Rotary Type Micro-Engineered Tool

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Abstract
The disk is with ultrasonic excitation in the radial direction. Laser-machined cutting edges are aligned to have a sinusoidal phase shift corresponding to successive grit point spacing.
The sinusoidal phase shift is designed and calculated so that single cutting edge has the depth of cut below critical depth of cut and intermittent cutting is attained. As a result, single cutting realize shear-mode step-wise removal of brittle materials, tool depth of cut is several hundred times of critical depth of cut, that is proportional to the numbers of cutting edges. At the same time, intermittent cutting is expected to enable shorter edge contact period with materials and eventually minimize cutting edge wear.

1 Introduction

We developed and reported an micro-engineered diamond tool to perform high –quality shear-mode machining of brittle materials. It was found that the tool realize very large tool depth of cut compared conventional fine grit grinding tools and diamond cutting tools. However, the use of the tool was limited to the machining of flat surface and convex surface with no inflection points. Rotary type micro-engineered tool to be described here, can be applied to the machining of any type of surfaces such as asphereres.

2 An "Successive grit Point Spacing Model" and the pri n ciple of Rotary Type Micro-Engineered Tool

Ultrasonic cup-wheel grinding showed almost constant grinding force and smooth surface with roughness in nanometers.1) The removal mechanism shown in Fig. 1 is supposed to be explained by the following sinusoidal motion of grits.

The successive grit point spacing (p) is give by P(=w • 2/b)

Here, w is the average grit point spacing and b is the average width of the groove.

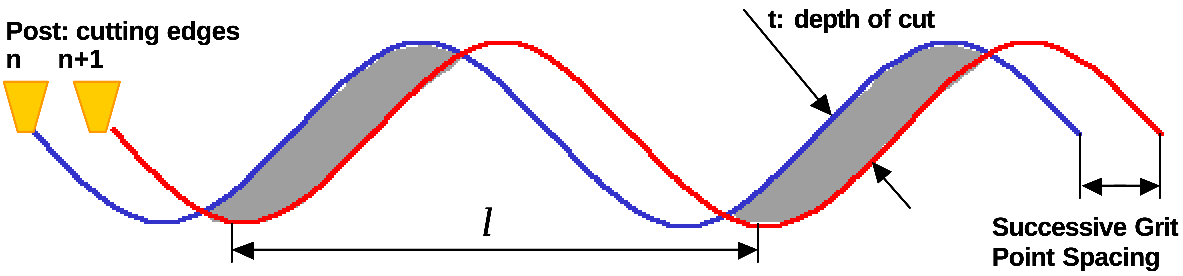


Fig.1 Successive grit motions with vibration-excitation

When the wheel is excited with ultrasonic vibration of frequency f and amplitude a, the motion of grits can be expressed by a sinusoidal function and each grit has a phase shift of (P)

$f(x) = a/2 \cdot \sin[(2\pi/\lambda) \cdot \{x - n \cdot p\}]$

Here, λ is the wave length.

Thus distributed grits are presumed to remove material at a depth lower than the critical depth of cut under certain machining conditions depending on feed velocity, ultrasonic frequency and amplitude.
Figure 2 shows the principle of Rotary type micro-engineered tool.

