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Fabrication of the lens array mould with embossing type surface by using a fast tool servo with large displacement up to hundreds of micro meter

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Abstract

We performed the fabrication of the lens array mould with embossing type surface by using a fast tool servo. To overcome the nonlinear hysteresis characteristics of the piezoelectric actuator in fast tool servo, the proportional integral controller with feedforward compensator was used. Also, to meet the large optical sag required in most of commercial optical devices, the fast tool servo with large displacement up to hundreds of micro meter has been integrated into the diamond turning machines. To synchronize the fast tool servo and the diamond turning machine, the precision encoder signal from the CNC was read and used to update the control input to the high voltage amplifier for the piezoelectric actuator. The machined result shows that the proposed controller and tool servo can be successfully integrated into the machine and can fabricate the complex optical surfaces with embossing shape.

Key words: Embossing type surface, Fast Tool Servo (FTS), Diamond turning machine

1. Introduction

Recently, the optical device with complex shape such as the lens array has been used increasingly in the small size electronic devices – for example, the mobile projector, etc. But it is difficult to fabricate the lens array because of the surface roughness and form accuracy required in optical industry though its complex shape [1][2]. In addition, to meet the mass production requirement, there have been difficulties in manufacturing the mould insert with lens array shape by chemical method. To overcome these difficulties, the fast tool servo in diamond turning machine was applied to fabricate the lens array mould with embossing type surface [3][4]. We synchronized the fast tool servo to the diamond turning machine by getting the encode signal from the precision linear oil & hydrostatic bearing guide. In addition, by employing the displacement amplification mechanisms, the stroke of fast tool servo was enlarged to several hundreds of micro meter. The machined result shows that the proposed fast tool servo can be successfully integrated into the diamond turning machine and can fabricate the complex optical surfaces with embossing shape

2. Lens array mould fabrication with fast tool servo

2.1. Lens array mould with embossing type surface

According to the advances of mobile technologies and small size electronic devices, the demand for the optical system with high performance and small size has increased outstandingly. Especially, recent optical system has realized the high performance and lightweight designs which are employing the lenses with micro-structures surface. As an example of such a micro-structure, we can take the lens array which has several spherical lenses in small rectangular area - Fly-Eye lens. This type of lens is usefully used in the small size micro-projector widely used in consumer electronics market. Figure 1 shows the lens array mould core for mobile projector. It has 84 (12x7) spherical lenses with a radius of 1.07 mm. It is included in the plastic injection moulding machines for mass production. We used a STAVAX flat plate for mould core which has a thin Ni coating layer at the top side. Generally, the diamond tool can turn the Ni coating area and it is possible to generate the array of spherical lenses by providing the non-rotationally symmetric components through the fast tool servo.

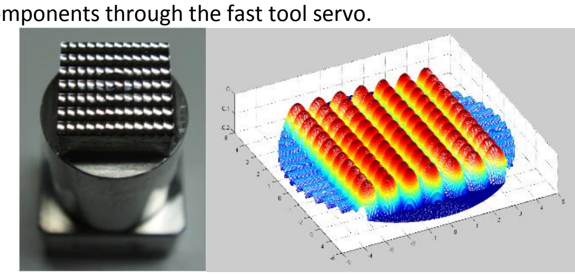
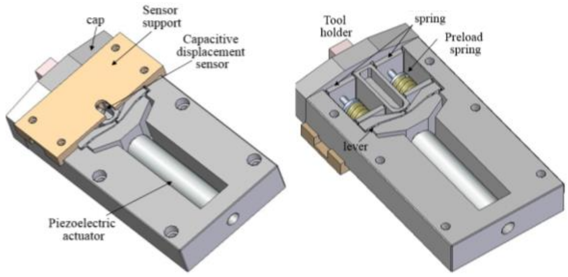


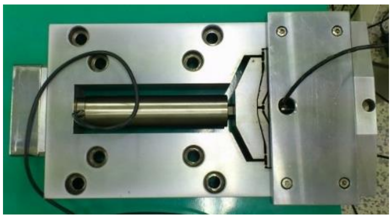
Figure 1. Lens array mould core for mobile projector machined by fast tool servo in diamond turning machine (STAVAX, 12x7)

2.2. Fast tool servo with several hundreds of micro meter and diamond turning machine

The details of the fast tool servo designed for machining lens array optics are shown in Figure 2(a) and (b). It has a single-point diamond tool fixed at post flexure with four elastic parallel hinges. The tip motion can be amplified by the mechanical hinges and levers while the piezoelectric actuator moves back and forth at several hundred Hz. The piezoelectric actuator is of the stacked type, 118 mm in length and 29 mm in outer diameter. Through the displacement amplification mechanism and piezoelectric actuator, the fast tool servo can provide the stroke of 400 mm and bandwidth of 80 Hz. Also, a capacitive-type displacement sensor with resolution of 0.01 μm was installed into the fast tool servo to measure its end tip motion. It can be utilized to compensate for the nonlinear hysteresis characteristics of the piezoelectric actuator of fast tool servo [5].



