A newly developed nano-pattern generator equipped with an on-machine measuring function

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Abstract

Demands for machining and measuring of complex three dimensional (3D) nano-geometries have recently increased in a variety of industries. In order to meet such requirements, nano-machining systems with an on-machine shape measuring function are required. This paper presents a newly developed nano-pattern generator equipped with an on-machine measuring function. In this system, an astigmatic focus error detection method is applied to the on-machine measuring system. In addition, the compensating function of the uneven reflection from the surface is developed. Experimental results of shape correction confirmed that the nano-pattern generator with an on-machine surface profile measuring function provides nano-pattern generation with high machining accuracy.

1 Introduction

Demands for machining and measuring of three dimensional (3D) shapes with the dimensions of several hundred mm scale and the profile accuracy of nanometer scale have recently increased for realizing precise products such as semiconductors and optical lens. In order to fabricate and evaluate such geometries, ultraprecision machining systems require shape measuring function that can quantitatively evaluate the generated shape. In general, a machined shape is measured with a traditional measuring system, i.e., a surface roughness measuring instrument or a coordinate measuring machine. In such case, it is necessary to unload the objective workpiece after machining and then to mount it on the measuring instrument. However, when the shape correction is required, it is necessary to load the workpiece on the machine again and consequently the setting error occurs. An on-machine measuring system enables to achieve an effective shape correction. This paper presents a newly developed nano-pattern generator equipped with an on-machine measuring function.

2 Structural configuration of nano-pattern generator equipped with an on-machine measuring function

Figure 1 shows a structural concept of the proposed nano-pattern generator equipped with an on-machine measuring function. This system includes a cutting tool, a shape measuring system, an X-Y planar motion table and a Z-axis motion platform. By the Y axis motion, a machining function and a measuring function can be switched.

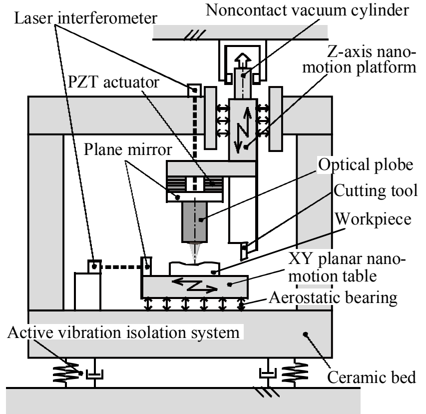

Figure 1: Proposed concept of nano-pattern generator

The 3D positioning system is shown in Fig.2. An optical probe is attached to the Z-axis motion platform, and the Z-axis is controlled to keep the distance in focus during the X-Y planar scanning. Both the X-Y planar nano-motion system and the vertical nano-motion system are driven by voice coil motors and guided with aerostatic bearings. In addition, the vertical nano-motion system has a noncontact gravity compensator using a pair of vacuum cylinders. In consequence, this system provides complete noncontact structure, so that the system is free from non-linear phenomena such as stick-slip, backlash and thermal drift. The positioning system has a high positioning resolution of 1 nanometer and high structural stability [1][2].

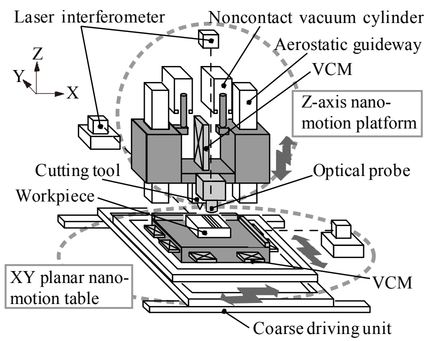

Figure 2: The 3D positioning system

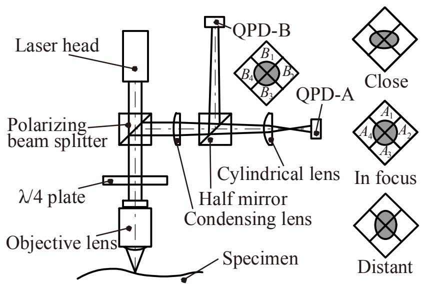

Figure 3: Optical probe with compensating function of uneven reflection

An astigmatic focus error detection method is used for an optical probe. If an uneven reflection occurs at a measuring point, an accurate distance to the measuring point cannot be obtained. Therefore, this study proposes the optical probe with the compensating function of uneven reflection. Fig.3 shows the proposed optical probe with the compensating function of uneven reflection. The quadrant photo diode B (QPD-B) is used for compensating the influence of uneven reflection. This optical probe can compensate an uneven reflection effectively [3].

3 Shape correction experiments

Shape correction experiments were conducted to evaluate the performance of the nano-pattern generator developed. Fig.4 shows the procedure of shape correction. First, the shape of a workpiece was measured with on-machine measuring function. Next, the tool paths were planned on the basis of measured shape and then the workpiece was machined with a pick-feed motion. By repeating this cycle, a grove was formed. A single crystal diamond tool with nose radius is 0.8 mm was used for machining and a brass was used as a workpiece. Desired depth of the grove was 5.000 micrometer. Fig.5 shows the shapes of a workpiece measured by on-machine measuring function. Lines a, b, c and d show the shape after first, second, third and forth machining, respectively. The machining conditions are shown in Table 1.
After machining, the machined shape was measured by a surface profile measuring instrument (Taylor Hobson, Form Talysurf PGI820). The measured profile is shown in Fig.6. The measured depth was 5.019 micrometer and the error of depth was 0.019 micrometer.

Table 1: Machining conditions

	Depth of cut [μm]	Cutting speed [mm/s]	Depth of groove [μm] (by on-machine measurement)
1st machining	2.400	5.0	2.400
2nd machining	1.600	5.0	4.000
3rd machining	0.900	5.0	4.895
4th machining	0.105	5.0	5.000

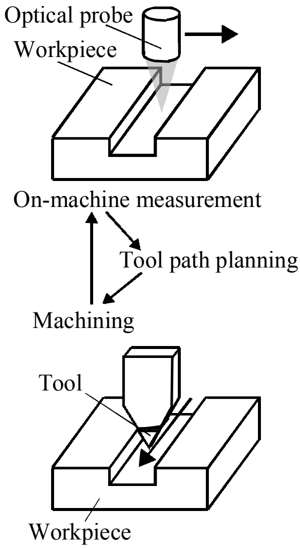

Figure 4: Procedure of shape correction

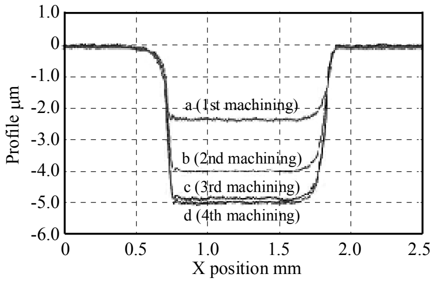

Figure 5: Profile measured with on-machine measuring function

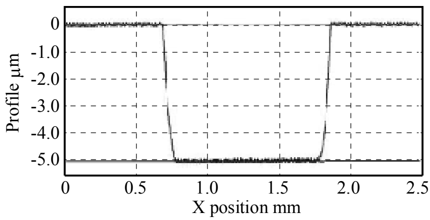

Figure 6: Profile measured with surface profile measuring instrument

4 Conclusions

This paper presented a newly developed nano-pattern generator equipped with an on-machine measuring function. Results of shape correction experiments confirmed that the nano-pattern generator with an on-machine surface profile measuring function provides nano-pattern generation with high machining accuracy.

References:

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