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Monitoring of Tool Behavior in End-milling Under Different Cutting Conditions Using Projection Image

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Abstract
Recently, small-diameter tool is used for high-speed milling and it is indispensable for high-quality and high-productivity manufacturing. However, tool breakage occasionally occurs, and this becomes a serious problem in automated production. In-process monitoring and measuring techniques such as spindle power, cutting forces or vibration are proposed so far. However, the spindle power, cutting force in this process is too low to apply these methods to the small diameter milling process. This study aims to develop an in-process monitoring system for monitoring the cutting state and thus preventing tool breakage for milling using a small-diameter tool. The proposed system consists of charge-coupled device (CCD) camera, an image processing device, a man-machine controller (MMC), and a machining center with an open computer numeric (CNC). Our previous study demonstrated that the monitoring technique is based on the analysis of the tool projection image by the CCD camera. It enables the precise measurement of tool deflection during high-speed milling. In this study, we applied this system to the measurement of the tool deflection in the end milling under the different cutting conditions: tool type, workpiece, feed rate, and machining shape. Also, we examined the relationship between tool deflection and the cutting conditions. The result clarified that this system enabled the in-process monitoring of tool deflection. The measured tool deflection with this system was influenced by the cutting condition. In addition, the tool deflection showed the periodical change in one turn, which seemed to be related to a number of tool's edges.

Monitoring, Tool deflection, Tool behavior, Projection image, In-process, End-milling

1. Introduction

In the field of production technology, processing technologies are advancing along with various demands such as miniaturization, high accuracy and high efficiency of parts. Phenomena such as tool wear, vibration, tool deflection, etc. are involved in the machining. Several types of monitoring techniques using these phenomena have been proposed [1][2]. The small-diameter tools have been widely used for the precision end-milling. This tool is operated at high speeds and produces high quality with high productivity. However, small-diameter tools are prone to be deformed and broken easily [3]. Therefore, in-process monitoring and measuring techniques are needed to detect the condition of the tool during the cutting process. The authors have proposed the fundamental system which is based on technique of image processing for monitoring the tool during cutting [4].

2. Monitoring system

The schematic illustration of monitoring for tool behavior and in-process control system is shown in Fig.1. This system is constituted by the CCD camera, image processing device, machining center, etc. The image processing device processes tool projection images taken with the CCD camera. Monitoring of the tool behavior is based on the measurement of tool deflection with projection image taken by this system. LED units are used as a backlight for taking a picture with the CCD camera. The shutter timing of the CCD camera is controlled by the trigger signal which is output by detecting reflecting tape pasted on the side of the tool holder with the laser sensor. It is possible to take a projection image in the optional rotation angle of the tool.

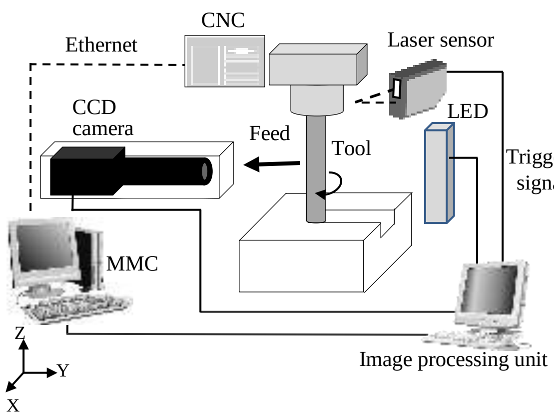

Figure 1. Schematic illustration of experimental setup

Table 1. Cutting conditions

Tool	Squared end mill: 3, 4 flutes (Sintered carbide)
Work piece	Pre-hardened steel Steel (S45C)
Tool diameter d (mm)	2.0
Length of cut l (mm)	12.0
Cutting speed V (m/min)	10 ~ 80
Feed rate V_f (mm/min)	10 ~ 40
Axial depth of cut a_a (mm)	0.6
Radial depth of cut a_r (mm) (side-milling)	0.4

3. Experimental Procedure

In the experiment, this system was applied to the end milling under different cutting conditions: tool types (3, 4 flutes), machining shape, cutting speed, and feed rate. The cutting conditions were determined as shown in Table 1. The cutting was conducted in two types, slotting and side-milling. The cutting experiment was carried out on a vertical CNC machining center. Cutting was carried out in the Y axis direction of the machining center. The tool deflection in the X axis direction was measured with the CCD camera as shown in Fig.2.

In this CCD measuring system, 1 pixel is equivalent to 4.54 μm. Figure 3 shows, as an example, the tool projection images of two types of tools. The tool deflection is calculated from the difference between the position of the tool during cutting and that before cutting.

