

Ultra Precision Grinding of Micro Aspherical Surface – Development of a Three-Axes Controlled Single Point Inclined Grinding Method –

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1. Introduction

Needs of digital devices increase rapidly in recent years, and the demand for a micro axis-symmetric aspherical glass lens of large NA (numerical aperture) is expanding rapidly especially in the device for digital camera, camera-equipped mobile phone, DVD pick-up and the optical transmission [1][2]. Moreover blue lasers have been increasingly used to make wavelengths short and the maximum tangent angle of the lens reaches to 70 degrees. In addition, demand of glass lenses is high because glass lenses are superior to plastic lenses in optical characteristics. The glass lenses are manufactured by glass molding method by using ceramics dies such as WC (tungsten carbide) or SiC (silicon carbide) [3]. Therefore ultra-precision grinding technology of ceramic dies is gaining importance.

Authors have successfully to develop inclined grinding method, and micro aspherical shape has been obtained. In previous researches the grinding system shown in Figure 1 was developed. The grinding wheel axis was 45 degrees inclined from workpiece rotational axis. The grinding spindle was an air bearing and the maximum rotational rate of grinding wheel was $15 \times 10^4 \text{ min}^{-1}$. The grinding head was actuated by two-axes (X, Z) drives, the wheel center point was calculated numerically by using Newton-Raphson method. This system was suitable for grinding micro aspherical surfaces and a form accuracy of less than $0.1 \mu\text{m P-V}$ was obtained. The improvement of the form accuracy will be required because the specifications of micro lenses become more and more strict in future. However, the shape correction cannot be done satisfactorily, because the wheel wear is not even and the grinding point on the wheel moves as shown in Figure 2. In this case, wheel truing is necessary and it will increase the non-processing time. In this paper, a new grinding method is proposed to solve the above problems. In this method, three-axes (X, Y, Z) are controlled simultaneously so that the position of the grinding point on the diamond wheel is fixed. Then the grinding system was developed and grinding experiments of using tungsten carbide micro dies were carried out.

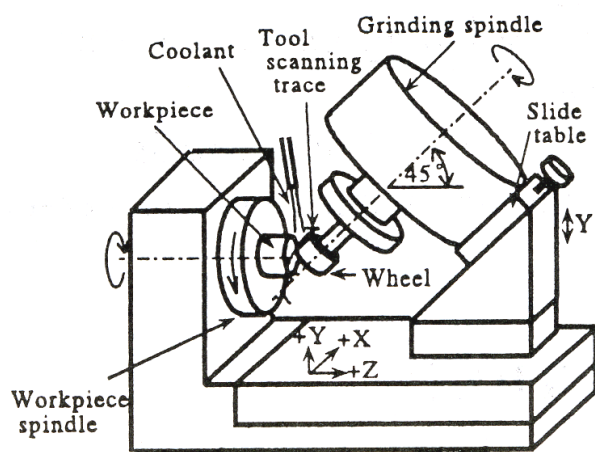


Fig.1 Micro axis-symmetric aspherical grinding system

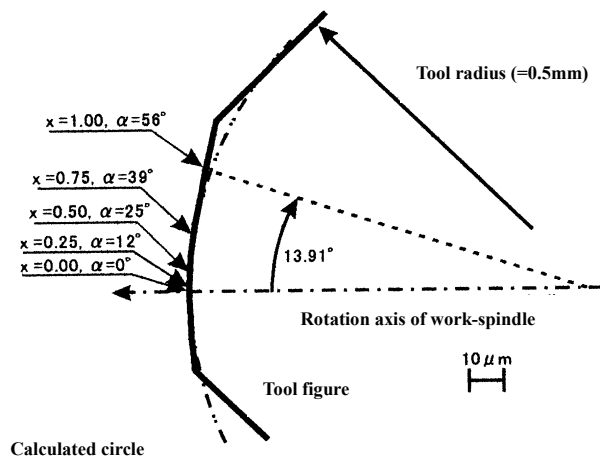


Fig.2 Changes of grinding point and unequal wheel wear (conventional micro aspherical grinding method)

