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A study of optimization of machining strategy for enhancing the efficiency of process chain in ultra-precision machining

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Abstract
Ultra-precision machining technology is widely used in machining precision components. Due to both the geometrical complexity of those components and the properties of difficult-to-machine materials, they are usually fabricated by a machining process chain so as to meet the stringent requirement of the surfaces. However, the enhancement of the efficiency of machining process chain through the optimization of machining strategy is of prime important. In this paper, a framework of a process chain optimization system in ultra-precision machining is presented. Hence a series of experiments have been conducted to investigate the influence of machining parameters in preceding machining process on surface generation in subsequent processes. It is interesting to note that the subsequent machining process is affected by both surface roughness and surface topography in the preceding machining processes. This paper also verifies that it is technically feasible to enhance the efficiency of machining process chain through an optimization of machining parameters so that the surface quality of products has been enhanced.

Keywords: ultra-precision machining, optimization, machining process chain, surface generation

1. Introduction

Ultra-precision machining technology is indispensibleto fabricate precision components with nanometric surface roughness and sub-micrometric form accuracy. Those precision components are widely used in many industries such as telecommunication, optics, biomedical, aerospace, etc [1]. However, considering the complexity of the geometry of these components and their materials which are difficult to be machined, the precision of the machining is usually realised by a series of machining process steps which consist of different process chains. Although there research of individual ultra-precision machining process has attracted a lot research attention, little attention is found to be paid for the studying of process chain in machining. Cheung et al [2] studied the effect of process chain design on the surface generation in ultra-precision machining. They designed two different process chains based on relevant models. This paper conducts a series of experiments to investigate the influence of machining parameters in preceding machining process on surface generation in subsequent processes.

2. Framework of process chain optimization system in ultra-precision machining

A process chain optimization system in ultra-precision machining is presented in Figure 1. This system contains of five modules which are input module, design module, simulation module, output module and metrology module, respectively. This system illustrates the functions of different modules from input to output. Finally, a series of experiments are conducted and the experimental results are compared with the theoretical results so as to verify and optimize design module and simulation module.

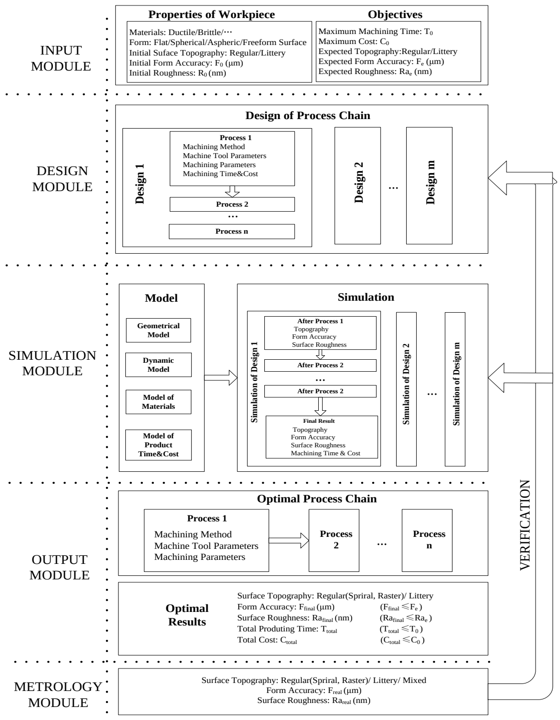


Figure 1. A framework of process chain optimization system.

3. Optimization of machining strategy for enhancing the efficiency of process chain

Considering the efficiency of machining in the whole of process chain, a way to optimize the machining strategy is to know about what extent of preceding process is enough to transfer to subsequent processes. For example, if the surface roughness of a product is required to be less than Ra_n, the product should be machined by the following process chain consists of two machining processes: P_1 -> P_2. It is interested to note that the surface roughness (Ra_2) of subsequent process P_2 should be less than that Ra_n, but what extent should the workpiece be machined by preceding process (P_1) is interesting to be investigated. Moreover, whether surface roughness is the only criteria to determine the influence of preceding process on subsequent process, whether different surface topographies with the same value of roughness have the same impact on the subsequent process, these questions are valuable for enhancing the efficiency of machining and they are needed to be studied.

