

Sealing Test of Gas Valve Cover of Gas Meter Based on Line Laser Triangulation Method

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Abstract: The surface topography characteristics of the working surface of the gas valve cover of a gas meter can be used to quantitatively evaluate the sealing performance of the gas valve. A set of surface topography measurement devices based on line laser triangulation was fabricated to study the relationship between the flatness of the valve cover and valve tightness. In the experiment, several qualified and unqualified valve covers were selected for the measurement, and the original data of the three-dimensional topography of the valve cover surface were obtained; the data were tilted and corrected to obtain the flatness error of the valve cover surface. The experimental results showed that when the sampling data point interval is optimized, the flatness error can be used to distinguish the air valve cover sealing characteristics. When the X-axis sampling interval is 0.1 mm and the Y-axis sampling interval is 0.02 mm, the air valve cover rotates at 0°, and the flatness error threshold for distinguishing whether the air valve is qualified or not is approximately 0.1105 mm. Tightness testing method is verified, which provides an important foundation to realize higher accuracy measurement of gas meter.

Keywords: Flatness Error, Line Laser Triangulation Method, Air Valve Cover Tightness, Surface Topography Detection

1. Introduction

The diaphragm gas meter has wide market prospect as an important measuring instrument for household gas. The valve cover and valve seat affect the metering performance of the diaphragm gas meter, and the two should be sealed and matched during the rotating movement process to achieve accurate gas metering [1]. According to "JJG577-2012 National Metrological Verification Regulations for Diaphragm Gas Meters," the sealing test of diaphragm gas meters is verified by the soap bubble method. This detection method cannot perform quantitative detection and has low identification efficiency [2], which makes it difficult to meet the production detection needs of modern gas meter companies. Mao et al. [3] developed a diaphragm gas meter air tightness tester using the principle of direct pressure, but the measurement accuracy is limited. Cui et al. [4] developed a new diaphragm gas meter valve tightness tester, which uses the average deviation of the valve fitting surface to evaluate the gas meter valve tightness. Since the evaluation range can only be collected locally, the accuracy of the evaluation results

is affected. Studies have shown that the surface morphology of the working surface of a valve cover is closely related to its tightness [5]. Therefore, a series of surface morphology detection technologies, especially optical detection technologies, has been applied in numerous applications and research [6]. Laser triangulation is a typical non-contact optical inspection method [7]. It has the advantages of simple structure, high measurement frequency, small size, and light weight. It is widely used in agricultural development, industrial manufacturing, aerospace, and remote sensing applications, such as quantitative soil structure [8], laboratory turbulent water surface ranging [9], ceramic tile surface defect detection [10], aircraft engine blade measurement [11], and vegetation observation [12]. The laser triangulation method is very suitable for the production site requirements of gas meter companies. However, the design of the measuring device and selection of the sealing evaluation parameters are key issues to be resolved.

According to the number and arrangement position of the emitted lasers, the measurement light source of laser triangulation is classified as point laser, line laser, and surface

laser. Among them, point laser has the highest measurement accuracy, followed by line laser and surface laser. The laser and spot laser are sequentially reduced. In order to ensure measurement efficiency and accuracy while considering economy and applicability, it is advisable to adopt the line laser triangulation method in combination with a motion platform to realize the collection of topographic data on the surface of the gas valve cover of the gas meter. Surface roughness can be used to evaluate the sealing characteristics of the valve cover [13], but there are problems such as local selection and slow measurement speed. To fully consider the influence of the surface topography of the entire working surface on the sealing performance, this paper intends to use the flatness error to evaluate the sealing performance of the valve cover. Simultaneously, we use the least squares evaluation method to calculate the flatness error. The theory of least squares evaluation method is mature, and it is a linear problem when evaluating the flatness error. The solution is convenient and simple, with good accuracy, and is not restricted by the distribution position of the sampling data points [14]. The research content of this article is conducive to the advancement of gas meter valve sealing detection technology and provides research ideas for the realization of more accurate measurement of gas meters.

