

A STUDY OF PATTERN AND FEATURE ANALYSIS OF SURFACE GENERATION IN FAST TOOL SERVO MACHINING OF OPTICAL MICROSTRUCTURES

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ABSTRACT

Nowadays, there are lack of definitive international standards, surface parameters and techniques for the characterisation of the surface generation of optical microstructures with the articulation to their quality specifications in practical applications. This paper presents a study of factors affecting the surface generation in FTS machining of optical microstructures. The surface quality and defects of the machined surfaces are examined by a non-contact interferometric surface profiler. Surface features and patterns are analysed based on power spectrum analysis and are correlated with the surface quality of the optical microstructures. The results form the basis for the development of the pattern and feature analysis algorithms for the characterisation of surface generation in FTS machining of optical microstructures.

Keywords: Fast Tool Servo Machining, Optical Microstructures, Pattern and Feature Analysis, Surface Generation, Surface Characterization.

1. INTRODUCTION

Nowadays, the role of optical microstructures such as micro-lens arrays is becoming increasingly important as the need for the parallelism and density grows for display, communication, and storage applications. This trend toward highly parallel compact optical systems leads to a growing need for high performance optical microstructures such as micro-lens arrays [1]. Optical microstructures are small scale topologies generally classified as grooves, pyramids, microlens arrays, lenticulations and echells. Applications of optical microstructures can be found in the flat panel displays used in hand held devices such as mobile phones, personal data assistants (PDA) and broad band optical fibre connectors.

Although ultra-precision machining based on fast tool servo (FTS) machining provides a solution for machining optical microstructures with sub-micrometer form accuracy and nanometric surface finish without the need for any subsequent post processing, the methodologies for the characterisation of surface generation have received relatively little attention. Optical microstructures are usually characterized by their surface quality such as surface roughness and their optical properties. Most previous research work on micro-optics testing is based on interferometric methods [2-4] and wavefront measurement such as Mach-Zehnder interferometer (MZI) [2]. Some research work has been found in the application of (2D) discrete Fourier transform (DFT) of the interference microscope image to evaluate the fabricated grid surface [5]. However, the interferometric testing of micro-optics incurs certain difficulties due to their small dimension such as Fresnel diffraction artefacts, coherent noise and distributing interferences, etc [6]. On the other hands, they fail to articulate the surface quality of the optical microstructures to the functional specifications of the micro-optics systems.

The surface quality of a FTS machined optical microstructures depends largely on the selection of cutting conditions and of the tool path. Nowadays, the achievement of functional specifications of the optical microstructures still depends largely on the experience of the optics designer through an expensive trial-and-error approach when new optics design is used. As the optimal optics design for ensuring good quality depends largely on the functional specifications, machine tolerance and measurement errors. There is a need for a characterisation system and standardized tools which can characterize the effect of different factors on surface quality and hence the functional specifications of the optical microstructures. As a result, this paper presents a preliminary study of characterization of surface

generation of optical microstructures using pattern and feature analysis.

2. PATTERN AND FEATURE ANALYSIS

In the present study, the factors affecting the surface generation in FTS machining optical microstructures were identified and analyzed through a series of cutting tests conducted on the Nanoform 200 ultra-precision machine incorporated with a FTS system located in the Ultra-precision Machining Centre of The Hong Kong Polytechnic University. The surface quality and defects of the machined surfaces were examined by a non-contact interferometric surface profiler (Wyko NT8000). Power spectrum analysis is used to extract the patterns and features from the measured surfaces. The power spectrum analysis is done by Vision software. The features are correlated with the quality specifications of the optical microstructures. This forms the basis for the development of the pattern analysis algorithms for the characterisation system.

The characterisation system is composed of three major components which are the data acquisition module, the pattern analysis module and the characterisation module, respectively. The data acquisition module is used to acquire surface data from measurement instruments based on a stitching algorithm. Hence, the measurement data are analyzed by pattern analysis algorithm built based on power spectrum analysis. In the characterisation module, the spectrum features are correlated to different types of defects and errors artifacts of optical microstructures.

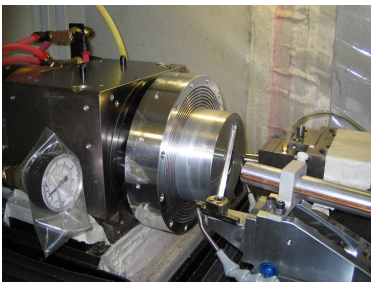


Figure 1 Configuration of the experimental setup

3. EXPERIMENTAL

A series of cutting experiments were conducted on FTS of microlens array under various surface speeds and feed rate conditions. The experiments are basically divided into two groups i.e. Group A and Group B. Group A consists of cutting tests conducted under different

surface speed while Group B consists those conducted under different feed rates.

