Error Analysis and New Principle Research of Aspheric NC Forming

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Abstract. Aspherical parts are the hot issues in the field of optics. With the rapid development of science and technology, optical aspherical surface has become an indispensable component in optical system because of its unique structure, the application and development of aspherical surface are restricted by the residual annular ripple error. In this paper, the main causes of the residual toroidal corrugation error on aspheric surface are analyzed in detail, and the causes of toroidal corrugation are demonstrated and analyzed from five key points, a new method of aspherical NC forming is proposed, and the concrete steps of the new principle of aspherical forming are analyzed.

Keywords: Aspheric Surface, Optical System, Band Ripple, NC Forming, Machining Verification

1 Introduction

Today, from the photographic objective of a digital camera to the projection objective of a projection system, from the field of satellite communications to the field of Fiber-optic communication, from the optical system of aerial mapping to the conformal optical system of a missile, from the extreme ultraviolet lithography objective lens [1.2] to the Large Telescope [3] , from the Fig.hter night vision scanning system to the cruise missile guidance system, aspherical optical elements have become their indispensable optical devices. However, in the current feasible aspheric surface processing method, whether it is for large aspheric surface, or small and medium aspheric surface, in its processing process, due to the machining principle, the shape of the machining tool, the feed direction of the machining tool and the relative position of the machining tool and the workpiece, the formed aspheric surface will remain the ring ripple of different frequencies [4-6] , therefore, the application and development of aspheric surface are limited by the current aspheric machining methods.

2 Error Analysis of Aspheric Forming

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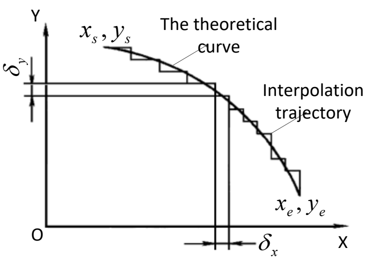
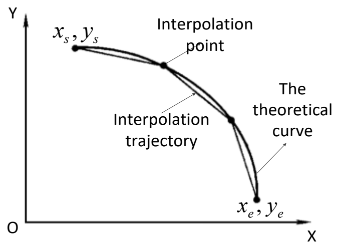
During the processing of aspheric optical parts, whether it is rough grinding, fine grinding or polishing forming, there will be ring-band ripples with different frequencies on the surface of the workpiece, for example: small grinding head polishing formation of the surface of the workpiece easy to produce high-frequency ripples, ultra-precision turning or grinding is also easy to produce high-frequency ripples on the surface of the workpiece [7] , however, if the stress plate is polished, it is easy to produce if ripple on the surface of the workpiece. The toroidal corrugation on the surface of the workpiece is the most important problem in aspheric forming, the main causes of this problem include the following five points: 1) ring-band error caused by forming control principle; 2) ring-band error caused by the shape of machining tool; 3) ring-band error caused by the relative position of machining tool and workpiece; 4) ring-band error caused by the feed direction of machining tool; 5) ring-band error caused by physical factors.

2.1 Ring band Error is Produced by Forming Control Principle

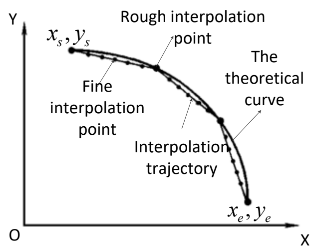
At present, in the process of NC turning, grinding and polishing, the control methods of tool path are mostly pulse increment method, digital sampling method and hybrid interpolation method, as shown in Fig.ure 1, in principle, the above three methods all rely on the tiny broken line segment to approximate the theoretical forming curve. In theory, it is considered that the number of segments is controlled to be infinite or the distance between segments is made to be infinite, however, due to the limitation of the resolution and machining efficiency of the control system, the number of segments of the curve cannot be infinite, the current control principle of aspherical forming can theoretically make the residual corrugation error on the machined surface inevitable. Fig.ure 2 shows the pulse incremental interpolation method and data sampling of the forming trajectory diagram, Fig.ure 3 shows the ultra-precision turning forming of the workpiece surface ripple example.