2. Experimental Device for Surface Topography Measurement

2.1. Experimental Device for Measurement

The principle of point laser triangulation measurement [15] is shown in Figure 1(a). The laser generator emits a point laser, which forms a small spot after passing through a condensing lens. The laser beam is perpendicularly incident on the surface of the object to be measured, and then imaged by the imaging objective lens. When the measured surface movement is x , the image offset on the position detector is δ . The geometric relationship is $x = \frac{d_0 \delta}{d_1 \sin \theta}$, where θ is the angle between the

projection optical axis and the imaging optical axis, d_0 is the distance from the measured point to the imaging objective lens, and d_1 is the distance from the position detector to the imaging objective lens. The line laser triangulation method consists of a certain number of laser points arranged in a straight line and is emitted by the laser transmitter. The measurement principle is the same as that of the point laser triangulation method, as shown in Figure 1(b). Because the position detector of the line laser triangulation method can simultaneously receive the scattered images of the measured surface at different positions, and obtain the change in height of multiple measured surfaces, it has the characteristics of high measurement efficiency.

The gas valve cover of the tested gas meter is shown in Figure 2(a). The entire surface is the working surface (shaded part in the figure). The maximum length of the working surface is 60 mm; therefore, KEYENCE with a laser line of 80 mm was selected. The LJ-V7200 line laser sensor performs a single scan on it, reducing the errors caused by data splicing. A

three-dimensional surface topography measurement experimental device based on an electric displacement platform and KEYENCE LJ-V7200 laser displacement sensor was fabricated, as shown in Figure 2(b). The cross slide is used to adjust the working position of the laser displacement sensor (the distance from the measured surface is approximately 200 ± 48 mm), and the electric displacement platform provides one-dimensional movement in the Y direction. The working computer is used for parameter setting, data collection, flatness calculation, and result display. The line length direction of the laser sensor is along the X-axis. When the electric displacement platform moves at a constant speed, the laser displacement sensor performs line scanning at a certain frequency to obtain the Z-direction height data at the two-dimensional position. The main parameters of the experimental device are listed in Table 1. The sampling point interval of the Y-axis is determined by the speed v of the electric translation stage and the sampling frequency f of the laser sensor. To improve the measurement accuracy, the scanning interval in the Y-direction was 0.02 mm, to collect as much height data as possible in the limited sampling area. The sampling period of the laser displacement sensor was set to 200 Hz, and the linear motion speed of the electric displacement platform was $0.02 \text{ mm} \times 200 \text{ Hz} = 4 \text{ mm/s}$. Therefore, each scan can collect the height information data for the entire surface area of the valve cover.

