FLOMEKO 2022

Performance Improvement of Stack Simulator

L Zhang[1], H Guo[2], G Lu[2], Y Chen[2]

[1]National Institute of Metrology, No.18 Beisanhuandonglu, Chaoyang District, Beijing, China
[2]Zhengzhou Institute of Advanced Metrology Technology, Zhengzhou, China
E-mail (corresponding author): zhangliang@nim.ac.cn

Abstract

In order to improve the performance of the old Stack Simulator, NIM built two new facilities. One is a close loop wind tunnel, which can simulate the real flue gas conditions. The wind tunnel can change the flow rate, temperature, pressure, gas composition and turbulence in the test section. It is used to calibrate the velocity measurement devices such as three-dimensional pitot tubes used in Relative Accuracy Test Audit (RATA). Another facility is a new Stack Simulator, which can simulate the flow field conditions in the real stack. It is used to evaluate the average velocity measurement of RATA devices.

1. Introduction

Stack or duct is the main emission path of exhaust gas in industrial, commercial, residential and other fields. In order to realize the supervision and control of air pollutants or greenhouse gas emissions from them, Continuous Emission Monitoring System (CEMS) is usually installed on stack or duct [1]. The accuracy and reliability of monitoring data are ensured through regular calibration of CEMS [2]. The RATA of the U.S. Environmental Protection Agency (EPA) is a method for periodic calibration of stack CEMS, including flowmeters [3]. Due to the great difficulty of flow measurement in complex flow field, it is usually impossible to get a low uncertainty measurement result. Therefore, the same procedure is used for calibration of flowmeter in different stack to ensure that the flow measurement values after calibration are relatively accurate (but not necessarily accurate in practice). The stack test in China is usually based on the environmental protection standard HJ397, which is similar to the EPA method. Due to the lack of a real traceability system, the accuracy of stack flowmeter after calibration is difficult to be guaranteed [4].

Therefore, the National Institute of Standards and Technology (NIST) took the lead in building a Smoke Stack Simulator (SMSS), which is a scaled model of the real stack. The SMSS can provides low uncertainty standard flowrate and simulate real flow field to test different stack flowrates [5]. On the basis of cooperation with NIST, National Institute of Metrology, China (NIM) has developed the first smoke stack simulator in China. Combined with the independently developed on-site stack flowrate calibration facility, a stack flowrate tractability system from the laboratory to the field is established, and the uncertainty of on-site flowrate calibration is greatly improved from more than 30% to lower than 5%. On this basis, NIM developed a new Smoke Stack Simulator and a Stack Velocity Standard Facility, the calibration capabilities were further improved.

2. New Smoke Stack Simulator

2.1 Facility introduction

In April 2020, NIM technical team built a new SMSS. The facility is equipped with test sections with different shapes and sizes to simulate the geometric characteristics of the actual stack. The maximum length of the test section is more than 60 meters, and the flowrate calibration range is 900~190000 m³/h. Combined with the high-precision optical primary measurement system, the flowrate uncertainty of SMSS can reach about 4.3 ‰.

Figure 1: New Smoke Stack Simulator.

2.2 Uncertainty evaluation

The SMSS uses a high-precision optical primary measurement system to obtain the primary flowrate. This paper evaluates the SMSS flowrate measurement uncertainty. The SMSS flowrate measurement uncertainty mainly comes from the uncertainty of Laser Doppler Velocimeter (LDV) average velocity measurement, the uncertainty of pipe radius measurement and the uncertainty caused by temperature and pressure correction.

2.3 Uncertainty of LDV average velocity measurement

The uncertainty of LDV single point velocity measurement is mainly composed of the uncertainty of LDV interference fringe spacing and the repeatability of velocity measurement. That is:

$$u_{\mathrm{LDV}} = \sqrt{u_{\mathrm{int}}^2 + u_{\mathrm{rep}}^2} \qquad (1)$$

2.3.1 Uncertainty of LDV interference fringe spacing u_{int}

The uncertainty of LDV interference fringe spacing is calibrated by the spinning disk, and the fringe spacing of LDV is obtained by dividing the rotating speed of the disk by the Doppler frequency measured by LDV. In the actual measurement process, the speed direction measured by the LDV is not completely perpendicular to the tangent direction of the edge of the disk, but there is a small angle β. In addition, there are other influencing factors that will affect the uncertainty of the system, such as the stability of the laser wavelength, the stability of the swing of the spinning disk when running at high speed, etc. these additional influencing factors need to be taken into account when evaluating the uncertainty of the LDV. The relative standard uncertainty of LDV interference fringe spacing is 0.211% after calibration by the spinning disk of NIM.

2.3.2 Uncertainty of the repeatability of velocity measurement u_{rep}

The repeatability of velocity measurement is the standard deviation of the average value of velocity measured at each measuring velocities. The relative standard deviation values at different measuring velocities are different, and the maximum value of different measuring velocities is taken as the repeatability of LDV flow rate measurement.

2.3.3 Uncertainty of average velocity u_d

When LDV is used to scan and measure the average velocity in the reference section of the facility, the cross-sectional area of the pipe is divided into 80 equidistant rings from outside to inside, and the weighted coefficient of each ring is calculated. According to the uncertainty of single point velocity measurement in each ring, the uncertainty of average velocity is calculated using weighted coefficient multiply the uncertainty of corresponding point velocity measurement.

2.4 Uncertainty of pipe radius measurement u_r

The uncertainty of radius measurement is obtained by combining the repeatability of radius measurement results and the uncertainty of laser tracker itself. According to the calibration certificate, when measuring the pipe radius, the measurement uncertainty of laser tracker absolute ranging (ADM) is 6.3 × 10-6, which can be ignored.

