Journal of Manufacturing Science and Mechanical Engineering
ISSN:2959-989X

RESEARCH ON INTEGRATED METHOD OF ULTRA-PRECISION MACHINING AND MEASUREMENT OF CONTACT LENS MOLD

Zhang Li[1,*], Jinze Bao [2]
[1]Xi'an University of Finance and Economics, 710100, China;
[2] Chongqing Jiaotong University, 400000, China.

Abstract: According to the ultra-precision machining principle and high-precision requirements of contact lens molds, the main factors affecting the quality and efficiency of mold machining were comprehensively analyzed. The analysis and machining tests proved that the tool setting error in the horizontal direction is the most critical factor. Using the Nanotech 250 UPL machine tool as the processing equipment, combined with the precise detection principle of the Zygo profiler, a calculation model based on the detection data was constructed for the tool setting error in the horizontal direction. Through processing experiments on corresponding molds of different contact lens models and sizes, it has been proved that the mathematical model can quickly and accurately express and correct small tool setting errors, thereby effectively integrating ultra-precision machining and testing of contact lens molds, greatly improving The ultra-precision machining quality and production efficiency of the mold are improved.
Key words: Contact lens mold;Ultra-precision machining;Tool setting error;Precision inspection;Ultra-precision production efficiency

1. INTRODUCTION

Contact lenses are lenses worn on the cornea of the eye to correct vision or protect the eyes. It not only gives Pei the appearance and convenience.
The wearer has brought great improvement, and also played a special role in controlling various vision defects [1-2]. At present, there are about 150 million contact lens wearers in the world, with a wide variety of lenses and a huge amount [3].
At present, the production methods of contact lenses are mainly divided into three categories: centrifugal molding method, compression molding method and turning molding method.
Its high processing efficiency, low cost and good wearing comfort are the most widely used, and most of the current contact lenses are produced through the molding process [4] .
The compression molding method is a large-scale combined batch production method that uses ultra-precision machining technology to manufacture molds, and then precision injection molding [4-5], as shown in Figure 1. In this method, the metal mold (mold) ofUltra-precision processing and testing are the technical key to realize the precision production and manufacturing of lenses.
The key and bottleneck links are also the basic conditions to ensure the final quality of contact lenses, and are crucial in the entire process chain. At the same time, molds have certain timeliness in lens production and are consumables that require multiple models and mass production. Therefore, it is very urgent and necessary in the industry to study an efficient integrated method for ultra-precision machining and measurement of contact lens molds.

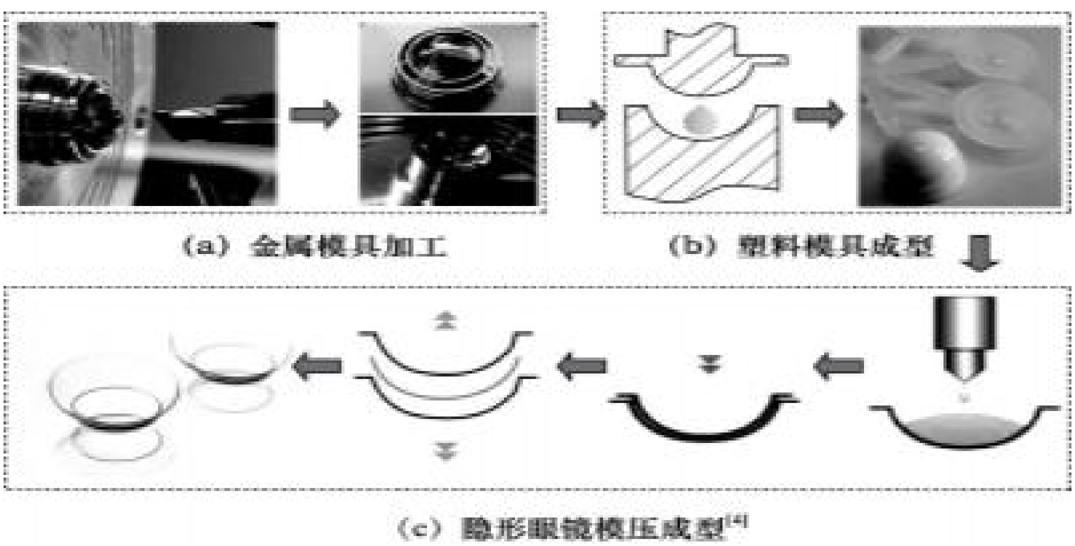

Fig. 1 Molding process roadmap for contact lenses

2. SURFACE CHARACTERISTICS AND HIGH PRECISION REQUIREMENTS OF CONTACT LENS MOLDS

A set of contact lens molds usually consists of a concave mold and a convex mold, which correspond to the inner and outer surfaces of the contact lens respectively, and the materials are mainly non-ferrous metals such as copper and aluminum [7]. Taking the punch as an example, its visual function area is usually composed of smooth

The transitional multi-segment arcs are rotated along the central axis, and different vision conditions correspond to different curvatures of the arcs of rotation. This is a common contact lens mold design method.