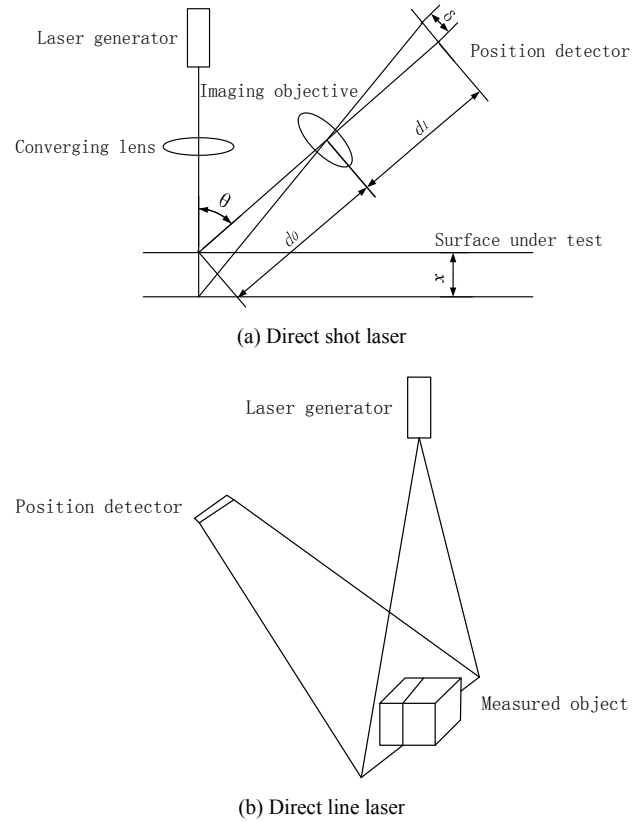
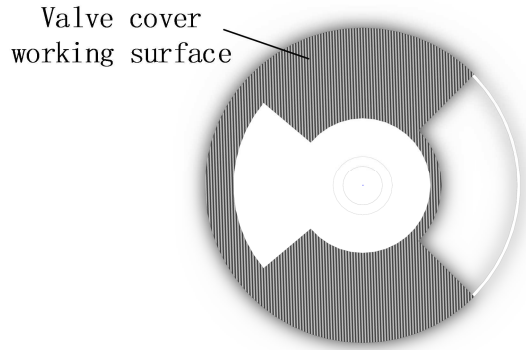
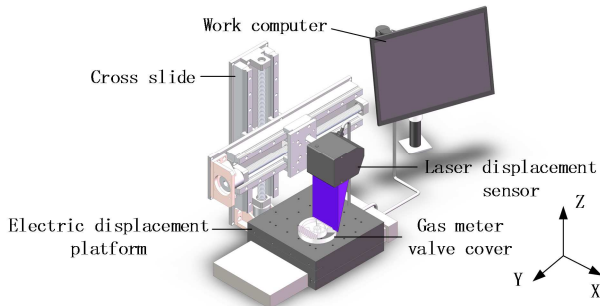


Figure 1. Basic principle diagram of laser triangulation.



(a) Gas meter valve cover



(b) Testing of the experimental device

Figure 2. Illustration of valve cover and experimental device for measuring the working surface of the valve cover.**Table 1.** Main parameters of the experimental device for measuring the working surface of the gas valve cover.

Axis	Measuring range (mm)	Sampling point interval (mm)	Repeatability (μm)
X-axis	80	0.01	20
Y-axis	170	v/f	<10
Z-axis	96		1

2.2. Flatness Error Calculation Method

The point cloud data of the three-dimensional topography of the valve cover surface can be obtained by using Keyence laser displacement sensor software. MATLAB was used to compile a program for calculating the surface flatness error of the gas meter valve cover. The entire calculation process is shown in Figure 3.

First, the height profile data points $z_1(x, y)$ on the surface of the gas valve cover of the gas meter in the Z-axis direction are obtained using the laser displacement sensor. By limiting the scope of $z_1(x, y)$, the effective area data point $z_2(x, y)$ on the surface of the air valve cover is selected as the original contour data point, and then the least square plane of the original contour data point is calculated to obtain its plane equation $z = a_1x + b_1y + c_1$.

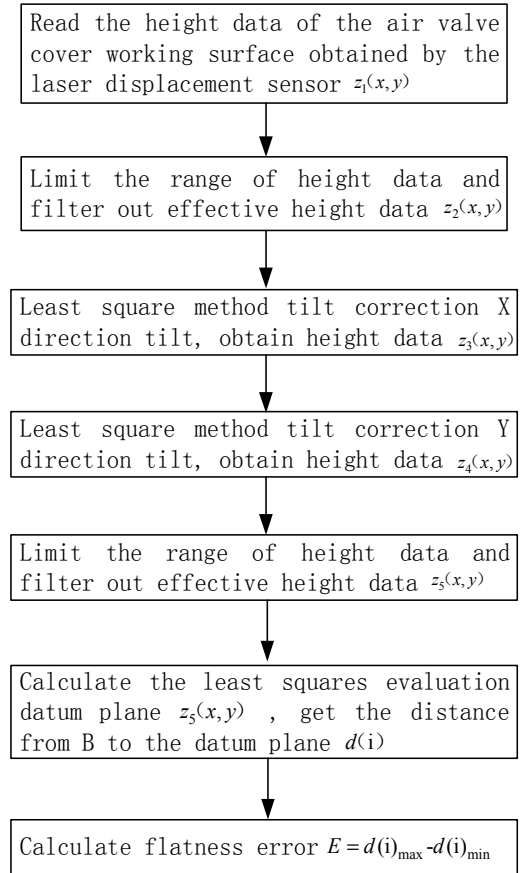
The height data after correcting the inclination angle of the X-axis is

$$z_3(x, y) = z_2(x, y) + X_1 \times \sqrt{a_1^2 + b_1^2}. \quad (1)$$

In the formula, X_1 is the set of X-axis coordinates.

