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# Application of 3D laser scanner and total station in measurement of flue structure parameters of power plants

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**Abstract.** The quantity of the greenhouse gas emissions from stationary sources is an important indicator of air pollution monitoring. Real-time monitoring of the quantity of greenhouse gas emissions from a stationary source can be achieved by measuring its instantaneous flow rate and carbon oxide emission concentration. Flow rate measurement of stationary emission sources mainly uses velocity-area method. How to ascertain the structural parameters of stationary emission sources is a prerequisite to ensure the accuracy of instantaneous flow rate measurement. Two methods for measuring the flue structural parameters are presented in this paper. By laying the observation site around the flue, the total station can obtain the structural parameters of every external parts of the flue. Under the condition of the known wall thickness of the flue, the internal structure parameters can be calculated. In addition, if the flue has the entrance left for the surveyor, the 3D structure model of the flue can be directly obtained by using the 3D laser scanner with the assistance of the target ball. In this paper, the above two methods are used to measure the structure parameters of a flue in a coal-fired power plant in Henan. The results of the two methods are in good agreement.

## 1. Introduction

In recent years, greenhouse gas emissions have attracted wide attention from the people and government. With the development of economy and society, China is playing an increasingly important role in reducing greenhouse gas emissions in the international community. The environmental regulatory authorities propose that greenhouse gas emissions should be "measurable, reportable and verifiable". Under this background of environmental protection, greenhouse gas emissions from stacks and flues are requested to be measured accurately.

## 2. Brief introduction of gas flow rate measurement

At present, the "Determination of particulates and sampling methods of gaseous pollutants emitted from exhaust gas of stationary source" and "Technical specifications for emission monitoring of stationary source" are the main basic regulations for the sampling and monitoring of air pollutants in China. The mass chromatograph analyzer and the flue gas analyzer are the mainly two kind devices used in the measurement of the emission concentration of carbon oxide while the instantaneous flow rate measurement mainly depends on the pitot tube or ultrasonic flowmeter. Due to the complicated flow field and boundary layer effect in the flue, it is necessary to carry out division and multipoint measurement of the measured cross section in order to obtain better representativeness of flow rate. While using the ultrasonic flowmeter, multi-path ultrasonic flowmeter is highly recommended, so as



to obtain the flow velocity in different height of the flue, then the gas flow rate through a certain section of the flue within a certain period of time is calculated by a given integral method.

### *2.1 Pitot tube measurement method*

According to EPA 1 "SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES", EPA 2 "DETERMINATION OF FLUE GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)" proposed by U.S. Environmental Protection Agency[1, 2] and "Determination of particulates and sampling methods of gaseous pollutants emitted from exhaust gas of stationary source" released by Ministry of environmental protection, People's Republic of China, the S-type pitot tube is mainly used in measurement of gas flow rate by air pollution emission enterprises and regulators. For the pitot tube measurement method there are four main factors including the flow velocity representativeness, the integration algorithm, the flow field distribution of the measured flue and the area of the measured cross section affecting the measurement results. In addition, consideration should also be given to the accuracy of the pitot tube and the differential manometer connected to it.

### *2.2 Ultrasonic flowmeter measuring method*

In recent years, with the development of ultrasonic speed measurement technology, the method of ultrasonic flowmeter in flue gas flow rate measurement has been paid more attention. The ultrasonic flowmeter applies the principle that the difference of propagation velocity of ultrasonic wave between upstream and downstream is related to the velocity of the medium. So the velocity of the medium can be obtained by ultrasonic time difference method, and then the instantaneous flow rate through a certain cross section can be acquired by velocity-area method. The ultrasonic flowmeter can be subdivided into single path ultrasonic flowmeter and multi-path ultrasonic flowmeter according to the number of ultrasonic paths. While, it also can be subdivided into pipe ultrasonic flowmeter and insert type ultrasonic flowmeter according to the installation of probe. The insert type ultrasonic flowmeter is suitable for the field condition of large size or heterotype in cross section area where pipe ultrasonic flowmeter cannot install in the measured pipeline directly, so the insert type ultrasonic flowmeter is usually used in the measurement of the flow rate of the flue gas. Secondly, because of the progress in the research of integration algorithm, in order to get better representativeness of flow velocity, multi-path ultrasonic flowmeter is more and more applied in the actual measurement. In order to accurately calculate the integral weight of each ultrasonic path, it is particularly important to get the structural parameters of the tested flue section.

In summary, in the process of flue gas flow rate measurement, whether using the traditional pitot tube or multi-path ultrasonic flowmeter, it is necessary to acquire the structural parameters of the measured pipeline in the velocity-area flow rate measurement method.

