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Grinding marks in cross grinding of spherical and aspherical surface

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Abstract
Grinding marks on the spherical and aspherical surface are generated by the kinematics of cross grinding between wheel and workpiece. And surface quality is affected by grinding marks differently with different grinding parameters in precision grinding. In this paper, firstly, based on the kinematics of cross grinding between wheel and workpiece, the expression of grinding points distribution was established to characterize the grinding marks with various processing parameters. And then, the precision grinding experiments of monocrystal silicon for aspheric surface were carried out to investigate the influence of grinding marks on surface quality. Finally, the parameters matching criterion was proposed to obtain fine grinding marks with appropriate grinding parameters. And the ground surface quality was optimized by the homogenisation of grinding marks subsequently. This research gives an indication of the strategy to follow to achieve high quality ground aspheric surface.

Keywords: grinding marks, cross grinding, surface quality, parameter matching criterion

1. Introduction

Spherical and aspherical components and moulds of hard and brittle materials have been more and more widely used in aerospace, optical system and digital products with the rapid development of science and technology [1,2]. To achieve high quality of aspherical surface, abundant investigations were proposed for grinding spherical and aspherical surface by a lot of scholars [3,4]. Grinding marks on the spherical and aspherical surface are generated by the kinematics of cross grinding between wheel and workpiece. And surface quality was affected by grinding marks differently with different grinding parameters in precision grinding. However, the relationship between grinding marks on the spherical and aspheric surface and grinding parameters had not been investigated.

In this paper, the expression of grinding points distribution was established to characterize the grinding marks with various processing parameters. The precision grinding experiments of monocrystal silicon for spherical surface were carried out to investigate the influence of grinding marks on surface quality. The parameters matching criterion was proposed to obtain homogeneous grinding marks with appropriate grinding parameters.

2. Grinding points distribution of single abrasive grain

The material of workpiece is extruded and removed by high speed abrasive grains of the wheel, and then the grinding surface morphology of workpiece is generated. In other words, the grinding marks on workpiece which are ground by numerous abrasive grains on the workpiece constitute the surface morphology.

Unlike line grinding in face grinding, the point grinding is the contact type between the arc-shaped wheel and workpiece in cross grinding of spherical and aspherical surface. And the abrasive grains on the peak circle of the wheel tool are the main grains which extrude and remove the material of workpiece. In this paper, the grinding marks on workpiece are investigated by a single abrasive grain of the peak circle. A grinding point on the workpiece surface is generated by a single abrasive grain when the wheel tool turns a round, and the time period is described as:

$$t = \frac{1}{n_s} \quad (1)$$

where n_s is the wheel speed. The length of the spherical and aspherical curve which is used to machine the spherical and aspherical surface can be expressed by:

$$L = \int \sqrt{1 + f^{'}(R_x)} dR_x \quad (2)$$

where $f(R_x)$ is the spherical or aspherical equation, R_x is variable of the equation. And the total time of finishing the spherical and aspherical curve can be calculated by:

$$T = \frac{L}{F} \quad (3)$$

where F is feed rate. Therefore, the equation between the theoretical curve length and the motion curve length ground by the single abrasive grain can be established as follow:

$$F \bullet t_i = \int_{R_{x_0}}^{R_{xi}} \sqrt{1 + f^{'}(R_x)} dR_x \quad (4)$$

where t_i is any time in grinding process, i is at the range of 0-N, and it is an integer, where $N=T/t$. R_{xi} is the variable of the spherical or aspherical equation at that time, and R_{xi} can be calculated about t_i by Eq.(4). The grinding points distribution expression of single abrasive grain can be described as follow:

$$\begin{cases} x_i = R_{x_i} \cos(w_w t_i) \\ y_i = R_{x_i} \sin(w_w t_i) \\ z_i = f(R_{x_i}) \end{cases} \quad (5)$$

where w_w is the angular velocity of the work spindle.

3. Simulation of grinding marks

According to the Eq.(5), the grinding marks of spherical surface by different grinding parameters (listed in Table.1) are simulated as shown in Figure.1.

Table 1 Grinding parameters

Feed rate	Wheel speed	Work spindle speed	Spherical radius
40μm/min	6045rpm	9,155,156,157,158,159rpm	25mm

For the same feed rate and length of spherical curves, the quantity of grinding points is equal in different grinding parameters. As shown in Figure.1, the distribution of grinding points is quite different with the same quantity and similar grinding parameters. Overall, the grinding points in the center of surface are distributed more than edge in every parameter, and there are three kinds of distribution. The first is grinding marks along circumferential direction with low work spindle speed (9rpm), it is caused of the low work spindle speed, which makes the distance between two neighbouring grinding points in circumferential direction is much less than which in radial direction. The second is grinding marks along the radial direction in the work spindle speed of 155, 157, 159rpm, it is caused of the unmatched parameters. The third is the grinding points are distributed relatively equally without apparent grinding marks in the work spindle speed of 156 and 158rpm.

