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Study on Non-Contact Micro Tool Tip Nano-Position Detection by Means of Evanescent Field Penetration Depth

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Abstract

This study proposes a non-contact measurement method for detecting a micro tool tip position at a nanometre precision in atmospheric environment as a non-contact tool setter. Particularly, to measure rotating small tools, optical measurement method are applied in non-contact tool setters. However, the generally used geometrical optical measurement methods do fundamentally not have nanometre precision due to the well-known light diffraction phenomenon, notably when measuring a micro tool. Furthermore, the non-contact tool setter for measuring a rotating micro tool has been indispensable because the position of a tool tip during rotation is different from the position of a static tool. The precision of tool position non-contact measurement is definitely required in nanometre scale due to the miniaturization of micro rotating tool size down to smaller than 50 µm.

An evanescent light field is applied to detect a micro tool tip position in nanometre scale without contacting between a micro tool and a reference surface. In this paper, non-rotation micro tools with diameter of 50 µm were experimentally approached to and/or departed from a reference surface of a plano-convex lens by a nano-controlled piezo actuator to verify our proposed detection method. Consequently, the tool tips were recognised in the evanescent field during 300 nm range (or the evanescent field effective penetration depth) from the reference surface. It implies that the tool tip position could be detected more precisely than ±150 nm by only recognising the scattering light from the evanescent light field without tool contacting.

Keywords: tool setting , measuring instrument, optical microscopy, evanescent wave, measurement

1. Introduction

Contact tool setter is widely used in machine tools. However, in micro machining process [1] that uses micro tools definitely prefers non-contact tool setter to prevent the tool damage, and also to indicate the exact tool tip position during rotation, particularly in rotating tool. There are several optical methods applying geometrical and wave optics to monitor tool cutting edge configuration or position [2, 3]. Additionally, this study proposes a use of a localized light, the evanescent field, that penetrates from a higher refractive index surface such as glass, sapphire, etc. to detect a micro tool tip position in nanoscale.

2. Principle of tool tip position detection

Figure 1 describes the principle for detecting a tool tip position distant from a reference surface that already exists an evanescent field by internal reflection. When a tool tip moves into this evanescent field penetration depth or distance from the reference surface, there will be recognisable light that scatters from the tool tip as shown in figure 1 (b). Because the effective penetration depth is few hundred nanometres [4-6], we would be able to detect the tip position in nanoscale precision by only recognising the scattering light from the tool tip to be measured.

3. Experimental setup

Figure 2 shows our experimental setup for observing the scattering light from a micro tool tip that approaches into an evanescent field. A plano convex lens was employed in order to

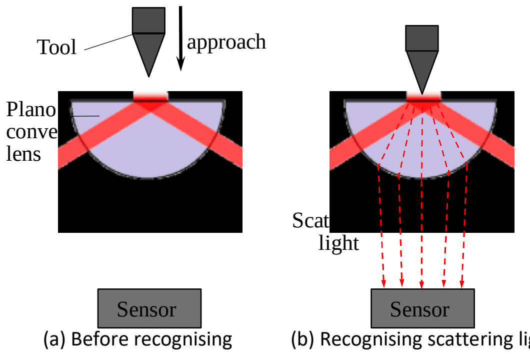


Figure 1. Principle of non-contact tool tip position detection using evanescent field

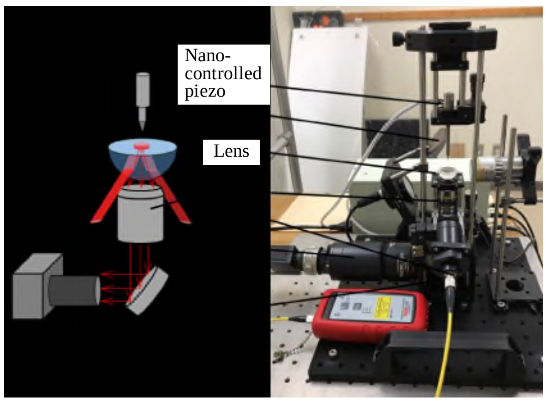


Figure 2. Optical systems of experimental tool tip detection

generate the evanescent field on the plane surface. An optical microscope is not only for observing the scattering light but also for imaging the geometrical configuration of tool tip during approaching. A tool tip was approached to a reference glass surface from the upper side with a nano-controlled piezo actuator (Mess-tek; MPA-UA1S, displacement repeatability: ± 1 nm). Table 1 shows specifications of the experimental set up.