## **3. Measurement method of flue structure parameters**

In practice, we use the two instruments of total station and 3D laser scanner to measure the flue structural parameters. The total station is mainly used to measure the external structure parameters of the flue. The flue is divided into several parts, and the measuring site is set around the flue reasonably. The structure parameters of each part are spliced to get the overall outer structure parameters of the measured flue. The 3D laser scanner mainly carries out the internal dimension measurement, obtains the interior space point-cloud through the target ball assistance and the different measuring sites, and then the 3D space model in the flue can be directly depicted after the postprocessor and data filtering.

### *3.1 Total station measuring method*

Total station is an engineering surveying instrument developed on the basis of electronic theodolite in recent years. It combines electronic theodolite, rangefinder and microcomputer organically. After selecting the station site, it can directly give the 3D coordinates of the space measured points and automatically store them [3, 4]. Compared with traditional electronic theodolite, it has the

characteristics of simplicity in operation, high degree in automation, and strong adaptability in complex measurement environment [5].

*3.1.1 The principle of total station measuring method. The principle of 3D geometric measurement with total station is essentially the process of expressing unknown coordinates of space points by using known coordinates of total station site. The relationship between two points in space can be expressed by the angle, distance and height difference of the two points measured by the total station. Suppose the fixed eyepiece coordinates of the total station are A ( $X_1, Y_1, Z_1$ ), and the coordinates of the measured points are B ( $X_2, Y_2, Z_2$ ), while ( $x, y, z$ ) are the coordinates of vector  $\overrightarrow{AB}$ . The mathematical relationship between them are shown as follows:*

$$x = S \sin V \cdot \cos H \quad (1)$$

$$y = S \sin V \cdot \sin H \quad (2)$$

$$z = S \cos V \quad (3)$$

$$S^2 = x^2 + y^2 + z^2 \quad (4)$$

$$\tan H = -\frac{y}{x} \quad (5)$$

$$\cos V = \frac{z}{S} \quad (6)$$

$$\begin{aligned} x &= X_2 - X_1 \\ y &= Y_2 - Y_1 \end{aligned} \quad (7)$$

$$z = Z_2 - Z_1$$

$S$  is the distance between the known total station site and the unknown measured points.  $V$  is the horizontal angle obtained by the total station observing the measured points from total station site.  $H$  is the zenith distance from the total station to the measured point. Then, through the above 7 formulas, the coordinates ( $X_2, Y_2, Z_2$ ) of the measured point B can be obtained in the case of the coordinates ( $X_1, Y_1, Z_1$ ) of the eyepiece point A is known.

*3.1.2 The realization of total station measuring method.* The total station structural parameters measurement is mainly realized according to the following procedure. First, the location of the total station observation sites should be chosen in a reasonable way according to the location of the measured flue. The principle is to include the overall structural elements of the measured flue with the least observation sites. When observing the location of measured points from the observation sites, the light and field of vision should be as wide as possible. According to the principles, 6 positions of the front, back and side of the flue are selected as the observation sites of the total station. All the coordinates of measured points and the corresponding structural parameter are acquired respectively, and then they are transferred to the same coordinate system. Finally, the length, width and height of the measured flue section are 24620mm, 5080mm and 9140mm respectively. Figure 1 is the photo of the measured flue in Henan. Fig. 2 is a structural diagram with the outer parameters of the flue (including the installation of the flowmeters).

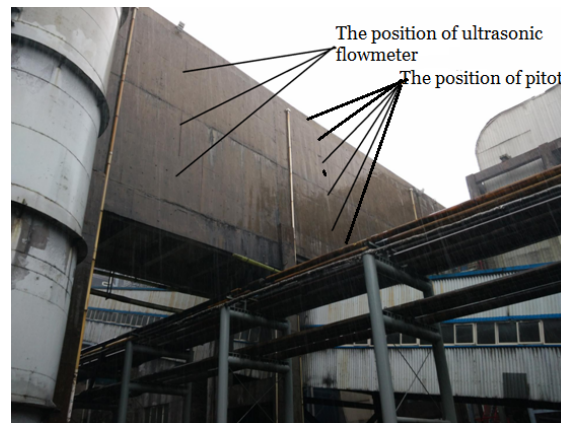


Figure 1. A flue of a coal-fired power plant in Henan.

