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Three-dimensional micro shape creation by on-machine scanning measurement

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Abstract
Machining accuracy is generally guaranteed by a dedicated measurement equipment that requires the removal of workpieces from a machine tool. Therefore, in terms of improving productivity based on the automation, on-machine measurement is an indispensable technology to achieve the speedup of ultraprecision machining. In the study, an influence caused by the attitude of measurement probe is firstly investigated by using a scanning measurement device installed on a machine tool. It appears that the results of scanning measurement are largely affected by the probe attitude. Thus, in order to measure three-dimensional micro shapes with high accuracy, it is recognized that the probe should contact the workpiece surface from the normal direction by multi-axis control. Furthermore, the relationship is clarified between machining error and the probe displacement based on targeted CAD model. In order to realize on-machine scanning measurement by multi-axis control, machining error is estimated, and machined shape is compared with the result measured with a confocal microscope.

Ultraprecision machining, Three-dimensional micro shape, Multi-axis control, On-machine scanning measurement

1. Introduction

According to the miniaturization of optical parts, the demand is increasing to fabricate precise micro shapes on ultraprecision machine tool [1]. However, machining accuracy is affected even by errors such as tool/workpiece setting, tool configuration, material to be machined, machining environment and so on [2]. As a result, machining accuracy should be guaranteed by a dedicated measurement equipment.

However, a dedicated measurement equipment requires time and effort to remove the workpiece from a machine tool. Therefore, in terms of improving productivity based on the automation, on-machine measurement is an indispensable technology to achieve the speedup of ultraprecision machining. On the other hand, the shapes to be machined are shifting to more complicated curved or three-dimensional shape such as Blue-ray lens, micro Fresnel lens and so on. If a machined shape has large inclination angle, non-contact type measurement is not suitable. Thus, in this study, a contact type on-machine measurement device is used to detect the machining errors.

The authors have been studying the effect caused by the probe attitude of contact type on-machine measurement device installed on a machine tool [3]. It appears that measurement results of scanning a sphere are largely affected by the probe attitude toward the sphere's surface. As a result, it is recognized that the probe should contact the workpiece surface from the normal direction by multi-axis control to achieve high accuracy measurement.

However, the relationship has not been clarified between machining error and the probe displacement obtained in scanning measurement. Therefore, in order to realize on-machine scanning measurement by multi-axis control, machining error is estimated and machined shape is compared with the measurement result obtained with a confocal microscope in this study.

2. Experimental setup

Figure 1 shows a 5-axis control ultraprecision machining center ROBOnano Ui (FANUC corp.) and a contact type on-machine measurement device NANOCHECKER (FANUC corp.) used in this study. The machining center is equipped with three translational axes (X, Y and Z) and corresponding two rotational axes (B and C). The resolutions of the translational axes and the rotational axes are 1 nm and 0.00001 degrees, respectively. These axes are equipped with aero-static bearings to achieve friction-free movements. The probe displacement of the measurement device is detected with 1 nm resolution and a diamond ball having a 0.25 mm radius is adhered to the tip of the probe.

A workpiece is set up on C table and the measurement device is set up on B table next to the cutting tool. The measurement device is controlled by NC controller and displacement of the probe which contacts the workpiece surface is recorded together with machine coordinates in a PC.

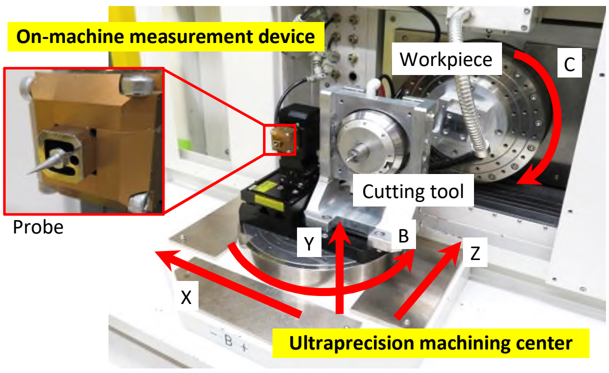

Figure 1. Experimental setup of ultraprecision machining center and on-machine measurement device

