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Full Length Article

A study of the ultra-precision truing method for flank face of round nose diamond cutting tool

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ABSTRACT

Round nose diamond cutting tool lapping is a key technology in ultra-precision turning technology which is a promising technique widely used in micro- and nano-cutting in various industrial sectors. So far, manual operation with sufficient experience is still irreplaceable for lapping process of high precision diamond cutting tools. In this work, a truing method based on the tiny wear loss measurement on the flank face of round nose diamond cutting tool is presented. The tiny wear loss measuring results provide a reference for truing process of round nose diamond cutting tool. Based on our method, the finished profile of flank face with Pv = 78.2 nm and Pa = 21.4 nm is obtained easily and deterministically.

1. Introduction

Diamond turning has been thought as a promising technique and widely applied in micro- and nano-cutting in various industrial sectors [1,2]. Ultra-precision machining based on single-point diamond turning (SPDT) is capable of directly lathing optical quality components with micrometer to sub-micrometer form accuracy and surface roughness in nanometer range [3]. For example, in the field of soft-brittle optical functional crystal material's aspheric and free-form surface machining, the ultra-precision cutting with round nose single crystal diamond tool is recognized as the most efficient method [4–7]. It is shown that nanometric surface finish can be achieved for ZKN7 glass by ultra-precision cutting when the undeformed chip thickness is of sub-micrometer [4]. Surface roughness less than 1 nm R_a, and 5 nm R_{max}, can also be generated on the Ge surface by SPDT [5]. Even silicon wafer can be machined in ductile mode [6] by ultra-precision turning. Such ultra-precision turning technology heavily relies on the quality of diamond cutting tool, besides the super stable environment and ultra-precision machine tool [8,9]. Since the ultra-precision machine tools under computer control can position the tool relative to the workpiece to a resolution and positioning accuracy in the order of 1 nm [10], the accuracy of the nose of diamond tool is of great importance in form accuracy of component, especially under the condition of that many points on the cutting edge are involved in cutting process. Generally, the tool radius, as an important geometrical parameter, is considered in the models of the turning process [11]. The single crystal diamond tool has the properties suitable for ultra-precision turning machining such as extreme hardness, good wear resistance, perfect chemical stability and satisfactory service life. The quality and the shape accuracy of complex surfaces are sensitive to cutting tool parameters such as the cutting edge radius and profile tolerance [7].

Because of the strong anisotropy and super hardness of diamond, the material removal rate is very small in its lapping process and influenced by the crystal anisotropy [9]. This strong anisotropy mainly comes from diamond carbon atoms arrangement, which causes a great difficulty in lapping of high precision round nose edge diamond cutting tool. Based on an on-machine image processing approach, the round cutting edge of profile tolerance less than or equal to ±0.5 μm can be achieved [7]. However, lapping for higher precision single crystal diamond cutting tool is completed by manual operation experience of skilled workers until now.

The cutting edge profile tolerance of the round nose diamond cutting tool is mainly determined by the profile tolerance of the flank face. Usually, the profile tolerance about ±1 μm of the flank face can be obtained after the preliminary lapping process. In the truing process of diamond tool, the wear loss on the flank face must be appropriately controlled to avoid the excess removal of the diamond material and achieve a good efficiency. Obviously, a wear loss

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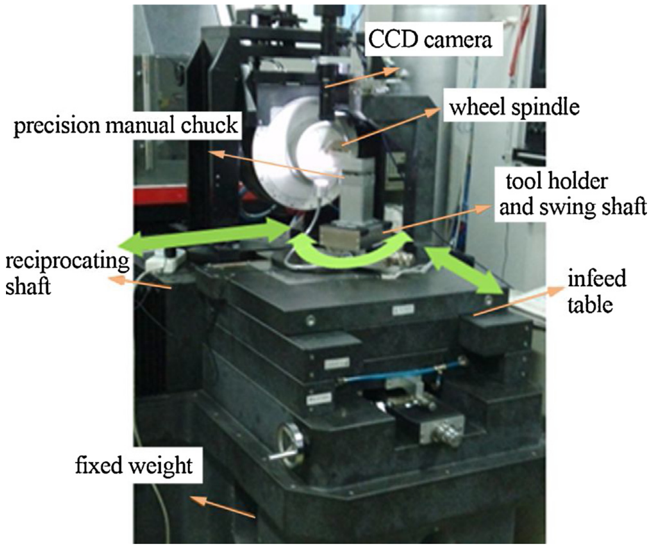

Fig. 1. Round nose diamond cutting tool lapping system.

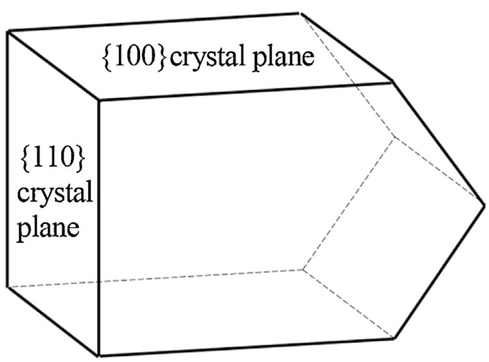

Fig. 2. The schematic of the diamond specimen.

of an order of magnitude of 100 nm–1000 nm should be well kept under control in truing process. So, the focus is on foreknowing the tiny wear loss on the flank face under a certain lapping condition.

