Study on the Influence of Hemispherical Dome Thickness on Aerodynamic Thermal Radiation

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Abstract. Aspheric optical lens is a key optical component used in infrared optical system for transmission, refraction and incident light. The application prospect in the field of modern national defense science and technology and civil industrial products is promising. At the same time, a large number of aspheric infrared optical lenses are used. The processing precision and machining materials of aspheric infrared optical lens are proposed. The surface quality and precision are higher and higher. To ensure the accuracy of the surface profile of the aspheric infrared optical lens. In the grinding process, the grinding wheel center should be aligned as far as possible with the axisymmetric turning center of the rotary surface part. There are many cutting edges on the surface of the grinding wheel in the grinding process. It is often difficult to determine the precise position of the grinding point for a knife. The inaccuracy of the knife will result in the error of the knife. It is a difficult problem to make the precision of the knife in the aspheric grinding process. To improve the accuracy of the knife, in this paper, the influence of X-axis on the surface profile accuracy of aspheric surface infrared optical lens is analysed. This paper proposes a method to compensate the error of the knife caused by the axis of the X-axis. The accuracy of surface profile of aspheric surface infrared optical lens is improved. The results show that the error of X-axis is corrected by polka dot method. The surface profile accuracy of the aspheric surface infrared optical lens was 382nm before the adjustment. The surface profile accuracy of the aspheric surface infrared optical lens is 145nm after the adjustment of the knife. It has obviously improved.

1. Introduction
In recent years, the demand for aspheric infrared optical lenses is increasing. At the same time, the processing precision and machining materials of aspheric infrared optical lens are presented with new requirements. In this context, this paper starts with the application of industrial application. The monocrystalline silicon with a diameter of 20mm and a thickness of 10mm was studied. The aspheric surface infrared optical lens is experimentally studied with grinding technology. To ensure the accuracy of the surface profile of the aspheric infrared optical lens. In the grinding process, the grinding wheel center should be aligned as far as possible with the axisymmetric turning center of the rotary surface part. In this paper, the error analysis of the knife during the grinding process of aspheric surface infrared optical lens is analyzed and the compensation is made to improve the grinding process.
At present, the knife method is mainly used for the acoustic emission method, the main shaft power method, the test grinding method and the trigger method. There are many cutting edges on the surface of grinding wheel during grinding. It is often difficult to determine the precise position of the grinding point for a knife. The inaccuracy of the knife will result in the error of the knife, how to be more accurate in the grinding process of the knife is a difficult problem.

Using the vertical grinding method, the aspheric infrared optical lens is ground. In the case of a knife error. The axis of the circular arc of the end section of the grinding wheel is combined with the axis z axis of the aspheric surface. The circular arc formed by the grinding point of grinding wheel is tangent to the aspheric curve. Because of the existence of the knife error. In the xz plane, the center axis of the grinding wheel often deviates from the axis of symmetry of the aspheric surface. That's the error in the x direction. Deviation distance for Δx as shown in figure 1.

![Figure 1. Grinding wheel to knife error](image)

**Figure 1.** Grinding wheel to knife error

**Figure 2.** Influence of x direction on the precision of machining shape

### 2. The X-axis's mathematical model of knife error establish in grinding process

Set of cutter error value of the x axis Δx, when Δx > 0 for grinding wheel movement had a lens center axis; Δx < 0 for grinding wheel movement through the lens center axis. The contour trajectory of the aspheric infrared optical lens in the xz plane is designed to be a circle of radius R. The diameter of the aspheric infrared optical lens is D and radius of the grinding wheel is Rs. The curve of contour error is the error curve obtained by subtracting the actual aspheric curve from the ideal aspheric curve. Take the convex lens as an example, the ideal track of the aspheric infrared optical lens, the grinding wheel is grinding into the center by the right end of the lens. When there is no X-axis to the knife error, the center axis of the grinding wheel coincides with the axis z of the lens center. The ideal contour trajectory of the xz plane can be expressed as:

\[
y = \sqrt{R^2 - x^2} \quad \left(-\frac{1}{2}D < x < \frac{1}{2}D\right)
\]

(1)

In the processing of aspheric infrared optical lens, If the x axis to the error Δx knife, when Δx > 0, called a centerline of cutter error, Distances from the center of the lens in Δx axis location stop grinding wheel. Aspheric center area near Δx radius is not normal grinding. However, the grinding wheel has a radius Rs, and the cutting depth is also produced in the area that is not normally grinded, and the cutting depth is related to the grinding wheel radius Rs. The grinding trajectory of the edge of the lens and the center axis of the lens will be deviated from the ideal trajectory. The track and depth of the grinding wheel will change. Grinding wheel of cutter offset Δx distance, namely the actual grinding trajectory arc corresponds to circle the center offset Δx distance, lens diameter D is the same, actual grinding trajectories have changed in whole. The influence of the knife error on the surface profile accuracy of the lens is shown in figure 2 (a). When Δx < 0 grinding wheel movement is called a lens center shaft, actual infrared optical aspheric lens grinding path corresponds to circle the center a central axis z axis Δx distance. Grinding wheel movement has been near axis cause lens center axis Δ
radius are two grinding x scope. When the grinding track of the lens changes, the grinding depth will increase. The influence of the center axis on the precision of the surface profile is shown in figure 2 (b).

