L,m}}{q_m} = \frac{m_1 - m_2}{\rho \times q_N} = \frac{(P_2 - P_1) \times V \times T_N \times \rho_N}{\rho \times q_N \times p_N \times t} \quad (4)$$

Where, p_1 is the pressure before air leakage, Pa. p_2 is the pressure after air leakage, Pa. T_1 is the thermodynamic temperature before air leakage, K. T_2 is the thermodynamic temperature after air leakage, K. V is the volume of the pipeline, m³. p_N is the pressure in the standard condition, $p_N=101325$ Pa. T_N is the thermodynamic temperature in the standard condition, $T_N=293.15$ K. ρ_N is the air density in the standard condition (ρ_N ,



T_N), $\rho_N=1.205\text{kg/m}^3$. t is leak detection time and 60s is taken. $q_{L,m}$ is the leak rate per unit time, kg/s. q_m is the mass flow in the test condition, kg/s. ρ is the air density in the actual temperature, kg/m³. q_N is the instantaneous flow in the test condition and minimum flow 3m³/h is taken.

After time t , the pressure difference is expressed as follows.

$$\Delta p = p_2 - p_1 \quad (5)$$

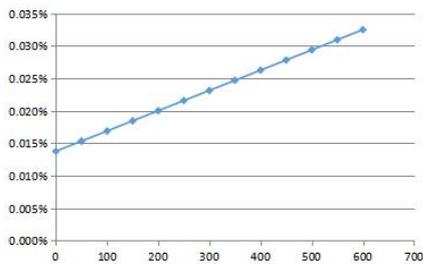


Figure 8: Graph of leakage pressure and the relative error
As shown in Figure 8, the relation curve between the pressure difference and the relative error could

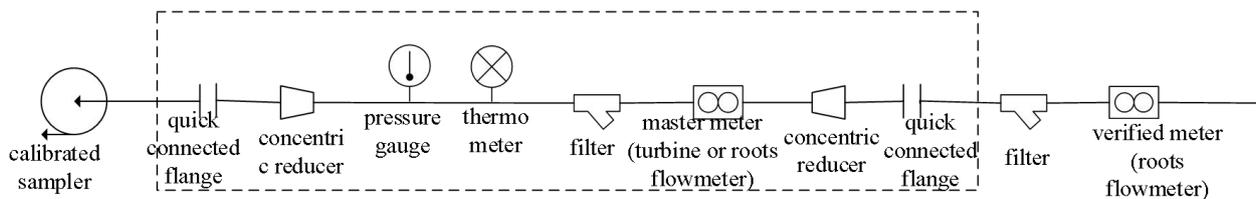


Figure 9: Mutual verification of double master meters

When receiving a remote calibration task, the master meter and the verification meter should be calibrated in the laboratory firstly and the results should be consistent at the target verification point. On the site of remote calibration, the verification meter and the tested sampler are connected for verification test after sealing test and before calibrating. Select a specific flow point, start the tested sampler, read data of the master meter and the verification meter after stabilization, and make judgements. The allowable variation of the master meter and the verification meter is 1.5%, and the criterion is referred to Eq. (6).

$$\left| \frac{Q_1 - Q_2}{Q_1} \right| \leq 1.5\% \quad (6)$$

Where, Q_1 is the flow of the master meter, m³/h. Q_2 is the flow of the verification meter, m³/h.

3.3 Intelligent video monitoring system

During the remote calibration, although metering professionals are not present, the task of monitoring is still very difficult. Firstly, SN number of the tested meter should be confirmed to prevent malicious replacement. Secondly, it is necessary to monitor whether the data of the master meter are

be obtained. It could be seen that if the leakage is 200 Pa (on X-axis), the relative error is 0.02% (on Y-axis). In the actual test, the indicators are much better. Therefore, the leakage of 200 Pa has far less influence than 0.02%.

3.2 Verification test of double master meters

After sealing test, the vacuum pump and the switching valve are removed. The verification meter is installed to replace the blind plate. The quick connected blind plate at the upstream is replaced with the quick connected dead end, whose hose is directly connected to the outlet of the sampler to begin verification test. The schematic diagram is shown in Figure 9. Mutual verification could be realized at the typical flow rate within the measurement range of the master meter and the verification meter to ensure that there is no abnormality in the transportation and installation and verify the validity and accuracy of process data.

normal. The transmitted data shouldn't be tampered. Thirdly, human intervention needs to be monitored throughout the test to prevent unreliable data.

Intelligent video monitoring system could be not only used to ensure the safety of the test process, but also save labour, playing an important role.

