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6-axis control ultraprecision machining based on compensation of tool setting errors

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Abstract
The development of highly integrated machining technology is strongly required in order to fabricate tiny and complicated shapes with high accuracy in 6-axis control ultraprecision machining. However, the serious problems caused by the accumulation of various kind of errors happened in the experiments, and deteriorated the accuracy of the machined microparts. One of the main causes influencing the machining accuracy is setting errors of the cutting tool. It is difficult to prevent the setting errors, which may increase in accordance with the number of the control axes. Therefore, it is necessary to develop a setting error compensation method and to establish an accurate tool setting technique. With the proposed method, it is enable to measure and calculate the setting errors of the tool edge point against the rotational center by simple grooving. From the experimental result of 6-axis control ultraprecision machining, it was found that the proposed method in the study is effective for compensating the tool setting errors.

Ultraprecision machining, Setting error, Multi-axis control

1. Introduction

The needs of high-performance electronic and optical devices are increasing recently. For example, the use of concave reflection grating, which consist of a number of microgrooves on an arbitrary free-form shape is recently expected. The study deals with a compensation method of tool setting errors in multi-axis control machining, so that V-shaped microgrooves are created on a concave surface by using a non-rotational cutting tool in 6-axis control machining.

The development of highly integrated machining technology is strongly required in order to fabricate tiny and complicated shapes with high accuracy. The authors have created some complex microparts by means of diamond cutting with a multi-axis control ultraprecision machining center [1, 2]. However, the serious problems caused by the accumulation of various kind of errors happened in the experiments, and deteriorated the accuracy of the machined microparts.

One of the main causes influencing the machining accuracy is setting errors of the cutting tool. However, it is difficult to prevent the setting errors, which may increase in accordance with the number of the control axes. The tool setting errors have been reduced by measuring a preliminarily machined simple shape roughly and adjusting the tool position manually. These processes are time-consuming and cause the uncertainty in multi-axis control ultraprecision machining. Besides, the tool setting technique depends on the levels of workers' skills.

In order to solve these problems mentioned above, it is required to reduce the machining errors and improve the machining efficiency. The authors have proposed a compensation method of setting errors of a non-rotational cutting tool in 5-axis control ultraprecision machining [3]. Then, it is necessary to develop a setting error compensation method and to establish an accurate tool setting technique in 6-axis control ultraprecision machining.

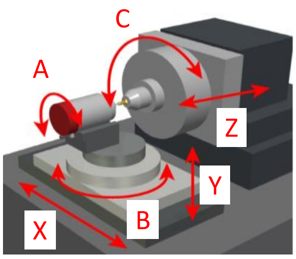


Figure 1. Machine tool structure

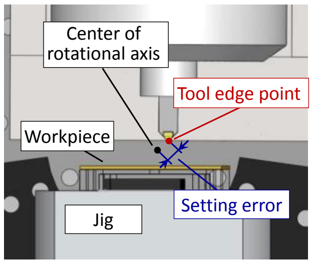


Figure 2. An example of setting errors

2. Compensation of tool setting errors

Figure 1 illustrates the 6-axis control ultraprecision machining center that is used in the study of ROBOnano Ui made by FANUC corp., which is equipped with three translational axes (X, Y, Z) and corresponding three rotational axes (A, B, C). The resolutions of the translational axes and the rotational axes are 1 nm and 0.00001 degrees, respectively. NC data is generated where the tool edge point would be located on the center of rotational axes as a tool initial position. However, as shown in Figure 2, it is extremely difficult to precisely locate the edge point on the axes since the initial tool is set by rough measurement and manual adjustment. This results in the deterioration of machining accuracy. Thus, the compensation method is devised to reduce the tool setting errors that can occur between the tool edge point and the center of rotational axes, in addition to the precise error measurement.

The proposed compensation method of tool setting errors has three stages. At the first stage, the simple shapes are created on a plane surface of soft material such as brass, as shown in Figure 3. At the second stage, the setting errors are calculated by measuring the positional relation between grooves, which are known from the coordinate value of the actual tool edge position. At the third stage, compensated NC data are generated based on the estimated setting errors.

