Error Comparison Analysis and Optimization Research on the Measurement Method for the Extension Position of Engine Threaded Holes

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Abstract: The accuracy of measuring the extension position of threaded holes with three-coordinate measuring is a difficult problem in the field of mechanical manufacturing. This paper conducts an in-depth analysis of the sources of fundamental errors in the two mainstream three-coordinate measurement methods currently available - the section sampling point method and the spiral step method - and points out that they respectively have measurement instability problems caused by sampling points deviating from the true axis and inconsistent sections. In response to this, this paper introduces and systematically evaluates the performance of the thread mandrel measurement method. Through multiple repeated comparative experiments on the same workpiece, the deviation distribution, fluctuation amplitude and stability of the three measurement methods were analyzed in detail from the X, Y and Z axes. The research results show that the deviation fluctuation of the thread mandrel measurement method is the smallest in all three axes, the measurement results are the most stable, and the out-of-tolerance rate is 0. The research in this paper provides data support and theoretical basis for choosing the optimal measurement strategy for the position of threaded holes, and analyzes the residual error of the thread mandrel method.

Keywords: Three-Coordinate Measurement Threaded Hole Position Degree; Error Analysis Comparison of Measurement Methods Stability

1. Introduction

The precise measurement of the positional accuracy of threaded holes is directly related to the assembly quality and reliability of complex mechanical products such as engines[1-3].However, due to the particularity of the threaded structure, the results of three-coordinate measurements are often questioned by operators, process and design personnel[4,5].At present, in production, the main methods adopted are directly measuring the smooth holes or taking points on the threads themselves. However, all these methods have inherent defects[6], which lead to deviations between the measurement results and the actual processing accuracy[7]. This article aims to conduct a systematic error analysis of several major current measurement methods and, through experimental comparisons, clarify the advantages and disadvantages of different methods, providing guidance for choosing high-precision and high-stability measurement schemes in industrial production[8].

2. Existing Measurement Methods and Error Analysis

There are mainly two measurement methods currently in use. One is to take points on the same cross-section of the threaded hole. On the same cross-section of the threaded hole as the measurement light hole, four points are taken to measure a circle, and the positional degree of the center of this circle relative to the evaluation reference is calculated. Generally, at least two cross-sections need to be measured, and eight points are used to construct a cylindrical element. The axis of this cylinder is taken as the axis of the threaded hole. Similarly, It is also possible to determine whether the axis of the threaded hole is inclined. The three-coordinate sampling diagram is shown in Figure 1. When measuring points at the same cross-section in a threaded hole, the center of the circle formed by four points at the same cross-section must not be on the axis of the threaded hole. When estimating the position of the threaded hole, this error is introduced into the estimation result, and the centers of different cross-sections and different holes are measured. The deviation of the same hole from the thread axis position is the main cause of inaccurate

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measurement such as poor repeatability and large dispersion of the threaded hole position measurement.

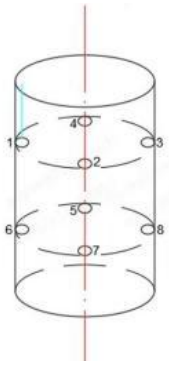


Figure 1. Schematic Diagram of Sampling Points on the Same Section of Threaded Holes

The second measurement method is to take samples step by step based on the direction of the threaded hole and the size of the pitch P. That is, after each point is taken in the threaded hole, the probe moves backward by P/4 to take the second point, and so on. After taking the fourth point, the probe moves forward by mP distance (m is an integer), then takes the fifth point, and moves backward by P/4 distance, and so on. After taking the eighth point, a cylinder is constructed. Taking the cylindrical axis as the axis of the threaded hole, the three-coordinate sampling diagram is shown in Figure 2.

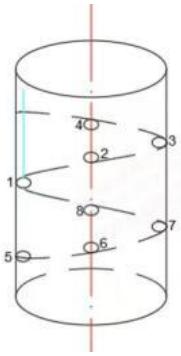


Figure 2. Schematic Diagram of Step-by-Step Sampling Points for the Rotation Direction and Pitch P of Threaded Holes

This method involves step sampling along the direction of the thread rotation of the threaded hole. Although it ensures that the center of the circle constructed by the sampled points is theoretically on the axis of the threaded hole, the error in the evaluation of positional accuracy is smaller than that of the previous two measurement methods. However, since the four collected points are not on the same cross-section, a slight inclination of the axis will cause a significant sampling error. All these errors will be carried into the evaluation results of the positional accuracy of the threaded holes.

