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The prediction of surface morphology with detecting the real-time vibration during ultra-precision diamond cutting

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Abstract
This paper presents a method for the prediction of surface morphology in ultra-precision diamond cutting. This method considers some key factors with machining parameters, tool geometry, and the relative vibration between the tool and work-piece. The real-time vibration between the tool and work-piece is obtained by multi capacitance probes during ultra-precision cutting. The surface morphology can be predicted accurately by simulation algorithm with the real-time vibration obtained. A series of cutting experiments are carried out to verifying the method. The prediction of surface morphology have a good agreement with the experiments results acquired by measurement instruments. Furthermore, the influence of vibration signals on surface morphology is analyzed from the point of conservation law.

Keywords: Ultra-precision diamond turning, Surface morphology, Relative vibration, Three-dimensional simulation

1. Introduction

Ultra-precision diamond turning (UDT) has developed into one of the most successful machining technologies and is widely used to fabricate high precision components for optical, photonics and telecommunication products. Mirror finished surface quality is required in the above applications. The surface roughness is influenced by many factors, such as cutting parameters, material pile-up, material swelling and recovery, crystal orientation, and the relative vibration between tool and workpiece. The tool-workpiece relative vibration can be introduced into the cutting system mainly by spindle vibration, tool vibration, material induced vibration, which would deteriorate surface quality and form of components.

Researchers have theoretically and experimentally made great contributions to the influence of tool-workpiece vibration on the surface quality. Takasu et al. [1] presented that tool vibration with a small amplitude affected surface roughness in diamond machining by means of inspection with a contact type stylus instrument. Considering the relative vibration between tool and workpiece, Cheung and Lee [2] also built a model for the prediction of surface topography in UDT, which can well predict surface generation with the relative tool-workpiece vibration, and the simulation result revealed that the relative vibration between tool and workpiece is one of dominant factors influencing surface generation and tool interference in UDT. Cheung and Lee [3] developed a multi-spectrum analysis method to research tool-workpiece relative vibration which would cause apparent variation of the surface modulation at the finished surface. Kim et al. [4] have investigated the influence of the ratio between the vibration frequency and spindle speed on the surface topography with theoretical analysis and experimental verification. Zhou and Cheng [5] introduced an integrated simulation approach to analyze the relationship between the cutting process and the surface topography.

Tool-workpiece relative vibration and its effect on surface generation in UDT have been theoretically and experimentally explored in depth. And the good results have been obtained. However, the previous simulation models of surface topography in UDT adopted the estimated vibration displacement rather than the actual tool-workpiece vibration displacement (TWVD) during the cutting process. It is great difficult to predict the real machined surface topography without TWVD. In this paper, an effective approach to detect the actual TWVD during UDT is presented. This leads to the accurate simulation model of surface topography considering the actual TWVD during the UDT process.

2. Online tool-workpiece vibration detecting system

TWVD is the one of dominant factors influencing mirror finished surface quality. In this paper, an online detecting method for tool-workpiece relative vibration during UDT is presented. The schematic diagram of online vibration detecting system is shown in Fig 1. Three capacitance displacement sensors are adopted to detect the vibration of workpiece and tool respectively. In this detecting system, the workpiece should be mounted on the end face of spindle. The end face has been machined by diamond tool with proper cutting parameters, which possess good flatness. Probe 1 and Probe 2 are set out with special angle around the peripheral direction of the end face to detect the spindle axial vibration and the end face flatness error. And the spindle axial vibration can be obtained by end face error separation method, and so do the workpiece vibration. In addition, the Probe 3 is employed to obtain the tool vibration with straight edge mounted rigidly in the tool post. The three displacement probes are fixed on the machine base like the absolute coordinate system. Therefore, the TWVD can be detected with three displacement probes fusion technology.

The flow chart surface morphology simulation shown in Figure 2 depicts the surface morphology simulation model including cutting process and TWVD.

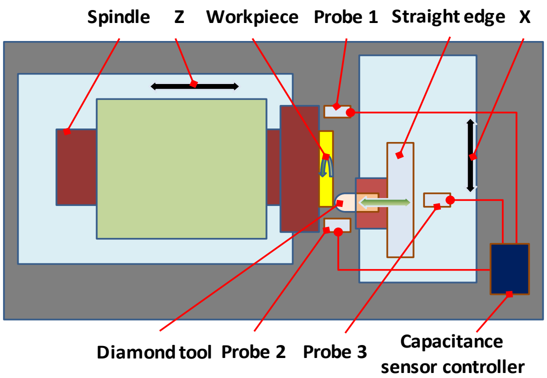

Figure 1. The schematic diagram of online vibration detecting system.