In the process of processing, deviations in the shape and size of the mold will lead to changes in the functional luminosity of the lens, affecting the wearing effect, and may even cause damage to people's vision in severe cases. Therefore, ensure that the shape and size of the mold processing

Precision and good surface roughness are the key to control the quality of contact lenses [6].

Under normal circumstances, after the mold processing is completed, the shape and size of the mold will be tested by professional optometry instruments, such as the BRASS curvature radius tester of ROTLEX company. 5 μm. Then use white light interferometer, profiler and other instruments to test the surface quality of the mold, requiring Ra ≤ 15 nm. The process of this method is complicated, and the influence of processing factors on the test results has not been established. It can only be adjusted through passive compensation and repeated testing. The efficiency is low and the rejection rate is high.

At present, the existing single-point diamond turning technology can easily meet the quality requirements of the mold surface Ra ≤ 15 nm, which will not be discussed here.

In this paper, according to the shape characteristics and precision requirements of the mold, the main factors affecting the surface quality of the mold are analyzed, and based on the working principle of the testing equipment, a mathematical relationship model between the processing error and the influencing factors is constructed, and the cause of the error is quickly determined by using the testing results And make corrections to provide support for improving the quality and efficiency of mold processing.

3. DESIGN AND ANALYSIS OF ULTRA-PRECISION MACHINING EXPERIMENTS FOR MOLDS

3.1 Ultra-precision Machining Test Conditions

In this paper, the Nanotech 250 UPL ultra-precision single-point diamond lathe produced by Moore Company of the United States is used as the main processing equipment, combined with the high-precision optical surface profiler Zygo-ZeGage, to carry out research on the integrated method of ultra-precision machining and detection of contact lens molds, as shown in Figure 2 shown.

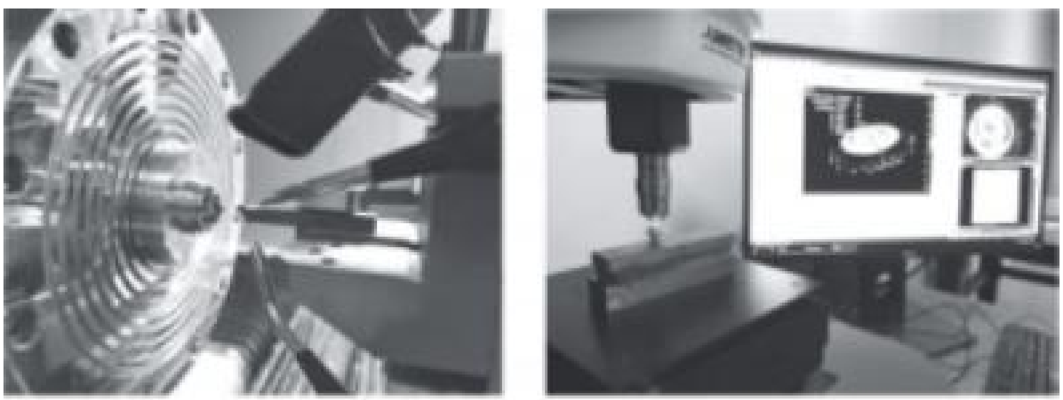

Fig. 2 Processing and detection of metal convex modes

Nanotech 250UPL single-point diamond lathe adopts ultra-precision air-floating spindle and hydrostatic guideway system, which has extremely high motion control accuracy and working stability. Zygo-ZeGage profiler uses non-contact coherent scanning interferometry to image and measure samples. It has a good detection effect on the surface roughness and local surface shape of the workpiece. The main performance parameters of the equipment are shown in Table 1.