The configuration of the machine setup is shown in Figure 1 while the geometrical patterns and specifications of microlens array are shown in Figure 2 and Table 1, respectively. Tables 2 and 3 summarize the cutting conditions in the present study. To determine the variation of surface quality of the microlens array with respect to the distance from the centre of the workpiece, the form error and surface roughness of the microlenses were measured at location L4.

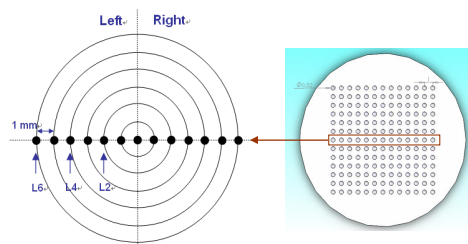


Figure 2 Geometrical pattern of microlens array

Table 1 Design specifications of microlens array

Dot Spacing	1 x 1 mm ²
Radius of curvature of the microlens	1.1705 mm
Angle of curvature of the microlens	13°
Depth of the microlens	0.03 mm
Number of the microlens	13 x 13
Diameter of the lens	0.5266mm

Table 2 Cutting conditions for Group A

Cutting Conditions	A1	A2	A3
Surface speed, V_s (m/s)	1.25	2.50	8.00
Feed rate, f (mm/min)	1.00	1.00	1.00
Depth of cut, d_c (μ m)	5	5	5

Table 3 Cutting conditions for Group B

Cutting Conditions	B1	B2	B3
Surface speed, V_s (m/s)	1.25	1.25	1.25
Feed rate, f (mm/min)	0.50	1.00	5.00
Depth of cut, d_c (μ m)	5	5	5

4. RESULTS AND DISCUSSION

4.1 Effect of surface speed

Figure 3 shows the results of the effect of surface speed on the surface generation in FTS of microlens array. The surface measurement was done at location L4. It is interesting to note that the geometry of the lens change with increasing surface speed. As surface speed decreases, better surface quality can be achieved.

