euspen's 16th International Conference & Exhibition, Nottingham, UK, 2016

www.euspen.eu

Development of a novel tool holder with six degree of freedom and the related tool path generation for ultra-precision machining

W. Yuan[1], W.B.Lee[1], C.Y.Chan[1], L.H.Li[1]

1 The State Key Laboratory of Ultraprecision Machining Technology, Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong

15901591r@connect.polyu.hk

Abstract

Multi-axis ultra-precision machining plays an important role in manufacturing freeform surface and microlens arrays. In this paper, a 6-axis positioning system, Hexapod, is modified to be used as a tool holder that can be attached to mid-range turning machines to improve their repeatability to sub-micrometric level. A novel tool path generation method utilizing 6 axis motion was designed to improve the surface finish by adapting the unique movement pattern of a hexapod and by attaining surface normal cutting through adjusting the orientation of the diamond tool. The face turning and compound eye cutting experiments were conducted to verify the performance of the tool holder system and tool path generation algorithms. Experimental results show that the form error and surface roughness of the specimen machined by the proposed tool holder could attain the sub-micrometric level.

Keywords: Ultra-precision machining, freeform surface, tool path generation

1. Introduction

With the rapid development of the aerospace, military defences, optics and microelectronics, high quality components with complex surface play increasingly significant role in such fields. The complex surfaces which have relatively high degree of freedom or consist of micro-structures could make improvement of special properties or functions. Ultra-precision machine tools are advanced machines to fabricate complex surface by the removal of the surface materials of work piece with a single point diamond tool [1, 2]. However, the machinability of conventional turning lathe cannot meet with the increasing demand of the optical components that have more complex surface. By adding more degrees of freedom to the machine, the multi-axis machine possesses a number of benefits as follows: 1) multi-axis machine reduces multiple cyclic repetitive alignment setups which are required to proper re-position the cutter or workpiece. Over-cut, under-cut and even toolpath interference are possibly eliminated by auto-adjusting the position and orientation of cutter during machining process. 2) Multi-axis machining technology can improve the surface quality. By employing reasonable tool paths incorporating all the axes, sudden changes of both relative linear velocity and angular velocity of cutter and workpiece could be avoided. Thus, the variation of cutting force is smoothened, and the stability of machining process is improved, which ultimately improve the quality of the machined surface. 3) Multi-axis machining technology can further overcome tool wear. To avoid interference as much as possible, diamond tool with small tool tip radius are adopted as cutter. However, even as hard as diamond, this kind of cutter still suffers rapid tool wear, resulting in short service life. Tool wear often appears on a small circular range of cutting edge in contact with the workpiece [3]. If the wear appears on a part of tool tip, multi-axis machine could provide the possibility to continue cutting by shifting the point of contacts to other parts of tool tip. In that way, the service life of diamond tool will be extended.

Although the ultra-precision machine plays such important role in complex surface generation, the 6-axis machines exhibit a lack of not only synchronization of axes and high precision positioning system, but also tool path planning based on multi-axis motion. Besides, although the orientation of diamond tool, e.g. with respect to rake angle, is reported to have profound effect on chip formation and tool wear [4], in any existing commercial ultra-precision machine, the orientation of cutting tool is not able to change freely during the machining process.

In this paper, a novel tool holder was developed by modifying a six-axis Hexapod. A novel tool path generation method was developed to adapt the unique movement pattern of a hexapod and to improve the surface finish by avoiding interference, setting proper orientation of diamond tool and extending the service life of diamond. A microstructure—compound eye was fabricated utilizing the above system to assess its performance.

2. Methodology

Hexapod is a fast, compact positioning device with sub-micrometric repeatability. The model used in this work was purchased from the PI (Physik Instrumente) Company. It consists of 1 upper plate, 6 struts and 1 base plate. In each strut, there is a DC motor inside driven by sophisticated controller using vector algorithms, virtual pivot point. The hexapod coordinate contains 6 axes. U, V, W are the rotation axes of the upper plate with respect to translational the X, Y, Z axes respectively.

To convert the Hexapod into a functional tool holder, an adaptive tool path generation system is needed. Generally, the process flow of the proposed tool path generation is shown in figure 1. Firstly, the surface topology is put into the system to generate the model data in workpiece coordinates. After the model is transformed into tool holder coordinate, the machining allowance is calculated. By analysing the interference of the allowance and tool geometry of the selected cutter, whether the surface could be machined is evaluated. If the outcome is "No", a new cutter with different geometry will be selected. If the outcome is "Yes", constraints of tool path are added to calculate the tool path in Hexapod coordinate. These constraints includes constant rake angle of cutter and variant slide edge angle. If the tool path has no solution, certain constraints would be deleted. If the tool path has more than one solution, certain constraints would be added. When the tool path has only one solution, the NC program would be generated based.