a. Principle of pulse incremental interpolation

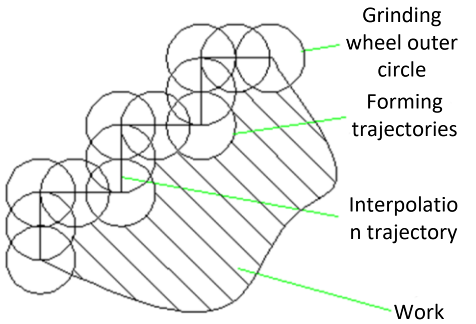


b. the principle of data sampling interpolation

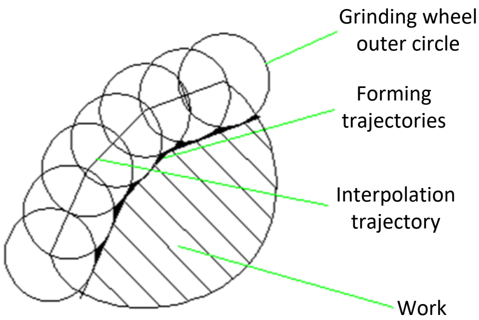


c. the principle of hybrid interpolation

Fig. 1. The traditional interpolation principle of NC machine tool



a.Pulse Incremental interpolation



b.Data sampling interpolation

Fig. 2. The forming track diagram of traditional interpolation principle

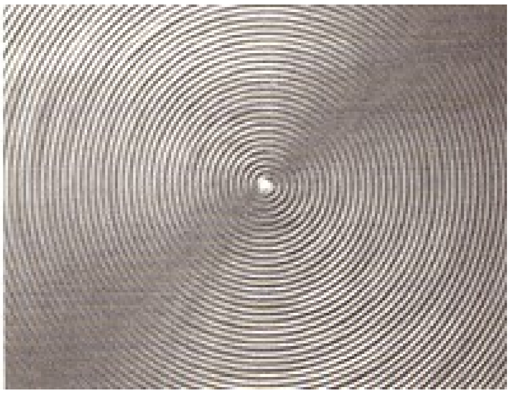


Fig. 3. Example of workpiece surface formed by ultra-precision turning

2.2 The Shape of the Machining Tool Produces a Band Error

In the JIS standard, turning Surface roughness is defined as shown in Fig.ure 4[8], and the theoretical roughness value Ry for turning a workpiece surface can be given by formula (1) .

$$R_Y = f^2 /(8R \times 10^3) \tag{1}$$

In formula (1): Ry is the theoretical surface roughness value of turning workpiece in µm, r is the arc radius of turning tool tip in mm, and F is the cutting amount in mm/rev.

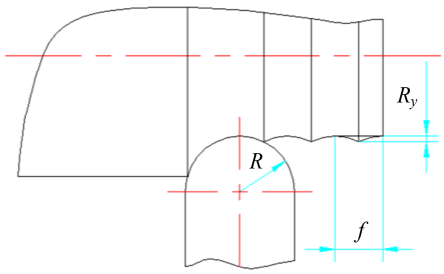


Fig. 4. Diagram of the definition of turning Surface roughness

Formula (1) can be explained: in order to obtain a non-wavy turning surface, either R is infinite, or F is infinitely small, otherwise there will always be obvious ring ripples, the value of ripple depends on the feed f and the tip radius R. Similarly, similar problems exist in grinding and polishing processes, and Fig.. 5 shows a schematic diagram of the ripples formed on the workpiece surface by the milling cutter feed face arc [9].

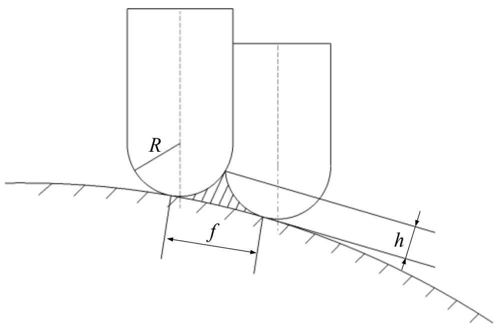


Fig. 5. Milling cutter feed formation ring ripple

2.3 The Relative Position of the Machining Tool and the Workpiece Produces a Band Error

At present, in the forming process of aspherical surface, the commonly used position setting method between workpiece and cutter is shown in Fig.ure 6 and Fig.ure 7, the setting method of this position can also cause the error of the band Ripple of the residual tool movement on the workpiece surface.

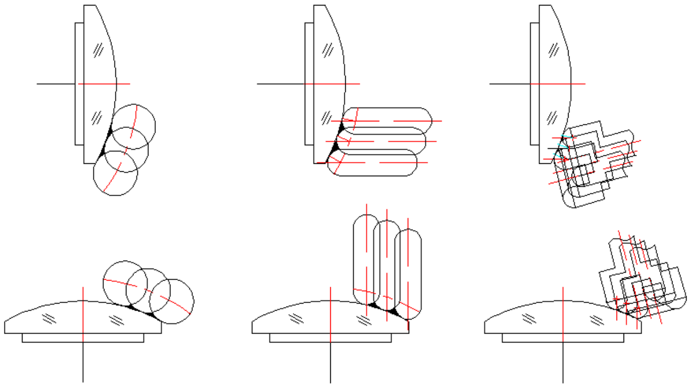


Fig. 6. Position of workpiece and grinding wheel when machining convex aspheric surface