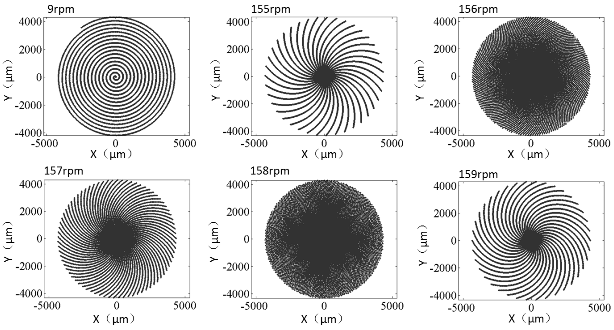

Figure.1 Grinding marks in different parameters

4. Experiments and results

In order to investigate which kind of grinding marks is better for surface quality, the precision grinding experiments of spherical surface on monocrystal silicon were carried out with parameters as listed in Table.2.

Table 2 Grinding parameters

Feed rate (μm/min)	Wheel speed (rpm)	Work spindle speed (rpm)	Depth of cut (μm)	Convex spherical surface radius	Arc-shaped Diamond Wheel
40	6045	9,157,158,	2	25mm	D3

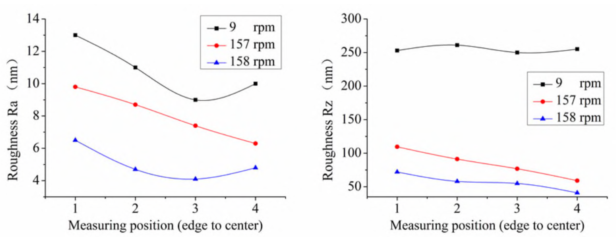

Figure.2 Roughness in different parameters

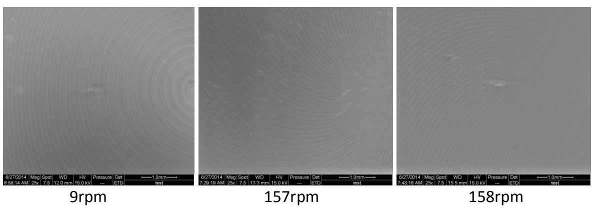

Figure.3 SEM photos in different parameters

Figure.2 shows the roughness of surface (Ra and Rz) ground in different parameters. As shown in Figure.2, the roughness of surface (Ra and Rz) obtained by work spindle of 158rpm are smaller than the other two parameters. Therefore, the distribution of grinding points without apparent grinding marks is better for surface quality.

Figure.3 shows the SEM photos of surface ground in different parameters. As shown in Figure.3, the surface profiles with grinding marks agree with the simulation analysis in Section 2.

Above all, the apparent grinding marks on workpiece surface may reduce the surface quality, and increase the workload of subsequent polishing for optical component. Therefore, the matching parameters should be chosen to avoid apparent grinding marks on workpiece surface.

5. Discussion

According to analysing the distribution of grinding points, the apparent grinding marks both along circumferential direction and radial direction were caused of the small distance between two neighbouring grinding points in each direction, while the distance is greater in its vertical direction. Therefore, the comparison of distances can be used to investigate the distribution of grinding points is relatively equal or not.

An arbitrary grinding point is chosen as the research object, the distance between it and the nearest grinding point is defined as d_{01}, the distance between it and the second nearest grinding point is defined as d_{02}, and the distance between it and the third nearest grinding point is defined as d_{03}. If the apparent grinding marks have been formed, the chosen point, the second nearest grinding point and the third nearest grinding point are in a straight line approximately, and the distance between two neighbouring grinding points is nearly equal. Therefore, the discriminating standard of apparent grinding marks can be expressed as:

$$\triangle d = (d_{03} - d_{01}) / d_{01} \approx 1 \qquad (6)$$

And the discriminating standard of relatively equal distribution of grinding points can be expressed as:

$$\triangle d = (d_{03} - d_{01}) / d_{01} < 1 \qquad (7)$$

Based on the Eq.(6) and Eq.(7), the distribution of grinding points with parameters simulated in section 2 are judged and listed in Table.3. As shown in Table.3, the judgement results agree well with the simulation. In apparent marks, $0.98<\triangle d<1$. In homogeneous distribution of grinding points, $0<\triangle d<0.6$.

Table 3 Judgement results

Work spindle speed	$\triangle d$	Apparent marks ?	Work spindle speed	$\triangle d$	Apparent marks ?
9	0.9999	yes	157	0.9964	yes
155	0.9985	yes	158	0.1596	no
156	0.5161	no	159	0.9971	yes

6. Conclusion

Through the distribution simulation of grinding points, the apparent grinding marks may be generated by some parameters, and the experiment results shows surface with apparent grinding marks may reduce surface quality. In order to choose the matching parameters without apparent grinding marks, the parameter matching criterion was proposed.

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