Simulation Research on Three-point Contact Outside Diameter Online Measuring Device

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Abstract. In the grinding process of workpiece, because the grinding wheel will produce wear, it is difficult to control the machining accuracy of the workpiece by the grinder itself. Using radial measuring instrument to measure the size of the workpiece in real time, detect the change of the size of the workpiece, and guide the adjustment of grinding parameters can improve the production efficiency of the grinder and reduce the machining cost. It is an important link in the grinding process of the grinder. Different from the traditional two-point contact on-line measurement technology of outer diameter, this paper designs and develops a set of three-point contact on-line measurement device of outer diameter based on the principle of bow height and chord length. In the measuring process, two fixed probes and one displacement sensing probe are in contact with the outer diameter of the workpiece at the same time, and the on-line measurement of the outer diameter of the workpiece is realized by solving the positional relationship among the three probes. In order to explore the force-measuring extrusion deformation of the device in the measuring process, this paper simulates and analyzes the three-point contact on-line measuring device for outer diameter.

Keywords: Three-point contact type, Outside diameter measurement, Extrusion deformation, Simulation

1. Introduction
In the grinding process, because the grinding wheel will wear, it is difficult to control the machining accuracy of the workpiece by the grinder itself. During grinding, a large amount of grinding heat will be generated between the grinding wheel and the workpiece [1]. In order to avoid irregular phenomena caused by high temperature, grinding fluid needs to be used for cooling and lubrication, and grinding fluid will interfere with most non-contact engineering measurement technologies [2-3]. Therefore, it is necessary to use contact measurement technology to measure the outer diameter of workpiece in real time during grinding.

Most of the existing radial measuring instruments for on-line detection of the outer diameter of workpieces are of two-point contact type, such as the Italian Marbos measuring instrument [4]. The two-point contact measurement method is a direct measurement method. The diameter of the workpiece is solved by comparing the positions of the two ends of the diameter of the outer circle of the workpiece and finding the difference. The two-point contact measurement method requires that the
two contacts between the probe and the measured workpiece and the center of the measured section of the workpiece are collinear. And when the outer diameter of the workpiece to be measured changes, the position of the probe must be adjusted accordingly to ensure that the two probe can contact both ends of the diameter of the workpiece. Therefore, in the process of batch grinding of the workpiece, this method has the problems that the measuring position is difficult to accurately locate and the position of the probe needs to be adjusted frequently [5]. The three-point contact measurement method of workpiece outer diameter proposed in this paper is an indirect measurement method based on bow height and chord length method. The outer diameter of workpiece is solved by calculating the relative position relationship between three points in contact with the outer circle of workpiece.

Based on the principle of bow height and chord length, a set of three-point contact on-line measuring device for outer diameter of workpiece is designed and developed in this paper, which can realize on-line measuring of outer diameter of workpiece with a single displacement sensor. When the device is used to measure the outer diameter of the workpiece, the three probe only need to contact the outer circle of the workpiece to be measured on one side, and the workpiece with the outer diameter within a certain range can be measured online without adjusting the position of the probe. Using this device in the grinding production process, the outer diameter of the workpiece can be measured in real time, so as to control the feeding and retreating of the grinder, and it is not necessary to stop the machine tool to measure the workpiece in the machining process, thus improving the production efficiency.

2. Three-point contact on-line measuring device for outer diameter

In order to ensure that the upper and lower fixed probe of the measure-hand can always contact with the outer diameter of the workpiece, a three-point on-line outer diameter detection device as shown in Fig. 1 is designed. When the measuring device measures the outer diameter of the workpiece during grinding, At first, that device is place on one side of the workpiece, So that the three measuring heads are completely in contact with the outer diameter of the workpiece, Then a certain initial measuring allowance is given, and the measuring allowance does not exceed the effective measuring range of the displacement sensor. At this time, the spring inside the matrix is in a compressed state, and the elastic force of the spring on the precision guide rod uniformly acts on the measure-hand through the connecting plate to ensure that the upper and lower fixed measuring needles of the measure-hand are always in contact with the outer diameter of the workpiece.

![Figure 1. Three-point contact on-line measuring device for outer diameter](image)
The displacement sensor is fixed on the connecting plate through a group of flange screws and nuts, and the relative position of the displacement sensor and the measure-hand can be appropriately adjusted according to the size of the outer diameter of the workpiece to be measured, so as to ensure that the probe of the displacement sensor is always in contact with the outer diameter of the workpiece. The design of the connecting plate can facilitate the disassembly and installation of the measure-hand. When the outer diameter of the workpiece to be measured changes, different types of measure-hand can be easily replaced to measure the workpiece. The two adjusting screws at the end of the base body are used to adjust the deformation of the compression spring to ensure that the upper and lower guide rods are subjected to uniform and equal thrust. The leather sheath is installed at the joint between the precision guide rod of the matrix and the connecting plate of the measure-hand, so that it is not polluted and damaged, and the working reliability of the on-line detection device is ensured.

3. Static Analysis of Measure-hand and workpiece

In order to understand the error of the measure-hand caused by the force measurement extrusion deformation in the measurement process of the on-line measuring device, the static simulation analysis of the measure-hand was carried out in the ANSYS Workbench 17.0 finite element simulation software.