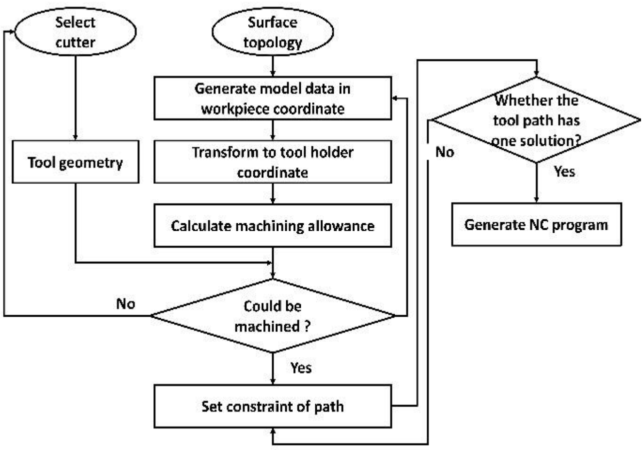
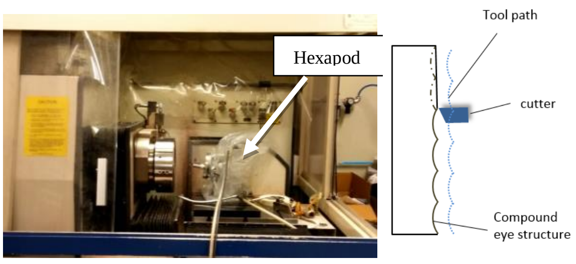


Figure 1. Process flow of tool path generation.

3. Experiment setup

The experiments were conducted by the 6 axis tool holder mounted on the Nanoform 300, a 2-axis ultra-precision machine as shown in figure 2 (1). In order to study the mechanical performance of the tool holder, face turning experiments are first conducted by utilizing the movement of machine slide and Hexapod struts respectively. The cutting conditions are: spindle speed at 1500 rpm, depth of cut at 1 um, feedrate at 1 mm/min. Then an array of compound eye with sagittal height of 2 um is machined by the tool holder. The material of work piece adopted in the mentioned experiments is aluminium 6061.



(1) (2)

Figure 2. (1)Tool holder mounted on Nanoform 300 (2) schematic of cutting compound eye structure.

4. Results and discussion

The surface roughness of the machined surface by face turning experiments was measured by Zygo NewView8000, a 3D optical surface profiler. The results shown in table 1 indicate that the surface roughness of the workpiece cutting by Hexapod movement is a little worse than that cutting by machine slide. However, it is acceptable because the surface roughness is still nanometric range.

Table 1. Surface roughness comparison.

item	Roughness (nm)
Workpiece cut by Hexapod	23.5
Workpiece cut by machine slide	19.8

The compound eye structure was achieved by the movement of Hexapod while the spindle did not move as shown in figure 2 (2). The result compound eye array is shown in figure 3. Good uniformity is found along the cutting trajectory. The form error is 0.1706 um. The experimental results show that the form error and surface roughness of the specimen machined by the proposed tool holder reach the sub-micrometric level.

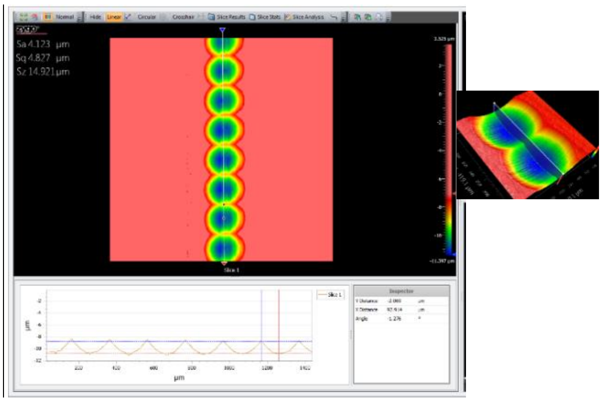


Figure 3. Compound eye array.

5. Conclusion

The paper proposes a novel a 6 axis tool holder mounted on an ultraprecision turning machine to provide extra motion ability. The corresponding tool path generation method is developed to improve the surface finish by avoiding interference, proper alignment of diamond tool. The results show that the form error and surface roughness of the specimen machined by the proposed tool holder reach the sub-micrometric level.

Reference

[1] F.Z.Fang, X.D.Zhang, X.T. Hu. Cylindrical Coordinate Machining of Optical Freeform Surfaces. Optics Express. 2008, **16**(10): 7323~7329

[2] E. Brinksmeier, W. Preuss, A. Gessenharter. Manufacturing of Calibration Standard by Diamond Machining. Proc. of 2nd Euspen International Conference. Turin, Italy. 2001: 680~683

[3] Jiwang Yan, Katsuo Syoji, Jun'ichi Tamaki, Some observations on the wear of diamond tools in ultra-precision cutting of single-crystal silicon, 14th International Conference on Wear of Materials,2003, **255**(7–12): 1380~1387

[4] A. Pramanik a,b, K.S. Neo a, M. Rahmana,∗, X.P. Li a, M. Sawac , Y. Maedac. Ultra-precision turning of electroless-nickel: Effect ofphosphorus contents, depth-of-cut and rake angle. journal of materials processing technology **208** (2008) 400–408