euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

Tool setting error induced structure distortion in fast tool servo assisted diamond turning of microlens array

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Abstract
The effect of tool setting error in fast tool servo assisted diamond turning is studied in this paper. First, the tool setting errors are classified into radial and tangential errors, and their effects on the machining accuracy are theoretically analysed respectively. Then the manufacturing of a microlens array considering the tool setting error is simulated. The results reveal that the tool setting errors can distort the microlens array, and the distorted patterns depend on the sort of different tool setting errors. The tool setting errors have larger effects on the microlenses which are close to the rotating centre of spindle.

Keywords: fast tool servo, microlens array, tool setting error

1. Introduction

Fast tool servo (FTS) assisted diamond turning has been widely regarded as a very promising technique for the generation of microlens array (MLA) [1, 2]. Generally, the quality of FTS turned MLA are highly dependent on a variety of factors, including tool geometries, cutting parameters, motion errors of the machine tool, dynamics of the servo system, and so on [2-4]. To date, a large amount of efforts have been devoted in determining the optimal cutting parameters, the optimal toolpath, and the compensation of machine tool errors to improve the machining quality [3-5].

Tool setting errors (TSE), which are inevitable in diamond turning, have been identified in processing aspheric optics as well as continuous micro-structured surface [6, 7]. It would lead to significant distortions of the machined surfaces, resulting in unacceptable form errors. However, effects of the TSE on FTS assisted turning of MLA, which featured discontinuous structures, are lack of systematic investigations.

Motivated by this, a theoretical model for describing the effects of TSE on turned MLA is developed. By conducting numerical simulations, the error patterns induced by different kinds of TSEs are characterized. This would help precision manufacturing engineer to a) have a deeper understanding of the sources of forms errors in turning MLA, and b) provide guidance for the correction of TSEs.

2. Analysis of the effect of TSE

TSEs in diamond turning contain two categories: tool setting error in radial direction and in tangential direction.

2.1. Effect of radial TSE

Taking the fabrication of MLA for example (Fig 1), the distance between the two points A and B on a microlens will be enlarged or shrunk along the radial direction because of the tool setting error δx in radial direction. The microlens can consequently be compressed or stretched in the tangential direction while the size of the microlens in the radial direction remains unchanged. The distance between A and B can be expressed as:

$$d = 2 \cdot r \cdot \tan\frac{\alpha}{2} \tag{1}$$

where r is the distance from the rotating centre of the spindle to the AB, and α is central angle related to AB.

The variation of d d can be calculated:

$$\Delta d = \left|2 \cdot r \cdot \tan\frac{\alpha}{2} - 2 \cdot (r - \delta x) \cdot \tan\frac{\alpha}{2}\right| = \left|2 \cdot \delta x \cdot \tan\frac{\alpha}{2}\right| \tag{2}$$

The degree of variation of d depends on the central angle of α, i.e. if a microlens (microlens 1 in Fig. 1) is close to the rotating centre of spindle, the variation will be larger than a microlens (microlens 2 in Fig. 1) which is far away from the centre.

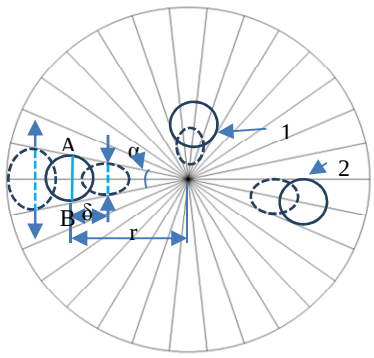

Figure 1. Schematic of radial TSE

2.2. Effect of tangential TSE

If an ideal cutting point is located at a position with a radius of r, the actual cutting point position due to TSE in tangential direction δy is determined with a radius of r' and angle of α as shown in figure 2.

$$\alpha = \tan^{-1}\frac{\delta y}{r} \tag{3}$$

For two cutting points shown in Fig. 2, point 1 is located at a position with a radius of r_1 and point 2 with a radius of r_2.

If $r_1 > r_2$, then $\alpha_1 < \alpha_2$ and $\frac{r_1^{'}}{r_1} = \frac{1}{\cos\alpha_1} < \frac{r_2^{'}}{r_2} = \frac{1}{\cos a_2}$, i.e. the TSE in tangential direction has more effect on a microstructure which is close to the rotating centre of spindle.

