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Optimization of polishing parameters in contactless polishing of curved surface

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Abstract

In recent years, the precision and accuracy requirements of optical lenses are higher and more accurate with the rapid development of smartphones and the wearable electronic equipment industry. Ni-P alloy is widely used in the production of aspheric and free-form surfaces molds due to its excellent machinability, but the tool marks formed by ultra-precision turning or grinding will seriously affect the performance of optical components. Recently, Compliant polishing technology has begun to attract the attention of researchers, especially the shear thickening polishing technology. Shear-thickening polishing has the advantages of low cost, good form adaptability and low subsurface damage, and has great application prospects in the field of optical finishing. In this paper, a spherical polishing tool is used to achieve ultra-smooth polishing of Ni-P alloy by setting a certain working gap. The effects of tool speed and working gap on surface roughness are studied. The results show that ultra-smooth surface with a roughness of Sa 0.5 nm was obtained under the working gap of 0.1 mm and tool speed of 5000 rpm. Finally, by designing the tool path, an aspheric Ni-P alloy mold with an aperture of 8 mm was processed. An undamaged smooth surface with a roughness of Sa 0.5 nm was obtained. Surface error caused by non-contact polishing is less than 600 nm.

Keywords: Optical mold; non-contact polishing; nickel-phosphorus alloy; tool mark removal; surface morphology

1. Introduction

In recent years, with the rapid development of the consumer electronic equipment industry represented by smart phones, the precision and accuracy requirements of optical components such as optical lenses have become higher and higher [1].

Due to the form complexity of curved optical elements, researchers have been seeking reliable and efficient ultra-precision polishing methods. For softer materials, traditional methods have failed to achieve good results, and will produce tool marks, scratches and subsurface damage on the surface of the workpiece [2]. Currently commonly used non-contact polishing methods include ion beam polishing, plasma polishing, magnetorheological polishing and shear thickening polishing(STP). But the material removal efficiency is extremely low (60 nm/min), which limits its application in the optical field [3]. Magnetorheological polishing is also one of the non-contact methods. But the equipment is very expensive. Shear-thickening polishing(STP) is a new type of non-contact polishing technology that has attracted more and more attention in recent years. Compared with other contact and non-contact polishing methods, STP has the advantages of low cost and high removal efficiency. Zhu et al. [4] used the rubber ball head to polish the nickel alloy flat workpiece by the method of sub-aperture, and the surface roughness reached 3.9 nm, and pointed out that the STP was better than the airbag polishing. Li et al. [5] polished lithium niobate wafers by adding chemical action to the shear thickening solution, and obtained a smooth surface with Ra 1.46 nm, and the damage layer was less than 5 nm. The above studies have confirmed the great application potential of STP in the optical field. However, the surface quality achieved so far is not good.

In this study, a new type of STP fluid was prepared, the effects of tool speed and working gap on surface roughness of the workpiece were obtained, and the optimal process parameters were obtained. A non-contact polishing method for optical aspheric surfaces was proposed. The optimal parameters were used to finishing the aspheric surfaces of nickel-phosphorus alloy molds, and the surface roughness, material removal rate (MRR)and form accuracy of the aspheric surfaces were evaluated.

2. Method and principle

In this work, the shear thickening effect of non-Newtonian fluid is used to achieve non-contact removal of workpiece material. [6].The workpiece sample in this study is a nickel-phosphorus alloy aspheric form with a diameter of 8 mm, the polishing tool is spherical with a damping pad attached. Before polishing, tilt the polishing tool to 60°, and scan the tool back and forth from the axis to the edge along the diameter of the workpiece. Working gap between tool and workpiece is fixed during polishing process. The feed scan speed is set to 100 mm/min.