Table 1 Main performance parameters of equipment/instruments

Nanotech 250UPL Single Point Diamond Lathe				Zygo-ZeGage Profiler		
Processing range / mm	Linear resolution/ nm Angular resolution/ (°)	Linear positioning accuracy/ nm Rotary positioning accuracy/ (″)	Maximum spindle speed (bidirectional) / (r / min)	Surface topography Refolding/nm	RMS repeatability/nm	optical resolution /μm
Diameter: 300 Length: 200	Linear: 0.01 Angular: 0.000 0001	Linearity: 12.5 Rotation: ±1	10 000	<3.5	0.1	0.52

3.2 Analysis of Influencing Factors of High Mold Machining Precision

Analyzing the ultra-precision turning process of molds, we can know that the motion accuracy of the machine tool, the dimensional accuracy of the tool and the position accuracy of the tool are the three main factors affecting the processing quality.
From the equipment performance parameters in Table 1, it can be seen that the motion control accuracy of the machine tool itself is at the nanometer level in this experiment, and the impact on the mold processing accuracy is completely negligible; Repeated measurements within the radius of the arc ± 2 μm, and such errors are easily eliminated through detection and compensation, so this article does not make a detailed analysis.
Compared with the first two factors, the tool space position is not easy to measure accurately [7-10], including the horizontal distance x between the tool tip and the spindle rotation center and the height difference h in the vertical direction, as shown in Figure 3.

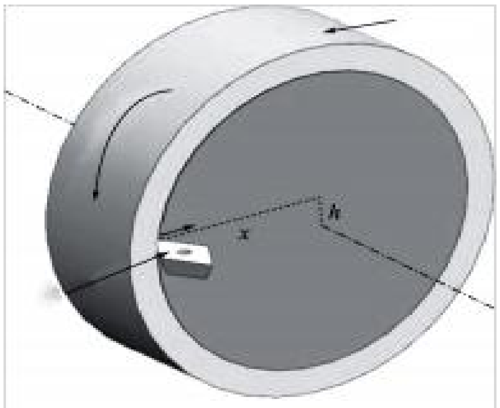

Fig. 3 Position accuracy of the tool

The values of x and h often need to be corrected repeatedly through the process of "multiple trial processing-testing-adjustment" of the tool block, and eventually there will still be micron-level errors that cannot be accurately identified, and this error will directly affect the final shape of the mold Accuracy and test results are the main factors restricting the quality of mold processing. Therefore, this paper focuses on the detection method of the tool position error and its influence on the mold processing accuracy to explore the integrated method of mold ultra-precision machining and detection integration.

3.3 The Influence of Diamond Tool Position Error on Machining Accuracy

The tool setting error in the vertical direction has the low tool nose and the tool. There are two forms of pointed high [11-12]. If the tool nose is too low, a small cylinder will remain in the center of the tool block. The value of the cylinder radius is the height difference h between the cutting edge and the center of rotation; Angle $\alpha 0$, the radius of the bottom of the cone is the distance h between the cutting edge and the center of rotation. With the help of microscopes, profilers and other instruments, the above two situations are easier to identify and can be quickly and accurately ruled out.
Assuming that the horizontal distance between the tool tip and the workpiece rotation center is x, the measured value is x1, the actual value is x2, and the horizontal tool setting error x' = x1-x2.
It can be seen from Figure 4 that when x'>0, the tool tip will cross the center of rotation during machining, and overcut will occur, but it will not affect the surface shape of the machining plane; when x'<0, the tool tip cannot reach the center of rotation, and the center Formation of processing residues[13],
However, because of the large radius of the tool nose arc, when x'<0 and $|x'\approx 0|$, it is difficult to accurately detect the machining residue formed at the center with ordinary microscopes and profilers.
To sum up, the tool setting error h in the vertical direction is easy to identify and eliminate, and the tool setting error x' in the horizontal direction is the main factor affecting the quality of mold processing.
It can be seen from Figure 6 that when x'>0, the tool overcuts, and the radial dimension of the mold is too small; when x'<0, a small machining residue is formed in the center of the mold, and the radial dimension is too large. Both cases will cause deformation at the center of the mold and affect the quality of the lens. Therefore, the development of a method for accurately detecting the x' value is the key to improving the mold processing speed and yield, and is also the core of realizing the integrated method of mold ultra-precision machining and measurement.
As shown in Figure 4, this study uses the Zygo-ZeGage profiler as the main detection instrument, which can output the data of the ball diameter, center height and surface roughness of the inspected area through the method of surface fitting. Therefore, through the research The influence law of x' on the ball diameter detection value, and the mathematical calculation model of x' on the ball diameter detection value r, can quickly determine the value of x' through the test results, so as to make accurate corrections.

