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In-process monitoring of tool wear in small-diameter end-milling using an image photographing system

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Abstract

Because tool wear, tool deflection and cutting heat are the significant factors influencing machining accuracy, monitoring, and measurement and evaluation techniques, they are exceedingly important in a machining process. To monitor tool wear, methods based on changes in the measurement of cutting force and on indirect estimation of acoustic emission signals have been used, but direct measurement is considered relatively easy for the quantitative evaluation of wear and the analysis of measurement data. This study describes a system that uses images obtained using a charge-coupled device (CCD) camera in a machining process to recognize the state of the tools on a machining center and enable the measurement of tool wear. The proposed system consists of two CCD cameras, an image processing device, and a machining center with an open computer numerical control. The monitoring technique of tool deflection is based on the analysis of the tool projection image obtained using the CCD camera, as shown in our previous study. In this experiment, tool wear in end-milling was measured based on the projection image and actual image obtained using two CCD cameras without removal of the tool from a machine tool spindle. Slotting was conducted on a steel plate using a small-diameter tool under certain cutting conditions; changes in tool wear were obtained during processing. Moreover, the relation between tool wear and tool deflection in cutting was examined. As a result, the measurement of the cutting edge based on CCD image in a machining process enabled this system to monitor the tool wear. In addition, a correlation was demonstrated between the measured tool wear and tool deflection.

In-process, Monitoring, Tool wear, End-milling, CCD image, Tool deflection

1. Introduction

Owing to the miniaturization and high performance of products, the scope of precision processing technology has expanded, and the development of high-performance machine tools and cutting tools has been progressing in the field of machining. Research on process monitoring and process control is conducted with regard to the technology that optimizes the machining state [1]. Regarding cutting tools, the deflection, wear, and chipping of tools during machining are factors that affect the machining accuracy. For monitoring of the tool conditions, the detection of tool wear using the acoustic emission (AE) signals and on-machine monitoring of the cutting edge using laser diffraction are performed [2][3]. On-machine measurement is the measurement of tools and work pieces on the machine tool. We can expect to reduce the wastage of time and measurement errors by conducting on-machine measurements during the process. The tool wear and chipping of tool cutting edge influence the lead time in the processing quality and the production process, and a rapid determination of the tool state is desired. In this study, we investigated the method of measuring tool wear without the removal of tools in the cutting process for end milling. The tool state was recognized via on-machine measurement, based on the image photographed using a CCD camera.

2. Experimental setup

Based on image photography using a CCD camera, we constructed a system that recognizes the state of the tool on the machine tool and measures the tool wear without removal of the tool. The system configuration is shown in Fig.1. For end milling, two cameras and LED light units are installed around the spindle of the machining center to measure the state of the tool in the machining process. The measurement data is processed using a PC externally connected via a digital signal board. In this CCD measuring system, 1 pixel is equivalent to 4.54 μm and 2.25 μm in $camera_1$ and $camera_2$, respectively, according to the high-precision laser measurement instrument.

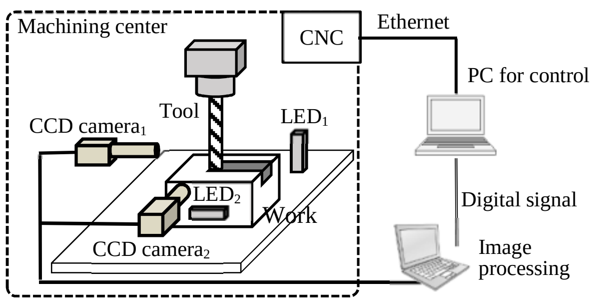
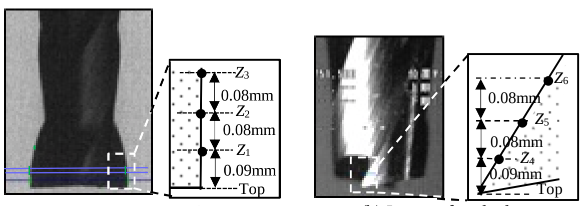


Figure 1. Schematic illustration of experimental setup



(a) Projection image of tool ($camera_1$) (b) Image of tool edge ($camera_2$)

Figure 2. Monitoring of tool wear with CCD images

3. Experimental Procedure

In this research, we examined methods to monitor tool conditions in the following two ways with respect to end milling: 1) By focusing on the reduction of the tool diameter owing to wear, we determine the wear change by measuring the tool width, and 2) by measuring the change in end mill cutting edge, we determine the change in wear and cutting-edge condition. In method 1), the tool width is measured based on the projection image acquired using camera$_1$ of the experimental system; an example of the image is shown in Fig.2(a). In method 2), the change in the cutting edge is measured using an image photographed using camera$_2$; figure 2(b) shows an example of the photographed image of the tool edge. A measurement program was developed for each measurement, to obtain the amount of changes from the difference between the data before and after cutting at each of the three measurement points set in the image processing system. The measurement position of camera$_1$ is Z_1 to Z_3, and that of camera$_2$ is Z_4 to Z_6, as shown in Fig.2.

