Tool setting of error compensation for multi-axis control ultra-precision machining

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Abstract

The errors that could be generated while setting the cutting tools can deteriorate machining accuracy. It is difficult to prevent the setting errors during the tool setting process, which may increase in accordance with the number of the control axes. These errors make it difficult to set accurately the tools at the right position in multi-axis control ultra-precision machining. For highly efficient and precise maicromachining, this study shows the setting error compensation method for the tools with high accuracy. From the results of machining experiments, it is found that the proposed method is effective for compensating tool setting errors.

1. Introduction

The needs of high-performance electronic and optical devices are increasing recently, so that the development of highly integrated ultra-precision machining technology is strongly required in order to fabricate the tiny and complicated shapes with high accuracy. The authors have created complex microparts by means of diamond cutting with a multi-axis control ultra-precision machining center [1]. 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 shapes.

One of the main causes influencing the machining accuracy is the setting error of cutting tools. It is difficult to prevent the setting errors, which may increase in accordance with the number of the control axes. Therefore, it is difficult to set accurately the tools in multi-axis control ultra-precision machining. The tool setting errors have been reduced by measuring a preliminarily machined simple shape roughly and adjusting the tool position manually. These processes are timeconsuming and cause the uncertainty in multi-axis control ultra-precision 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. Then, it is necessary to develop a setting error compensation method and to establish an accurate tool setting technique that is independent of workers' skills.

2. Compensation of Tool Setting Errors

Figure 1 illustrates the 5-axis control ultra-precision 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 two rotational axes (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 rotational axes of B and C 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 rotational center of B and C axes, in addition to the precise error measurement.

The setting error compensation method has three stages. At the first stage, the simple shapes are created on a plane surface, 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 error.

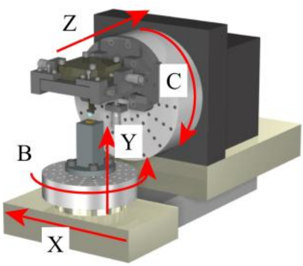


Figure 1. Machine tool structure.

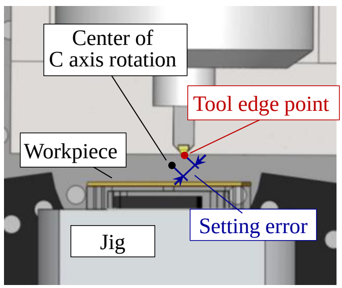


Figure 2. An example of setting error.

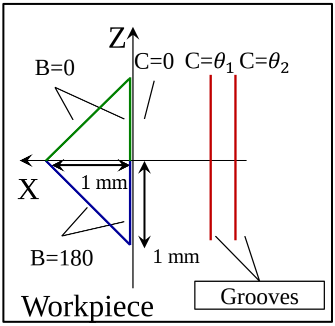


Figure 3. Machined simple shape.

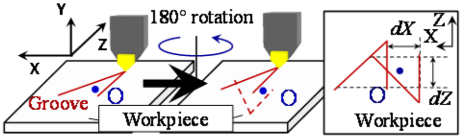


Figure 4. Setting error against B axis.

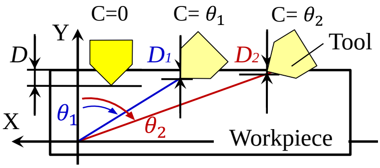


Figure 5: Setting error against C axis.

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

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 keeping B axis in 0 degrees and inclining the cutting tool by specific angles θ_1 and θ_2. If the tool edge point does not correspond to the rotational center of C table, X and Y axes require the compensation of NC data because the movement of the tool axis in accordance with the inclination of C axis is limited to X-Y plane. Then the tool setting errors, ΔY 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.

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 60 degrees and a brass plate was used as a workpiece with good transcription. Figure 6 shows a target shape that consists of four half circles with radius of 400 μm, where the ideal depth is 3 μm and C axis is continuously changed

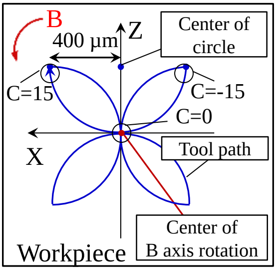
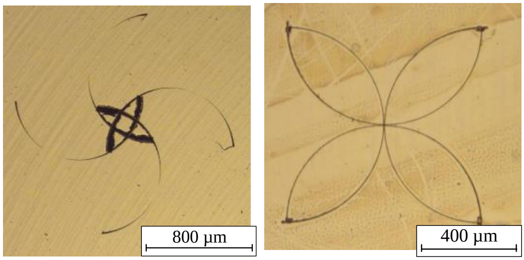


Figure 6. Target shape.



(a) Without compensation (b) With compensation
Figure 7. Machined results.

from -15 to 15 degree for each half circle. Figure 7(b) and 7(b) are microscopic images of the machined shapes with original NC data and with compensated NC data, respectively.

The half circles without compensation are extremely larger than the targeted shapes and also those with compensation. Table 1 shows the measured depths of machined grooves with a laser confocal microscope that has higher resolution than the tool setting error. It is found that the compensated NC data creates almost the same grooves as the original grooves regarding the depth of 3 µm.

4. Conclusion

Table 1. Measured groove depth.

C axis	Groove depth [µm]	
	Without compensation	With compensation
-15	32.40	4.27
0	2.67	2.84
15	11.12	5.51

In this study, the method to compensate the tool setting errors when machining tiny and complicated shapes by using a 5-axis control ultra-precision machining center was considered. With the proposed method, it is enable to measure and calculate the setting errors of the tool edge point against the rotational center of B and C 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 error.

References:

[1] Nakamoto K Ishida T Kitamura N and Takeuchi Y 2011 Fabrication of microinducer by 5-axis control ultra-precision micromilling *CIRP Annals* **60/1** 407-410.