

# Optimization of Nano-topography Distribution by Compensation of Grinding Conditions

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## Abstract

Precision optical parts have become increasingly important in various fields, including semiconductors and imaging technologies. Currently, the form accuracy of an aspherical lens is less than 50 nm, and the maximum height roughness is less than 20 nm. However, nano-topography, which is periodic waviness of small amplitude, remains on the ground surface, resulting in grinding marks[1]. The presence of grinding marks on the ground surface disturbs the uniformity and deteriorates the accuracy of optical components. Therefore, we propose “Uniformity” as an additional criterion of quality for a ground surface. As grinding marks deteriorate the accuracy of optical instruments, the nano-topography needs to be controlled and uniformity needs to be improved.

In this study, the distribution of the nano-topography on a ground surface is calculated theoretically. Using the calculated results, the actual grinding conditions can be estimated. The grinding conditions can then be compensated to optimize the distribution of the nano-topography.

## 1 Generation mechanism of nano-topography

The measured nano-topography on an axisymmetric aspherical ground surface is shown in Fig. 1. It was found that the nano-topography is caused by an unbalanced grinding wheel[2]. Even if the degree of unbalance is of nanoscale-order, a nano-topography will be generated. In fact, it is difficult to avoid generating a nano-topography. Therefore, the distribution of the nano-topography must be controlled in order to make it easy to be removed in the finishing process.

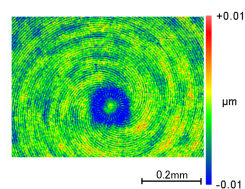


Fig. 1 Nano-topography

Fig. 2 shows a nano-topography generation model in an axisymmetric grinding process. A vibrating grinding wheel is fed over a rotating workpiece. Here,  $v_c$  is the feed rate of the grinding wheel,  $f_w$  is the revolution frequency of the workpiece, and  $f_d$  is revolution

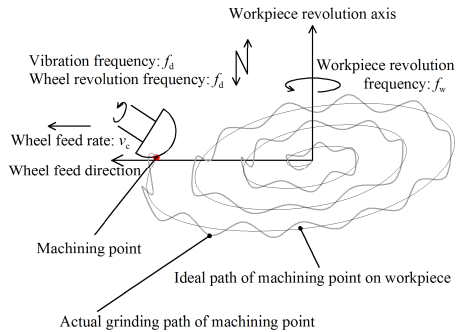


Fig. 2 Model of axisymmetric aspherical grinding

frequency of the grinding wheel. The distribution of the nano-topography is affected by the grinding conditions, especially the wheel revolution frequency, the workpiece revolution frequency, and the wheel feed rate. Based on the grinding model shown in Fig. 2, the nano-topography distribution is simulated. Fig. 3 shows the results of this simulation indicating a spiral patterned distribution. This simulated distribution pattern is similar to the actual distribution pattern (Fig. 4). Thus, the vibration of the grinding point, caused by the unbalanced grinding wheel, is transcribed to the ground surface and generates the nano-topography.

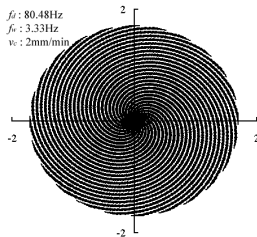


Fig. 3 Simulated pattern

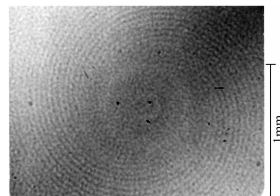


Fig. 4 Actual pattern

## 2 Development of calculation method of nano-topography distribution

In this study, the distribution of the nano-topography was estimated by the cross sectional profile along the radial direction.

In the axisymmetric aspherical grinding process, a spherical grinding wheel is used. The position of the tip of the grinding wheel ( $r_m, \theta_m, z_m$ ) can be calculated in terms of a cylindrical coordinate system in which the origin is the center of rotation on the workpiece surface, by the following equation.

$$\begin{cases} r_m = v_c t \\ \theta_m = 2\pi f_w t \\ z_m = a \sin(2\pi f_d t) \end{cases} \quad (1)$$

In these equations,  $a$  is the half amplitude of vibration, and  $t$  is the machining time. Grinding is carried out not only by the tip of the grinding wheel but also by the spherical surface of the grinding wheel. When the tip of the grinding point is  $P(r, \theta, z)$ , the point  $(r_m, \theta_m, z_m)$  is ground at a height  $z_p$ , which is calculated by the following equation.

$$\begin{aligned} z_p &= z + R - \sqrt{R^2 - (r_m \cos \theta_m - r \cos \theta)^2 - (r_m \sin \theta_m - r \sin \theta)^2} \\ &= z + R - \sqrt{R^2 - r_m^2 - r^2 + 2r_m r \sin \theta} \end{aligned} \quad (2)$$

If the value of  $z_p$  is smaller than  $z_m$ , the remaining ground surface is  $(r_m, \theta_m, z_p)$ . The calculation was carried out with various  $r$  and  $\theta$  in equation (2) to search for the smallest  $z_p$ , and the topography of the ground surface was simulated. The cross sectional profile was calculated by the simulated results and FFT analysis was carried out. Fig. 5 shows the results of FFT analysis. It is seen that Fig. 5 is similar to the actual ground surface shown in Fig. 6.

