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Research On The Measure Method Of Oblique Pinhole Parameters

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Abstract. There are many special advantages in measuring the diameter of blind and deep holes with a capacitive probe, there are still some challenges for the measurement of a oblique pinhole parameters because the measuring device is inconvenient to stretch into the oblique pinhole exactly. A five-dimensional measurement system was adopted in the paper which included a capacitive sensor probe and a three-coordinate measuring machine to accomplish the measurement for oblique pinholes. With the help of the three-dimensional coordinates measured from the pinhole axis, we put forward a comprehensive method of combining the projection method and the least squares method together for fitting spatial straight line to obtain the optimal equation of the spacial axis. Finally, a reliable and entire measurement system was set up.

1 Introduction

In a general way, the measurement of hole parts include the following parameters, the location of a hole on the part, the diameter or roundness of a hole on the part surface, the diameter or roundness in a certain depth of a hole, the orientation of a hole axis to the part surface, the straightness of axis and cylindricity[1-4].

When we do measure for a hole part, the operation space for the measuring instruments is restricted, then the adjusting operation is very inconvenience. We use a certain length of cylinder as a measuring probe of the capacitive sensor, which can form a capacitor with the inside surface of the hole. Due to the measurement area is a cylinder, the average effect of capacitance effectively overcome the influence of micro defects on the surface of the measured holes, it has obtained very good effect in the straight hole diameter measurement[5-6].

Some holes in a workpiece are special, the centerline of a hole named as axis is not necessarily vertical or parallel to the workpiece surface, but with a certain angle. In this paper, we will discuss a special workpiece with many oblique pinholes as shown in Figure 1.

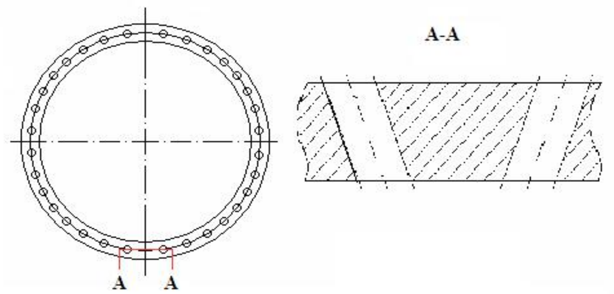

Figure 1. Drawing View of A Workpiece with Oblique Holes.

Many oblique holes with different angle were drilled in a annular metal workpiece with 3.5mm thickness, and the axis are at a certain angle between each pair of holes. For this kind of holes, not only should we get the diameter and axis position of single oblique pinhole, we should also get the position relationship namely impact height and impact error between two adjacent holes[7].

2 Measuring System Composition

To realize fast and automatic measurement for each pair of oblique holes on the annular workpiece, a five-dimension automatic adjustable measuring system is adopted to measure in high precision, the system composition is shown in Figure 2.

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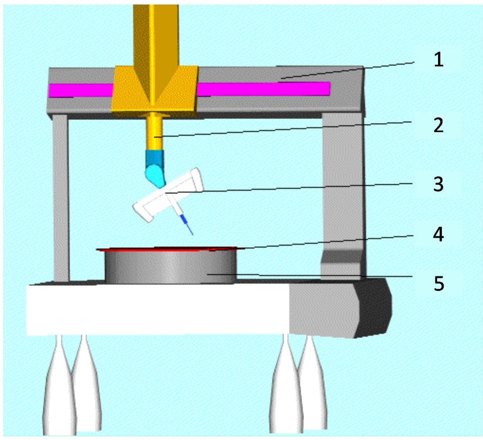


1-Three-coordinate measuring machine 2-Z axis
3-Intelligent guide measuring head 4-Annular work piece
5-Fixing and fastening bracket

Figure 2. Five-Dimension Measuring System for Annular Workpiece with Oblique Pinholes.