4. Experimental Results

Figure 4 shows the relation between tool rotation angle and tool deflection in the cutting process with the three-edge end-mill. The tool deflection is measured at the position with distance 2 mm from the tip of the tool. The cutting types were slotting and side-milling. The deflection data was measured every 30 degrees in the rotation angle of the tool. In this figure, it is understood that the deflection has changed according to the rotation angle of the tool. In addition, the change of deflection has reflected the state of cutting based on the three edges. And, the tool deflection of slotting is larger than that of the side milling. This result shows that the part of outer edge of the tool is not in contact with the workpiece in side-milling. It also demonstrates the difference of the contact between tool edges and workpiece in two types of cutting as shown in Fig.4. Also, we obtained similar tendency for four-edge end-mill as presented in Fig.5.

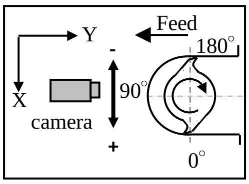

Figure 2. Camera orientation

(a) 3 flutes (b) 4 flutes

Figure 3. Projection image of tool

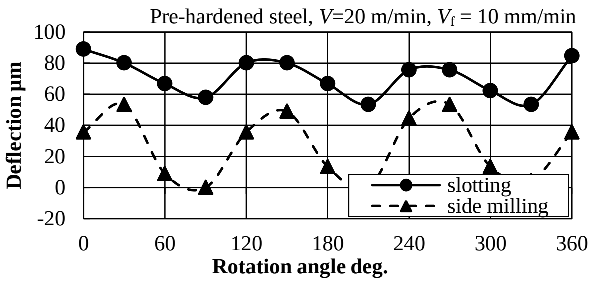

Figure 4. Relation between rotation angle and deflection (3 flutes)

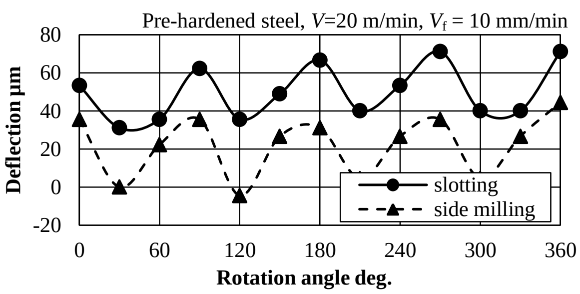

Figure 5. Relation between rotation angle and deflection (4 flutes)

Figure 6 shows the relation between feed rate and tool deflection in slotting which used the two-type workpieces. The cutting speed is 20 m/min for each condition. These deflections are obtained from the measurement at the given rotation angle with the three-edge tool. It is found that the deflection is proportional to the feed rate for each workpiece. Figure 7 shows the relation between cutting speed and tool deflection. In this experiment, the two-type-edge tools were used: 3 flutes and 4 flutes. The tool deflection was decreased when cutting speed was increased from 10 m/min to 40 m/min. After 40 m/min, the cutting speed did not greatly influence tool deflection in this result.

5. Conclusions

This study proposed a monitoring system for tool behavior in end-milling with small-diameter tools, which uses CCD projection images. In this experiment, the constructed system applied to the machining under the different cutting condition. The measured deflection data showed the characteristics of the number of the tool edges and machining shapes. The measured tool deflection during cutting showed the difference of workpiece materials and feed speed. Though the cutting speed was raised, the tool deflection did not change greatly in this experiment. This system is useful for the monitoring of tool behavior during cutting with the small-diameter tool.

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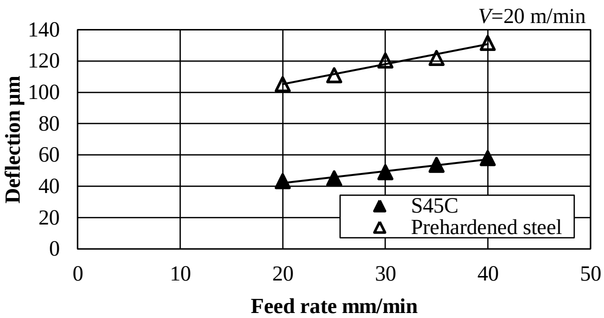

Figure 6. Relation between feed rate and tool deflection (3 flutes)

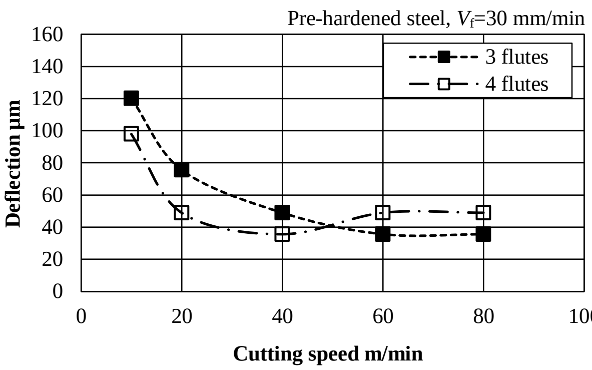

Figure 7. Relation between cutting speed and tool deflection