

On-machine measurement of a distance between high speed rotation tool tip and workpiece by laser diffraction

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Abstract

The Far-field laser diffraction has been applying to monitor tool cutting-edge position with sub-micrometre precision because of eliciting a diffraction phenomenon. In this paper, a pulsed laser was irradiated to a gap consisting of a high-speed ($150,000\text{min}^{-1}$) rotation tool and a workpiece edge in order to experimentally measured the distance of the tool tip away from the workpiece every 50 nm by the detected diffraction pattern.

1 Introduction

Light or laser shielding methods are widely used to measure the tool position or the tool cutting-edge profile. However, with conventional optical shielding methods, the diffracted light from the tool cutting-edge, leads to ambiguous measurements on the micrometre scale. In other words, obtaining tool measurements with sub-micrometre precision is difficult because of the unavoidable optical diffraction. To address this optical diffraction phenomenon, we developed an on-machine tool measurement device with a pulsed laser diode to experimentally measure high speed rotation tool displacements of order of tens of nanometres.

2 Principle of measurement

Figure 1 shows the fundamental measurement principle. This method can be applied to on-machine measurements having a resolution of tens of nanometres^[1-2]. Bringing the tool to be measured into close proximity with the reference knife edge creates a narrow edge gap of width x . A line laser beam with a wavelength of λ is then irradiated on the narrow edge gap. The diffracted light from the edge gap passes through a Fourier transform lens to build up an observable diffraction pattern at a distance of the focal length f behind the lens. Consequently, the value of gap x can be scaled by substituting the 1st-order peak-to-peak width W into the equation (1).

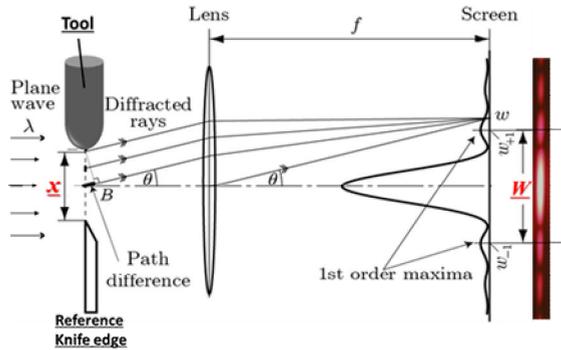


Figure 1: Fundamental principle for measurement

$$x(W) = 1.4303\lambda \sqrt{1 + \left(\frac{2f}{W}\right)^2} \quad \dots(1)$$

3 Developed Measurement Device

Figure 2 shows the developed on-machine tool measurement device, which can be installed on a machine tool. The measurement device dimensions are 180×80×86(H) mm³ and it is composed of a pulsed laser diode ($\lambda = 635$ nm), a lens, and a CMOS camera. The detected diffraction pattern data from the camera are processed in real time (9.5 frames per second) by a computer. In this paper, the new measurement device was tilted ($\omega = 15^\circ$) with respect to a workpiece as shown in Figure 3 and 4 in order to measure the distance between a tool tip and a workpiece with 45° chamfer angle edge. Figure 5 shows a detected diffraction pattern while the tool was rotating at $150,000 \text{ min}^{-1}$. The dotted curve and the solid curve show the initial data and data obtained after filtering off the central maxima peak, respectively. The effect of using a pulsed laser is shown in Figure 6 as causing considerably less fluctuation than in use of continuous laser irradiation.