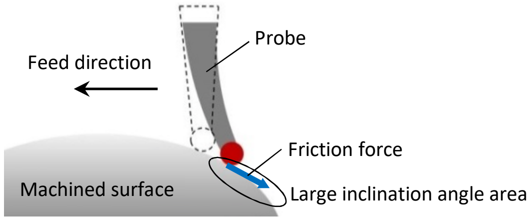

Figure 2. Probe deformation by a friction force

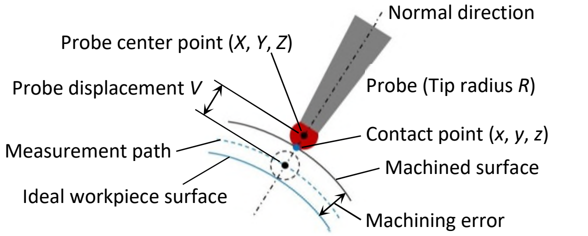

Figure 3. Relationship between probe center point and contact point

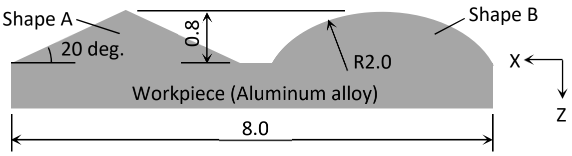

Figure 4. Target shape

3. Multi-axis control scanning measurement

3.1. Effect on measurement accuracy caused by probe attitude

When a shape having a large inclination angle is scanned, the probe obliquely contacts the workpiece surface as shown in Fig. 2. The probe displacement is not adequate due to the probe deformation by friction force. Thus, a conventional method that uses only two translational axes deteriorates measurement accuracy.

In order to improve the measurement accuracy, the authors proposed a method of scanning measurement by simultaneous multi-axis control [2]. In this method, measurement paths are generated by using three translational axes and two rotational axes so that the probe attitude constantly corresponds with the normal direction of workpiece surface.

3.2. Estimation of machining error with multi-axis control

The probe displacement is obtained with the machine coordinates of three translational axes and two rotational axes simultaneously. Figure 3 illustrates the relationship between the probe center point and the contact point (x, y, z) on the machined surface. The probe displacement is equal to the dimensional difference between the ideal workpiece surface and the machined surface. The contact point in workpiece coordinate system can be calculated by converting those coordinate values in machine coordinate system. Therefore, actual machining error should be estimated by using the calculated contact point. The contact point is expressed as following equation.

$$(x, y, z) = (X, Y, Z) - (V + R) * (\sin B \cos C, \sin B \sin C, -\cos B)$$

V: Probe displacement [mm]
R: Probe tip radius [mm]
B, C: Rotational angle of B, C axis [deg.]

4. Machining experiment and result

In order to confirm the measurement accuracy by multi-axis control, an experiment is conducted by using contact type on-machine measurement device. In the experiment, a shape having a cross-sectional shape shown in Fig. 4 is machined by using a diamond tool. Shape A is a triangle and shape B is a part of circle. Then, the machined shape is scanned by the conventional method using only the translational axes and the proposed method using both the translational axes and the rotational axes. Those measurement results are confirmed by comparing with the result measured with a confocal micro scope. Scanning conditions are summarized in Table 1.

Table 1. Scanning conditions

Probe tip	Ruby ball, R – 0.250249 mm
Scanning Speed	5.0 mm/min.
Scanning frequency	20 Hz

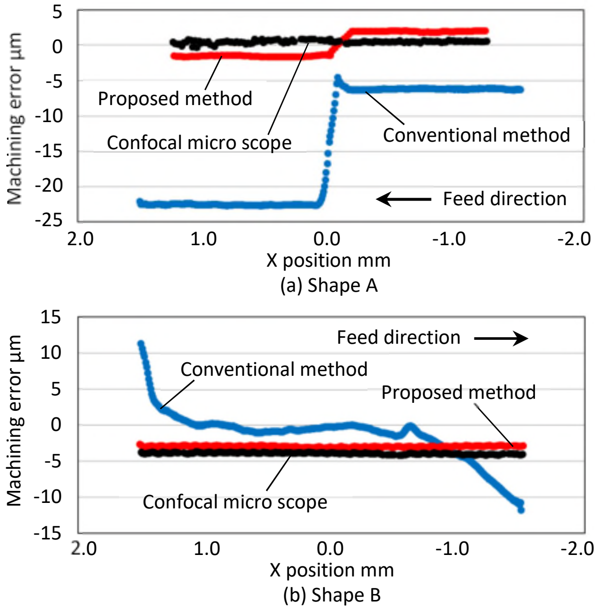

Figure 5. Estimated machining errors

Figure 5 shows estimated machining errors of shape A and B. Measurement result by using both translational axes and rotational axes is almost same as the result by using confocal microscope. Therefore, it is found that the estimation of machining error by the proposed method is more accurate than that by the conventional one.

5. Conclusion

In contact type on-machine measurement, the probe is deformed by a friction force between tip of probe and workpiece surface. Therefore, in order to reduce the deformation, a method to measure three-dimensional shape by multi-axis control is proposed. Moreover, the relationship between probe displacement and machining error is clarified. After the estimation of machining error, it could be compensated by modifying NC data.

Acknowledgements

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References

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