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Effect of turning parameters on surface quality of ultra-precision machining of progressive multifocal lens

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Abstract

Progressive multifocal lens is a typical optical free-form surface element. Compared with the traditional spherical lens, the diopter of the far-view area and the near-view area of the progressive multifocal lens are different, and the diopter gradually changes smoothly in the intermediate transition area. The wearer can continuously and clearly see objects at different distances. However, due to the complex surface structure of the progressive multifocal lens, the machining cost is high, so its application is limited. In this study, a new machining method named single-point diamond ultra-precision turning technology based on fast tool servo (FTS) is proposed, which can achieve the fabrication of progressive multifocal lens with high finished surface quality and low manufacturing cost. In this paper, the three-dimensional geometric model of progressive multifocal lens surface is converted into equidistant spiral line according to the principle of turning non-rotational symmetric curved surface. In addition, the effect of spindle speed, feed rate and cutting depth on the finished surface quality of the progressive multifocal lens are investigated. The experimental results show that the proposed method is feasible for the sustainable and high-efficiency fabrication of progressive multifocal lens.

Keywords: Progressive multifocal lens; surface quality; ultra-precision machining; turning parameters

1. Introduction

Optical free-form surface elements can not only realize some special optical functions, but also effectively reduce the volume and weight of optical system and greatly improve the imaging quality. Currently, it have been widely used in various frontier fields and daily life. Progressive multifocal lens is a typical optical free-form surface element. The wearer can continuously and clearly see objects at different distances. However, due to the complex surface structure of the progressive multifocal lens, the machining cost is high, so its application is limited. Single-point diamond ultra-precision turning technology based on fast tool servo (FTS) can achieve the fabrication of progressive multifocal lens with high finished surface quality and low manufacturing cost. This paper attempts to study the effect of spindle speed, feed rate and cutting depth on the finished surface quality of the lens for improving the surface quality of the machined lens based on the optimized processing parameters.

2. Material and methods

2.1. The turning principle and trajectory planning

Progressive multifocal lens has different diopters in the far and near vision areas, and is smoothly connected in the intermediate transition area [1]. The functional areas distribution are shown in Figure 1.

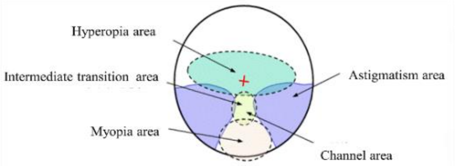

Figure 1. Illustration of the progressive multifocal lens

Progressive multifocal lens has excellent optical properties, is a typical non-rotationally symmetric curved surface, and its fabrication are difficult and expensive with traditional processing methods. With the maturity of ultra-precision machining technology, the single-point diamond ultra-precision turning technology based on FTS device is gradually applied to the fabrication of progressive multifocal lens [2]. The surface shape equation of the progressive multifocal lens is shown in formula (1), where c= -0.005, a_1= 4.957×10^{-5}, a_2= 1.45×10^{-5}, a_3= -1.56×10^{-6}, a_4= -2.3625×10^{-8}, a_5= 4.05×10^{-9} [3].

$$z=\frac{c\left(x^2+y^2\right)}{1+\sqrt{1-c\left(x^2+y^2\right)}}+a_1x^2y \qquad (1)$$
$$+a_2y^3+a_3x^3y+a_4x^2y^3+a_5x^5$$

The three-dimensional geometric model of the progressive multifocal lens surface drawn in MATLAB is shown in Figure 2.

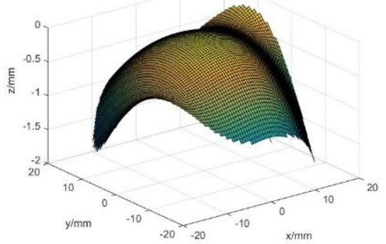

Figure 2. Three-dimensional model of progressive multifocal lens

2.2. Experimental setup

The experimental setup of the turning experiment was shown in Fig. 3. A home-made precision machine tool was used, and it mainly consisted of two horizontal hydrostatic sideways and an aerostatic spindle. The workpiece was affixed to the spindle axis. The FTS was positioned on the z-axis via a high-precision adjustment platform. More details on the machine tool can be found in our previous work [4]. In this study, the working stroke of the FTS device was 8.2 mm, the maximal response frequency was 50 Hz, and the static stiffness was 9.39 N/µm, which meets the machining requirements of progressive multifocal lens. In addition, the SCD tool has a nose radius of 1.0 mm, a rake angle of 0 and a clearance angle of 11. The workpiece material was PMMA with a diameter of 40 mm and a height of 10 mm. Three sets of experiment were set up to study the effect of spindle speed, feed rate, and cutting depth on the finished surface quality. The first set of experiment numbered 1.1 to 1.5 , the second set of experiment numbered 2.1 to 2.5, and the third set of experiment numbered 3.1 to 3.5. The detailed experimental parameters are shown in Table 1. After the completion of turning experiment, a Zygo white-light interferometer (NewView 5000) was used to measure the machined surface. It should be noted that, for each machined workpiece, six testing positions are averagely selected in the radial direction from the center of the lens to the edge.