The height data after correcting the inclination angle of the Y-axis is

$$z_4(x, y) = z_3(x, y) + Y_1 \times \sqrt{a_1^2 + b_1^2}. \quad (2)$$

**Figure 3.** Flow chart of the surface flatness error calculation method.

In the formula, Y_1 is the set of Y-axis coordinates.

By limiting the range of $z_4(x, y)$, the effective area data point $z_5(x, y)$ on the surface of the air valve cover is identified as the point cloud data for calculating the flatness error of the surface of the air valve cover. Finally, the least squares plane $z = a_2x + b_2y + c_2$ is calculated for $z_5(x, y)$ as a reference plane for evaluating the flatness errors, and the distance from each sampling point in $z_5(x, y)$ to this plane is calculated as

$$d(i) = \frac{z(i) - a_2x(i) - b_2y(i) - c_2}{\sqrt{1 + a_2^2 + b_2^2}}. \quad (3)$$

Then, the flatness error is

$$E = d(i)_{\max} - d(i)_{\min}. \quad (4)$$

In the formula, $d(i)_{\max}$ is the maximum deviation value of $z_5(x, y)$ and $d(i)_{\min}$ is the minimum deviation value of $z_5(x, y)$ relative to the evaluation reference surface.

3. Measurement Experiment and Discussion of Results

3.1. Roughness Verification Experiment and Results of Air Valve Cover Sealing Qualification

The gas meter manufacturer supplied the test sample gas valve covers comprising 4 unqualified and 3 qualified gas valve covers; the two types can be distinguished from each other. The Tokyo Precision SURFCOM 1910DX2 model roughness tester was used to test the roughness of the gas

meter valve caps, labeled A, B, C, D, E, F, and G, to verify their tightness. The physical structure of the test sample valve cover is shown in Figure 4. Six different sampling positions were selected on the working surface of each air valve cover; the estimated length of each sampling position was 7.0 mm, and the sampling interval was 0.02 mm. The roughness parameters Ra (contour arithmetic mean deviation) and Rz (contour maximum height) were used to verify whether the air valve covers were qualified. The experimental results are presented in Table 2.

Table 2. Measurement results of the surface roughness of the gas valve cover of the gas meter (Unit: μm).

Label	Parameter	Position 1	Position 2	Position 3	Position 4	Position 5	Position 6	Average value of Ra	Average value of Rz	Result
A	Ra	1.305	1.168	1.320	1.144	1.462	1.078	1.246	9.046	unqualified
	Rz	9.576	7.664	9.409	8.412	10.947	8.269			
B	Ra	0.915	0.895	1.004	0.943	0.914	0.886	0.926		
	Rz	6.295	7.264	8.163	7.565	6.891	6.535			
C	Ra	2.213	1.908	2.040	1.448	1.407	1.310	1.721		
	Rz	12.883	12.045	13.279	8.742	8.595	8.880			
D	Ra	1.016	1.194	1.014	1.068	1.002	1.006	1.050		
	Rz	7.511	8.142	7.502	6.921	6.140	7.690			
E	Ra	0.836	0.850	0.990	0.891	0.756	0.682	0.834	7.318	qualified
	Rz	6.077	6.974	7.730	6.740	6.437	6.133			
F	Ra	0.781	0.900	0.793	0.840	0.779	0.874	0.828		
	Rz	5.349	6.005	5.115	6.711	5.812	5.966			
G	Ra	0.618	0.711	0.660	0.716	0.814	0.992	0.752		
	Rz	5.319	5.706	4.485	6.115	6.404	7.980			