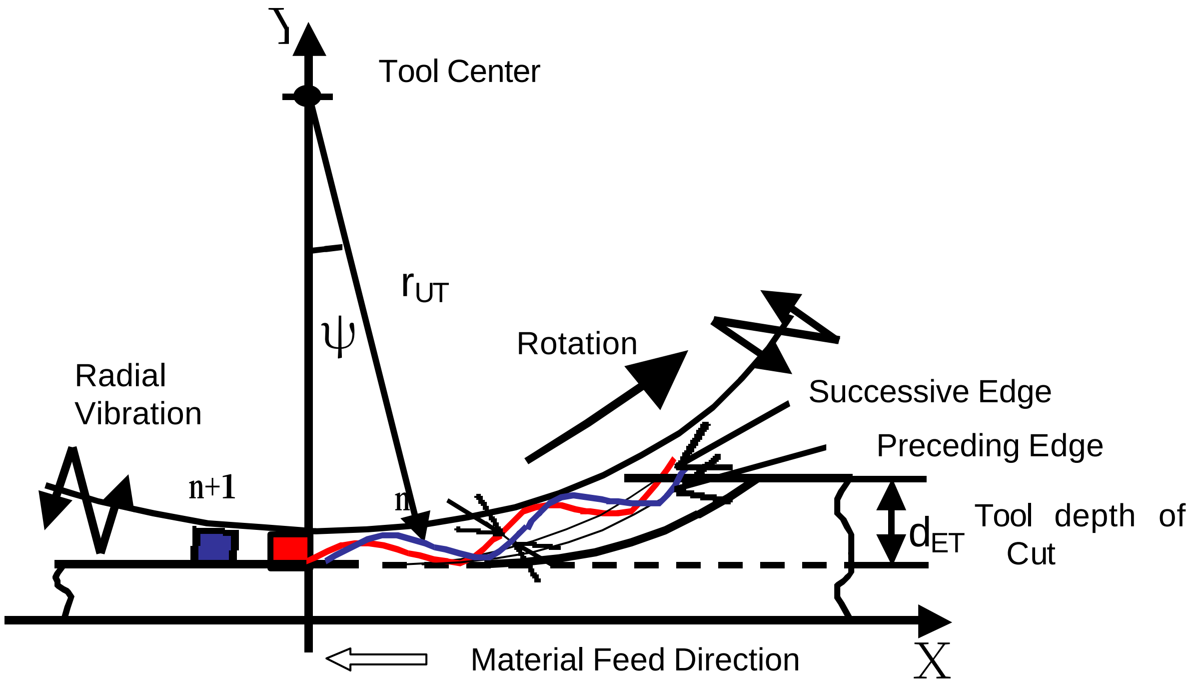


Fig. 2 Rotary Type Engineered Tool

Multi-cutting edges are arranged on the peripheral surface of a disk. The disk is rotated with ultrasonic excitation in the radial direction. When the disk is excited in the radial direction, the cutting edge radius r_{ut} of micro-engineered tool is expressed as,

$$r_{UT} = r_T + a \sin f$$

where r_t is the radius of the cutting edge, a is the amplitude and ϕ is the phase.
Suppose that the material feed rate, V_f, tool rotation, N, rotation angle, Ψ, and cutting edge motion are expressed as

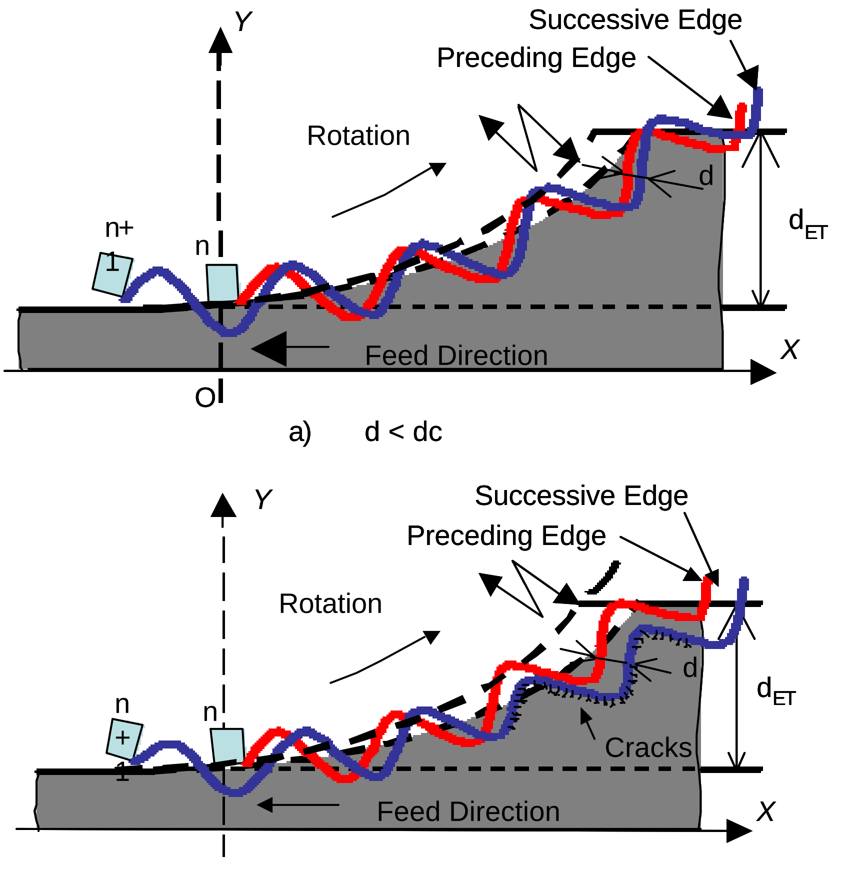
$$X_{post} = \frac{V_f}{2pN} + r_{UT} \sin \Psi$$

$$Y_{post} = r_T - r_{UT} \cos \Psi$$

The sinusoidal phase shift can be calculated so that a single cutting edge has a depth of cut lower than the critical depth of cut and intermittent cutting is attained. As a result, a single cutting can realize shear-mode step-wise removal of brittle materials, tool depth of cut is several hundred times the critical depth of cut which is proportional to the number of laser machined cutting edges. Moreover, intermittent cutting is expected to enable a shorter edge contact period with materials, minimizing cutting edge wear.

