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High Precision In-Situ Measurement and Compensation Method for Spherical Grinding Wheel

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Abstract. In parallel grinding, the processing accuracy is directly related to the spherical grinding wheel shape accuracy. Therefore, it is very necessary to obtain the change information before ultra-precision grinding. This paper proposes an in-situ measurement scheme of spherical grinding wheel, including building an in-situ measurement system based on laser tool setter. The systematic error of this scheme is analyzed, the installation error model of laser tool setter is abstracted. Furthermore, the compensation of measurement data and high-precision in-situ measurement of spherical grinding wheel are realized. Finally, the error angle value is calculated by calibrating the 12.5mm standard ball for calibrating, and then 3mm radius standard balls are measured for verification. Experiments show that the measurement accuracy after compensation can be improved to 1.2μm.

Keywords: parallel grinding, laser tool presetter, error compensation.

1. Introduction

Grinding can bring better surface roughness, geometric accuracy, and surface integrity, which makes it widely used in the high-precision manufacturing of hard and brittle materials [1]. Parallel grinding, as shown in Fig. 1, is a common grinding technique with a spherical (or truncated spherical) grinding wheel, and the point of contact between the grinding wheel and the workpiece moves along an arc that is on a horizontal (XOZ) plane [2]. In this grinding technique, the processing accuracy is directly related to the grinding wheel shape accuracy. Therefore, in this mode, the measurement of the wheel profile is the critical part of grinding accuracy.

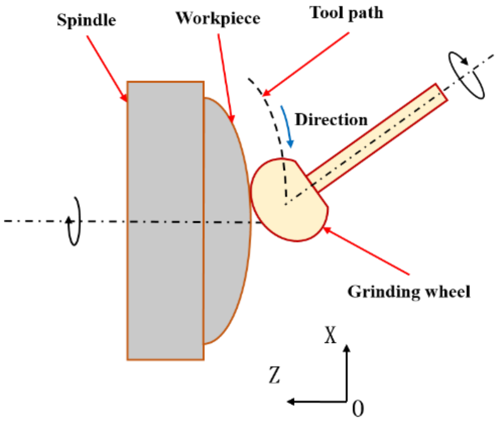

Fig. 1. Parallel Grinding Top View.

Compared to post-process measurement, in-situ measurement can avoid the additional installation errors induced by removal and remounting grinding wheel [3], [4]. Many studies have investigated the grinding wheel's profile in-suit measurement. Xu et al [5] developed an in-suit measurement system consisting of a high resolution CCD camera, a telecentric lens and a parallel backlight. Li et al [6] proposed a novel grinding wheel profile measurement method based on an image mosaic algorithm, which is more efficient and accurate compared with the traditional ones. Tang et al [7] realized the 3D reconstruction and measurement of grinding wheel topography by the shape from focus (SFF) method, and proposed a novel sharpness function which is based on the background subtraction and the gray level difference of images. Thang et al [8] installed two pneumatic gauging probes in different positions and measured the change of chamber pressure to reflect the situation about grinding wheel wear. Sioma and Struzikiewicz [9] used the laser triangulation method and 2D camera to get the height of the points, and created a three dimensional image of the surface of the grinding wheel.

In our research, a high-precision in-situ measurement device for grinding wheel installed in the ultra-precision grinding machine tool. The grinding machine tool, as shown in Fig.2, was designed and developed by Huazhong University of Science and Technology.

Fig. 2. Image of ultra-precision grinding machine tool.

The grinding wheel measurement system is based on a high- precision laser tool presetter. The laser tool presetter emits a laser with spot diameter of about 10μm, and the laser beam is perpendicular to the XOZ plane. In the measuring, the feeding system moves the grinding wheel on the XOZ plane, and the laser tool presetter would generate a trigger signal when the light beam across the edge of the grinding wheel profile. Each time a trigger signal occurs, the X-axia and Z-axis position data would be captured by the CNC system of grinding machine tool. However, for this grinding machine tool, it is hard to make sure the laser beam is perpendicular to the XOZ plane due to the absence of the Y-axis. The measurement error caused by the installation error exists objectively. Therefore, we analyzed the mappings between the measurement error and the installation error, and proposed an effective compensation method to correct the measurement error sourced from the installation error.