2. Wheel path of grinding point fixation method

The rotation axis of wheel-spindle inclines by 45 degrees. The wheel center point O (X_o, Y_o, Z_o), grinding point G (X_g, Y_g, Z_g), and the normal vector $\vec{n}(a, b, c)$ at the grinding point are shown in Figure 3. An axis-symmetric aspherical function is given by $Z=f((X^2+Y^2)^{0.5})$, and a normal vector in grinding point G (X_g, Y_g, Z_g) is given by Eq.(1).

$$\vec{n}(a, b, c) = \left(-\frac{\partial f}{\partial X}, -\frac{\partial f}{\partial Y}, 1 \right) \quad (1)$$

And the relationship between the wheel center point O and the grinding point G is obtained Eq.(2).

$$\left. \begin{aligned} X_o &= X_g + \frac{a}{1} \cdot R_1 + \frac{a}{L} R_2 \\ Y_o &= Y_g + \frac{b}{1} \cdot R_1 + \frac{b-c}{2 \cdot L} R_2 \\ Z_o &= Z_g + \frac{c}{1} \cdot R_1 + \frac{c-b}{2 \cdot L} R_2 \end{aligned} \right\} \quad (2)$$

Where, $|\vec{GP}| = R_1$, $|\vec{PO}| = R_2$, $l = \sqrt{a^2 + b^2 + c^2}$ and $L = \sqrt{a^2 + 0.5 \cdot (b-c)^2}$.

To let the grinding point in radial position $r = (X^2 + Y^2)^{0.5}$, an aspherical function is expressed as follows:

$$Z = f(r), X = r \cdot \cos \theta, Y = r \cdot \sin \theta \quad (3)$$

The normal vector is expressed as follows:

$$\begin{aligned} \vec{n}(a, b, c) &= (-\partial r / \partial X, -\partial r / \partial Y, 1) \\ &= (-\partial r / \partial X \cdot df/dr, -\partial r / \partial Y \cdot df/dr, 1) \\ &= (-f'(r) \cdot \cos \theta, -f'(r) \cdot \sin \theta, 1) \end{aligned} \quad (4)$$

In the conventional method, $\angle QPO$ becomes 45 degrees in case of $r=0$. On the other hand, $\angle QPO$ always becomes 45 degrees in the proposed method as shown in Figure 4. Therefore, the next relationship is obtained.

$$|\vec{PQ} \cdot \vec{PO}| = |\vec{PQ}| \cdot |\vec{PO}| \cos 45^\circ \quad (5)$$

From Eq.(5) of the following relationship is obtained

$$a^2 = 2bc \quad (6)$$

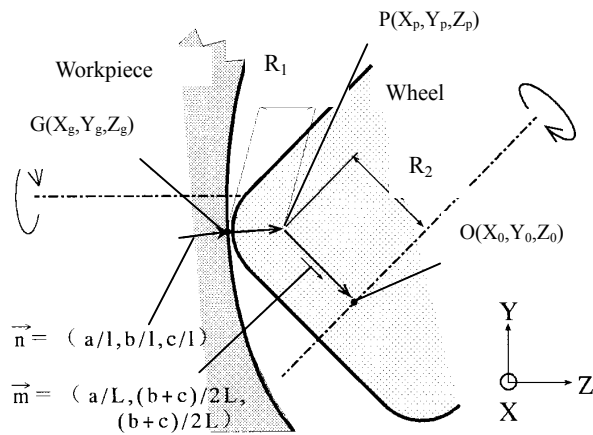


Fig.3 Calculation of tool path in the inclined grinding method

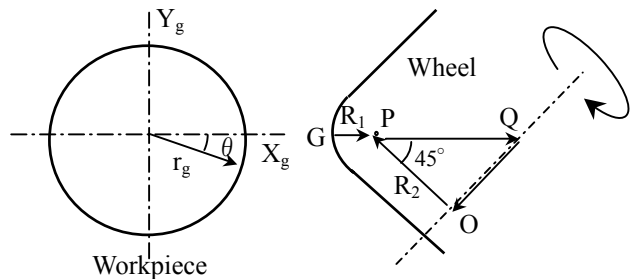


Fig.4 Calculation of tool path

The next expression is obtained from Eqs.(4) and (6).

