A Study of Effect of Tool Wear on Surface Quality in Fast Tool Servo Machining

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Abstract

Sharp diamond tool with small tool nose radius is usually used in Fast Tool Servo (FTS) machining and it is easily susceptible to wear. This paper presents an investigation of tool wear of the single crystal diamond tool and its effect on surface generation in ultra-precision machining with FTS. A cutting experiment has been conducted with sharp and worn diamond tools and the surface quality of the machined surfaces are measured and compared. The results show that the form accuracy of the machined workpiece is adversely affected by the tool wear of the diamond tool. The results of the study provide a better understanding of the performance of diamond tools in FTS machining.

Keywords: Fast Tool Servo Machining, Tool Wear, Microlens Array, Surface Quality, Ultra-precision Machining

1 Introduction

The diamond tool plays a crucial role in surface generation in ultra-precision machining with FTS. The profile of a machined surface is basically generated by the repetition of the tool profile in the plane of the normal cutting direction. The geometrical accuracy of the cutting edge and its stability has a great influence on the surface quality of the machined profile. Since diamonds have little affinity with many materials, a diamond cutting edge is considered to have high fidelity, which is the ability to transfer the profile of a cutting edge to the workpiece. The wear on the cutting edge grows substantially as the cutting length increases (Taminiau, 1991; Keen, 1971).

Tool wear not only degrades the product quality but also raises the machining cost. This is particularly true for the single crystal diamond tool employed in FTS machining, because it is expensive and easily susceptible to wear due to the fact that the tool is sharp with a very small tool nose radius. In this paper, an experimental investigation of the effect of tool wear on surface quality in FTS machining is presented.

2 Experimental Procedures

In the present study, the cutting tests were carried out on microlens array separately by sharp and worn diamond tools. The cutting tests were conducted on a microstructured surface using FTS machining as shown in Figure 1. The cutting conditions were kept constant at 100 rpm spindle speed, 0.5 mm/min feed rate and 5 µm depth of cut. Diamond tools with the same radius were employed. The fabricated profiles by using sharp and worn diamond tools were measured separately. The measurement of machined surfaces has been carried out at relative positions of the microlens array pattern.

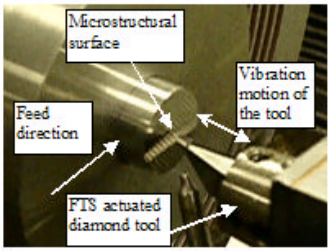

Figure 1: Graphical illlustration of fast tool servo machining of microlens array

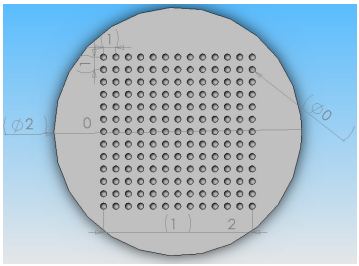

Figure 2: Design of micro-lens array on the workpiece

Figure 2 illustrates the design of micro-lens array on the workpiece. The diamond tips of the sharp and the worn diamond tools were observed by scanning electron microscopy (SEM) as shown in Figure 3 and Figure 4 respectively. The material of the workpiece is NiCu which is a material commonly used in mold inserts of ultra-precision optical molds. It's well known that a microstructured surface with large form error can hardly achieve its expected optical performance. Therefore, the highest impact of a worn tool in FTS machining should be the form accuracy of the machined

profile. As a result, the form error of a machined lens is thus used to project the effect of surface generation.

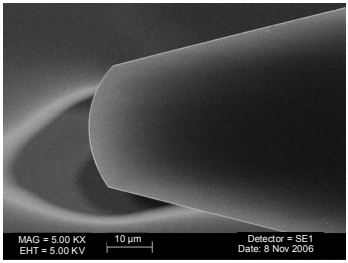

Figure 3: SEM monogram of a sharp diamond tool

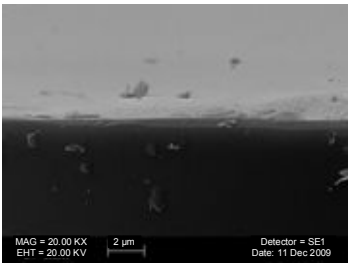

Figure 4: SEM monogram of a worn diamond tool

3 Experimental Results and Discussion

Two microlens array workpiece were machined and measured. One was machined by a sharp diamond tool while the other was machined by a worn one. The worn tool was cut for a distance of 2652 meters. Figure 5 shows the measured microlens array machined by the sharp diamond tool in central area (3x3 array). Table 1 shows a comparison of form error of the microlens machined by a sharp and a worn tool, which is based on 20 microlenses measured from each microlens array, and the results are represented by mean value and standard deviation of the form error in terms of root-mean-square (Sq) value of the measured microlenses. As shown in Table 1, the results show that there is notable increase in both the mean values and standard deviation of the form errors by the worn diamond tool which infers that tool wear should be considered as a critical factor affecting surface generation in FTS machining.

Table1: A comparison of form error of the microlenses machined by a sharp and a worn tool

Form Error	Mean Value		Standard Deviation	
	by a sharp tool	by a worn tool	by a sharp tool	by a worn tool
Root-mean-square value, Sq (nm)	168.45	317.86	14.29	50.98

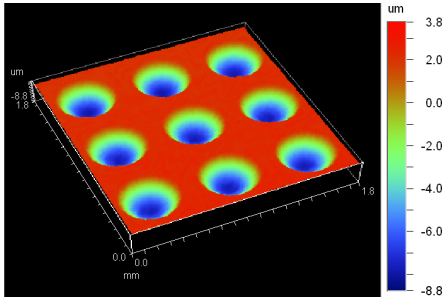

Figure 5: Measured microlens array in central area (3x3 array)

4 Conclusion

A small diamond tool radius is always employed for the fabrication of high added value optical profiles in FTS machining. Tool wear adversely affects the surface quality in FTS machining. To study the effect of tool wear on surface generation, an experiment has been carried out in correlating the tool wear with the quality of the machined surfaces. The results show that there is a significant increase of form error of the microlens if diamond tool wear is present. The form error for a machined microlens is also found to vary at different lenses in the microlens array. This infers that the wear of the diamond tool adversely affects the form generation in FTS machining of complex surfaces such as a microlens array.

Acknowledgement

The work described in this paper was fully supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. PolyU 5140/05E). Many thanks are also due to Precitech Inc. for their support of the research work.

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