This paper is organized as follows: Section 2 describes the in-suit measuring system for the grinding wheel. Section 3 analyzes the measuring error caused by installation errors and proposes a compensation method. The experiments and results will be discussed in section 4.

2. High precision in-situ grinding wheel measurement system

The schematic diagram of the ultra-precision grinding machine tool shows in Fig. 3. The machine tool has two translational axes, denoted as the X and Z axes, supported by hydrostatic slideways. The workpiece spindle mounts on the Z-axis slide carriage, and the grinding spindle installs on the X-axis one. For high precision grinding, this machine tool has an on-machine grinding wheel dressing system on the Z-axis slide carriage, and high precision in-situ grinding wheel measurement system mounts on the right of the workpiece spindle.

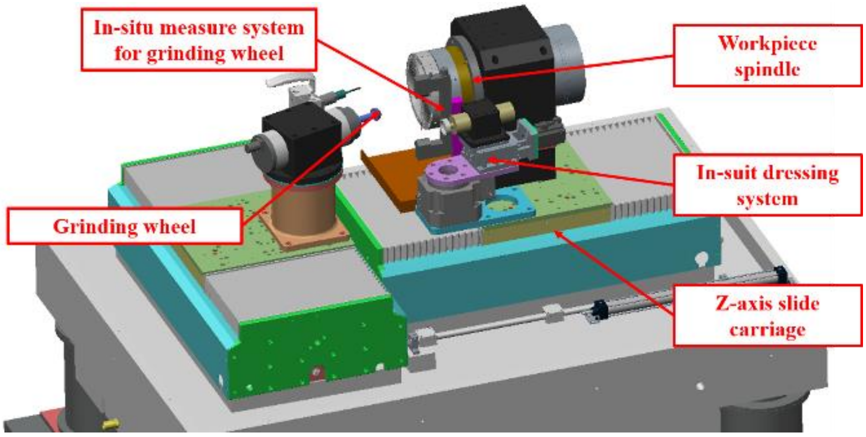

Fig. 3. Schematic diagram of ultra-precision grinding machine tool.

The grinding wheel measurement system is based on a high-precision laser tool presetter, whose schematic diagram is shown in Fig. 4. The laser transmitter emits a laser beam with spot diameter of about 10μm, the laser presetter would output an impulse signal to CNC system if the receiver find out the each change from bright to dark (or inverted). Because the feeding systems of ultra-precision grinding machine tool are X and Z axes, the laser tool should mount perpendicular to the XOZ plane.

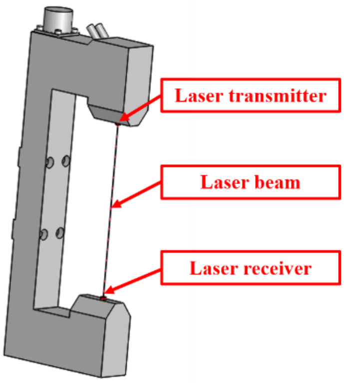

Fig. 4. Schematic diagram of laser tool presetter.