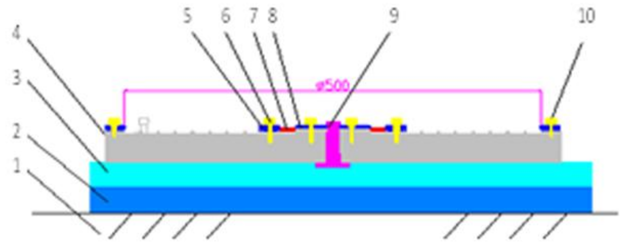
There are five parts in the entire measuring system, which are three-coordinate measuring machine, Z axis, intelligent guide measuring head, fixing and fastening bracket and annular workpiece to be tested. We regard the three-coordinate measuring machine as the main measuring unit to establish the main coordinate system to finish the coordinates measurement of oblique holes. A intelligent guide measuring head mounted with binocular vision camera is installed in Z axis of the three-coordinate measuring machine to realize the alignment of axis between the probe and hole, and the capacitive sensor is for the diameter measurement.

2.1 The Three-coordinate Measuring Machine

The precision of the coordinate converting in the entire system depends on that of the three-coordinate measuring machine. Considering the measuring requirement of the pinholes in the workpiece, a three-coordinate measuring machine produced in Hexagon company was adopted, the displacement measuring range for three coordinate axis is $X \times Y \times Z$=900mm × 1200mm × 800mm, and the indication error is [(1.4)+L/300]um.

2.2 The Fixing of Workpiece

To eliminate deformation in actual measurement, the fixing and fastening bracket with multifunction was used to compress the annular workpiece. Figure 3 shows the detailed structure. A one-dimension turntable with high angular resolution was installed on the workbench of three-coordinate measuring machine, a bracket was used to fix and fasten the annular part. The annular part to be tested (7) was placed at the center position which is concentric with centre pillar (9), compressed by external compressing plate (5) and internal compressing plate (8), several compressing screws (6) were fixed to tighten the plates.



1-Workbench of three-coordinate measuring machine
2-Fixing base 3-Rotating table 4-Tooling table
5-External compressing plate 6-Compressing screw
7-Annular part to be tested 8-Internal compressing plate
9-Center pillar of the rotating table 10-Compression screw

Figure 3. Detailed Structure of A Multifunction Bracket.

2.3 The turning of workpiece

There is precise turntable under the workpiece, it can turn a desired small angle driven by a motor under the control of the program. Every time when we completed the measurement for a pinhole, the turntable turned with the workpiece to move the next pinhole to the measure position, then measurement continued. This can alleviate the inertial displacement of activating and stopping frequently when the three-coordinate measuring machine is looking for the target workpiece along the X axis and Y axis. Figure 4 shows the schematic diagram.

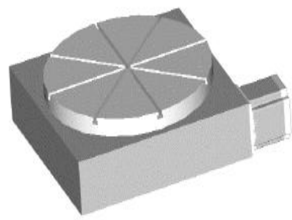


Figure 4. The Schematic Diagram of the Precise Turntable.

2.4 The Intelligent Measuring Head

The intelligent measuring head is composed of two parts, one part is a binocular vision camera which is used to find the centre point of the measured pinhole by the images captured from the surface of a pinhole. The recorded position coordinates of centre point will be helpful in the following step. Figure 5 shows the schematic diagram of the binocular vision camera.

Figure 5. The Schematic Diagram Of the Binocular Vision Camera.

The other part is a capacitive probe or several probes mounted on the Z axis together. The capacitive probe is used to detect the inner diameter of the pinholes. If the parameter of the pinhole is fixed, one probe is enough. If the pinhole diameter changes in the workpiece, the diameter of capacitive probe has to change with that to make sure the measurement is available. Figure 6 shows the schematic diamatic of the capacitive probes.

Figure 6. The Schematic Diagram of The Capacitive Probes.

Obviously, when we do measurement with the capacitive probe, the most important is to make sure the alignment of the probe axis and the pinhole axis. The measured centre coordinates by binocular vision camera is useful for capacitive probe to find the right position in a shortest time.