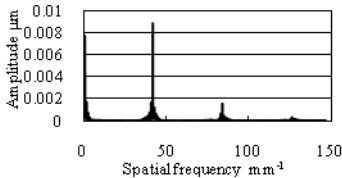


Fig. 5 Simulated ground surface

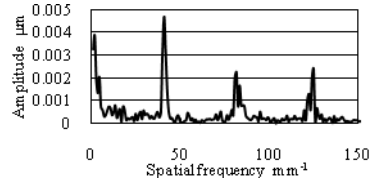


Fig. 6 Actual ground surface

### 3 Optimization of grinding conditions

An experiment was carried out to control the distribution of the nano-topography. The experimental conditions used are shown in Table 1. By utilizing the developed calculation method, the distribution of the nano-topography was calculated under these conditions. Fig. 7 shows results of the FFT analyzed cross sectional profile. Fig. 8 shows the FFT analysis of the actual ground surface, generated under the grinding conditions shown in Table 1. Comparing Fig. 7 and Fig. 8, it is found that there is a difference. It is considered that there is a difference between the intended grinding

Table 1 Grinding conditions

Wheel revolution frequency: $f_d$ Hz	82.53 (4952rpm)
Workpiece revolution frequency: $f_w$ Hz	3.33 (199.8min <sup>-1</sup> )
Wheel feed rate: $v_c$ mm/min	3
Radius of grinding wheel: $R$ mm	62.5
Wheel	SD3000
Workpiece	WC

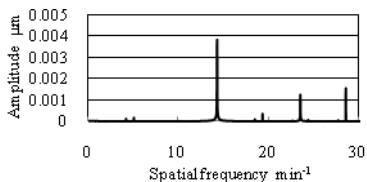


Fig. 7 Intended ground surface

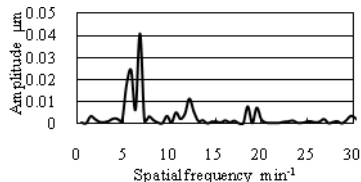


Fig. 8 Actual ground surface

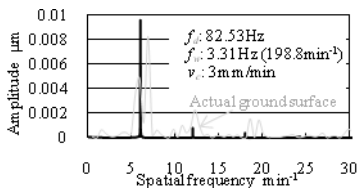


Fig. 9 Simulated ground surface

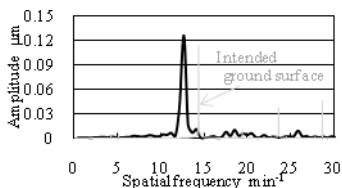


Fig. 10 Compensated ground surface  
( $f_w : 200.8 \text{ min}^{-1}$ )

conditions and the actual grinding conditions. This difference in grinding conditions likely caused the difference in the cross sectional profile.

In order to estimate the difference between the ideal grinding conditions and the actual grinding conditions, the calculation was carried out. Fig. 9 shows the results, indicating that the wheel revolution frequency has a  $1 \text{ min}^{-1}$  error. It is considered that the grinding force causes the error in the grinding conditions.

To make the grinding conditions to the intended conditions, the actual grinding conditions need to be compensated. Since it was found that the workpiece revolution speed was  $1 \text{ min}^{-1}$  short, the workpiece revolution speed was set  $1 \text{ min}^{-1}$  larger than the previous grinding condition shown in Table 1. The FFT analyzed ground surface for this is shown in Fig. 10. It was found that the distribution of the nano-topography was now similar to the intended distribution of the nano-topography.

#### 4 Conclusions

In this paper, a calculation method for the distribution of the nano-topography was developed. Compensation of the grinding conditions using the developed calculation method is proposed.

#### References:

- [1] Tsunemoto Kuriyagawa et al., Nano-topography Characterization of Axisymmetric Aspherical Surfaces, Key Engineering Materials, 238-239, (2003)p.125-129.
- [2] Nobuhito Yoshihara et al., Nano-Topography on Axisymmetric Aspherical Ground Surface, Int. J. Manufacturing Technology and Management, 9(1/2),(2006)p.51-63.