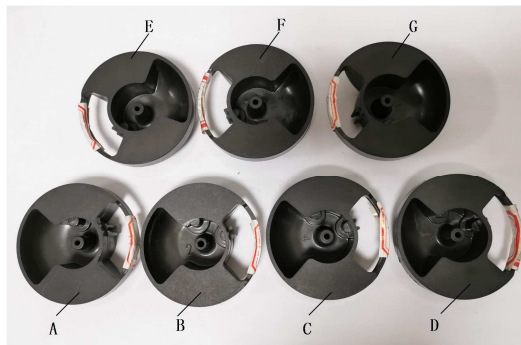
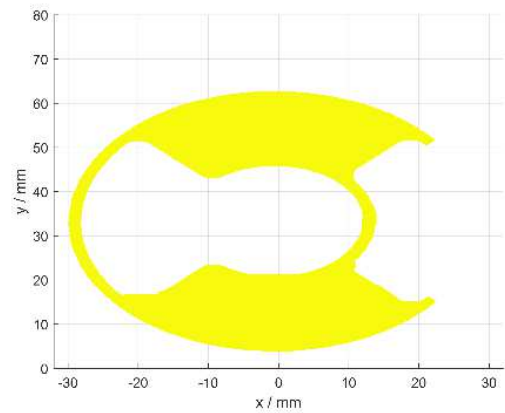


Figure 4. Test sample valve covers.

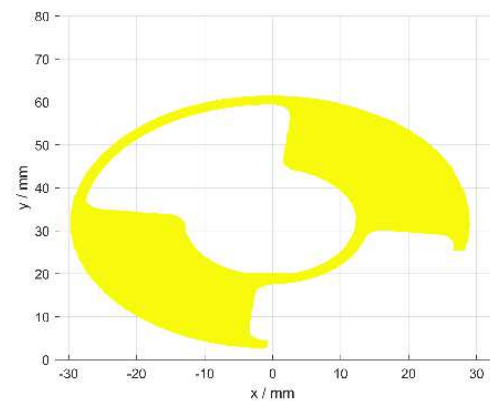
The experimental results show that Ra and Rz of the valve caps of the gas meters labeled A, B, C, and D are greater than those of E, F, and G. Therefore, through the surface roughness experiment, it was verified that the air tightness of valves A, B, C, and D was unqualified, and the air tightness of E, F, and G was qualified.

3.2. Measurement of Flatness Error and Discussion of Results

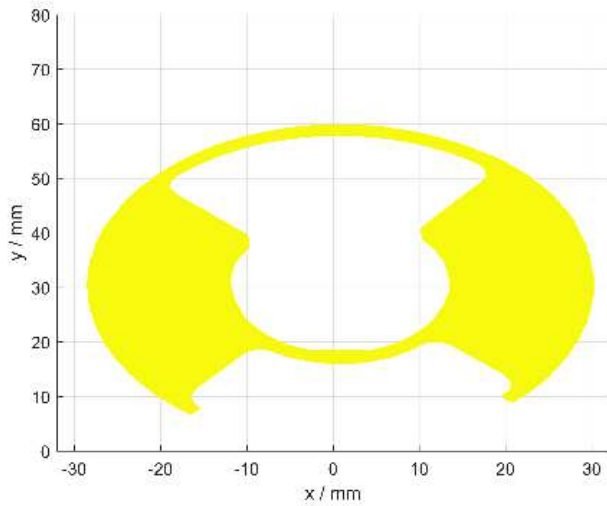
The flatness error of the air valve cover of the test sample was measured using the measuring device employed for the working surface of the air valve cover. The same air valve covers were scanned and measured according to the measurement process and method described in section 2.2 for in situ rotations of 0°, 45°, and 90°. As shown in Figure 5, the valve cover labeled A is at three different angles.



