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◆특집◆ 선삭 가공 공정의 가공 정밀도 향상

FTS시스템을 이용한 롤외 미세 패턴 가공

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Micro Patterning of Roll using Fast Tool Servo System

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ABSTRACT

The application of fast tool servo (FTS) for diamond turning has been investigated extensively. This paper focuses on the fabrication of the sinusoidal microstructure on a roller, which generated by a piezoelectric-assisted FTS. The influence of the machining parameters on the microstructure configuration was investigated. The experiment results point out that the configuration of the machined microstructure depends mainly on the spindle speed, the diameter of roller and the driving frequency of FTS. The calculation method of the microstructure dimension was reported. The turning test results show that the diamond tool can be moved up to 1kHz without any reinjected vibration in the machining and the peak-to-valley amplitude of the machined sinusoidal microstructure is about 12μm.

Key Words : Fast Tool Servo, Precision Diamond Turning, Piezoelectric Actuator, Microstructure

1. Introduction

At present, diamond turning has become a ripe manufacturing process of producing accuracy optical surface requiring complex surface configuration together with fine surface integrity. The advancement of the precision turning technology with single diamond tools has a long period of development for machining high quality microstructure. In the profile wavelength range from 10μm to 100μm, diamond turning is superior to the electronic method and the optical method, especially for fabrication of precision and complicated microstructure surfaces[1].

A recent approach made in diamond turning is to combine fast tool servos (FTSs) to produce complex geometries into a specimen. The piezoelectric-assisted FTS performs an additional motion perpendicular to the workpiece surface. This technology can provide high resolution and fast dynamic response and usually used in fabricating precision sinusoidal microstructure and optical surfaces[2,3]. Lu and Trumper[4] designed a spindle

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position estimator to improve both accuracy and resolution of the spindle angle feedback, thus the FTS trajectory generation was significantly improved in both 1-D and 2-D sinusoidal surface turning. Kim and Kim[5] developed a FTS to control depth of cut precisely and compensate the waviness of the machining surface. The results revealed that the peak-to-valley of the surface waviness profile has been decreased to 0.3μm (from 3.3 μm) in one particular case. Kim et al[6]. reported a long-stroke FTS used for fabricating the free-form surface. The machining test results show that the proposed procedures can machine a copper free-form mirror of diameter 50mm with a form accuracy of 0.15μm in peak-to-valley error.

The precision position control and surface finish depends on compensating static and dynamic deformations caused by the cutting farces, variations on the cutting process tool and material, and piezoelectric hysteresis. The control of the piezoelectric actuator becomes a very important issue in obtaining desirable positioning accuracy and machined surface quality. Kim and Kim[7] used a closed-loop control scheme including PI feedback control, which implemented besides a notch fiter and a simple predictor, in order to correct the hysteresis and drift of the piezoelectric actuator. The results show that the FTS can follow the command input sine wave with an amplitude of 7.5μm and frequency up to 100Hz effectively so that the peak-to-valley error level is 0.15μm. The thermal growth of the spindle in saw-tooth shape was removed by the real time compensation.

Fig. 1 Experimental set-up

In this work, a defined sinusoidal micro structure was fabricated during the diamond turning process. The machining evaluation of a novel FTS used to fabricate microstructure surface was reported. All actual machining tests were performed on a roller machine. A function generator provided the command signals to the FTS, which signals were magnified by a high power amplifier. The machining results showed that the profile of the microstructure is a sinusoidal wave with spatial wavelength of 340μm and the peak-to-valley amplitude of about 12μm. And the effectiveness of the designed FTS system was also indicated.