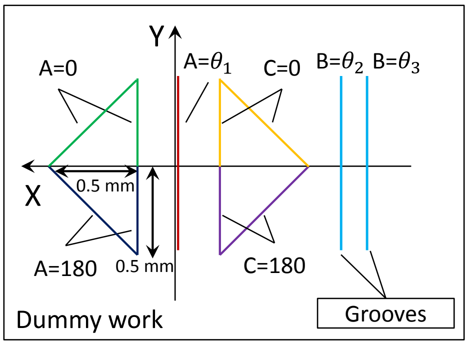


Figure 3. Grooved simple shapes to detect setting errors

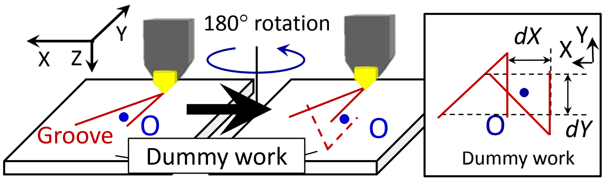


Figure 4. Grooving for detecting setting errors against A axis

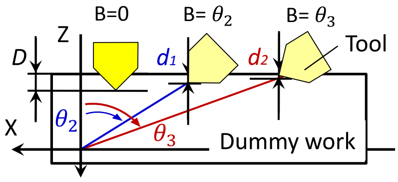


Figure 5. Grooving for detecting setting errors against B axis

At the first stage, a cutting tool is fed in Z direction with the depth of cut *D*, and fed on X-Y plane to create two grooves sharing start points, while keeping A axis in 0 degrees. After A axis is rotated by 180 degrees, the tool creates the same two grooves, as shown in Figure 4. The tool setting errors *dX* and *dY* against A axis are measured by the positional relation between these machined grooves. Then, the tool edge point can be accurately arranged by compensating *dX* and *dY* on NC data. In a similar way, the tool setting errors against C axis are measured by the positional relation of this triangle shape.

Additionally, a cutting tool is fed again in Y direction with the depth of cut *D*, and fed in Z direction to create other grooves, while inclining the cutting tool by specific angles A = θ_1, B = θ_2 and B = θ_3 and keeping other rotational axes in 0 degrees. If the tool edge point does not correspond to the rotational centre of B axis, X and Z axes require the compensation of NC data because the movement of the tool axis in accordance with the inclination of B axis is limited to Z-X plane. Then the tool setting errors, *ΔX* and *ΔZ*, can be obtained based on the difference of three groove depths shown in Figure 5. The compensation procedure is carried out by cancelling the amount of setting errors from original NC data as follows.

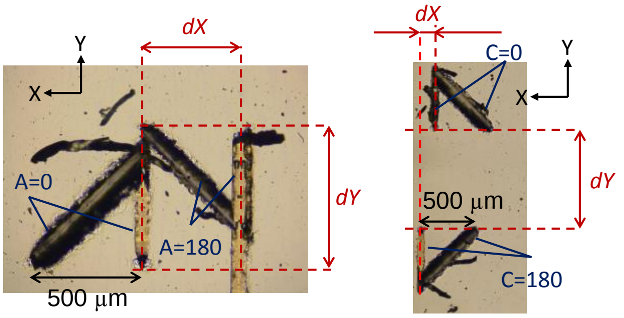
$$\Delta X = \frac{-(d_1-D)(1-cos\theta_3)+(d_2-D)(1-cos\theta_2)}{sin\theta_2(1-cos\theta_3)-sin\theta_3(1-cos\theta_2)} \quad (1)$$

$$\Delta Z = \frac{(d_1-D)sin\theta_2+(d_2-D)sin\theta_3}{sin\theta_2(1-cos\theta_3)-sin\theta_3(1-cos\theta_2)} \quad (2)$$

3. Machining experiment and result

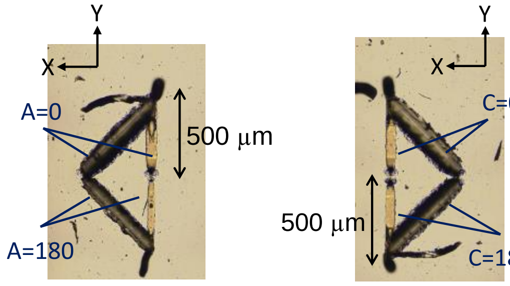
In order to confirm the above-mentioned compensation method, the machining experiments were conducted by using a single crystal diamond tool where the tip angle was 90 degrees and a brass plate was used as a workpiece with good transcription.

As an example of compensation of tool setting errors, Figure 6(a) and 6(b) are microscopic images of the machined shapes to detect the tool setting errors against A or C axis with original NC data, respectively. After NC data are generated based on the estimated setting errors, the same shapes are machined on the target plane, as shown in Figure 7.



(a) Against A axis (b) Against C axis

Figure 6. Machined results to detect setting errors



(a) Against A axis (b) Against C axis

Figure 7. Machined results with compensated NC data

Table 1 Measured machining errors against A and C axis

Distance between grooves [μm]		Original NC data	Compensated NC data
Setting errors against A axis	*dx*	490.04	4.06
	dy	680.12	2.97
Setting errors against C axis	*dx*	108.97	0.74
	dy	852.81	1.40

The machined grooves without compensation are extremely larger than the targeted shapes and also those with compensation. Table 1 shows the measured machining errors of grooves with a laser confocal microscope that has higher resolution than the tool setting error. It is found that the compensated NC data considerably decreases the setting errors and improve machining accuracy in 6-axis control ultraprecision machining.

4. Conclusion

In this study, the method to compensate the tool setting errors during machining tiny and complicated shapes was considered in 6-axis control ultraprecision machining. With the proposed method, it is enable to measure and calculate the setting errors of the tool edge point against the center of rotational axes by simple grooving. From the result of machining experiments, it was found that the proposed method in the study is effective for compensating the tool setting errors.

References

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