(a) Shape of the valve cover at 0° position



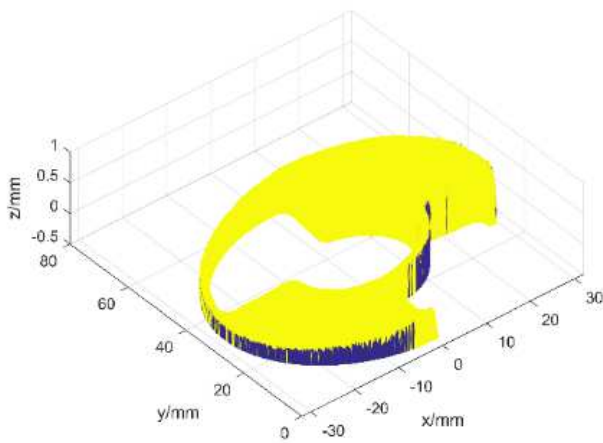
(b) Shape of the valve cover at 45° position



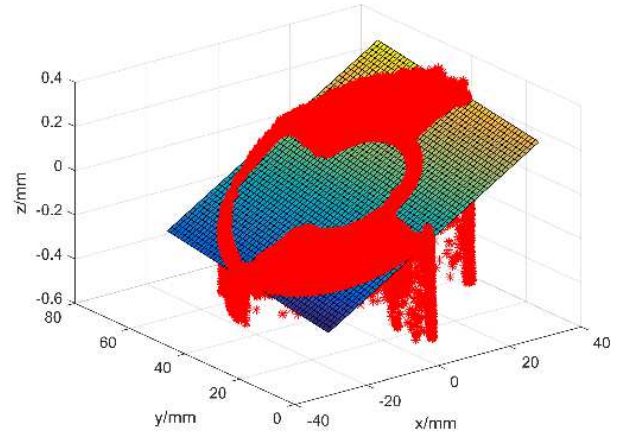
(c) Shape of the valve cover at 90° position

Figure 5. Surface topography of the valve cover at three different angles.

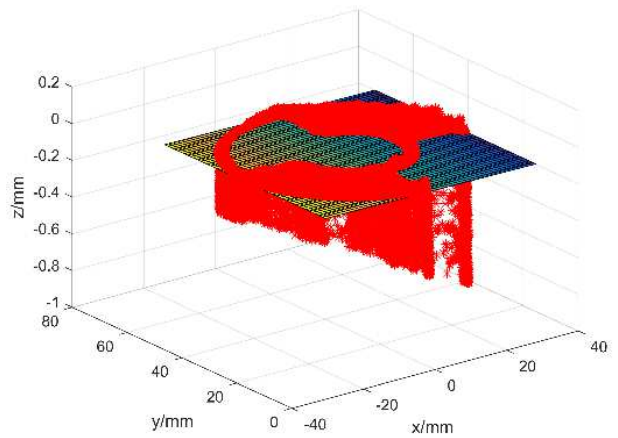
By limiting the range of the relative height of the data points on the Z-axis, the data points for the effective area on the air valve cover surface are screened out, as shown in Figure 6(a), which is the original three-dimensional topography of the air valve cover labeled A. The height data is corrected using (1) and (2), as shown in Figure 6(b) and Figure 6(c), which depict the appearance of the valve cover marked A before and after the tilt correction. Again, by limiting the range of the relative height of the data points on the Z-axis, the effective area data points on the surface of the air valve cover are screened out as point cloud data for calculating the flatness error of the air valve cover surface. The least squares evaluation method is applied to calculate the flatness error using (3) and (4). As shown in Figure 6(d), the flatness error of the valve cover labeled A is used to evaluate the point cloud data and the corresponding least square plane. By comparing the flatness errors of different valve covers, we can determine whether the gas meter valve covers A, B, C, D, E, F, and G are qualified.