2. Experimental system description

Turning experiments were carried out on the roller turning machine. The workpiece is a brass roller with length of 1.5m and diameter of 170mm. The machine is composed of three main parts: the aerostatic spindle and tailstock to rotate the roller, an X-axis linear servo to laterally move the diamond tool along the roller for providing the feed rate, and a Y-axis linear servo to translate the diamond tool for generating depth profile. A piezoelectric actuator from PI Inc. with a maximum expansion of 30μm and axial stiffness of 68N/μm is used to drive the diamond tool. The function generator produces the desired diamond tool motion trajectory that is sent to the amplifier as the reference input of the FTS. The output motion of the diamond tool was detected by a capacitive sensor. The quality of machined microstructures was evaluated by an optical microscopy and an Alpha-step.

Fig. 1 shows the photograph of the turning machine used for the fabrication of the sinusoidal microstructure in this study. The stacked piezoelectric actuator is mounted in a rigid main body base as shown in Fig. 2, and a set of leafspring guide the extension and contraction of piezoelectric actuator, which is bolted to the main body base. The symmetry structure in the design can inherently balance the flexure mechanism and avoid coupled interference motion. Since the mechanical flexure acts as a spring, it can be modeled by a single degree of freedom system. The mass (M) is upper carriage which holds the tool, and structural damping constant is C. The spring constant (K) is dominated by the set of leafspring.

The open-loop transfer function between the tool position (x) and the amplifier input (u) in Laplace domain[8] is :

$$x(s) = \frac{K_d G_a}{M_s^2 + C_s + K}\left[u(s) - \frac{1}{K_d G_a}F_d(s)\right] \quad (1)$$

where K_d is the gain of digital to analog converter, G_a is the amplifier gain, and F_d is the cutting force disturbance to the actuator. Expressing Eq. (1) as differential equation and rearranging

$$\frac{M}{K_d G_a}\ddot{x}(t) + \frac{C}{K_d G_a}\dot{x}(t) + \frac{K}{K_d G_a}x(t) = u(t) - \frac{1}{K_d G_a}F_d(t) \quad (2)$$

or

$$M_{eff}\ddot{x}(t) + C_{eff}\dot{x}(t) + K_{eff}x(t) = u(t) - d(t) \quad (3)$$

In order to reduce the mass of the moving part, the light diamond tool was used and the mass of tool holder was controled at a lowest level.

Table 1 Machining conditions

Workpiece	Material	Brass
Tool	Material	Diamond
	Nose angle	90°
	Clearance angle	9°
Turning	Feed rate	20μm
	Spindle speed	19, 38, 48rpm
FTS	Frequency	1000Hz

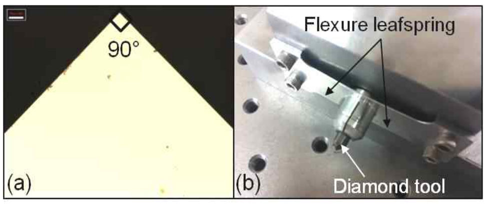


Fig. 2 Diamond tool (a) with 90° nose angle and (b) assembly on the tool holder

3. Turning Experiments

The turning conditions are illustrated in Table 1. In both cases the tool has been excited by a sinusoidal oscillation with the frequency of 1000Hz. A UV casting technique was performed to replicate the profile of the microstructure on a plane. The UV casting provided a high degree of accuracy and could be achieved at the room temperature and low pressures[9]. A UV resin was poured in the liquid state between the workpiece and the plastic film. The profile of the microstructure was molded on the plastic film when the UV resin curing. The quality of machined microstructures were evaluated by an optical microscopy and an Alpha-step.