3. Measurement Method of Threaded Mandrel and Its Error Sources

3.1 The principle of the Threaded Mandrel Measurement Method

The thread mandrel measurement method is an effective way to precisely measure the position of the thread hole's axis. During the measurement, a thread mandrel that matches the thread is installed on the thread hole. On the smooth cylindrical surface of the outer circle of the mandrel, set the step width of the probe for the measuring needle to 0.5mm. This step width is based on a comprehensive consideration of measurement accuracy and efficiency, ensuring measurement accuracy while also improving measurement efficiency. According to the pre-programmed measurement program, as shown in Figure 3, the outer circle of the mandrel is scanned and measured. Two sections were selected for scanning, and 57 points were collected from each section. The data measured by the three-coordinate measuring machine can be processed by the least square method, which can correct the probe measurement points, filter and eliminate gross errors, so as to eliminate the influence of large errors.

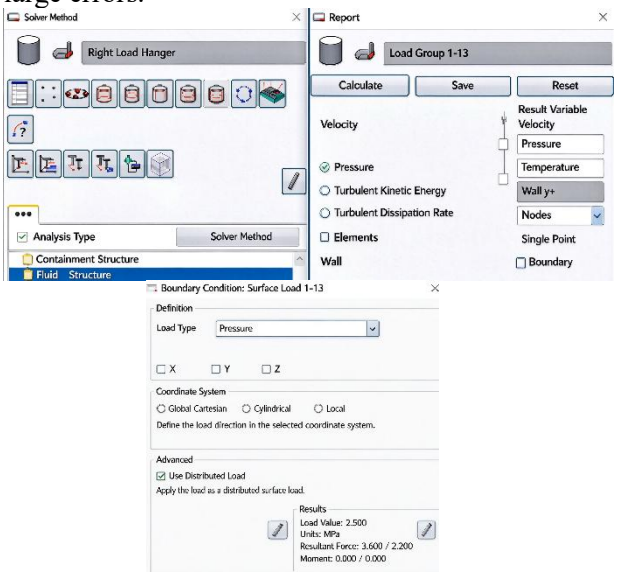


Figure 3. Three Coordinate Measurement Program Setting Diagram

3.2 Residual Error Analysis

Although the thread mandrel method has higher precision, it still has systematic errors by itself:

(1) Fit clearance error: There is a clearance between the tolerance zone of the threaded hole

and the tolerance zone of the threaded mandshaft, which causes a slight radial displacement of the mandshaft after it is screwed in.

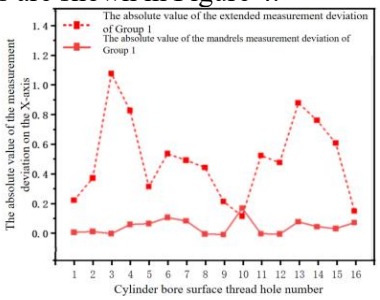
(2) Error of the mandrel itself: There is a coaxiality manufacturing error between the thread axis of the threaded mandrel itself and the smooth cylindrical axis.

(3) Perpendicularity error: The perpendicularity error between the axis of the threaded hole and its end face will affect the assembly posture of the mandrels, thereby introducing measurement errors.

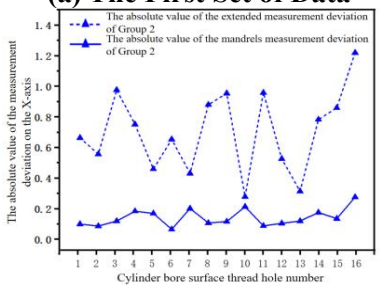
4. Analysis of Measurement Results

Three different measurement methods (elongation measurement method and thread core axis method) were used to measure the same threaded hole of the same workpiece, and the three axial measurement results were compared and analyzed.

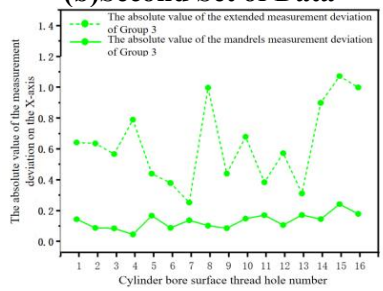
The absolute values of the X-axis deviation of the threaded hole position measured by the two methods are shown in Figure 4.



(a) The First Set of Data



(b)Second Set of Data



(c) The Third Set of Data

Figure 4. Comparison of X-Axis Measurement Deviation Data for Threaded Hole Positional Accuracy

It can be seen from the figure that the maximum absolute value of the three extended measurement deviations is 1.2358 mm, and the minimum value is 0.1916 mm. The overall numerical deviation is between 0.2 mm and 1.0 mm, with a large fluctuation range and weak stability. The maximum absolute value of the measurement deviation of the three threaded mandrel shafts is 0.2637mm, and the minimum value is 0.0468mm. The overall numerical deviation is about 0.1mm with a small fluctuation range and strong stability. It can be seen from this that the thread mandrel method has obvious advantages in measurement stability and repeatability, and is suitable for the detection of the positional accuracy of threaded holes in high-precision assembly requirements.