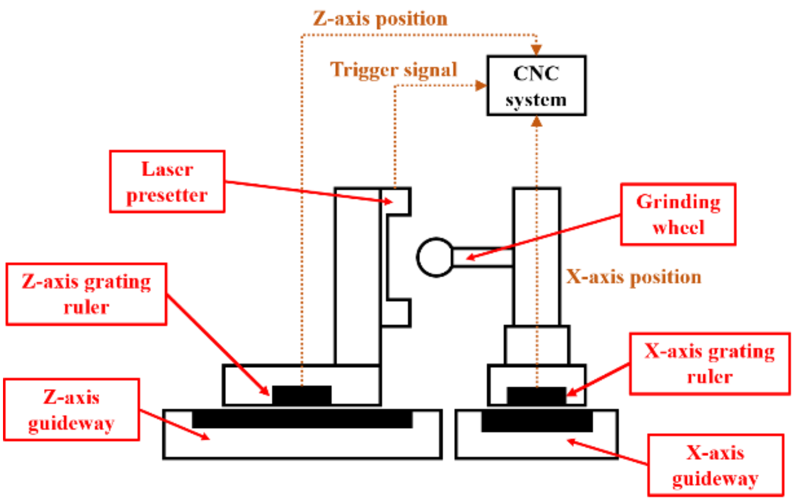

Fig. 5. Structure diagram of in-situ measurement system.

The structure diagram of the in-situ measurement system of the spherical grinding wheel is shown in Fig. 5. CNC system of machine tool controls the feeding system moves along the predetermined trajectory until the laser beam is tangent to the grinding wheel. At this time, the laser receiver finds out the light state is changed and sends an impulse signal to the CNC system. When the CNC system receives the laser presetter’ s trigger signal, the CNC system will capture the X and Z axes position and then make the feeding system stop. Repeating the above steps until the CNC system collects sufficient contour points of the grinding wheel.

3. Measurement error analysis and compensation method

Due to the absence of the Y-axis in the machine tool, it is hard to guarantee the laser beam is perpendicular to the XOZ plane in practice. The laser beam crosses the XOZ plane at a certain oblique Angle. In Fig. 6, the OP line can regard as the laser beam. The oblique Angle can decomposed to the α and the β, the α is the projection Angle between laser beam and X-axis on the XOZ plane, the β is the projection Angle between laser beam and Y-axis on the POP' plane.

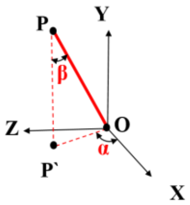

Fig. 6. Installation error of laser tool presetter.

Because of the laser beam has a certain oblique Angle with the Y-axis, the trigger position of measuring would also change accordingly, as shown in Fig. 7.

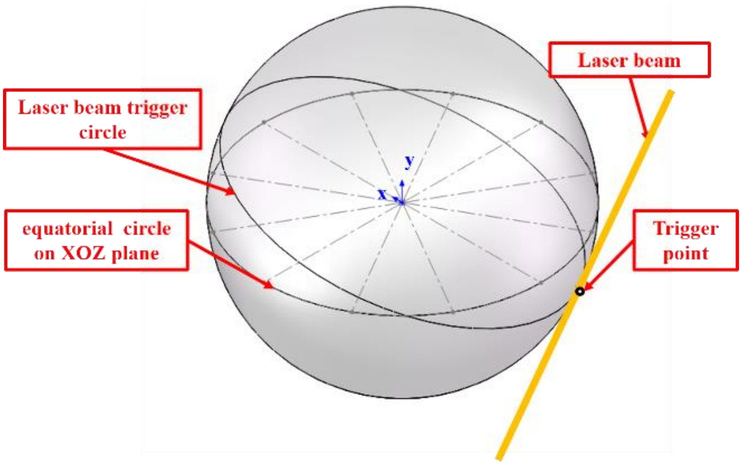

Fig. 7. Diagram of trigger points change.

The laser beam trigger circle does not coincide with the equatorial circle on the XOZ plane. Therefore, the trigger points captured by CNC system will deviate from the profile of grinding wheel, as shown in Fig. 8. The R represents the radius of the ideal trigger circle, and the ΔR represents the radius error of the actual trigger circle with the ideal ones at θ Angle. According to three dimensional geometric transformation theory, the ΔR, θ, α, and β can stablish an equation, as illustrated in Equ. 1.

$$\Delta R = \left| \frac{1}{\cos(\arctan(\tan\beta * \cos(\theta - \alpha)))} - 1 \right| * R \tag{1}$$

The Equ.1 is a typical nonlinear equation. Considering that the installation deviation of laser presetter is usually less than 2 arc-seconds. The β is very closed to zero, and the equ.1 can be simplified as,

$$\Delta R = \alpha * |\sin(\theta + b)| \tag{2}$$

The parameter of a and b in the Equ. 2 can be identified by measuring a high precision standard ball. According the value of a and b, the measuring position plus the ΔR calculated through Equ.2, the edge of grinding wheel can be corrected.