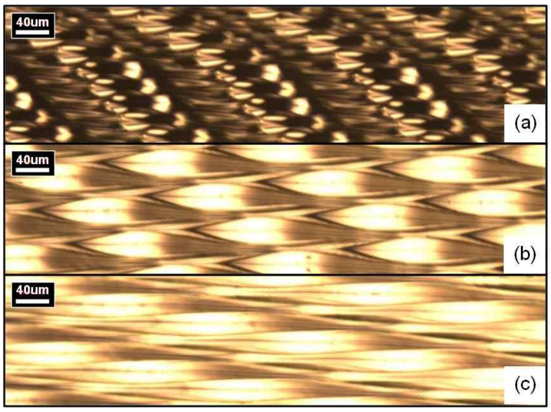
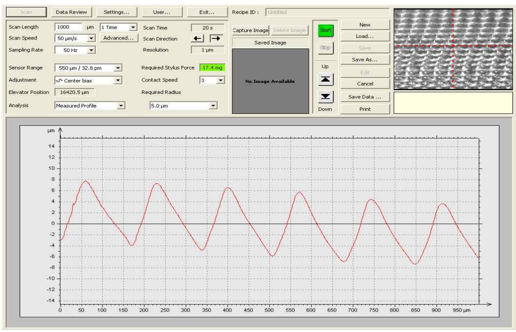
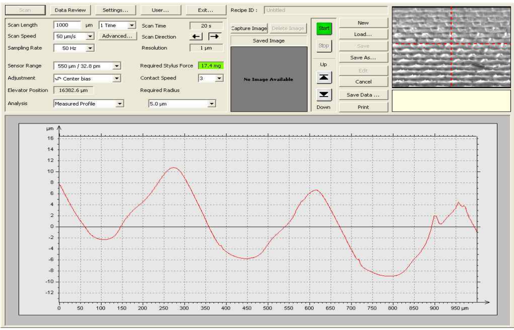


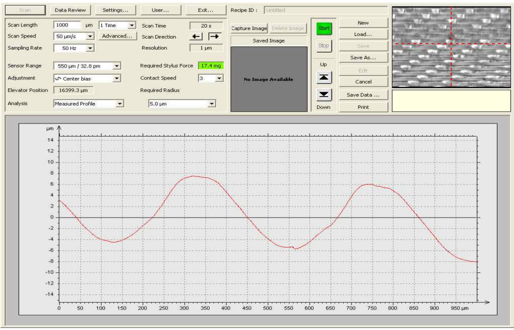
Fig. 3 Optical microscope photographs of microstructures in cases of driving frequency of 1kHz and spindle speed of (a) 19rpm, (b) 38rpm, (c) 48rpm, respectively



(a) Spindle speed=19rpm, FTS frequency=1kHz



(b) Spindle speed=38rpm, FTS frequency=1kHz



(c) Spindle speed=48rpm, FTS frequency=1kHz

Fig. 4 Profile wavelength of the microstructure in different spindle speed

4. Results and Discussion

Fig. 3 shows the optical microscopy graph of the microstructure for different turning tests. In both cases the tool has been excited by a same sinusoidal oscillation with a spindle speed of 19rpm for Fig. 3 (a), 38rpm for Fig. 3 (b) and 48rpm for Fig. 3 (c). Each single oscillation is clearly distinguishable and the microstructure is free of breakages. The machining parameters used for the workpiece in Fig. 3 are the result of several test series because the characteristics of the microstructure machined by this FTS can be exhibited adequately through these parameters.

An Alpha-step which the scan length is up to 1mm was used to evaluate the profile quality of the machined microstructure, as shown in Fig. 4. At the bottom of the height maps, the profile curve through one of the structure is shown. Its position is marked in the height map with a dashed line. From the profile graph, it is obvious that the wave length of the profile is defined by three factors: the spindle speed, the radius of roller and the driving frequency of FTS. The turning tests show that the wavelength of profile increased with spindle speed enhancing when the driving frequency and diameter of roller are the constant.

5. Conclusion

This paper presents the fabrication of the sinusoidal microstructure on a roller, which generated by a piezoelectric-assisted FTS. The experiment results point out that the configuration of the machined microstructure is depends mainly on the spindle speed, the diameter of roller and the driving frequency of FTS. The wavelength of the profile increased with the spindle speed added when the driving frequency and the diameter of the roller are the constant. The actual turning result of the sinusoidal microstructure has indicated the effectiveness of the designed FTS system.

In the future work, a large area sinusoidal microstructure surface on a roller, which has the diameter of 300mm and length of 2m, will be fabricated.

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