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Development of cutting tool edge measurement with a point autofocus probe

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Abstract
It is a crucial factor to measure roughness and contours of a cutting tool edge in order to improve surface roughness, machining efficiency and accuracy of a workpiece. However, it has not been easy for a contact stylus and a non-contact methods to measure roughness and contours of a sharp edge since it damages the contact stylus and its steep angles produce poor reflected rays for the non-contact method. A point autofocus probe (PAP) is widely used for the roughness and contour measurements of various precision processing surfaces due to its capability of measuring a large area in high precision and a steep angle with its small laser beam spot. The authors have developed a new cutting tool edge measuring method using PAP and three-axis liner stages with a rotary stage. The new measuring method will offer precision measurements of the entire cutting tool edge. In this study, a new measuring instrument was designed, and its accuracy was verified.

Keywords: point autofocus probe, cutting tool edge, precision processing, sharp edge, roughness, contour, surface texture

1. Introduction

A quantitative evaluation of cutting tool edges is significant element for improving a surface roughness of a machined surface, tool life and elucidation of phenomena in metal cutting processes. Microscopes and scanning electron microscopes (SEM) are used as the conventional evaluation method. However, it is difficult to quantitatively evaluate the cutting tool edges in sub-micrometer level with this method. A new measurement method, polygon measurement, using point autofocus probe (PAP) [1] was developed to offer sub-micrometre level measurements and quantitative evaluations. This study describes the new measurement method, the accuracy verification and the measurement example.

2. Instrument configuration and measurement method

Figure 1 shows the instrument configuration. The rotary (θ) stage is incorporated on to the XY stage. The workpiece is fixed on the θ stage. PAP is incorporated in the Z stage and measures radial heights. Each axis has an optical encoder for obtaining each focused coordinate value on the workpiece surface while scanning the XY stage in order to carry out 2D and 3D measurements. The autofocus (AF) axis has 1nm in height resolution and its laser beam spot diameter is 0.9 µm. The linear stages have 10 nm resolution and the θ stage has 0.0002°. The instrument has two stage scanning modes, INDEX mode and high-speed scanning mode [2]. The AF repeatability is σ = 15 nm.

3. Polygon measurement principle and accuracy verification

Cutting tools generally have sharp angles within 90 degrees. They need to be tilted 45 degrees in order to directly measure a tip. However, many optical measurements have a limitation to carry out high-precision measurements due to low reflected light (laser beam) from the inclined planes. Polygon measurement, a combination of the Y axis and the θ stage measurement, was developed to solve this limitation (Fig. 2). First, calculate the rotation axis of the θ stage by measuring the reference sphere. Second, set the rake face of a cutting tool parallel to the scanning direction and obtain its profile data (fig. 2 a). Third, rotate the tool (Fig. 2 b) so that the flank face is parallel to the scanning direction, and obtain the profile data (Fig. 2c). Last, connect all the data by converting them to a polar coordinate based on the rotation center of the θ stage. This measurement method is capable of obtaining high-precision data due to positioning the inclined planes of the sample parallel to the scanning direction for each measurement. On the other hand, it requires high accuracy in the axial roundness and the positioning of the rotation center and detection of the tip of the cutting tool.

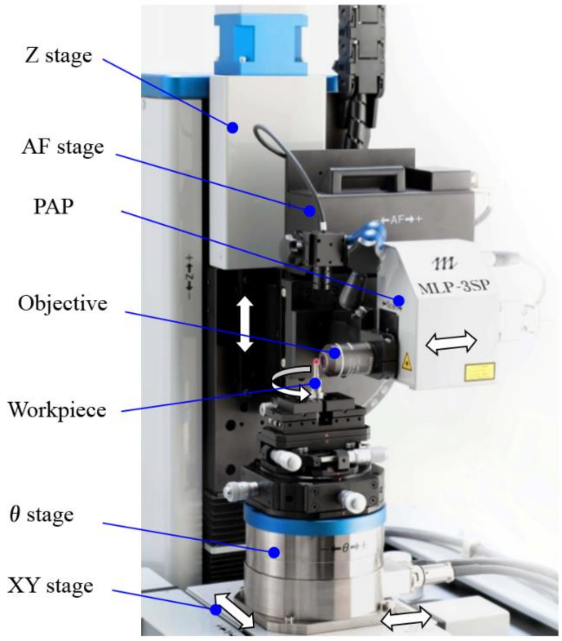

Figure 1. Point autofocus probe 3D measuring instrument.

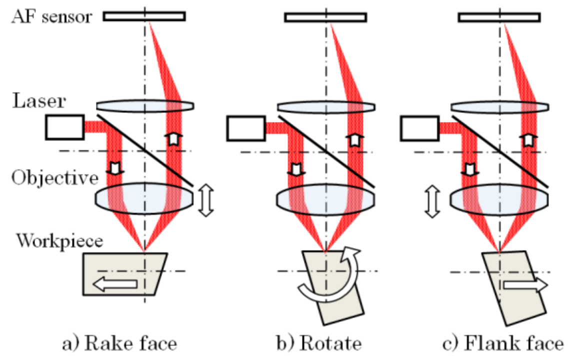

Figure 2. Measurement principle of polygon measurement.

The axial roundness accuracy was ± 0.07 um / 360° by measuring the reference sphere. Also, repeatability of the center position detection was ± 0.07 um as a result of 20-time measurements.