Figure 5 shows the relative values of the positional deviation of the threaded hole when using extended measurement and the threaded mandrel measured on the Y-axis. It can be seen from Figure 5 that the maximum absolute value of the three extended measurement deviations is 0.5893 mm, and the minimum value is 0.0658 mm. The overall numerical deviation is between 0.1 mm and 0.5 mm, with a large fluctuation range and weak stability. The maximum absolute value of the Y-axis deviation in the three mandrel measurements was 0.1366 mm, and the minimum was 0.0153 mm. The overall numerical deviation was approximately 0.05 mm with a relatively small fluctuation range, and its stability was largely superior to that of the extended measurement method. The absolute values of the deviations of the thread mandrel measurement method are mostly smaller than those of the extended measurement method. Among them, the Y-axis measurement deviation values of the thread mandrel at the second group of data holes 3-13, the third group of data holes 3-8 and 3-13 are slightly higher than those of the extended measurement, which are within the allowable error range. The reason for the error in the measurement of the threaded mandrels is that the tolerance zone of the threaded hole and the tolerance zone of the threaded plug gauge fit together, resulting in an error gap between the threaded hole and the threaded plug gauge. There is a coaxiality error between the axis of the thread plug gauge and the axis of the outer cylinder. There is an error affecting the perpendicularity between the thread hole axis and the end face.

In the extended measurement method, due to the thread profile, pitch, direction of rotation and depth of the threaded hole, when conducting

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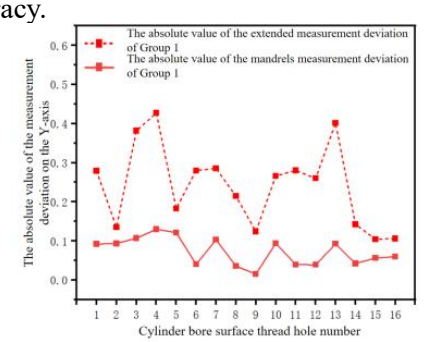
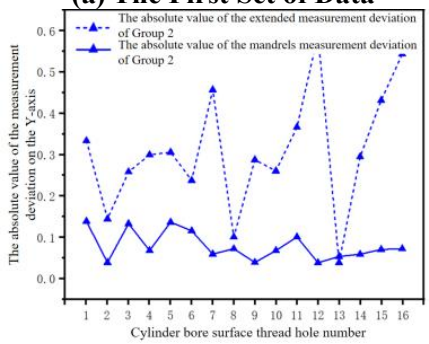
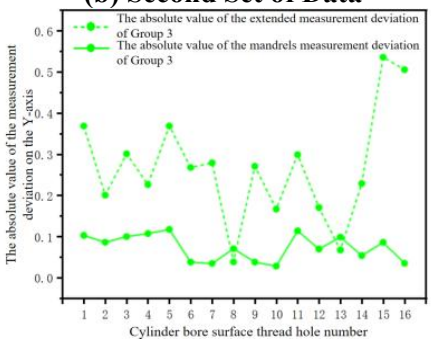
three-coordinate measurement of the position accuracy of the threaded hole extension, the specific position of the three-coordinate probe in the threaded hole is uncertain, resulting in different measurement positions each time, causing large deviations and low stability in the final measurement results. In the measurement method of threaded mandrel, after the threaded mandrel is screwed into the threaded hole, measuring the smooth cylinder above the surface of the cylinder hole can eliminate the error influence caused by the thread profile, pitch, rotation direction and depth of the threaded hole, making the measured extension position size of the threaded hole more accurate and stable. Therefore, it can be judged that the measurement result of the threaded mandrel and the measurement method have relatively high accuracy.



(a) The First Set of Data



(b) Second Set of Data



(c) The Third Set of Data

Figure 5. Comparison of Y-Axis Measurement Deviation Data for Threaded Hole Positional Accuracy

5. Conclusion

This paper, through the analysis of the principle errors of three methods for measuring the extension position of threaded holes and the comparison of experimental data, draws the following conclusions:

(1) Due to the limitations of the geometric features of the thread and the measurement principle, the traditional section point method and spiral step method have poor stability in measurement results and the accuracy is difficult to guarantee, which cannot meet the high-precision requirements.

(2) The thread mandrel measurement method fundamentally eliminates the main source of error by converting the internal thread datum into an external cylindrical datum. Its measurement results have the smallest deviation fluctuations in the X, Y, and Z axes, with the best stability and repeatability.

(3) Although the thread mandrel method still has residual errors such as fit clearance and coaxiality of the mandrel, its overall measurement accuracy (which can be controlled within 0.02mm) has far exceeded the traditional methods and is one of the best solutions for achieving high-precision detection of the position of threaded holes at present. Systematic error analysis of the measurement results is conducive to further optimizing the measurement process and improving the level of quality control.

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