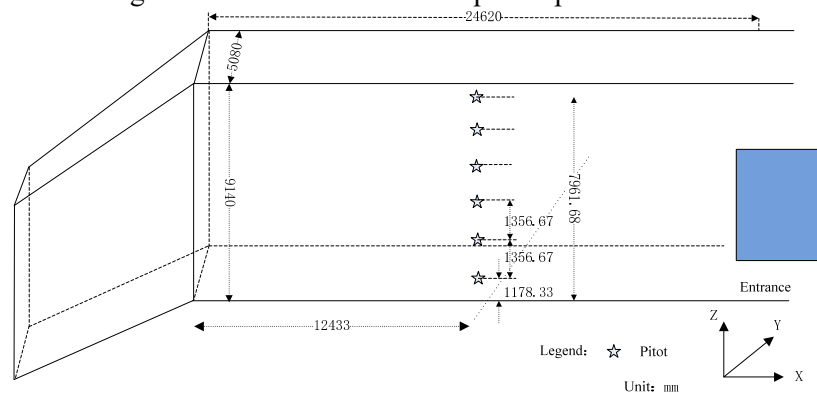


Figure 2. The structural diagram with the outer parameters of a coal-fired power plant in Henan.

### 3.2 3D laser scanner measuring method

With the continuous development of information technology in recent years, 3D spatial modeling based on 3D laser scanning technology has gradually become familiar to people, which is vividly called as real scene replica technique by relevant practitioners [6, 7]. By setting the program to control the rotation of 3D scanning instrument, it automatically completes the space information collection, which has the features of large data volume, fast scanning speed and good real-time performance. At present, it is widely used in medical and health protection, engineering deformation monitoring, cultural relics reproduction and other occasions [8].

**3.2.1 The principle of 3D laser scanner measuring method.** The 3D laser scanner is based on the principle of laser rangefinder. There are two kinds of ranging methods: pulse time ranging and trigonometric ranging. The calculation formula of the pulse time ranging method is shown in formula (8).

$$S=1/2*C*t \quad (8)$$

Whereas:

$S$ , the distance between the generating laser and the space point to be measured

$C$ , the velocity of laser propagation in the medium

$t$ , the propagation time of one laser round-trip

The pulse time method is especially suitable for measuring objects with far distance and large spatial scale, which has a good application in topographic survey, civil engineering, and restoration of monuments.

The laser triangulation measurement is mainly used to calculate the distance between the scanning center and the measured point by using the trigonometric function relationship formed by the scanning

center on scanning prism, the measured point and the center of the CCD lens. Figure 3 shows the principle of the laser triangulation measurement.

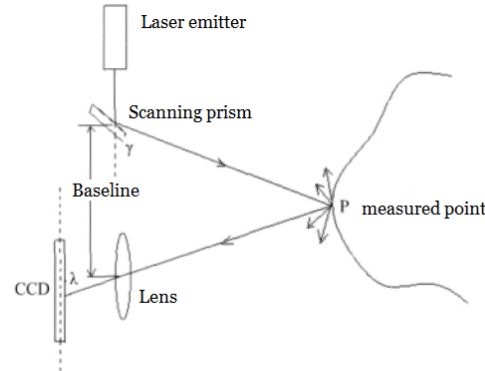


Figure 3. The principle of the laser triangulation measurement of 3D laser scanner.

Where, the distance between the center of scanning prism and the center of the CCD lens is a fixed value of  $L$  (called baseline). The angle obtained by the scanner angular transducer between the centers line of the measured point  $P$  and the scanning prism and the baseline is  $\gamma$ , while the angle between the centers line of the measured point  $P$  and the CCD lens and the baseline is  $\lambda$ . And the distance  $L_0$  between the measured point  $P$  and the center of scanning prism can be calculated by the sine theorem as formula (9).

$$\frac{L}{\sin(180 - \gamma - \lambda)} = \frac{L_0}{\sin \lambda} \quad (9)$$

However, the length of the baseline  $L$  is usually short, so the distance between the measured point  $P$  and the center of scanning prism is limited to a relative short length. Therefore, this method is more suitable for the measurement at short range.

**3.2.2 The realization of 3D laser scanner measuring method.** The 3D laser scanner structural parameters measurement is mainly realized according to the following procedure. Firstly, the number of measuring sites and target balls should be estimated according to the size of the 3D space to be measured. In this measurement, 4 measuring sites and 2 assistant target balls were set up. Secondly, the laser scanner is fixed at the selected measuring sites and parameters of the 3D laser scanner are set to make the laser scanner scan automatically. At last, with the assistance of the target ball, the scanning is completed at four measuring sites sequentially. Fig.4 is the scene of mapping the structure parameters of flue using the 3D laser scanner.



Figure 4. Mapping the internal structure parameters of flue using the 3D laser scanner.