The moving profile of the laser spot and its luminance were measured, by using a diamond cutting tool, in order to verify the accuracy of cutting edge position detection (Fig. 3). The laser spot profile changes only Z = 0.02 µm even if its center (diameter = 0.9 µm) reaches at the tip of the cutting tool edge. On the contrary, the laser spot luminance drastically decreases at X = -W / 2 position from the cutting edge. From this data, the edge position was defined as the laser spot luminance = 208, and its profile data was obtained. The repeatability of the edge position measurement was ± 0.07 µm as a result of 20-time measurements. The maximum connecting error is ± 0.16 µm by adding up these errors. Figure 4-b shows the polygon measurement result. The tip of the cutting tool was not precisely measured with the one direction measurement mode (Fig. 4-a) as the scattering light produced near the tip of the cutting edge affected the AF sensor to track the edge profile. On the other hand, polygon measurement obtained precise data as the displacement of the cutting edge intersection was less than 0.05 µm (Fig. 4-b).

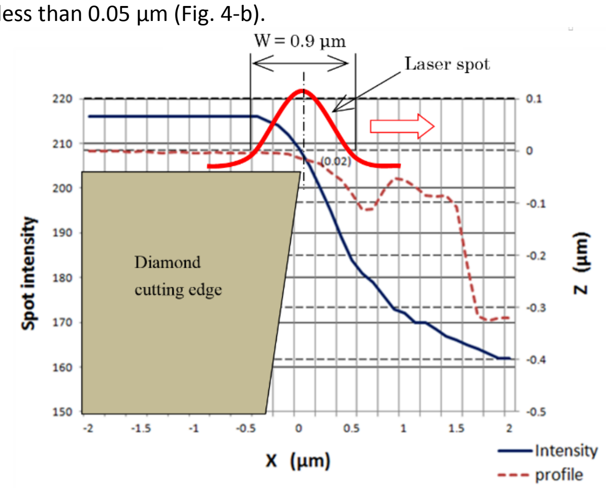

Figure 3. AF characteristics of the edge measurement.

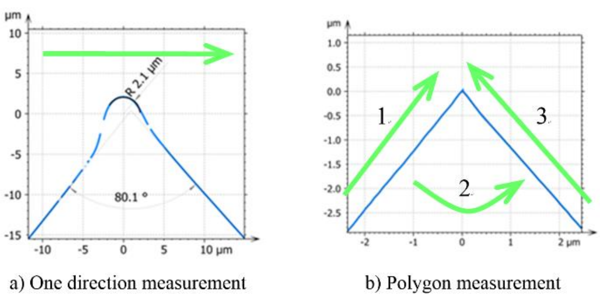

Figure 4. Measurement results of a diamond cutting tool edge with two different measurement methods.

4. Carbide tool edge measurement

As a measurement example, figure 5 shows the 3D measurement of a carbide tool for microfabrication (NS Tool Co., Ltd.) carried out by polygon measurement method. Figure 5-a shows the SEM image of the edge with its radius = 2 µm, whereas the 3D measurement shows the same result at the same position on the edge (Fig. 5-c). Also, the radius values of the edge varies in the 3D measurement. There is a position at the edge where its radius = 0.5 µm (Fig. 5-d). The edge roughness in the ridgeline direction 3µm inside from the tip edge of the rake face is Pa = 0.023µm and that of the flank face is Pa = 0.095µm. The flank face has 4 times larger roughness than the rake face (Fig. 5-b).

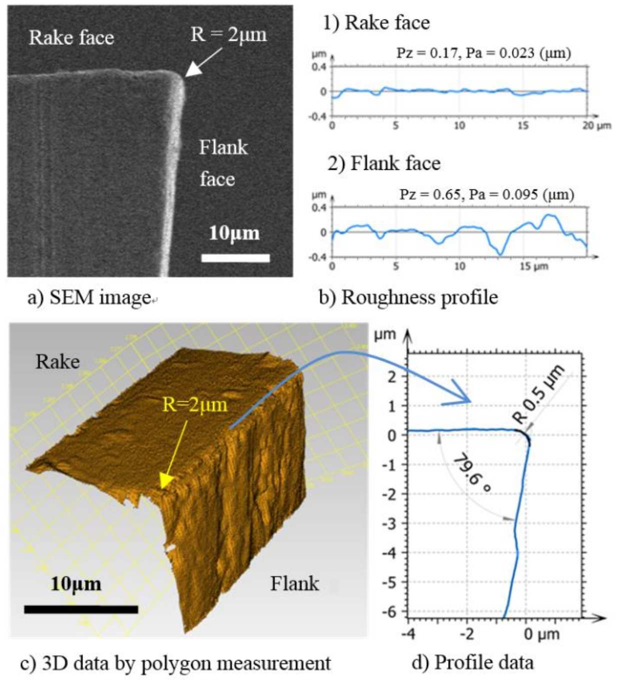

Figure 5. 3D polygon measurement of a carbide tool edge.

5. Conclusions

This paper presented a quantitative evaluation of a cutting tool edge by polygon measurement using point autofocus probe. The following specific conclusions are drawn from the study presented in this paper.

1. Polygon measurement method is capable of obtaining high-precision data of the tip of the cutting tool edge by positioning its measurement surface parallel to the scanning direction.
2. The maximum connecting error is ± 0.16 µm (excluding an environmental error).
3. Polygon measurement method enables to measure the tip of the round form with the same level as the laser spot diameter (W = 0.9 µm). This measurement method allows to precisely measure tips of tool edges that was used to be said difficult.
4. This method is effective for measuring tool edges in high precision, managing shape quality and evaluating tool life and elucidating phenomena in metal cutting processes.

References

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