3 Measuring Principle

When a part is reliably fixed on the workbench of three-coordinate measuring machine, the theoretical coordinate system is established accordingly and automatic measurement can start. While the three-coordinate measuring machine is moving under the program control, the intelligent measuring head with a binocular vision camera follows Z axis and moves to a hole, it first rotates an angle which is equal to the oblique hole axis angle, then the capacitive probe on the intelligent measuring head does the diameter measurement. By fitting the three-dimensional coordinate data obtained from three-coordinate measuring machine, we get the hole axis equation and complete a hole measurement. The intelligent measuring head rotates 180°around Z axis, and does the same measure for another hole. After we obtain the axis equations of a pair of holes, we can compute the position relationship between two adjacent holes.

4 The Coordinate Converting Principle

The entire coordinate system is composed of three-dimension displacement coordinates of three-coordinate measuring machine, one-dimension turning coordinate in horizontal direction from the precise turntable and one-dimension turning coordinate in vertical direction. It is a five-dimension coordinate system, the three-coordinate system is assigned as the main coordinate system, and the other coordinates will be normalized to the main coordinate system. This is the precondition for measuring accurately and correctly.

5 Fitting Algorithm of Axis Equation

The intelligent measuring head with capacitive probe is led by three-coordinate measuring machine to do measurement in a hole. To fit the equation of a axis, at least we should get two points along the axis of the hole. The axis of a oblique hole is a spatial line, it is necessary to measure the three-dimensional coordinates of each point.

Supposing there are a pair of oblique holes, their axis is named as Line A and Line B. We choose two points $M_1(x_1, y_1, z_1)$ and $M_2(x_2, y_2, z_2)$ in axis Line A, and two points $M_3(x_3, y_3, z_3)$ and $M_4(x_4, y_4, z_4)$ in axis Line B, based on the straight line equation, we get the equation for Line A and Line B,

$$\frac{x - x_1}{x_2 - x_1} = \frac{y - y_1}{y_2 - y_1} = \frac{z - z_1}{z_2 - z_1} \quad (1)$$

$$\frac{x - x_3}{x_4 - x_3} = \frac{y - y_3}{y_4 - y_3} = \frac{z - z_3}{z_4 - z_3} \quad (2)$$

In order to improve the accuracy of axis equation, we should get coordinate values in many cross sections of the hole, and adopt the points to fit the equation of the spacial line, which can eliminate the spacial distortion error greatly. Obviously, Line A and Line B are spacial three-dimensional straight line, there are six parameters in equation (1) and (2), which are not simple linear expression, we can't use the least squares fitting directly, but we can solve the problem by derivation.

Just as we know, a three-dimensional spacial line can be described with projective lines in three two-dimensional planes, vice versa, we can restore the original straight line in three-dimensional space by three projective lines. Based on this situation, we put forward a comprehensive method of combining the projection method and the least squares method together for fitting spatial straight line to obtain the optimal equation of the spacial axis.

First, we get some three-dimensional coordinate (x_i, y_i, z_i) points in the axis Line A by measurement, then we project the points to three orthogonal planes respectively, the two-dimensional coordinates on xoy plane are (x_i, y_i), xoz plane are (x_i, z_i) , and yoz plane are (y_i, z_i) , $i = 1 \cdots n$. Now we do fitting for the data (x_i, y_i) located in xoy plane with the least squares method, the fitting line is as follow,

$$y = a_1 + a_2 x \tag{3}$$

By computing, the coefficient of a_1 and a_2 are got as,

$$a_1 = \frac{q_2 q_4 - q_1 q_3}{n q_2 - q_1^{\ 2}} \, , \; a_2 = \frac{n q_3 - q_1 q_3}{n q_2 - q_1^{\ 2}} \tag{4}$$

$$q_1 = \sum_{i=1}^{n} x_i \, , q_2 = \sum_{i=1}^{n} x_i^{\ 2} \, , q_3 = \sum_{i=1}^{n} x_i y_i \;\; q_4 = \sum_{i=1}^{n} y_i \tag{5}$$