- (1) SN number of the tested meter is obtained by a handheld terminal and used to be compared with SN number read by the protocol, confirming the identity of the tested meter and ensuring the authenticity and validity of calibration.
- (2) Through digital recognition technology, the readings of the master meter are compared with the displayed data of the dial. The real-time data curve is monitored to detect abnormalities in time and ensure the accuracy of test data.
- (3) Perimeter intrusion prevention is realized to prevent human intervention, tampering of physical connection of equipments and other violations during the test process, thereby



ensuring the reliability of the testing process and data.

4. Test results

4.1 Sealing test

The mechanical pump and the electronic control valve are connected as shown in Figure 6. Taking the pipeline of the gas iodine sampler as an example, to obtain a higher pipeline pressure, the pressure sensor is replaced with another one, whose model is 3051GP and the measurement range is (-100~100) kPa. Open the switching valve, start the mechanical pump for 1 minute, then close the switching valve. Read the initial displayed value of the pressure transmitter after being stable for 1 minute. Then read the end displayed value again after keeping for 1 minute. The first pressure is -65.858kPa and the second pressure is -65.848kPa, whose difference is 10Pa, meeting the requirements.

4.2 Verification test

After installing the verification meter, start the tested sampler. The data of the master meter and the verification meter are collected at the same time and the results are shown as follows, meeting the requirements.

Table 2: Verification test data.

Master meter (m ³ /h)	Verification meter (m ³ /h)	Relative deviation (%)
9.46	9.52	0.7
14.50	14.59	0.6

4.3 Calibration test with a simulated sampler

Due to limited field conditions, a standard bell prover is used to simulate the tested meter. The target gas sampler is (1.2~12) m³/h, so 12m³/h is used as the calibration point. The results are shown as follows.

Table 3: Calibration test data.

Simulated meter (standard bell prover)			Master meter (pipeline of iodine gas flow samplers)			Qsm (m ³ /h)	E %
Flow (m ³ /h)	Temperature (°C)	Pressure (kPa)	Flow (m ³ /h)	Temperature (°C)	Pressure (kPa)		
12.14	26.3	0.02	12.12	27.3	0.02	12.08	0.5

5. Uncertainty evaluation

The mathematical model is established according to the flow error formula of the sampler, as shown in Eq. (2). The specific evaluation method is referred to Reference [7]. The uncertainty introduced by the standard flow is 0.62%, as detailed in Table 4^[8-9].

Table 4: List of uncertainty components introduced by standard flow

No.	Sign	Source	Relative standard uncertainty $u_r(X_i)$	Sensitivity coefficient $c_i(x_i)$	$ c_i(x_i) \cdot u_r(x_i)$
1	$u_r(Q_s)$	Superior standard flow on working condition	0.5%	1	0.5%
2	$u_r(T)$	Temperature difference between master meter and tested meter ^[10]	0.34%	1	0.34%
3	$u_r(p_s)$	Pressure of master meter ^[11]	0.08%	1	0.08%
4	$u_r(p_m)$	Pressure of tested meter	0.05%	-1	0.05%

The combined uncertainty and the expanded uncertainty are shown in Table 5.

Table 5: List of the source of measurement uncertainty

Number	Sign	Source	Relative standard uncertainty $u_r(X_i)$	Sensitivity coefficient $c_i(x_i)$	$ c_i(x_i) \cdot u_r(x_i)$
1	$u_r(S_r)$	Repeatability ^[12]	0.02%	1	0.02% (ignored)
2	$u_r(Q_r)$	Resolution of tested meter	0.024%	1	0.024%
3	$u_r(Q_m)$	Standard flow	0.62%	-1	0.62%

The combined uncertainty is calculated by Eq. (7).

$$u_{rel} = \sqrt{\sum_{i=1}^n [c_i \times u_r(x_i)]^2} = 0.62\% \quad (7)$$

Therefore, the expanded uncertainty is calculated as follows.

$$U_{rel} = 1.3\% \quad (k=2) \quad (8)$$

6. Conclusion

The remote monitoring platform, the control terminal of field test, the intelligent video monitoring system and the testing device for gas sampling are used to remotely and automatically complete sealing test, verification test, flow accuracy test, flow stability test, calibration tests and so on, fully guaranteeing the security, authenticity and effectiveness of remote calibration. The uncertainty level of the whole device is $U_{rel}=1.3\%$ ($k=2$), meeting the requirements of field calibration.

The application of remote calibration device enables field testing to be fast and convenient and quantity traceability could be completed without metering professionals at present, saving the cost. Remote calibration will play an irreplaceable role in the traceability of large-flow samplers in the automatic monitoring stations for atmospheric radiation environment.

Acknowledgment

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