Investigation of Optimal Conditions in Cube Machining Test on Five-axis Machining Center

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The cube machining test is a test method in which each face of a cube is divided into nine parts and each part is cut with a different tool angle using a ball end mill. Compared to the conventional accuracy test method, it can be evaluated without using dedicated equipment, so it is already used in the industry to demonstrate the high accuracy of 5-axis machine tools. However, this test method is currently carried out independently by each company, and no test method has been established. In addition, although the evaluation of machining results is based on the height difference and inclination of the machined surface, it is not clear whether the obtained results are caused by spindle performance, geometrical errors, or dynamic errors. In this study, existing parameters in the cube processing test is investigated, and examined the influence of these parameters on the processing results. In fact, machining tests were conducted by changing several parameters such as the distance from the center of rotation of the table and the order of machining. The causes of errors obtained from the results are discussed

OMENCLATURE

a = directional orientation of the system
h = strip thickness with strip thickness and strip thickness strip thickness

1. Introduction

5-axis machining centers are increasingly being applied to the machining of complex shapes and free-form surfaces because of their ability to simultaneously control the position and relative orientation between tool and workpiece. However, compared to conventional 3-axis machine tools, 5-axis machining centers are composed of three linear axes and two rotary axes, resulting in more geometric errors, which makes high-precision machining more difficult than with 3-axis machine tools. Therefore, it is necessary to evaluate the overall performance of 5-axis machining centers.

Methods to evaluate the performance of 5-axis machining centers can be classified into non-machining methods and machining-based methods. In the former method, a ball bar and R-test, which are specified in ISO 10791-61), are used to measure the relative positional relationship of the machine tools. The latter methods include the conical table machining test specified in ISO10791-72) and the cube machining test3)4) studied by Sakamoto et al.

The cube machining test has the potential to be an effective evaluation method in industry because it does not require a dedicated measuring device like the non-mechanical machining method, and can be measured with ordinary measuring devices used in production sites. On the other hand, since each company or researcher is currently performing this test method independently, no clear test method has been defined.

Therefore, with the ultimate goal of establishing a test method, this study examined the parameters that may affect the test results and explored the causes of errors based on the results on the machined surface.

2. Cube Machining Test

2.1Possible test parameters for the cube machining test

The cube machining test divides a cubic surface into nine parts, each of which is machined with a ball end mill at a different tool posture, and evaluates the overall performance of the machine tool based on the difference in height and inclination between the machined surface areas after machining. Therefore, if machining is performed in the absence of errors, no difference in the height of the machined surface occurs. In reality, however, differences in height occur between regions due to factors such as spindle performance, geometric error, dynamic error, and the machining process.

There are a variety of test parameters, but some of the most common are workpiece size and material, rotary axis angle, mounting position, machining process, and tooling. The size of the work material is directly related to the machining time, and as the machining time increases, various sliding parts heat up and undergo thermal deformation, which greatly affects the machining accuracy, such as spindle elongation. In addition, by increasing the angle of the rotary axis and changing the mounting position of the workpiece farther from the center of the table (farther from the swivel C-axis), it is thought that larger errors will appear, and the effects of positioning and assembly errors can be examined.

Since the above test parameters are considered, we will examine how they affect the machined surface.

2.1.1 Simulation (Times New Roman 9.5pt)

In this study, a reference test is conducted in accordance with the cube machining test3)4) proposed by Sakamoto et al. In ZONE II, which is located above, below, left, and right of ZONE I, the tool is tilted 30° to the Z-axis, and in ZONE III, which is located diagonally to ZONE I, the tool is further rotated 45° around the Z-axis.

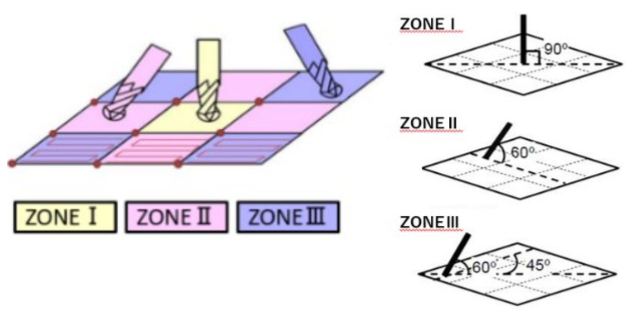

Fig. 1 Cube Machine Test model

3. Actual machining

3.1 Target Machine

The 5-axis MC with a swiveling table used in the test is shown in the figure. The specifications are summarized in Table 1.