In the same way, we do fitting for the data (y_i, z_i) located in yoz plane with the least squares method, the fitting line is as follow,

$$z = a_1^{'} + a_2^{'} y \tag{6}$$

We do fitting for the data (x_i, z_i) located in xoz plane with the least squares method, the fitting line is as follow,

$$z = a_1^{''} + a_2^{''} x \tag{7}$$

So, the planar equation of a plane which contains the straight line (3) and is perpendicular to plane xoy is expressed as,

$$a_2 x + a_1 - y = 0 \tag{8}$$

The planar equation of a plane which contains the straight line (6) and is perpendicular to plane yoz is expressed as,

$$a_2^{'} y + a_1^{'} - z = 0 \tag{9}$$

The planar equation of a plane which contains the straight line (7) and is perpendicular to plane xoz is expressed as,

$$a_2^{''} y + a_1^{''} - z = 0 \tag{10}$$

There is a common intersecting line between every two intersecting planes, so we can get three intersecting lines from the three planes. Next we compute the distance between the axis and three lines respectively with the three-dimensional coordintes in the axis, the line which has the least sum of distances is the optimal fitting spacial line. Also, we can get the axis equation of Line B in the same way.

6 Fitting Algorithm of Impact Parameters

As we have known that the axis of pinhole is a spacial line, so the axis between two adjacent holes is not sure to have a common point. After we get the two axis equations for a pair of holes, the shortest distance between two spacial axis can be computed, which is defined as imoact error, shown as figure 7.

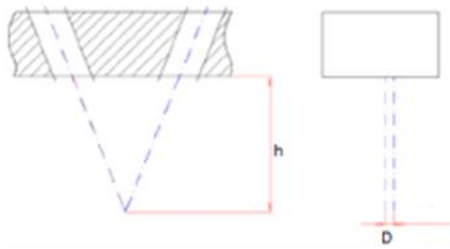


Figure 7. The Impact Height and Error.

Assuming that the point $M_0(x_0, y_0, z_0)$ in the axis line A, by computing the distance from that point to line B, we search the point which has the shortest distance, this is the impact error of two axis,

$$D = \sqrt{f_1(x, y, z) - f_2(x, y, z)} \tag{11}$$

Here,

$$f_1(x, y, z) = (x_3 - x_0)^2 + (y_3 - y_0)^2 + (z_3 - z_0)^2 \tag{12}$$

$$f_2(x, y, z) = \frac{l(x_3 - x_0) + m(y_3 - y_0) + n(z_3 - z_0)}{l^2 + m^2 + n^2} \tag{13}$$

$$l = x_4 - x_3 \tag{14}$$

$$m = y_4 - y_3 \tag{15}$$

$$n = z_4 - z_3 \tag{16}$$

Assuming that the equation of reference plane is as the following,

$$A_0x + B_0y + C_0z + D_0 = 0 \qquad (17)$$

Here, the reference plane is defined by at least three points in the same surface $P_1(x_1, y_1, z_1)$, $P_2(x_2, y_2, z_2)$ and $P_3(x_3, y_3, z_3)$, these point coordinates were got from the three-coordinate measuring machine, the plane is expressed as,

$$\begin{vmatrix} x - x_3 & y - y_3 & z - z_3 \\ x_1 - x_3 & y_1 - y_3 & z_1 - z_3 \\ x_2 - x_3 & y_2 - y_3 & z_2 - z_3 \end{vmatrix} = 0 \qquad (18)$$

Then the distance from point $M_0(x_0, y_0, z_0)$ to this reference plane can be obtained from the following expression,

$$h = \frac{|A_0x + B_0y + C_0z + D_0|}{\sqrt{A_0^2 + B_0^2 + C_0^2}} \qquad (19)$$

Here the h is defined as impact height of two axis.

7 Conclusion

We set up a five-dimensional measuring system in the paper. With the aid of three-dimensional measuring machine, we combine the advantages of capacitive sensor probe together to realize the measurement for oblique holes, this testing system can obtain the three-dimensional ordinates in the axis, by comprehensive fitting algorithm, the axis of a pair of oblique holes can be computed and the position relationship can also be figured out.

Acknowledgements

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