2.1. The X-axis does not cross the central axis of the lens mathematical model of error curve is established

Due to the symmetry of the aspheric infrared optical lens, the mathematical model of the actual trajectory of the grinding process can be programmed only on the x axis. The X-axis is a negative semi-axis grinding track, and the axisymmetric curve can be drawn with x=0 as the axis of symmetry. The actual grinding trajectory of x axis is divided into two parts. Curve of the highest point x = 0 to x = x Δ part and X = Δ x to lens edges, grinding the actual track y is:

\[
\begin{align*}
    y &= \sqrt{R^2 - (x - \Delta x)^2} & (0 < x < \Delta x) \\
    y &= \sqrt{R^2 - (x - \Delta x)^2} & (x > \Delta x)
\end{align*}
\]

(2)

When D=2R, the grinding track image is shown in figure 3.

![Figure 3. Grinding track of the grinding wheel without the central axis of the lens](image1)
![Figure 4. Grinding error curve of grinding wheel without the center axis of the lens](image2)
![Figure 5. p and q change with Δ x curve at two points](image3)

The curve of contour error is the error curve obtained by subtracting the actual aspheric curve from the ideal aspheric curve. The error curve was obtained by using MATLAB software, as shown in figure 4.

When -30<x<-25, the error value increases sharply from 0 to the maximum of the error. The effective grinding range of workpiece selection cannot be too large. It must avoid the area of maximum error. The smaller the effective part, the smaller the error. Because of the actual machining, the X-axis has very little error. The scope of the sharp increase in error is small and negligible.

When the x axis of cutter error Δ x > 0, grinding wheel movement has not passed the central axis of the lens. With the change of the error Δ x corresponding value against the knife, the actual grinding trajectory and error curve will change accordingly. In order to find out the variation of the error curve in the grinding process and the influence of the knife error on the surface profile accuracy of the aspheric optical lens. The two special points on the error curve are observation points as shown in figure 5. X=0 error curve corresponding points p and x=Δ x error curve corresponding points q. Using MATLAB to calculate different error against the knife Δ x, the value of p, q two corresponding, observe change as Δ x p, q value of the two axes in the changes, can be reflected in the workpiece diameter D phase. The Δ x knife error increase, the greater the value of p and q, the surface profile accuracy of workpiece is lower. The smaller the p and q, the higher the surface profile accuracy. The accuracy of the surface profile of the aspheric surface infrared optical lens can be improved by reducing the X-axis.

2.2. The X-axis cross the central axis of the lens mathematical model of error curve is established

The motion trajectories of aspheric infrared optical lens and grinding method are symmetrical. Therefore, in establishing the mathematical model, we also need to analyze the x positive semi-axis...
trajectory, and the X-axis is the symmetric curve with the z-axis as the axis of symmetry. When the knife error is over the central axis, the actual trajectory equation of grinding is \( y = \sqrt{R^2 - (x + \Delta x)^2} \) \((x > 0)\). When \( D=2R \), the trajectory diagram is shown in figure 6.

\[
y = \sqrt{R^2 - (x + \Delta x)^2} \quad (x > 0)
\]

**Figure 6.** Actual grinding trajectory of the grinding wheel through the central axis

**Figure 7.** Grinding error curve of grinding wheel over lens center

The curve of contour error is the error curve obtained by subtracting the actual aspheric curve from the ideal aspheric curve. The error curve was obtained by using MATLAB software, as shown in figure 7.

When the deviation on the x axis knife \( \Delta x < 0 \) through the lens center axis, With the change of the corresponding value of cutter deviation \( \Delta x \), actual grinding trajectory and error curve will change. In order to find out the law of the error curve with the change of error value. We take the error curve \( \Delta x \) error of the corresponding values for the observation point m, as shown in figure 8. Using MATLAB to calculate change with error \( \Delta x \) point m, take \( x=0 \), the error curve corresponds to m. In the case that the diameter D of the workpiece is constant, the error value of the knife increases with the X-axis over the center axis, absolute value of m is getting bigger, the surface profile accuracy of workpiece is lower, conversely, the smaller the absolute value of m points, the higher the accuracy of the surface profile of the work piece [2].