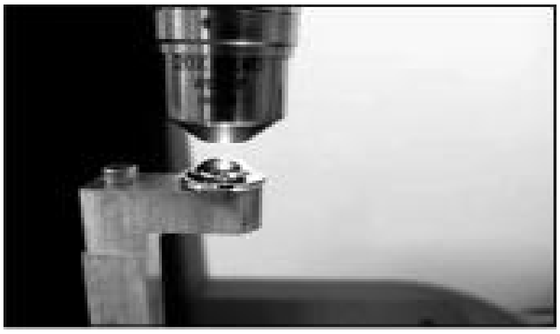

Fig. 4 Mold detection

4. CALCULATION AND ANALYSIS OF HORIZONTAL TOOL SETTING ERROR X'

4.1 Mathematical calculation model of x'

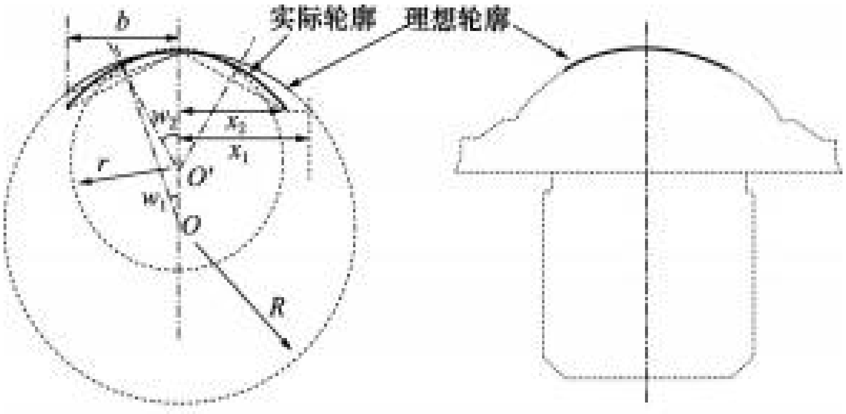

Fig. 5 Bread analysis of the fitted sphere

Taking x'>0, tool overcutting as an example, Figure 5 shows the influence of x' on the detection value of the mold ball diameter. The big circle is the ideal contour, and its radius is R, and the small circle is the actual contour obtained through surface fitting, and its radius is r. In addition, b is the radius value of the actual detection range of the mold in the vertical projection direction, and w1 is the ideal contour 1/4 central angle of , w2 is the 1/4 central angle of the actual contour corresponding to its fitting circle.

Analysis of Figure 8 shows that the horizontal tool setting error is:

$$x' = x1 - x2 \quad (1)$$

$$w1 = 2 \quad \sin\text{-}1 \frac{b}{R} \quad \text{(twenty three)}$$

$$R = \frac{x_1}{2\sin w_1 \times \cos w_1} \quad (4)$$

$$r = \frac{x_2}{2\sin w_2 \times \cos w_2}$$

When the profile of the mold only changes very slightly in the horizontal direction, that is, x' is very small, w1 ≈ w2. but:

$$R - r = \frac{x_1}{2\sin w_1 \times \cos w_1} - \frac{x_2}{2\sin w_2 \times \cos w_2} \approx$$

x1 - x2 = x' (5)

2sinw1 × cosw1 sin-1 $\frac{b}{R}$ sin-1 $\frac{b}{R}$

2 sin 2 × cos 2

Then the horizontal tool setting error is

$$x' = 2(R - r)\sin\frac{\sin^{-1}\frac{b}{R}}{2} \times \cos\frac{\sin^{-1}\frac{b}{R}}{2}$$

It can be seen that the horizontal tool setting error x' can be calculated by using the detected ball diameter r, standard ball diameter R and detection range radius b. When r<R, x'>0, the tool overcuts; when r>R, x'<0, there is machining residue in the center of the workpiece.

In the actual detection process, the detection method of large ball diameter and small area is usually used. The value of w1 in Fig. 8 is very small, and the value of w1 in formula (5)
2sinw1 × cosw1 = sin2w1 < 1
Therefore: R -r > x'
That is, the difference between the standard spherical diameter R of the inspected workpiece and the detected spherical diameter r is the magnified embodiment of the horizontal tool setting error x', which is easier to detect, and the derived x' is also more accurate.