In this paper, a measuring method of the tiny wear loss on diamond flank face is presented. The measuring results under certain lapping conditions provide reference values for our truing process of flank face of round nose edge diamond cutting tool. Based on the results, the flank face profile tolerance about 80 nm is achieved easily by the truing method proposed in this work.

2. Experimental setup

In our experiments a round nose diamond cutting tool lapping system is used. The lapping system used in our work is shown in Fig. 1. The reciprocating shaft and swing spindle are gas lubricated and servo-controlled. The water-cooled air bearing cartridge wheel spindle is controlled by a high frequency inverter, allowing smooth continuously variable speeds up to 12 000 r/min. The infeed table on which the swing spindle is mounted uses gravity acting on a fixed weight to provide smooth, constant infeed movement. The tool holder with a precision manual chuck is fixed on the swing spindle. The CCD camera is for the convenience of lapping observation. After rigorous balancing, a copper bonded diamond wheel with a grain size of 0.5 μm is installed on the fixture of wheel spindle.

At the start of our experiment, a raw natural diamond is shaped as shown in Fig. 2 by the traditional diamond lapping method. After lapping of this diamond on our lapping system, we get the diamond

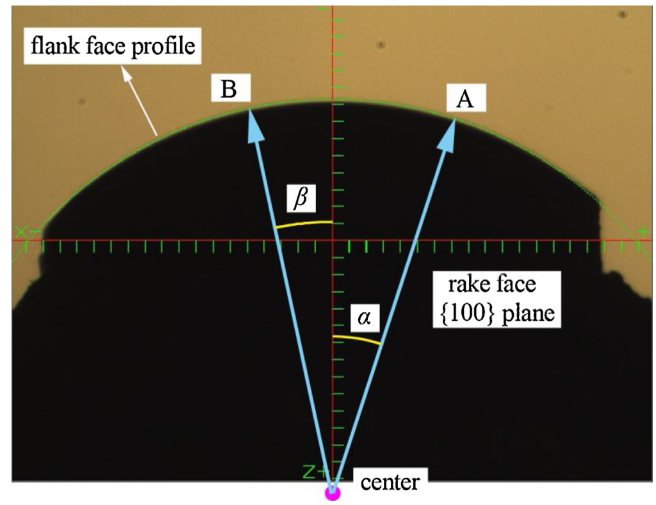

Fig. 3. The CCD image of diamond tool sample after preliminary lapping finished.

tool sample with a cylindrical flank face (the radius is 2.35 mm) as shown in Fig. 3.

The flank face profile of the diamond tool sample is measured using a Form Talysurf PGI 1240 profiler (lateral and vertical resolutions are able to achieve 0.125 μm and 0.8 nm respectively), as shown in Fig. 4(a). In our experiments, by moving the position stage, five cross sections of the flank face are scanned by the measuring tip of the profiler. Before our measuring operation, the flank face of the diamond tool sample is lapped at the position A (characterized by angle α), as shown in Fig. 3. In this way, a small plane (treated as a mark plane in our flank face wear loss measuring method described below) is emerged on the flank face (presented by profile line L_q) as shown in Fig. 4(b).

The flank face wear loss measured in our work is shown in Fig. 5. When the diamond tool sample, fixed on the tool holder, rotates to a certain position, the lapping process is carried out under a definite lapping process condition. The rotation speed of the wheel spindle is 3 000 r/min in our experiments, the linear speed of the reciprocating shaft is 1 mm/s, lapping pressure is 0.5 kg-force. After the homing search move of the reciprocating shaft, the move distance is set between −12 and 6 mm. The lapping system makes one full cycle in controlling the reciprocating shaft completely back and forth, which is called 1 lapping cycle in our work. In different lapping cycles the diamond sample is subjected to the same lapping conditions, such as the lapping velocity. Flank face wear loss characterized by H, as shown in Fig. 5, is measured under different lapping cycles in our experiments.

3. Flank face wear loss measuring method

After the initial lapping process of round nose diamond cutting tool, the finished cutting edge of profile tolerance about 1 μm can be normally achieved on a precision lapping system. So, in the truing process of flank face for high-precision round nose diamond cutting tool, we must carefully control the wear loss to remove the redundant material if the smaller profile tolerance of diamond cutting tool's edge is expected. If the wear loss on flank surface can be estimated, it doubtlessly will be conducive to the truing process. The flank face wear loss measuring method presented below will support this estimation, which ends up benefiting the accuracy improvement of diamond cutting tool edge.

By the initial lapping process, a flank face profile L_q is obtained shown in Fig. 4(b). After lapping, for example 3 lapping cycles at the point B ($\beta = 12^\circ$) as shown in Fig. 3, a flank face profile L_h is gotten as shown in Fig. 6(a). After this lapping a testing plane is formed, but