$$\sin \theta = \frac{1}{f'(r)} - \sqrt{\frac{1}{f'(r)^2} + 1} \quad (\text{Concave surface}) \quad (7a)$$

$$\sin \theta = \frac{1}{f'(r)} + \sqrt{\frac{1}{f'(r)^2} + 1} \quad (\text{Convex surface}) \quad (7b)$$

When a radial position of the grinding point on the ground workpiece surface is assumed to be r_g , the relationship of the next expression is obtained from Eq.(3).

$$X_g = r_g \cdot \cos \theta, Y_g = r_g \cdot \sin \theta, Z_g = f(r_g) \quad (8)$$

Therefore, in this method the angle θ in the grinding point on the workpiece is calculated from Eq.(7a), (7b), the coordinates G (X_g, Y_g, Z_g) of the grinding point is calculated from Eq.(8), and finally the coordinates of wheel center point O (X_o, Y_o, Z_o) is obtained by Eq.(2).

3. Grinding experiments

A view of the simultaneous 4-axis (X, Y, Z, C) controlled grinding machine (Toshiba Machine Co. Ltd. ULG-100D(SH3)) is shown in Figure 5. The grinding wheel actuated in X, Y and Z-axes by the linear scale feedback system of 1 nm positioning resolutions. In the grinding test, the aspherical workpiece was vacuum chucked to the workpiece spindle (C-axis). The diamond wheel was adjusted to grinding spindle with collet chuck on the Y-axis table. Table 1 shows the grinding conditions. As a wheel, a resinoid bonded diamond wheel of # 1200 was used and diameter was about ϕ 2 mm. The wheel shape was columnar shape and the tip end was trued to radius of 0.2 mm. As the workpiece, molding die of about 1.5 mm in radius curvature and radius was tested and the material was tungsten carbide (Figure 6). Micro aspherical surface was measured with contact type of surface measurement instrument (Form Talysurf) with a 2 μ m radius stylus.

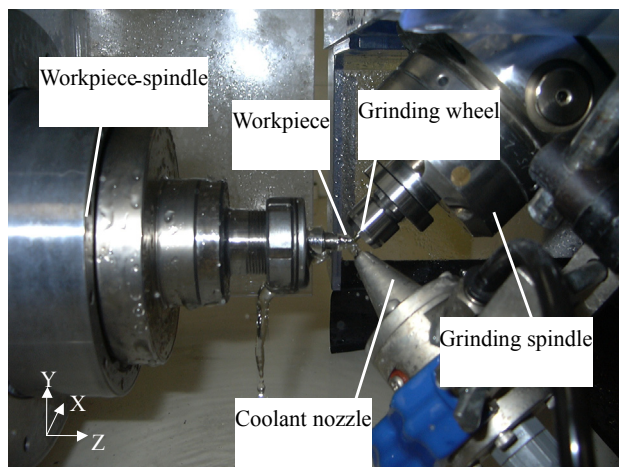


Fig.5 A view of the simultaneous 4-axes controlled grinding machine

Table 1 grinding conditions

Grinding wheel	Resinoid bonded diamond
Grain size	#1200
Diameter	ϕ 2 mm
Rotational rate	4×10^4 rpm
Workpiece	Tungsten carbide
Rotational rate	3×10^2 rpm
Depth of cut	0.5 μ m/pass
Feed rate	0.3 mm/min
Coolant	Solution type

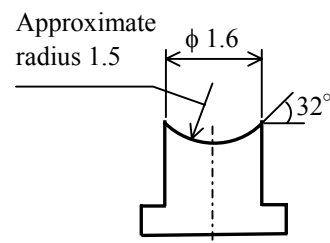


Fig.6 Shape of target aspherical molding die

4. Experimental results

Figure 7 shows the form deviation profile of first workpiece in the proposed grinding method. The form accuracy was about $0.09 \mu\text{mP-V}$. Figure 8 shows the change of form accuracy to the number of grinding passes in case of the conventional and the proposed method. The initial form accuracy was $0.09 \mu\text{mP-V}$. After 200 grinding passes (correspond to the finish grinding of 20 dies), the form accuracy was about $0.2 \mu\text{mP-V}$ in the proposed method and about $1.3 \mu\text{mP-V}$ in the conventional method. Moreover, wheel tip shape after 200 passes finish grinding is shown in Figure 9. It can be seen that there is a flat area in the wheel tip in the proposed method.