4.2 Ultra-Precision Machining of Calculation Model - Detection Integration Verification

Select 0°, 550°, and 900° myopia lens molds as processing and testing objects, use Zygo's 20x optical lens, and set the radius value b of the vertical projection direction of the detection range to 0.8mm through image stitching .
It is known that the ideal curvature radii of the center arcs of the above three molds are 7.63 mm, 8.55 mm, and 9.42 mm respectively, and the mathematical model obtained in the previous section is used as a guide for processing and inspection tests to verify The correctness of the model, the results are shown in Table 2.

Table 2 Test results

serial number	1		2		3	
Ideal spherical diameter R / μm	7 630		8 550		9 420	
x' adjustment formula / μm	x'=0.105×(R-r)		x'=0.094×(R-r)		x'=0.085×(R-r)	
r initial value/μm	7 663	7 678	8 495	8 520	9 444	9 428
x'adjustment/μm	-3.5	-5	+5.2	+2.8	-1.9	-0.6
Corrected r-value/μm	7 632.4	7 631.8	8 551.7	8 553.2	9 420.8	9 424.1
Corrected accuracy/μm	2.4	1.8	1.7	3.2	0.8	4.1

From the results in Table 2, it can be seen that using this model, combined with the Zygo round
The precision detection function of the profiler can display the horizontal tool setting error x' by nearly 10 times through the (R-r) value, providing support for more accurate determination of the tool position. Using this mathematical model, the tool setting error can be corrected quickly and accurately, and the ultra-precision machining and detection of the contact lens mold can be effectively combined to obtain a stable and reliable ideal product, as shown in Figure 6.

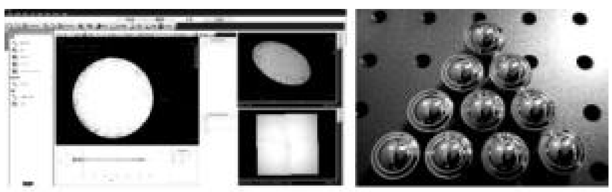

Fig. 6 Efficient, stable and controllable ultra-precision machining production of a type of mold

5. CONCLUSION

(1) In this paper, the wavelet energy step point analysis method is introduced into the research of signal decoupling of rough surface topography.
A new simulation method is proposed.
(2) Through the wavelet multi-scale decomposition of the measured plane milling surface topography signal and the wavelet energy analysis of the layered signal, the stripping of the main components in the complex topography signal is realized. And the information of high-frequency band and low-frequency band is reconstructed into a digital combination model, combined with the theoretical shape obtained by milling cutter parameters and processing parameters, and finally realizes the rough surface milling of plane milling
Shape simulation.
(3) The relative roughness parameters of the actual surface milling surface and the simulated surface are compared and analyzed. The comparison results show that the relative error between the simulated topography obtained by the method in this paper and the surface roughness parameters of the actual topography is small, which further verifies the feasibility and correctness of the method in this paper.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose

REFERENCES

[1] Bhushan B. Introduction to tribology. 2nd ed. New York : John Wiley & Sons, Inc. , 2013.

[2] An Qi, Suo Shuangfu, Lin Fuyan. Feature decoupling and shape simulation of turning rough surface.Chinese Journal of Mechanical Engineering, 2019, 55 (23): 200-209.
[3] Hu Songtao, Huang Weifeng, Shi Xi. Mechanical Seal Based on Double Gauss Layered Surface Theory Research overview. Chinese Journal of Mechanical Engineering, 2019, 55 (1): 103-117.
[4] Wu JJ. Simulation of rough surfaces with FFT. Tribology International, 2000, 33 (1): 47-58.
[5] Wang Y, Ying L, Zhang G. A simulation method for non-Gaussian rough surfaces using FFT and translation process theory . Journal of Tribology, 2018, 140 (2): 021403.
[6] Choudhury SK, Bajpai JB. Investigation in orthogonal turn-milling to-wards better surface finis． Journal of Materials Processing Technology, 2005, 170 (3): 487-493.
[7] Xu Anping, Qu Yunxia, Duan Guolin. Surface topography simulation algorithm for peripheral milling based on workpiece mesh division. Journal of Xi'an Jiaotong University, 2001, 1 (5): 502-505.
[8] Liu Wenjuan. Theoretical modeling and simulation analysis of milling surface three-dimensional topography. Beijing: North China University of Technology, 2009.
[9] Liu Mingcai. Wavelet analysis and its application. 2 editions. Beijing: Tsinghua University Press, 2013.
[10] Zhao Bin. Characterization of functional parameters of surface roughness of guide rail and its influence on friction characteristics. Jinan: Shandong University, 2017.