(a) Solid model of fast tool servo with displacement amplification mechanism



(b) Photograph

Figure 2. Sketch of fast tool servo with stroke 400 μm and BW 80 Hz and diamond turning machine

3. Fabrication

A lens array mould, which has 84 spherical individual lenses with their radii of 1.07 mm on its top side of rectangular area (7.2 x 8.9 mm^2), was fabricated using fast tool servo in the diamond turning machine. Figure 3 shows the sketch of machining schematic in the diamond turning machine. FTS controller can get the precision encoder signal from the C-axis and X-axis in commercial diamond turning machine - Nanoform 250, Precitech. Therefore, FTS actuator can respond synchronously to the motion of Nanoform 250 in X and C axis and its motion can be generated by considering the current positions of X and C-axis in real time. The FTS was actuated by following simple equation describing the FTS tool motion in Z-axis unlike the enormous amount of position data which are generated by CAM software [1].

$$Z = \sqrt{(R^2 - (X - X_{cen})^2 - (Y - Y_{cen})^2)}$$

Where, Z is the movement of the FTS which is added to the Z-axis of the diamond turning machine. And X and Y are X-coordinate and Y-coordinate of the cutting point. Also, X_{cen} and Y_{cen} are X and Y-coordinates of the lens center and R is cutting position of X-axis. The machining condition is in Table 1. The optical parameters are: the radius is 1.07 mm, its tolerance is 5 um, center sag is 126 um, and lens pitch is 0.988 and 0.580 mm. The FTS motion program has been implemented in general purpose platform – DeltaTau PMAC system – in which several feedback control algorithms and various interpolation schemes can be successfully realized. In our paper, the PI(Proportional Integral) feedback control algorithm has been embedded in PMAC system by getting the signal from the capacitive displacement sensor indicating the end tip motion of the FTS in Z-axis. Also, the linear interpolation has been selected to make the trajectories of the diamond tool. Therefore, the FTS can be applied to the most of diamond turning machines in which there exist various dynamic characteristics in X and C-axis because we can tune the feedback control gain of FTS and select the interpolation schemes according to the diverse features of diamond turning machines . After the completion of cutting, the profile error was measured along the radial direction to determine the form error when the radius is constrained to 1.07 mm. From Figure 4(a), it is found that the profile errors have been measured 2.65 μm in peak-to-valley level with Panasonc UA3P. This difference was caused by the uncertainty of tool radius and other environmental errors that we cannot quantify. From Figure 4(b), the surface roughness of machined surface is Ra 8.7 nm indicating the capability of proposed method for generating the optical mirror surface.

4. Conclusions

Fabrication process of the lens array required for micro projector system is described. The fast tool servo was adopted to deal with optical sag in the lens array mould and the FTS motion was synchronized with diamond turning machine by getting the encoder signal from Nanoform 250. By implementing the FTS motion program in general purpose platform, feedback control algorithm and interpolation scheme can be selected effectively according to the dynamic characteristics of X and C-axis in diamond turning machine. The actual fabrication test result shows that the proposed system can machine a STAVAX lens array mould of rectangular area 7.2 x 8.9 mm^2 with a form accuracy of 2.65 μm for radius of 1.07 mm in peak-to-valley error.

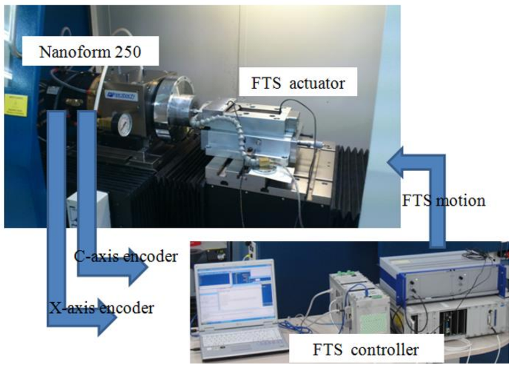
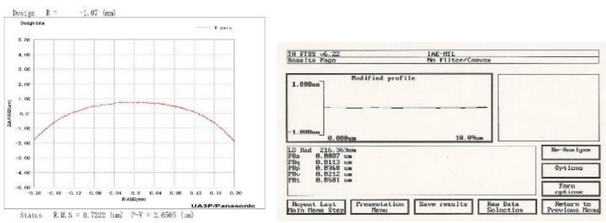


Figure 3. Sketch of the diamond turning machine with fast tool servo

Table 1 Conditions for the fabrication of the lens array mould with fast tool servo in diamond turnijng machine

Machining condition	Path interval (mm)	0.002
	Tool radius (mm)	0.1
	Spindle speed (rpm)	6
	Machining time (hour)	6.9



(a) Form accuracy (b) Surface roughness

Figure 4. Form accuracy and surface roughness of machined lens array

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