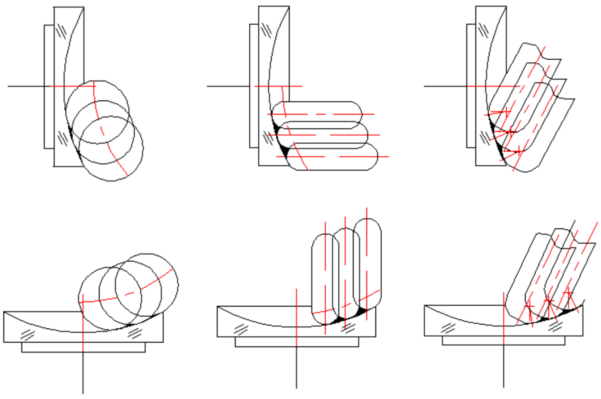


Fig. 7. Position of workpiece and grinding wheel when machining concave aspheric surface

2.4 The Feed Direction of the Machining Tool Produces a Ring-band Error

When a tool is machined to form a workpiece surface in a grinding manner, there is no annular ripple error when the tool feed direction is perpendicular to the grinding direction, as shown in Fig.ure 8[10] ; conversely, when the tool feed direction is parallel to the grinding direction, there must be obvious strip ripple error, as shown in Fig.ure 9.

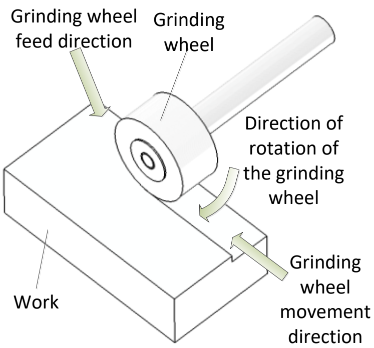


Fig. 8. Direction of feed without ripple

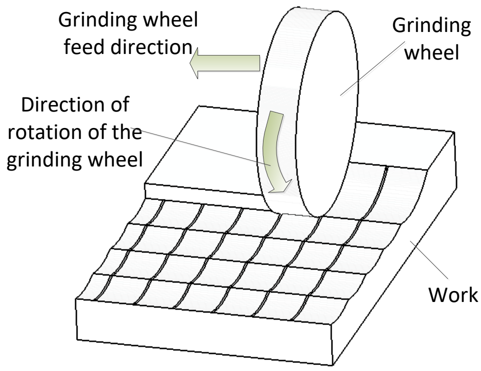


Fig. 9. The direction of feed to form the ripple

2.5 Ring Band Error Due to Physical Factors

In the process of aspherical surface machining, some physical factors also produce the ring ripple error, especially the ring ripple error caused by the vibration of the process system and the uneven rotation of the grinding wheel, Fig.ure 10 shows an example of a band error due to rotational vibration and uneven speed of the grinding wheel.

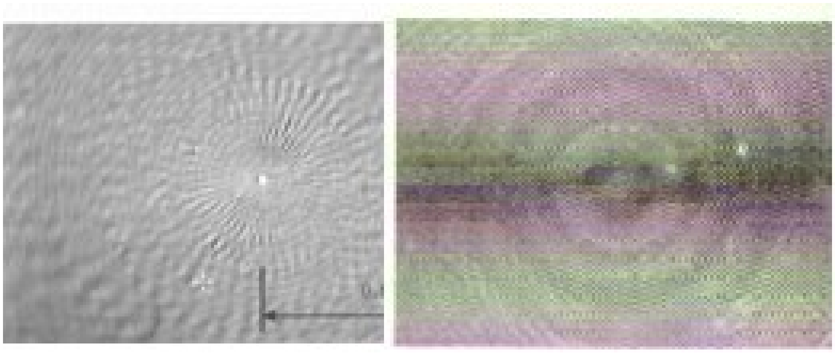


Fig. 10. An example of surface ripple error caused by rotating vibration and uneven rotating speed of grinding wheel

3 New Principles of Processing

In order to obtain a continuously smooth and high-precision aspheric surface without ring ripples, it is necessary to obtain an accurate trajectory curve on which the aspheric parts can be formed. With the accurate trajectory curve, combined with the reasonable tool movement and the control of related physical factors, the error of the corrugated band can be effectively reduced or eliminated.

In view of the problems existing in the current numerical control machining of aspheric surface parts, a new machining principle is put forward in the laboratory, that is, the tangent numerical control forming principle, this principle can effectively solve the problem of ring-band ripple residue in the current numerical control aspheric machining technology.