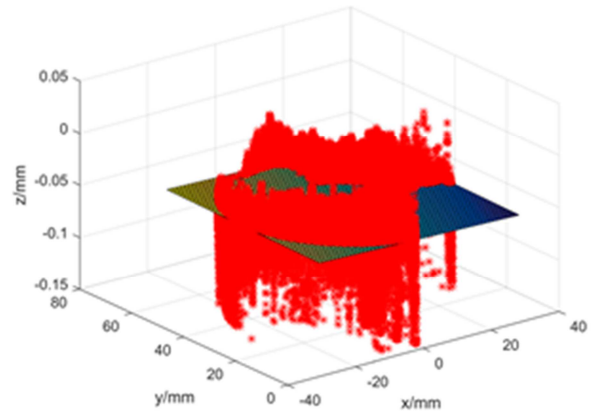
(a) Three-dimensional appearance of original valve cover



(b) Topography before tilt correction



(c) Appearance after tilt correction



(d) Point cloud data for flatness error assessment

Figure 6. Data processing (taking valve cover A as an example).

The air valve cover A was measured at the positions of 0°, 45°, and 90°, and the measurement was repeated 6 times for each position. Table 3 shows the six values of the flatness error when the air valve cover A is rotated by 45°. The calculated experimental standard deviation was 0.002 mm, and measurement repeatability was good. Each valve cap was measured and the average of the repeated measurements was considered the final flatness error of the air valve cap sealing, as shown in Table 4.

Table 3. Standard deviation in the repeatability measurement experiment (Unit: mm).

Serial number	Flatness error	average value	Standard deviation
1	0.173	0.177	0.002
2	0.179		
3	0.177		
4	0.177		
5	0.177		
6	0.177		

Table 4. Measurement results of flatness error of gas valve cover working surface of gas meter (Unit: mm).

	Label	Flatness error at 0° rotation	Flatness error at 45° rotation	Flatness error at 90° rotation
unqualified	A	0.113	0.177	0.114
	B	0.185	0.114	0.185
	C	0.212	0.259	0.149
	D	0.145	0.124	0.109
	E	0.097	0.098	0.101
qualified	F	0.108	0.106	0.103
	G	0.084	0.066	0.098

The measurement results show that the minimum flatness error of the gas valve cover surface of the unqualified gas meter is 0.113 mm at the 0° position, and the maximum flatness error of the working surface of the qualified gas valve cover is 0.108 mm. The median value of 0.1105 mm is taken as the threshold for distinguishing whether the sealing is qualified. When the position is rotated by 45°, the minimum flatness error of the gas valve cover surface of the unqualified gas meter is 0.114 mm, and the maximum flatness error of the working surface of the qualified gas valve cover is 0.106 mm. The median value of 0.110 mm is taken as the threshold for distinguishing whether the sealing is qualified. When the position is rotated by 90°, the minimum flatness error of the gas valve cover surface of the unqualified gas meter is 0.109 mm, and the maximum flatness error of the working surface of the qualified gas valve cover is 0.103 mm. The median value of 0.106 mm is taken as the threshold for distinguishing whether the sealing is qualified. Although different rotation positions have different thresholds for distinguishing whether the sealing performance is qualified, at each fixed rotation position, it is possible to distinguish whether the sealing performance of the air valve cover is qualified. Therefore, the shape measurement of the gas valve cover of the gas meter based on the line laser triangulation method can assess the sealing performance of the gas valve.

4. Conclusion

This paper reported a method for detecting the sealing performance of the gas valve cover of a gas meter. The line laser triangulation method was used to obtain the three-dimensional appearance of the gas valve cover of the gas meter. The least squares plane was calculated and used as the flatness error evaluation reference plane to obtain the flatness error. It was experimentally demonstrated that when the sampling data point interval is optimized, the flatness error can be used to distinguish the sealing characteristics of the valve cover. Compared with previous studies, when the flatness error is used to determine the sealing performance of the valve cover, the range of the evaluated valve cover

working surface can be increased, and the accuracy of the judgment can be increased; the line laser triangulation method can ensure high measurement accuracy, and the measurement efficiency is also improved at the same time. The detection method can quickly and accurately measure the tightness of the gas valve cover of the gas meter, which has positive significance for research on the measurement accuracy of the gas meter.

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