5. Conclusions

The micro aspherical grinding by the grinding point fixation diagonal axis grinding method of three axis control simultaneously was proposed, and examined in this research, therefore it was clarified that this proposed method was effective.

References

- 1) Hirofumi Suzuki, et al., Precision Grinding of Aspherical CVD-SiC Molding Die, Int. JSPE,1998, 32(1):25-30.
- 2) Hirofumi Suzuki, et al., Precision Grinding of Micro Aspherical Surface, Proc. of ASPE98, 1998:149-152.
- 3) Hirofumi Suzuki, et al., Ultra Precision Grinding of Micro Fresnel Shape, Proc. of ABTEC'99, 1999:59-65.

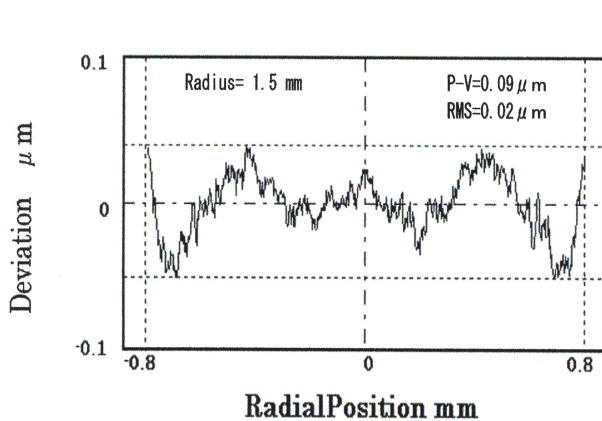


Fig.7 Form deviation profile after grinding

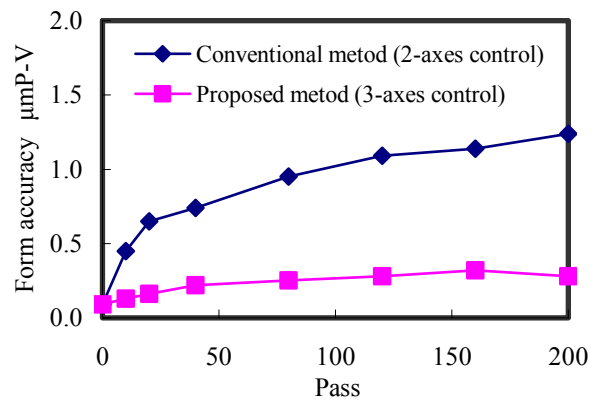
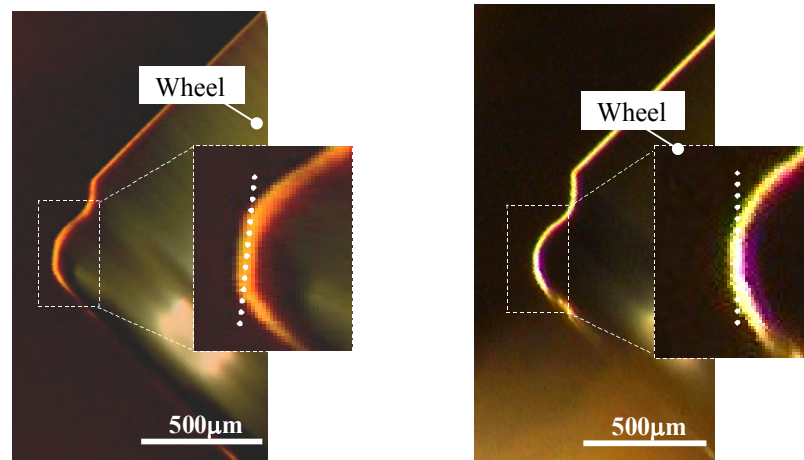


Fig.8 Changes in form accuracy of conventional and proposed method



(a) Conventional method (2-axes control)

(b) Proposed method (3-axes control)

Fig.9 Wheel tip shape after 200 passes of finish grinding