In this system, when taking measurements, it is possible to obtain the measurement without removing the end mill from the spindle. In this experiment, the changes in tool wear in the cutting process were measured in slotting with a small diameter end mill. The experimental conditions are listed in Table 1. In addition, this constructed system is able to measure the tool deflection during cutting [4]. It was previously shown that the measured deflection data showed the characteristics of the number of the tool edges and machining conditions. In the experiment, we investigated the relationship between tool deflection and tool wear during machining.

4. Experimental Results

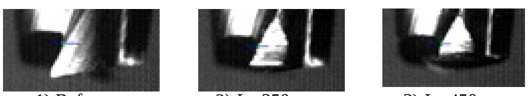
The decrease in tool width and cutting edge of the end mill tip for each constant cutting length L_C were measured using the constructed system in slotting. Examples of the tool images obtained by this measurement are shown in Figs.3(a) and (b).

Table 1. Experimental conditions

Tool	Squared end mill: 2 flutes
Work piece	Steel (S45C)
Tool diameter d (mm)	1.0
Length of cut l (mm)	3.0
Cutting speed V_c (m/min)	30
Feed rate V_f (mm/min)	10.0
Axial depth of cut a_a (mm)	0.3

1) Before use 2) L_c=350mm 3) L_c=450mm

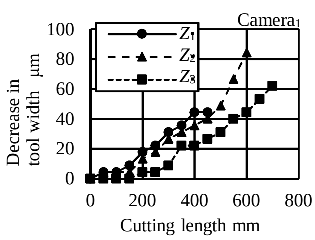
(a) Projection image of tool edge width (camera$_1$)



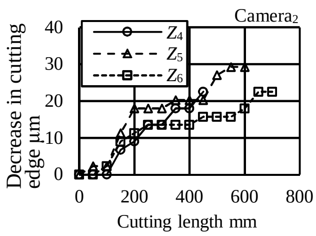
1) Before use 2) L_c=350mm 3) L_c=450mm

(b) Image of tool cutting edge (camera$_2$)

Figure 3. Monitoring image of tool wear



(a) Decrease in tool width



(b) Decrease in cutting edge

Figure 4. Relation between cutting length and tool wear

Figure 4(a) shows the change in the decrease in tool width, measured using camera$_1$. Figure 4(b) shows the decrease in the cutting edge, measured using camera$_2$. The cutting length L_C = 100 mm does not correspond to significant wear; however, the wear gradually increases subsequently. In this cutting condition, abrasion also proceeded in the Z axis direction, and measurement was impossible after L_C = 450 mm and 600 mm at positions Z_1 and Z_2, respectively. Tool breakage occurred at L_C = 700 mm and the measurement was terminated.

Camera$_1$ was diverted for tool deflection measurement. The tool deflection was measured at three positions with a distance of 2 mm (Z_7), 3 mm (Z_8), and 4 mm (Z_9) from the tip of the tool during cutting as shown in Fig.5(a). Tool deflection is determined by the difference between the central positions before cutting and during cutting at each measurement position. The Tool deflection as shown in Fig.5(b) was increased with the accumulation of cutting length. The relationship between the measured tool deflection and the decrease in tool width shown in Fig.6 represents a good correlation. By using this system, it is also possible to estimate the state of tool wear based on the monitoring of the tool deflection.

5. Conclusions

In this research, based on the tool image photographed using two CCD cameras, we studied the method of recognizing the tool state on the machine tool in the cutting process and measuring the tool wear without the removal of the tool. The constructed system enabled us to determine the change in the amount of tool width reduction and that of cutting edge retraction with regard to tool wear during cutting using small-diameter end mill. In addition, a significant correlation existed between tool deflection and tool wear. By improving the accuracy of the system, it can be expected to contribute to the monitoring of the tool state.

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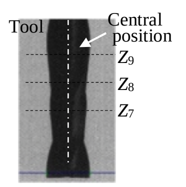
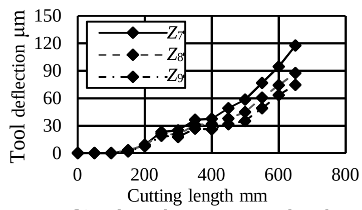


(a) Measurement position of tool deflection (Camera$_1$)



(b) Relation between cutting length and tool deflection

Figure 5. Measurement of tool deflection

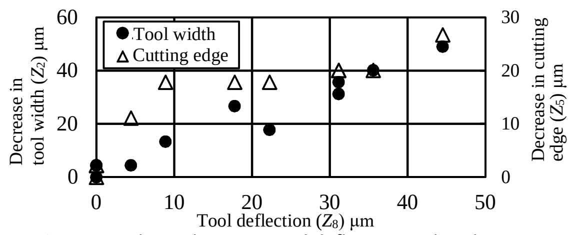


Figure 6. Relation between tool deflection and tool wear