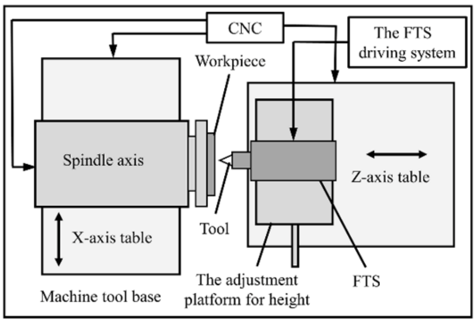

Figure 3. Illustration of experimental setup

Table 1 Experimental parameters

No	n/(r/min)	f/(μm/r)	a_p/μm
1.1	50.0	20	20
1.2	33.3	20	20
1.3	25.0	20	20
1.4	20.0	20	20
1.5	16.7	20	20
2.1	50	10	20
2.2	50	15	20
2.3	50	20	20
2.4	50	25	20
2.5	50	30	20
3.1	50	20	1
3.2	50	20	5
3.3	50	20	10
3.4	50	20	20
3.5	50	20	30

3. Results and discussion

It can be seen from Figure 4(a), the five polylines are on a downward trend as a whole, which indicates that the surface roughness value from the center to the edge gradually decreases. This can be explained that when the spindle speed is constant, as the radius increases, the cutting speed increases. A large cutting speed is conducive to the discharge of chips, and the quality of the machined surface is better. In addition, the five polylines have a large degree of coincidence, which indicates that within the range of experimental data, the spindle speed has little effect on the surface quality of the lens processing. Therefore, in order to improve the processing efficiency, the spindle speed can be appropriately increased. As can be seen from Fig. 4(b), when the values of the feed rates are equal to 15μm/r, 20μm/r, and 25μm/r, the processed lens surface roughness values are all less than 0.1 μm. When the feed rate is in the range of 15 μm/r to 25 μm/r, a progressive multifocal lens with satisfactory finished surface quality can be obtained through ultra-precision cutting technology. When the value of the feed rate is 30 μm/r, the roughness values of the machined surface are greater than 0.1μm, which cannot meet the manufacturing requirements of progressive multifocal lenses. Therefore, the optimal value of the feed rate is 20μm/r. It can be seen from Figure 4(c) that the five polylines are all in a downward trend, indicating that the surface roughness from the center to the edge gradually decreases. This can be explained that when the spindle speed is constant, the cutting speed from the center to the edge is increased. The large cutting speed is conducive to the discharge of chips, so the quality of the machining surface is improved. In addition, the overlap of the five polylines is large, which indicates that the cutting depth has little effect on the surface quality within the experimental data range. In order to improve the manufacturing efficiency, a larger cutting depth can be selected.

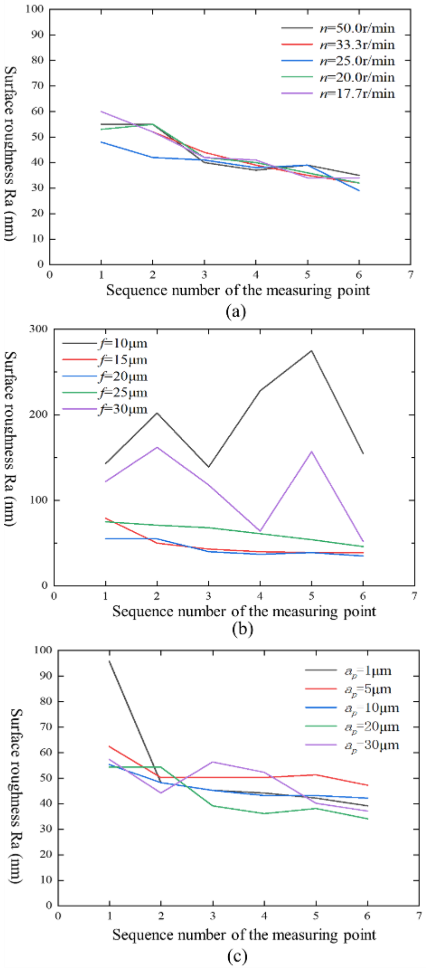

Figure 4. Comparison of surface roughness of machined surface at different machining parameters

4. Conclusions

In this study, a comparative investigation of turning parameters on surface quality of progressive multifocal lens was performed. The experimental results indicate that the sustainable and high-efficiency machining of progressive multifocal lens was achieved by using the single-point diamond ultra-precision turning based on FTS technology.

Acknowledgments

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