(a) Appearance (b) Machine structure drawing

Fig. 2 DMU75monoBLOCK

Table 1 Specifications of DMU75monoBLOCK

X-axis travel [mm]	750
Y-axis travel [mm]	650
Z-axis travel [mm]	560
A-axis travel [deg]	+120° ～ -120°
C-axis travel [deg]	360°
Table size [mm]	φ 650 in 800×650
Max. table loading mass [kg]	600
Shape of table top	14Tgroove9
Max. workpiece diameter [mm]	φ 840
Max. workpiece height [mm]	500
Max. table speed (A/C) [rpm]	20 / 40
Max. spindle speed [rpm]	20000
Feed speed (X・Y・Z axis) [m/min]	40

3.2 Processing conditions

The cutting order in each zone was assigned a number, the reference conditions for the A and C axes were set as shown in Table 2, and actual machining was performed. In this study, both the A and C axes are fixed when cutting each zone, and the table is tilted 30° to the front side of the machine while cutting ZONE II and ZONE III. Figure 3 shows the cutting position of each area as viewed from the front of the machine. The machining position of ZONE Ⅰ is the same location as ZONE Ⅱ-1, but the A-axis angle is 0°.The arrows indicate the cutting start position and direction.

Table 2 Standard Conditions

	ZONE-I	ZONE-II	ZONE-III
Cutting order	1	1, 2, 3, 4	1, 2, 3, 4
C (°)	0	0, 90,180, 270	45, 135, 225, 315
A (°)	0	-30	-30

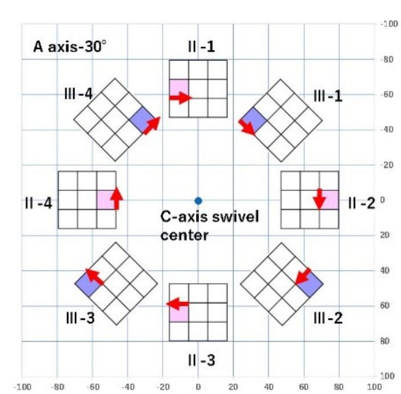

Fig. 3 Cutting position of each ZONE viewed from the front of the machine

Work piece	SKD61 30×30×30mm
Tool	NS TOOL MSBH230
Number of revolutions	16000rpm
Feed speed	1860mm/min

Depth of cut	0.1mm
Pitch	0.1mm
Machining time	13min4.7s

The mounting position of the workpiece was determined to be 5 0 mm offset from the center of the table in the Y-axis + directi on.

3.3 Measurement results

In this study, four points on each surface were measured five times using a touch probe without removing the workpiece after machining. In order to observe the relative displacement of the height of each surface in this study, an average was calculated and used as the height of each area. The measurement results are shown in Figure 4.

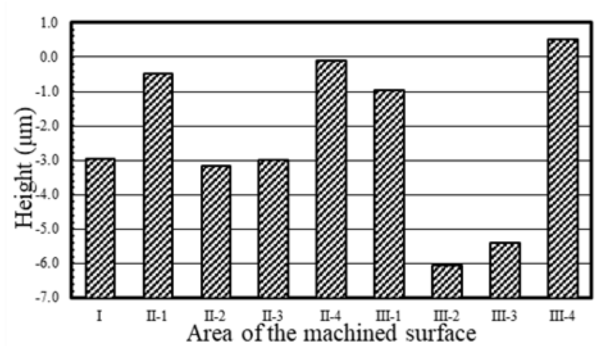

Fig. 4 Height of each ZONE

It was found that the C-axis rotation produced variations in the height of each surface due to changes in the cutting position. In particular, it was found that in ZONE II, the machined surfaces were higher at the negative X-axis and positive Y-axis positions from the center of the C-axis rotation. Similarly, in ZONE III, the machined surface was found to be higher when cutting at the positive Y-axis position.

4. consideration

Figures 3 and 4 indicate that the cutting position is a factor in the height difference of the machined surface. This may be the reason for the angle deviation between the swivel C-axis and Z-axis. We believe that the table assembly error or the A-axis positioning error may be a major factor.

5. conclusion

In the future, we will examine how the difference in height is generated by actually offsetting the mounting position, since the error is thought to be more pronounced when the distance from the C-axis swivel center to the mounting position of the workpiece is changed. In addition, possible test parameters will be considered on a case-by-case basis, and the effects on the machined surface will be investigated.

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