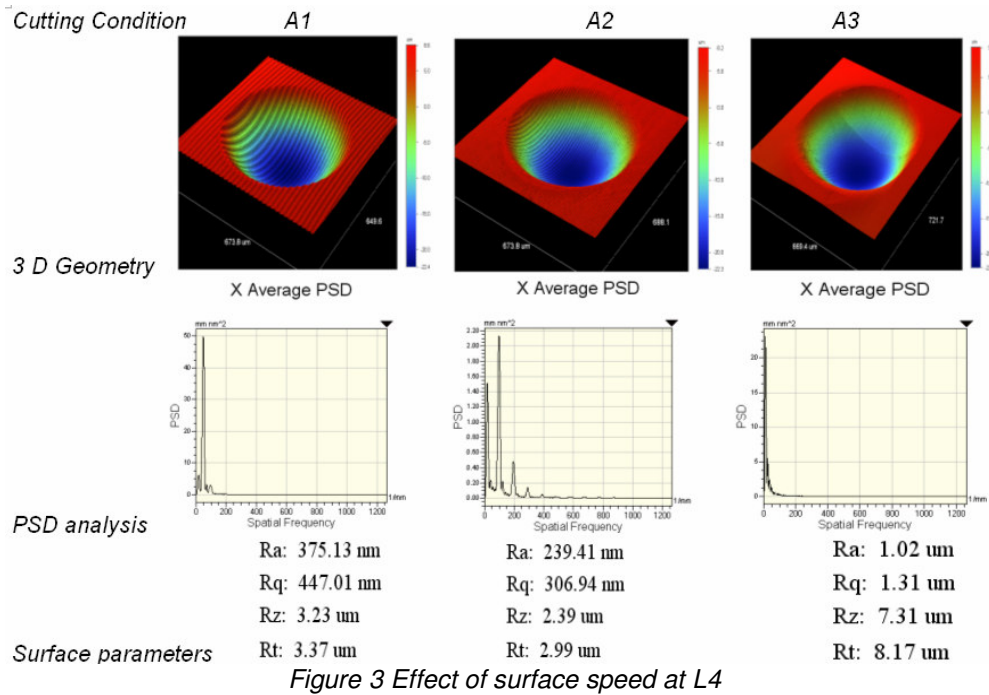


Figure 3 Effect of surface speed at L4

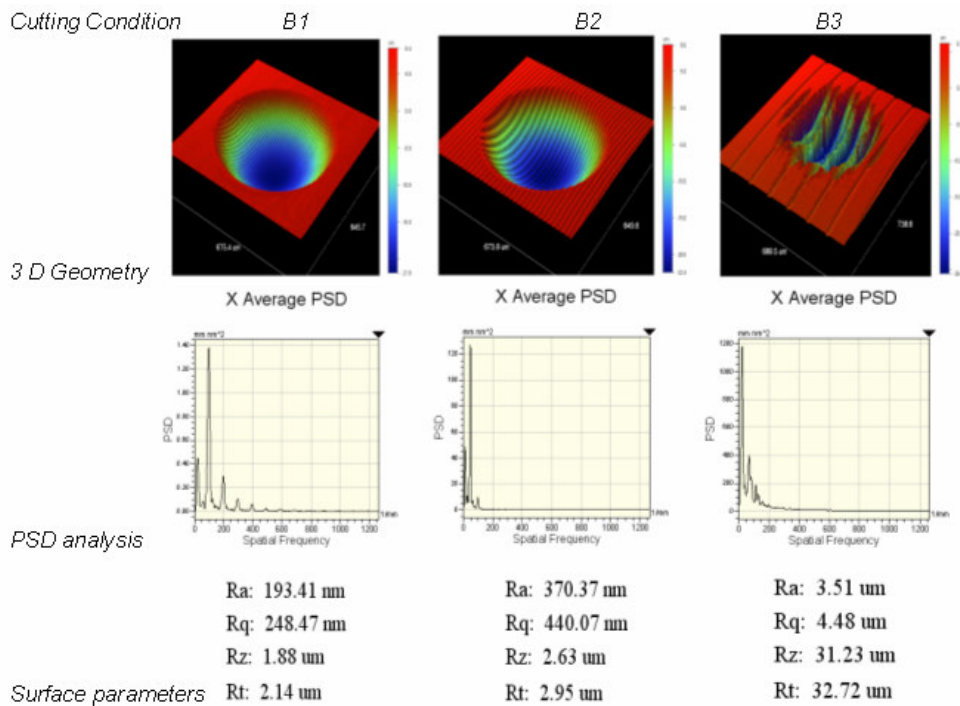


Figure 4 Effect of feed rate at L4

The distortion is not desired for practical applications and can be described as the failure of cutting path positioning. The diffraction efficiency and thus the optical performance are severely degraded. It may be due to insufficient time for FTS to stack back the diamond tool between two

successive cuttings. Therefore, the diamond tool cannot perform accurately during the cutting process.

In the PSD plot, it appears that the patterns of the power spectrum change with increasing surface speed. The spark peaks shift to a lower

frequency as surface speed increases. This provides an important means for correlating the features of the power spectrum with surface quality of the microlens array.

4.2 Effect of feed rate

Figure 4 shows the effect of feed rate on surface generation in FTS machining of microlens array. Different feed rates were used while the other cutting conditions were kept constant. It is interesting to note that deeper and wider tool marks were formed on the microlens with a higher feed rate. In other words, the surface roughness of the microlens increases as feed rate increases and imperfect surface profile of the micro lens is found as feed rate is high.

This may be due to the tool feed rate which is defined as the ratio of the feed rate and the spindle rotational speed. As tool feed rate increases, the width and the depth of the tool marks formed on the surface increase. An increase in feed rate together with decreasing spindle rotational speed results in an increase in tool feed rate and hence the formation of imperfect surface profile in the microlens array. It is found that the power spectra of the surface profiles change with the variation of feed rate. This infers that the power spectrum of the surface profile is possible to be used to characterize the surface generation under different feed rates.

5. CONCLUSION

Although ultra-precision machining based on fast tool servo (FTS) machining provides a solution for machining optical microstructures with sub-micrometer form accuracy and nanometric surface finish without the need for any subsequent post processing, the methodologies for the characterisation of surface generation have received relatively little attention.

In this paper, the factors affecting the surface generation in FTS machining optical microstructures are identified and analyzed through a series of cutting tests. The surface quality and defects of the machined surfaces are examined. Patterns and features are extracted by power spectrum analysis based on the experimental findings and they are correlated with surface quality of the optical microstructures.

The preliminary results indicate that the form accuracy and surface roughness of the microlens array are significantly affected by the surface speed and feed rate, respectively. Better form accuracy can be achieved with a lower surface

speed while the surface profile of the microlens distorts significantly as the surface speed increases. Such a distortion reduces the diffraction efficiency and thus the optical performance. It is also found that the surface roughness of microlens array increases with increasing feed rate. Moreover, it is interesting to note that the patterns and features of the power spectrum of the machined surface can be correlated to the form and surface roughness of the optical microstructures. This not only provides an important means for the surface characterisation but also forms the basis for the development of the pattern analysis algorithms for the surface characterisation system for optical microstructures.

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