2.5 Uncertainty caused by temperature and pressure correction

When LDV measurement standard flowrate is used to calibrate the flowmeter in the test section, the measurement uncertainty of temperature and pressure correction should also be considered.

According to the calibration certificate, the measurement uncertainty of the digital barometer is:

$$u_{\mathrm{p}} = 0.02\%,\ k=2$$

Similarly, the uncertainty of temperature measurement is:

$$u_T = 0.064\%,\ k=2$$

2.6 Flowrate measurement uncertainty of SMSS

To sum up, the uncertainty of flow measurement through LDV point by point scanning is:

$$u_{\mathrm{F}} = \sqrt{u_{\mathrm{int}}^2 + u_{\mathrm{rep}}^2 + u_d^2 + u_r^2 + u_p^2 + u_T^2} \qquad (2)$$

It is calculated that the relative expanded uncertainty of the device is 0.43% (k=2).

3. Stack Velocity Standard Facility

3.1 Facility introduction

Stack Velocity Standard Facility is a close loop wind tunnel, which can adjust the temperature, pressure, turbulence and gas components, simulate the actual stack environment. The facility can calibrate the 3D pitot tubes and other stack velocity measurement instruments under simulated flue gas conditions, and evaluate the impact of real stack gas conditions on the velocity measurement. The velocity range of the test section is 0.5~70m/s and it can change more than five gas components. The temperature adjustment range is room temperature to 200 °C, and the relative expanded uncertainty of the simulated stack gas velocity is 0.52%.

Figure 2: Stack Velocity Standard Facility.

3.2 Uncertainty evaluation

Stack Velocity Standard Facility uses LDV as the velocity standard, and the measured velocity is corrected to the value under standard conditions through the measurement of temperature and pressure parameters. Since the meter under test will be placed in the central area of the test section, the uniformity of velocity in the central area will also introduce measurement uncertainty.

The analysis shows that the uncertainty of velocity measurement is mainly caused by the uncertainty of LDV single point velocity measurement, the uniformity of velocity in the test section, the uncertainty of static pressure measurement and the uncertainty of temperature measurement.

3.2.1 Uncertainty of LDV single point velocity measurement u_{LDV}

The uncertainty of LDV single point velocity measurement mainly consists of two parts: the uncertainty of interference fringe spacing and the repeatability of velocity measurement. Among them, the repeatability of velocity measurement takes the maximum value of repeatability under each measurement velocity, and the value obtained from the test is 10-4, which is ignored. Therefore, the combined standard uncertainty of LDV single point velocity measurement is 0.211%.

3.2.2 Uncertainty of static pressure measurement u_{ps}

The static pressure of the test section is measured by the digital pressure gauge. According to the calibration certificate, the measurement standard uncertainty of the digital pressure gauge is:

$$u_{ps} = \frac{0.01\%}{\sqrt{3}} = 0.006\%$$

3.2.3 Uncertainty of temperature measurement u_t

The same, according to the certificate, the uncertainty of temperature measurement standard is:

$$u_t = \frac{0.15}{2*300} = 0.025\%$$

3.2.4 Uniformity of velocity in the test section u_R

In this paper, the velocity uniformity test is carried out at room temperature, and the velocity measurement points including 0.5m/s, 1m/s, 3m/s, 5m/s, 10m/s, 15m/s, 20 m/s, 25m/s, 30 m/s respectively. The velocity measurement is carried out in the designated central measurement area. 10 samples are taken at the location of the measurement points at each velocity to calculate the uniformity. Take the maximum value of uniformity under different velocity as the flow velocity uniformity. After measurement, the uniformity of velocity is 0.15%.

3.2.5 Uncertainty of velocity measurement u_v

Since each uncertainty component is independent of each other, the relative standard uncertainty of velocity measurement is synthesized according to the following formula:

$$u_v = \sqrt{u_{\mathrm{LDV}}^2 + u_{ps}^2 + u_t^2 + u_R^2} \quad (3)$$

According to the calculation, the relative expanded uncertainty of velocity measurement of Stack Velocity Standard Facility is 0.52% (*k*=2).

4. Conclusion

NIM has developed new SMSS and Stack Velocity Standard Facility, with the uncertainty of flowrate measurement and velocity measurement reaching 0.43% (*k*=2) and 0.52% (*k*=2) respectively, setting a foundation for improving the accuracy of stack flowrate measurement in China.

Reference

[1] Gao W. Continuous Emission Monitoring System (CEMS) Technologies and Application[J]. CHINA INSTRUMENTATION. 2009(1):43-47.

[2] Wang Q, Xu F. Discussion on Continuous Emission Monitoring System (CEMS) and Comparison Testing[J]. JOURNAL OF EMCC. 2013,23(6):57-60.

[3] H Zheng, T Guo. Relative Accuracy Test Audit Evaluation for Flue Gas Continuous Emission Monitoring Systems in Power Plant[C]. Workshop on Computational Intelligence & Industrial Application. Wuhan, China, 2008.

[4] Zheng HM, Cai XS. Relative Accuracy Test Evaluation for Flue Gas Continuous Emission Monitoring Systems[J]. ACTA METROLOGICA SINICA. 2007,28(1):85-88.

[5] Aaron N. Johnson, Joey T. Boyd, *et al*. Design and Capabilities of NIST's Scale-Model Smokestack Simulator (SMSS)[C]. 9th ISFFM. Arlington, Virginia, 2015.