4. Experiments

The trajectory of measurement is shown in Fig. 9, the calibrating experiment is illustrated in Fig. 10, and the gathering software interface is shown in Fig. 11. The radius of the high precision standard ball is 12.5mm, the shape error of the standard ball is less than 50nm. This calibrating experiment measured 100 points totally. The data collected were fitted by least square method, the best fitting value of a and b are 0.00501820 and 1.281833 respectively, the fitting result shows in Fig. 12.

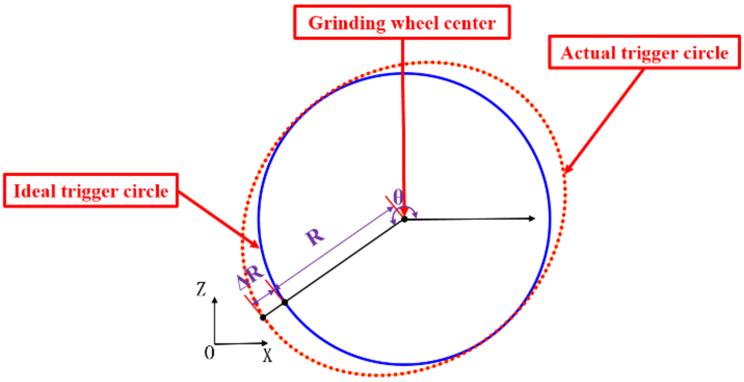

Fig. 8. The ideal and actual trigger circle projected to XOZ plane.

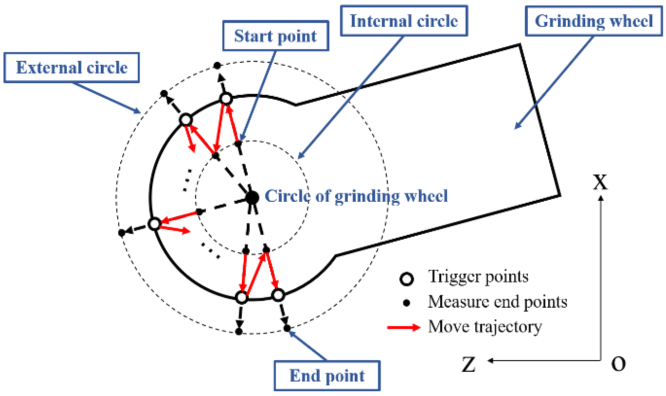

Fig. 9. Diagram of motion trajectory during measuring.

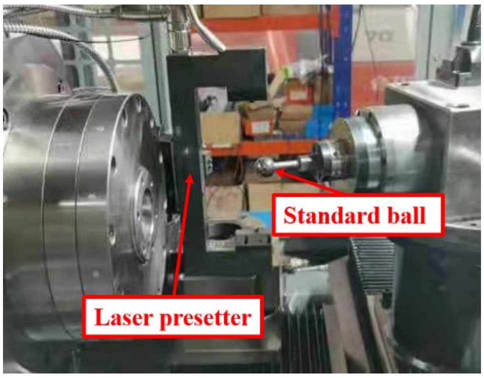

Fig. 10. Image of the calibrating experiment.