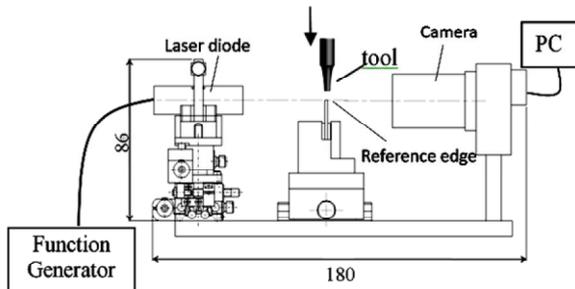


Figure 2: Developed device with a pulsed laser diode

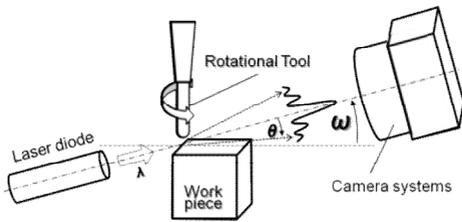


Figure 3: Optical systems to measure the distance between tool tip and workpiece

4 Experimental Results

A ball endmill with a radius of 750 μm was used for inspecting the measurement precision of our developed device. In this experiment, the distance x was measured about 95 times as the tool was moved vertically up and down relative to the workpiece by a piezo-drive stage. Figure 7(a) and (b) shows a trial measurement of the tool displacement (black solid line) every 200 and 50 nm, respectively, compared to the value recorded (dashed grey line; the solid grey line shows the 15 points averaged values) from a capacitance displacement metre (Microsense4810) to verify the precision of the developed measurement device. The horizontal axis represents the measuring time and the vertical axis represents the measured distance values. The experimental results show that the device could measure changes in the tool displacement with less than 40 nm in error.

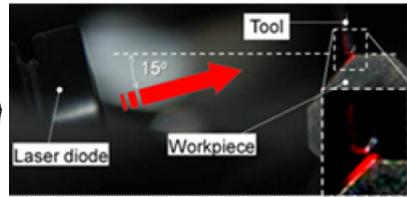


Figure 4: Appearance of the measurement

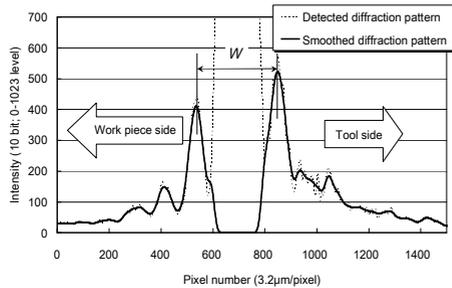


Figure 5: Detected diffraction pattern

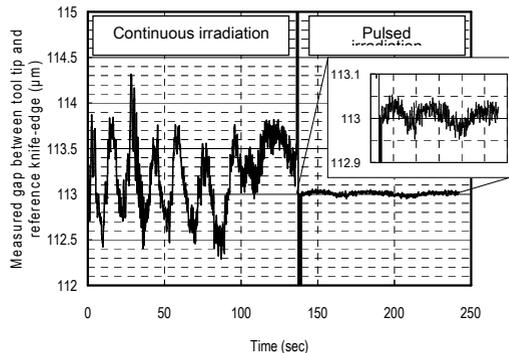
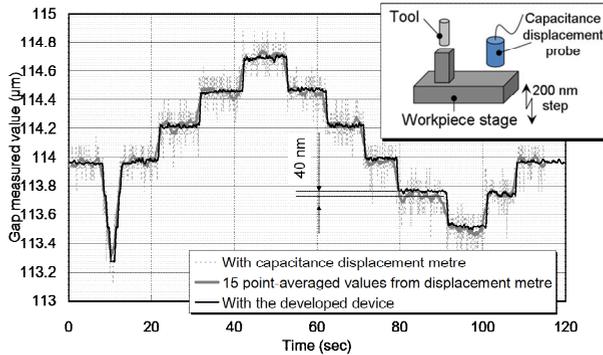


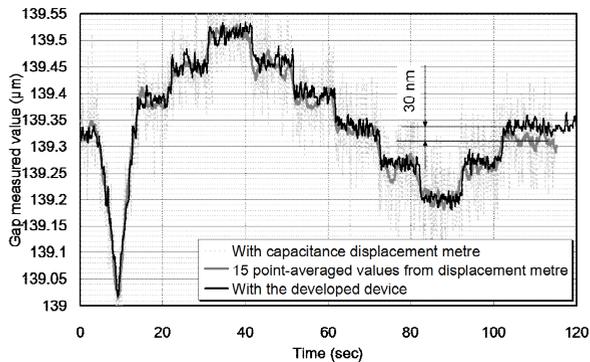
Figure 6: Effect of pulsed irradiation mode

5 Conclusions

The diffraction pattern can be detected to measure the rotating tool tip position relative with the workpiece. The experimental displacement measurements of tool movement imply the nanometre order of measurement precision of the method.



(a) 200 nm step displacement



(b) 50 nm step displacement

Figure 7: Tool-to-workpiece gap measurement comparison with displacement metre

References:

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- [2] P. Khajornrungruang, T. Miyoshi et al.: On-Machine Cutting Edge Profile Measurement for Micro Milling Tool, *Trans. of the Japan Society of Mechanical Engineers, Series. C*, 70, pp. 3556-3563 (2004). [in Japanese]