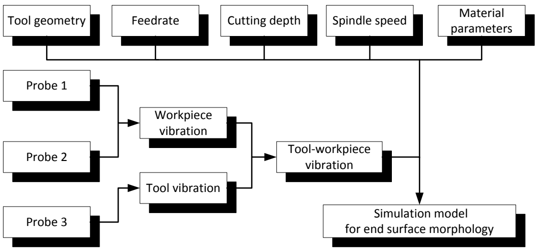

Figure 2. Flow chart of surface morphology simulation.

3. Experiment result

The cutting experiment is carried out in an ultra-precision diamond turning machine. The material of workpiece is the pure copper. The cutting parameters are shown in Table 1. When the cutting process begins, the online vibration detect system is on the work. In addition, the vibration detect system should gather a series of signals before the cutting, which filter the outside vibration like ground vibration.

Table 1. Parameters for cutting.

Parameters	Value
Tool nose radius	3mm
Rotational speed of spindle	360rpm
Feed rate	100μm/s
Cutting depth	10μm
Workpiece radius	40mm

Fig 3 shows the vibration signals obtained by the online vibration detect system. The spindle vibration mainly exist foundation frequency and doubled-frequency, this will influence the end surface error and waviness rather than surface morphology. The tool vibration in frequency domain spreads from low frequencies to 500Hz, which produce serious tool interference and deteriorate the surface morphology.

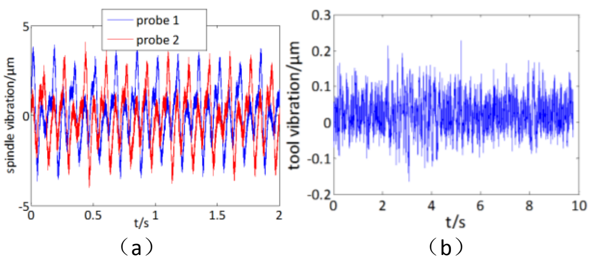

Figure 3. The measurement result (a) the vibration signal of Probe 1 and Probe 2, (b) the vibration signal of Probe 3.

The machined workpiece is detected by laser confocal microscope and profilemeter, and the results are shown in Fig 4(a) and Fig 4(c), respectively. The tool lines can be identified clear, the feed distances among tool paths show good in consistency, but not the widths of tool paths, which means that the tool vibration along the feed direction (X) is very slight and the tool vibration in Z direction conducts the inconsistency of the widths of tool paths due to tool interference.

The simulated surface morphology and radial profile acquired by simulation model are shown in Fig 4(d) and Fig 4(f), respectively. Compared with the measured results, Fig 4(d) reveals the similar surface morphology like in Fig 4(a), in which the widths of tool paths are not consistent because of the tool interference caused by tool vibration along Z direction. In addition, there are good agreement for the features points of the radial profiles in Fig 4(c) and Fig 4(f) through the contrast analysis in Fig 4.

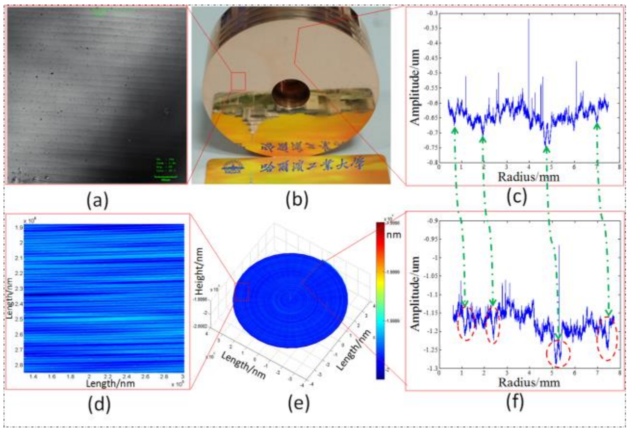

Figure 4. (a) surface morphology taken by confocal microscopy, (b) the machined end face, (c) radial profile taken by profilometer, (d) the simulated surface morphology, (e) the simulated end face and (f) the simulated radial profile.

5. Conclusion

The online detecting system for TWVD accomplish the measurement of vibration of workpiece as well as diamond tool during cutting process, and with the use of surface morphology simulation model, the influence of TWVD on surface morphology is analyzed. For verifying the method of measurement and simulation model, certain of turning experiments have been carried out. The results illustrate that 3D surface morphology can be predicted well by the gathered vibration signals with simulation model. Based on the results of simulation and experimental analysis, the conclusions present as follows:

(1) The relative vibration between tool and workpiece has serious impact on surface morphology.

(2) The online detecting system for TWVD can obtain tool-workpiece relative vibration during UDT effectively.

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