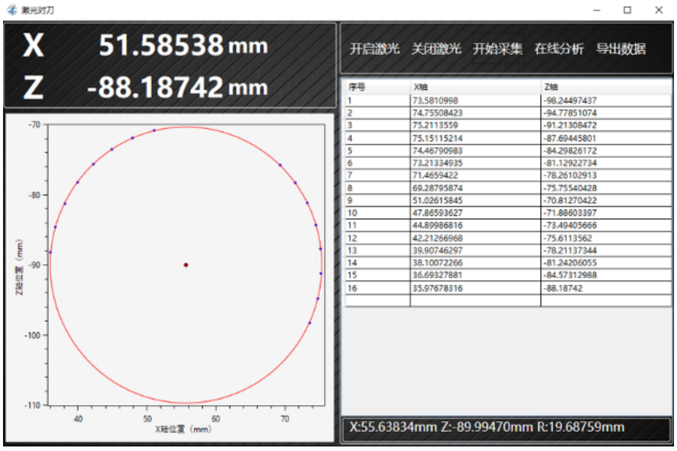

Fig. 11. Software interface for gahtering trigger points.

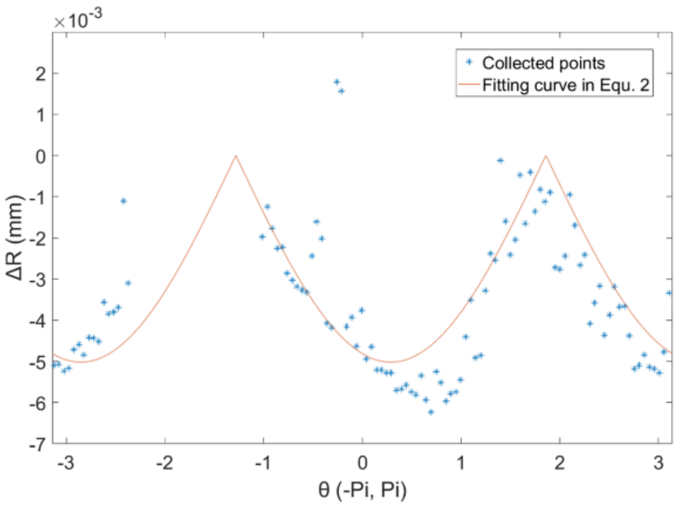

Fig. 12. Fitting result in calibrating measurement data.

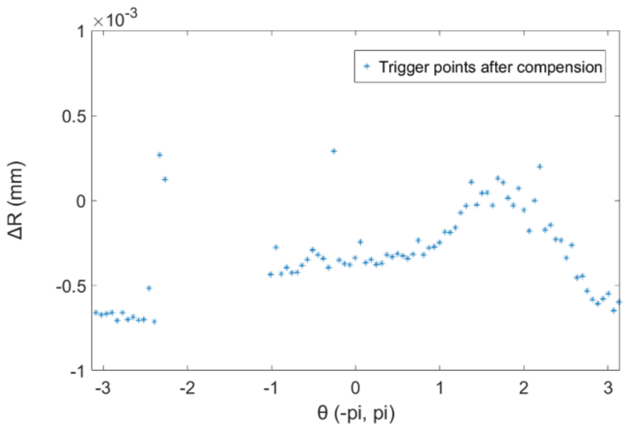

Fig. 13. After compensation results of the 3.0mmstandard ball.

In order to verify the effectiveness of the compensation method, this research has measured another standard ball. The radius of the second standard ball is 3.0mm, and its shape error is less than 100nm. The measurement results after compensation is shown in Fig. 13, it is clear that error of radius is less than 1.2μm after compensation.

5. Conclusions

This paper proposes an in-situ measurement scheme of spherical grinding wheel, including building an in-situ measurement system based on laser tool setter. The systematic error of this scheme is analyzed, the installation error model of laser tool setter is abstracted, the error formula is deduced combined with homogeneous coordinate transformation, and the parameter is identified by least square method. Furthermore, the compensation of measurement data and high-precision in-situ measurement of spherical grinding wheel are realized. Finally the error angle value is calculated by calibrating the 12.5mm standard ball for calibrating, and then 3mm radius standard balls are measured for verification. Experiments show that the measurement accuracy after compensation can be improved to 1.2μm.

6. Acknowledgment

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