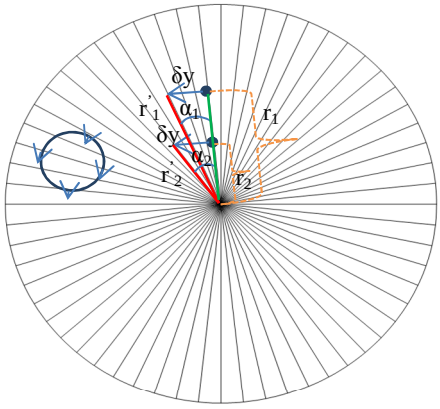

Figure 2. Schematic of tangential TSE

3. Results and discussion

Based on the analysis in section 2, the manufacturing of a MLA was simulated with consideration of TSEs.

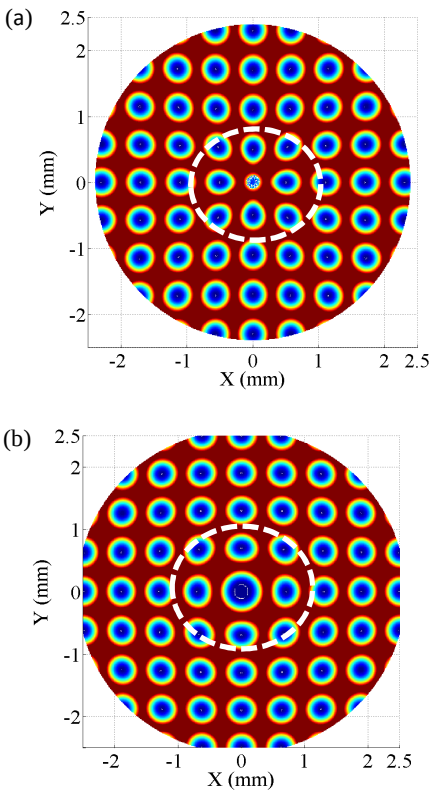

Figure 3. Simulation results of the effect of radial TSE

The simulation results considering the radial TSEs are shown in figure 3. As can be seen from figure 3, the microlenses shrink in the tangential direction if the direction of TSE points to the rotating centre of spindle as shown in figure 3a, and enlarge if the direction of TSE is away from the rotating centre of spindle as shown in figure 3b. Those microlenses which are close to the rotating centre of the spindle (as shown in the circle drawn with the white dotted line) are affected significantly.

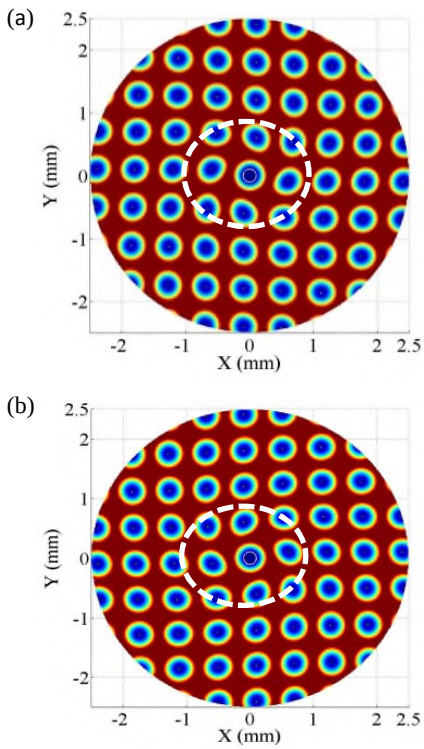

Figure 4. Simulation results of the effect of tangential TSE

The simulation results under the effect of tangential TSE are shown in Fig. 4. From figure 4 it can be seen that the microlenses which are closer to the centre have obvious distortion. The pattern of distortion depends on different tangential directions. The distortion pattern shown in figure 4a indicates that the direction of tangential TSE is clockwise while the pattern in figure 4b has opposite tangential TSE direction. The results show good agreement with the analysis in section 2.

4. Summary

In this paper, the effects of TSEs on machining accuracy in the FTS assisted diamond turning are studied by means of theoretical analysis and simulation. The results indicate that the TSEs can distort the shape of machined microlenses of MLA. The degree of the effect depends on the location of microlens with respect to the rotating centre of spindle. A series of experiments will be conducted in the future to explore the effects of TSEs.

5. Acknowledgement

The work described in this paper was supported by the Research Committee of The Hong Kong Polytechnic University

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