4. Experimental work and results

Based on the above, a series of experiments are conducted to investigate the optimization of machining strategies in process chain machining. Six samples of flat surface are firstly machined by fly cutting (P_1) with the machine tool Nano 705G, followed by mechanical polishing (P_2) with the machine tool Zeeko 200. In fly cutting process, different machining strategies and machining parameters are conducted, as shown in table 1. Since this paper emphasizes on the influence of preceding process on subsequent machining process the machining parameters of polishing are constant in the whole of experiments, as shown in table 2. Samples are measured by Zygo Nexview™ 3D Optical Surface Profiler and the experimental results are shown in table 3. It is found that

1) Different preceding processes have different influence on subsequent process. Compare samples 1,3,and 5 with samples 2,4, and 6, using the same machining parameters in fly cutting. It is interesting to note that the surface roughness with vertical cutting is much better than that of horizontal cutting.
2) On condition that the values of (Feed rate/ Spindle speed) are kept to be constant, the surface roughness in fly cutting shows no significant increase increasing feed rate. It infers that an increase of feed rate is a feasible way to enhance the efficiency of process chain consists of fly cutting.
3) Compare samples 2, 4 and 6, even though their roughness are nearly the same, the roughness of sample 6 after polishing is much lower than samples 2 and 4. It infers that besides surface roughness, the surface topography of preceding process has also influence on the surface generation of subsequent processes.

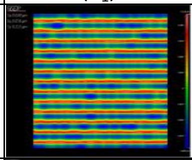
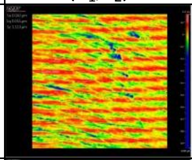
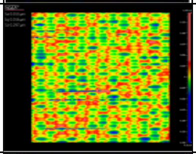
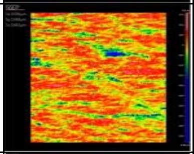
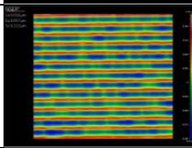
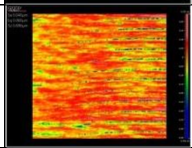
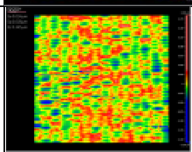
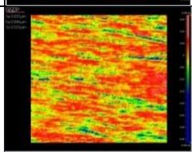
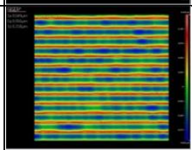
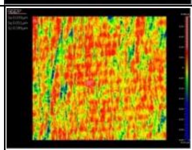
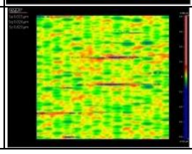
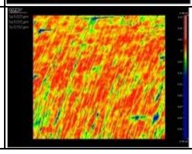
Table 1. Machining Parameters in fly cutting process (other constant parameters: step distance: 60 µm, swing distance: 25.28 mm, tool nose radius 2.430mm).

Sample	Cutting Strategy	Spindle speed (rpm)	Feed rate (mm/min)
1	Horizontal	3000	60
2	Vertical	3000	60
3	Horizontal	4000	80
4	Vertical	4000	80
5	Horizontal	5000	100
6	Vertical	5000	100

Table 2. Machining parameters in mechanical polishing process.

Spindle speed (rpm)	1500
Feed rate (mm/min)	100
Inclination angle (°)	5
Tool offset (mm)	0.1
Tool Pressure (bar)	0.5
Polishing mode	Raster Polishing
Track Spacing (mm)	0.4
Polishing cloth	Soft
Polishing Slurry	SiC #8000
Polishing bonnet radius (mm)	20

Table 3. Experimental results.

Sample	Topography (P_1)	Ra (P_1)	Topography (P_1,P_2)	Ra (P_1,P_2)
1		49nm		42nm
2		13nm		36nm
3		50nm		48nm
4		14nm		35nm
5		49nm		39nm
6		15nm		23nm

Based on the experimental results, it is interesting to notice that:

5. Conclusions

Surface generation in ultra-precision machining is usually realised by machining process chains which are composed of a series of machining process steps. Both surface roughness and surface topography machined by preceding process have influence on the surface generation of subsequent processes. Optimization of machining parameters in preceding process is helpful to both improve surface quality of products and enhancing the efficiency of process chain in ultra-precision machining.

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