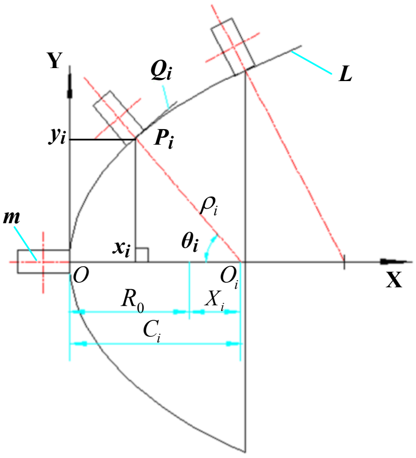


Fig. 11. Schematic diagram of aspheric surface machining principle

In the whole process of machining, if the grinding wheel moves laterally and longitudinally along the forming track, it can keep the grinding wheel tangent to the workpiece node all the time If the motion trajectories of adjacent nodes are approximately a continuous smooth curve approximating the ideal trajectories, the aspheric surface can be formed by tangent method, and the whole forming trajectory obtained will be accurate, continuous, smooth, no theoretical ripple error curve.

The forming principle can obtain accurate, continuous and smooth trace curves, the reasons are as follows:

1) The end face straight line or circular arc of the grinding wheel is always tangent to the tangent of every point on the given curve, so this forming method is called tangent method;

2) The axis of the workpiece and the grinding wheel is coplanar in the horizontal plane, and the direction of the grinding wheel feed and the direction of the grinding wheel rotation are perpendicular to each other, so the ring belt error caused by the setting of the feed direction and position of the workpiece and the cutter can be avoided.

The principle of tangent numerical control forming aspheric surface is applicable not only to aspheric surface machining, but also to spherical surface machining. The application and popularization of the machining principle can effectively improve the machining accuracy and efficiency of aspheric optical parts, and reduce the machining cost.

4 Process Validation Analysis

Fig.ure 12 shows the aspheric parts processed according to the new principle of aspheric numerical control forming at the end of the project. Fig.ure 13 shows the inspection data of the aspheric parts, which can be seen from Fig.ure 13, without error compensation, the precision of aspherical surface is 14.1300 μm and the Surface roughness is 3.3302 μm, which has reached the actual requirement of aspherical surface close machining, and the problem of annular ripple on aspheric surface is solved effectively.

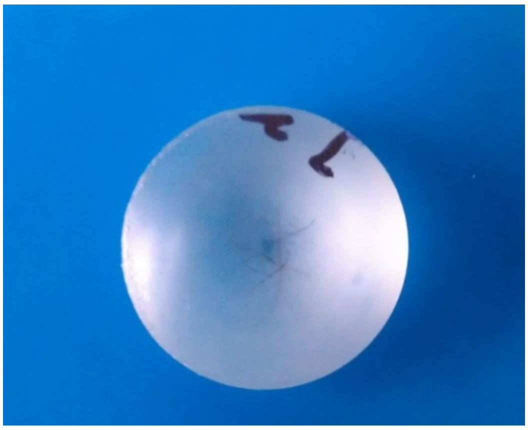
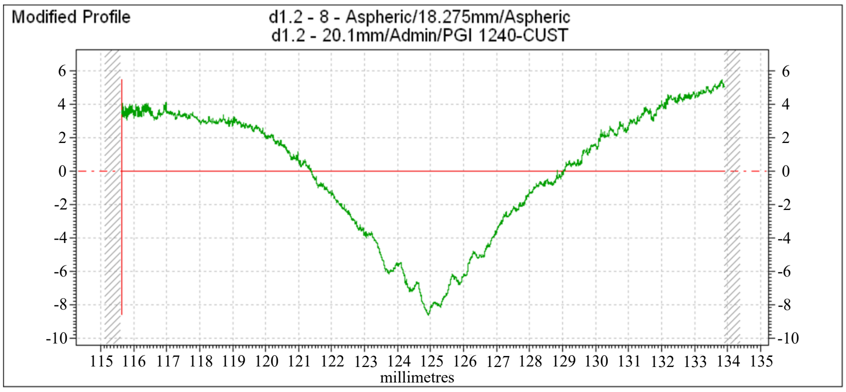


Fig. 12. Machining parts



Rt 14. 1300 µm		
Ra 3. 3302 µm		

Fig. 13. The inspection data of part surface

5 Summary

(1) The application range of aspherical optical elements in optical systems is analyzed in depth, and the problem of"Ring-band ripple", which is the main factor restricting the rapid development of aspherical optical elements, is put forward.

(2) The problem of residual ring ripple on aspherical surface after machining is analyzed in detail, and five factors causing residual ring ripple on aspherical surface after machining are summarized, the correctness of the analysis is proved by mathematical theory and illustration.

(3) The new principle of aspheric NC forming is put forward, and the concrete process of the new principle is given.

(4) The validity of the study is verified by the actual machining of aspheric optical elements, and the processing principle can effectively solve the residual ring ripple on aspheric surface.

Acknowledgments

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