The parameters of the compression spring of the known on-line measuring device are shown in Table 1.

### Table 1. Compression spring parameters of three-point contact outer diameter online measuring device.

| Shear elastic modulus G/MPa | Wire diameter d/mm | Effective number of turns n/turn | Center diameter D/mm | Free length L/mm | Installation Initial Length L0/mm |
|----------------------------|------------------|----------------------------------|----------------------|-----------------|---------------------------------|
| 8000                       | 0.5              | 9                                | 7.5                  | 30              | 26                              |

Formula for calculating elastic coefficient of compressed spring:

\[
K = \frac{Gd^4}{8nD^3}
\]  
(1)

According to Hooke's law:

\[
F = K \cdot x
\]  
(2)

The thrust range of the two compression springs of the on-line measuring device to the measure-hand can be obtained: \(0.066N \leq 2F \leq 0.165N\).

3.1. Minimum force deformation of the measure-hand

When the thrust of the compression spring is minimum, constraints and loads are applied to the ferrule and the measure-hand, the end face of the workpiece is fixed, and a pressure of 0.066 N is uniformly loaded at the left end of the measure-hand. After simulation calculation, the overall deformation result of the measure-hand is shown in Fig. 2.
As can be seen from Fig. 2, the maximum deformation area of the measure-hand is in the middle of the measure-hand. When the thrust force of the compression spring against the measure-hand is a minimum value of 0.066 N, the maximum force deformation amount of the measure-hand is 0.018 μm.

3.2. Maximum force deformation of the measure-hand

When the thrust of the compression spring is maximum, constraints and loads are applied to the ferrule and the measure-hand, the end face of the workpiece is fixed, and a pressure of 0.165 N is uniformly loaded at the left end of the measure-hand. After simulation calculation, the overall deformation result of the measure-hand is shown in Fig. 3.

As can be seen from Fig. 3, the maximum deformation area of the measure-hand is in the middle of the measure-hand. When the thrust force of the compression spring against the measure-hand is the maximum value of 0.165 N, the maximum force deformation amount of the measure-hand is 0.046 μm.

According to the combination of (1) and (2), when the measure-hand measures the workpiece, the force measuring deformation range is: 0.018μm ≤ ΔX ≤ 0.046μm

4. Static Analysis of Measurehand-Workpiece-Sensor

When the contact displacement sensor is installed on the measure-hand, the displacement sensor will be supported by the workpiece and transmit the acting force to the measure-hand. In order to explore the influence of the sensor on the deformation of the measure-hand, the static simulation of the measure-hand, the workpiece and the sensor was carried out in the ANSYS Workbench environment.
4.1. Minimum force deformation of the measure-hand
When the thrust of the compression spring is minimum, constraints and loads are applied to the ferrule and the measure-hand. The displacement sensor is fixed on the measure-hand and contacts with the surface of the workpiece. The end face of the workpiece is fixed. A pressure of 0.066 N is uniformly loaded at the left end of the measure-hand. After simulation calculation, the overall deformation result of the measure-hand is shown in Fig. 4.

As can be seen from Fig. 4, the maximum deformation area of the measure-hand is at the bending of both ends of the measure-hand. When the thrust force of the compression spring against the measure-hand is a minimum of 0.066 N, the maximum force deformation amount of the measure-hand is 0.0006 µm.

4.2. Maximum force deformation of the measure-hand
When the thrust of the compression spring is maximum, constraints and loads are applied to the ferrule and the measure-hand. The displacement sensor is fixed on the measure-hand and contacts with the surface of the workpiece. The end face of the workpiece is fixed. A pressure of 0.165 N is uniformly loaded at the left end of the measure-hand. Through simulation calculation, the overall deformation result of the measure-hand is shown in Fig. 5.

As can be seen from Fig. 5, the maximum deformation area of the measure-hand is at the bending of both ends of the measure-hand. When the thrust force of the compression spring against the
measure-hand is the maximum value of 0.165 N, the maximum deformation amount of the measure-hand is 0.017 μm.

According to the synthesis of (1) and (2), when the measure-hand measures the workpiece, the maximum force-measuring deformation range is: $6 \times 10^{-4} \mu m \leq \Delta X \leq 0.017 \mu m$.

**Table 2.** Force deformation of measuring paw before and after installing displacement sensor

| Status   | Minimum force deformation (μm) | Maximum force deformation (μm) |
|----------|--------------------------------|--------------------------------|
| Sensorless| 0.018                          | 0.046                          |
| Sensor   | $6 \times 10^{-2}$             | 0.017                          |

5. Conclusion

(1) In this paper, in the ANSYS Workbench 17.0 environment, static simulation analysis is carried out on the measure-hand of the three-point contact outer diameter online measuring device, and the maximum deformation range of the measure-hand when the contact displacement sensor is not installed and the contact displacement sensor is installed is solved respectively.

(2) As can be seen from the solutions, installing a sensor in the middle of the measure-hand can reduce the force-measuring deformation of the measure-hand. The maximum force-measuring deformation of the measure-hand is reduced from 0.046 μm to 0.017 μm, and the deformation is reduced by 63%.

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