3 Expected micro-removal mechanisms

Cutting edges draw combined sinusoidal and trochoidal motions as shown in Fig.3.



b) d < dc ⇒ d > dc

Fig.3 Micro removal mechanism

Conditions under d dc in the range of smaller d_{ET}, machining is realized in all shear-mode as shown in Fig.3 a).

When the total depth of cut d_{ET} is increased, material is removed in brittle-mode on the upper surface of material and in shear-mode near the surface to be left as finished surface as shown in Fig.3 b). Then the shear–mode machining with a large d_{ET} is to be expected in a fairly low machining force.

4 Cutting experiments of Si on the nanometer-resolution machine tool, Robo-nano, produced by Fanuc

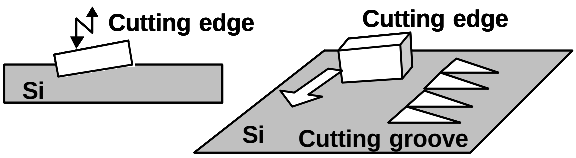
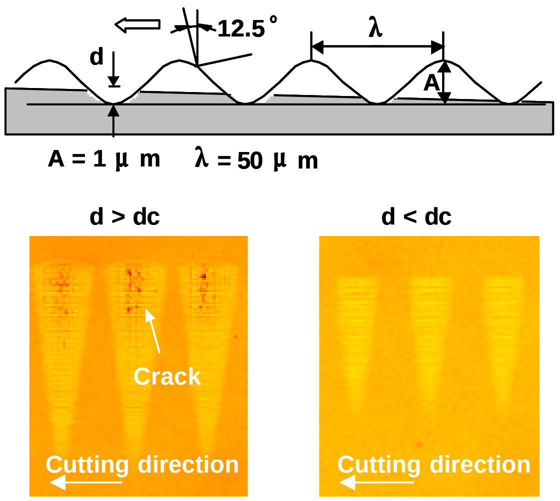
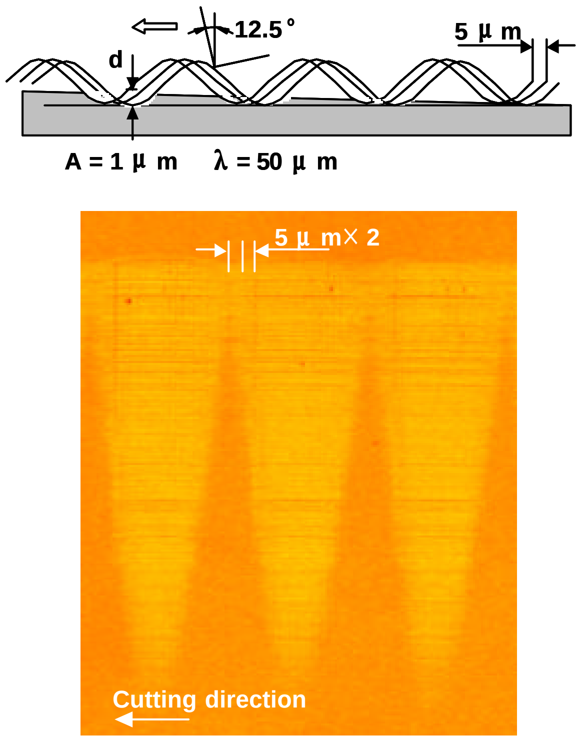


Fig.4 Cutting edge motion



(a) Single pass cutting



(b) Phase-shifted three passes cutting

Fig. Experimental results

5 Conclusions

The principle of rotary type multi-edge diamond tools were investigated to attain the higher productivity in shear-mode machining of brittle materials. Further, some experiments were conducted.

The features of the micro-engineered tools are;

1) It was found that tremendous cutting edges with vibration excitation make it possible to give a large depth of cut at a time, while each cutting edge removes materials under critical depth of cut.
2) Designing cutting edges to have the phase shift one next to each other, Cutting edge removes materials intermittently. This is expected to enable a shorter edge contact period with materials, minimizing cutting edge wear.
3) Cutting experiments of Si showed material removal in shear-mode when the depth of cut is lower than the critical depth cut 0.2ìm.
4) It was found that the phase shift of successive edge motion does not cause any defects such as brittle fractures.

References

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