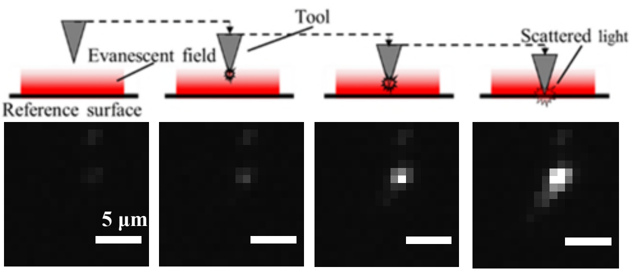
Table 1 Specifications of experimental set up

Laser Illumination		
- Wavelength	nm	635
- Incident angle	deg	70
Refractive index		
- Glass lens		1.5
- Atmosphere		1.0
Numerical Aperture (NA)		0.3

4. Experimental micro tool tip position detection

4.1. Endmill edge tip position

Figure 3 shows observed scattering light from the tip of an endmill micro edge (NS tool; NSME100-0.05, φ 50 µm) when the tool moved closer to the reference surface. Relative displacement was set as 0.0 µm at the tip position that began scattering the localised light. Thence, figure 4 shows the repeated increase of scattering light when the tool tip repeatedly moved closer until contact to the reference surface at the 3rd approach. This replies that a tool tip was recognised in approximate range of 300 nm from the reference surface, namely, the tool tip position could be detected in precision of ±150 nm.



(a) ~0 µm (b) 0.1 µm (c) 0.2 µm (d) 0.3 µm

Figure 3. Scattering light from tool tip at various displacements

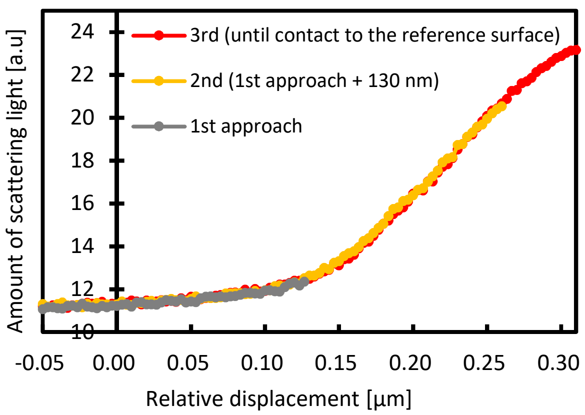
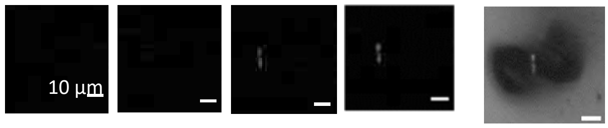


Figure 4. Scattring light from endmill micro edge tip (φ50 µm)

4.2. Non-contact detection of a drill tip position

A micro drill (NS tool; NSMD-0.05, φ50 µm) was approached to and then depart from the reference surface. The observed scattering light was shown in figure 5. Figure 5 (e) shows a bright field microscopy image of chisel edge at the position of figure 5 (d). Not only geometrical configuration but also scattering light from micro drill in the evanescent field were observed simultenously. Subsequently, repeated increase and decrease of amount of scattering light when this micro tool approached to and departed from the reference surface are shown in figure 6. These demonstrated the detection of a tool tip position without contacting to the reference surface.



(a) ~0 µm (b) 0.1 µm (c) 0.2 µm (d) 0.22µm (e) Chisel edge at 0.22µm

Figure 5. Recognition of scattering light from tool tip at various displacement and a bright field microscopy image

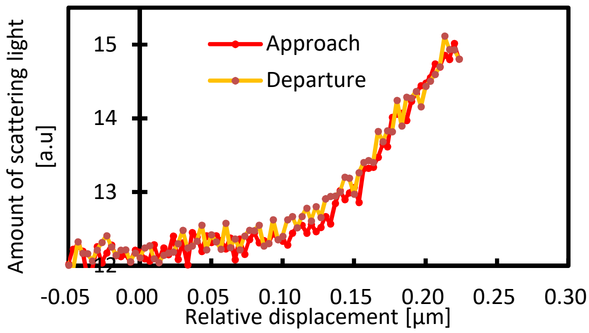


Figure 6. Scattering light from a φ50 µm tool chisel edge (non-contact approach)

5. Conclusions

A non-contact micro tool tip position detection or a non-contact tool setter in nanoscale using penetration of evanescent field was proposed and experimentally verified. According to the experimental recognition of scattering light, this method could achieve ±150 nm precision position detection of micro tool tip depending on the effective penetration depth of the evanescent field.

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