The axial positive deviation of the grinding wheel is the same as that of the axial negative deviation. That is, when the grinding wheel passes the center axis of the lens and the center axis of the lens is not shifted. The absolute value of the residual error of the aspheric surface is the same, but the positive and negative signs are opposite. The residual error of the convex aspheric surface is positive when the grinding wheel has a center axis of the lens. It means that the aspheric infrared optical lens after grinding and the machining allowance can be compensated. When the grinding wheel has the offset of the center axis of the lens. The residual error of the convex aspheric optical lens is negative, which means that the grinding amount exceeds the preset value. Although it can also be compensated for processing, it requires more time to correct and difficult to correct. Therefore, when machining convex aspheric surface, it is necessary to avoid the error of the center axis of the grinding wheel. When the
grinding wheel has not been shifted by the center axis of the lens, it can be compensated for the knife error to obtain the workpiece with higher surface profile precision [3].

3. The center method determines the study of knife error

3.1. Theoretical analysis
The grinding of aspheric surface is characterized by symmetry. We need to analyse the x positive half axis. The workpiece has only one center point, and the actual grinding track produces two circles with a symmetry of x=0. Due to error Δ x knife, result in artifacts area center Δ x radius is not grinding. Analysis of the semi-spherical grinding trajectory of the workpiece with x - positive half axis. Is equal to the ideal trajectory translational Δ x distance to the right, we need to find the two centers of the right and left hemisphere trajectories. Can draw the value of Δ x and compensate. Using MATLAB, the data obtained from the measurement is drawn into a function curve. As a result of the numerical control extra bed for knife error within 0.5 mm, and Δ x location near the center axis inevitably. Therefore, the position of the z axis at the edge of the aspheric infrared optical lens is selected, take the points as dense as possible, remove the point from the highest point of the z-axis at 0.5mm. The circle is fitted to the point and the center of the left and right arc is found, center distance center axis of symmetry is Δ x.

In the actual machining process, it is necessary to pre-process the nc machine tool. The surface profile of the pre-processed workpiece can be detected by on-line detection and the surface location data point and the actual contour curve of the workpiece can be obtained. Use MATLAB to draw into the actual machining path curve function, and the function analysis of the data found grinding wheel for Δ x knife error value. Due to the possibility of eccentric error in the installation of grinding wheel, it is impossible for the center of the circle to be absolutely symmetrical according to the data fitting circle. In order to reduce the data processing error, use MATLAB to find the peak value of the z-axis corresponding to the x value before taking the point. This x value is the central axis of symmetry of the actual trajectory. Use of symmetry axis x numerical correction from the above two center point, accurate grinding wheel of cutter error value of Δ x as shown in figure 9 [4].

![Theoretical data fitting diagram](image1)

![Data graph](image2)

**Figure 9.** Theoretical data fitting diagram

**Figure 10.** Data graph

3.2. Error compensation experiment analysis results
Before the grinding of aspheric surface infrared optical lens, we need to fix the X-axis for the knife error. It is necessary to use specimens for grinding experiments to obtain spherical optical lenses, determine the x axis to the knife error and make compensation. The experiment used single crystal silicon with a diameter of 200mm and 10mm as the material for grinding. The precision of the surface profile of the aspheric surface infrared optical lens is measured by contact measuring instrument.
Output x axis per 0.001mm unit, the coordinates of the non-spherical optical lens corresponding to the Y-axis, and the data analysis of each point coordinate on the aspheric surface is shown in figure 10. Using MATLAB software to analyse the data to obtain the error point.

**Table 1. Grinding parameters**

| Feed speed F (mm/min) | Grinding depth ap (μm) | Grinding wheel radius r (mm) | Grinding wheel speed Ns (r/min) | Work piece speed Nw (r/min) |
|-----------------------|------------------------|-----------------------------|-------------------------------|---------------------------|
| 3                     | 2                      | 40                          | 6000                          | 160                       |

After sorting out the data points, the data obtained by the center method were 267.823mm and 260.223mm respectively. According to the theoretical model, the error value of the two symmetric center distance is 0.300mm. According to the analysis of the error value in the numerical control add bed to adjust. After the adjustment, the same parameter is used to grind the optical lens, and the accuracy of the contour is measured and the accuracy of the contour is compared with that of the pre-adjusted contour, as shown in figure 11. The accuracy of the surface profile of the aspheric surface infrared optical lens was 235nm before the adjustment of the knife, and the accuracy of the surface profile of the aspheric infrared optical lens after the adjustment was 145nm. The surface profile accuracy of the aspheric surface infrared optical lens has been improved obviously before and after adjustment, and the method is feasible to compensate the error [5].

![Figure 11. Measurement results of surface profile accuracy](image)

**4. Conclusion**

Using MATLAB software for grinding trajectory simulation, the effect of the X-axis y axis on the surface profile accuracy of the aspheric surface infrared optical lens is analysed. The center axis of the X-axis is compensated by the center axis and accuracy of surface profile of aspheric surface infrared optical lens is improved. Combined with the grinding experiment, it is concluded that the center method can effectively compensate the X-axis for the error of the knife, so that the surface profile of the aspheric infrared optical lens is more accurate.

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