After scanning, the data obtained from different measuring sites are transformed into the same coordinate system according to formula 10, and the data stitching process is completed.

$$\begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} = R_0 \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} + T \quad (8)$$

Whereas:

$R_0$  is a rotation matrix;

$T$  is a translation matrix;

$X_1$  is a point measured by site 1;

$X_2$  is a point measured by site 2;

Similarly, the points measured by site 3 and site 4 are also represented by the coordinate system of site 1. Then denoises the above point cloud data using the median filter method and  $3\sigma$  criterion and simplifies them using the equal space simplification method. That is to say when the number of data in a single space has already met the requirements for the modeling of the space, the equal number of data in the equal space is properly deleted so that the calculation can be converged faster, and the calculation results will be obtained in a short time. The results of the flue structure parameters measurement using the 3D laser scanner are shown in Figure 5. The graph shows the scanning results (not all cross sections) of the 10 cross sections with the zero point of the 3D laser scanner measuring site 1, from 0 to 45 meters, and the internal model of the flue based on all the reconstructed cross sections.

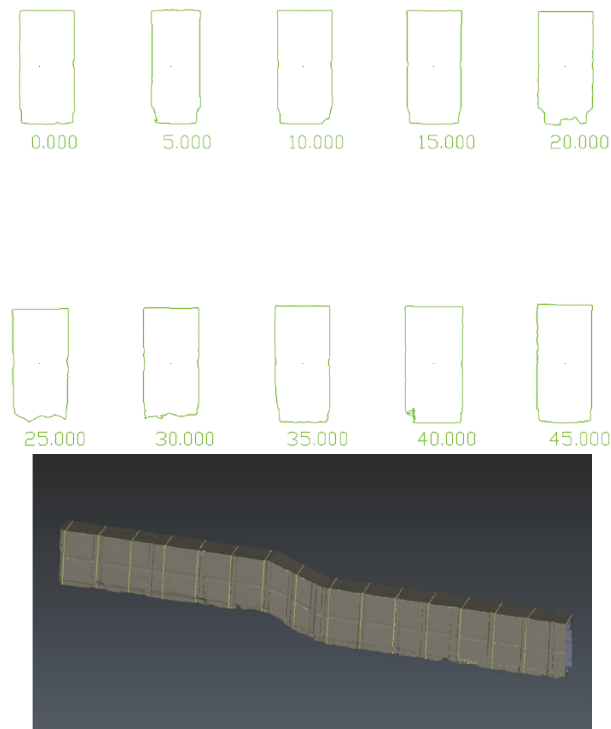


Figure 5. The internal section scanning results and 3D model reconstruction of 3D laser scanner.

Table 1 lists the height and width data of the 10 cross sections above, which are consistent with the measuring results obtained by the total station measuring method with consideration the thickness of the flue wall (47mm-50mm).

Table 1. The measuring result of flue cross section using 3D laser scanner.

Number of cross section	Width(mm)	Height(mm)
1	4988	9044
2	4984	9038
3	4980	9038
4	4978	9042
5	4988	9044
6	4984	9048
7	4982	9046
8	4980	9044
9	4980	9038
10	4982	9040

#### 4. Data comparison and analysis of two measuring methods

The consistency of the results of the two measuring methods proves that both the total station method and the 3D laser scanner method are suitable for the measurement of flue structural parameters. However, the total station method is more suitable for the situation of known flue thickness, with which the internal structure parameters of the flue can be calculated through the outer structure parameters. While, the 3D laser scanner method is more suitable for the situation of which the flue can be entered directly and meticulous description of the space interior details are required. Fig. 6 shows the CFD mesh of 3D geometry model of the measured flue based on the measuring results of total station method and 3D laser scanner method. In addition, the data post processing of the total station



method is relatively complex, while due to the maturity of the software of 3D laser scanner data post processing, lots of convenience is brought for the application of 3D laser scanner method.

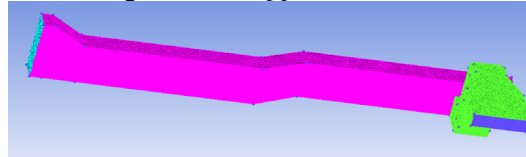


Figure 6. The CFD mesh of 3D geometry model of the measured flue.

## 5. Conclusion

This paper introduces two methods for measuring the flue structural parameters in coal-fired power plants, and based on these two methods, the flue structure parameters of a power plant in Henan are measured, of which good results have been achieved. The above work has laid a good foundation for the numerical simulation of flue flow field and the measurement of instantaneous flow rate of the flue gas. The total station method and the 3D laser scanner method introduced in this paper can also be applied to the measurement of other structural parameters in the flow measurement based on velocity-area method, and also the measurement of the structure parameters of the large space model in other applications.

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