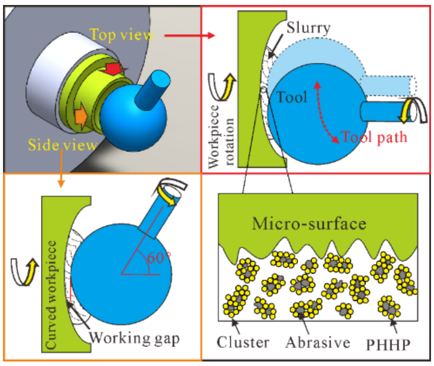

Figure 1. Diagram of the method and principle

3. Experimental equipment and parameters

3.1 Equipment

As shown in Figure 2, this work was carried out on a high-precision CNC grinding machine (QGM3050, ZCS, China). The flat and curved nickel-phosphorus alloy workpieces are mounted on the spindle through a fixture, and the spindle Ⅰ with the polishing tool installed is connected to the Y-axis through an XYZ micro-displacement platform. The polishing slurry is transported to the polishing interface through the supply pipeline. Adjust the distance between the tool and the workpiece by moving the Y axis. Spindle II with polishing tool installed can be adjusted between 100-12000 revolutions. Spindle Ⅰ speed can be adjusted between 0-3000 rpm. The XY axis accuracy is ±2μm.

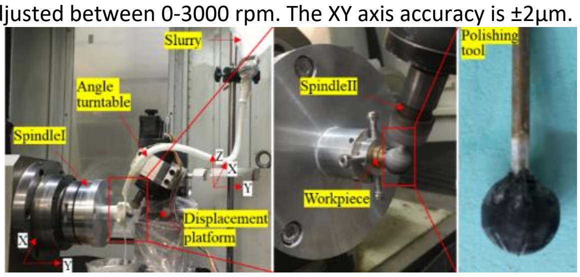

Figure 2. Experimental equipment and tools

3.2 Parameters

In this study, the polishing slurry was prepared by mixing 20 nm silica sol, polyhydroxy polymer and deionized water, the proportion of polyhydroxy polymer is 58 wt%, and the concentration of SiO_2 abrasive particles in the system was 10 wt %. The working gap interval used in the polishing experiments was 0.01–0.3 mm, the tool speed was 2000, 5000 and 8000 rpm, and the workpiece speed was 100 rpm.

4 Results and discussion

4.1 Influence of working gap on surface roughness

Figure 3 indicating that the non-contact polishing process used in the study has a good continuous removal capability.The initial surface roughness (NewView9000, Zygo, USA) of the nickel-phosphorus alloy flat part is 3.2 nm, and the surface roughness tends to decrease with the increase of the working gap.

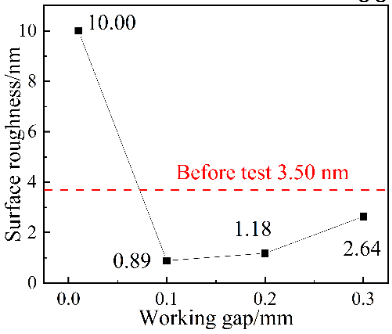

Figure 3. Surface roughness at different working gaps

4.2 Influence of tool speed on surface roughness

Figure 4 shows the three-dimensional topography (NewView9000, Zygo, USA) at different rotational speeds. The results show that a smooth surface with sub-nanometer roughness and no scratches can be achieved at tool speeds of 2000, 5000 and 8000 rpm.

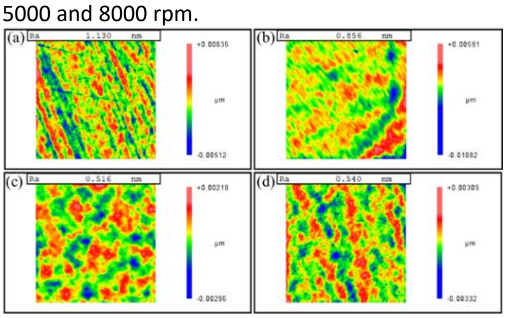

Figure 4. Surface topography of (a) before polishing and (b) 8000rpm, (c) 5000rpm and (d) 2000rpm after polishing

4.3 Aspheric surface polishing test

Based on the previous experiments, the non-contact polishing experiment of aspherical nickel-phosphorus alloy optical surfaces was carried out. It can be seen (Figure 5) that there are obvious tool marks formed by turning on the surface of the workpiece before polishing, and the surface roughness before polishing is between 2.5-3.5 nm. After contact polishing, the tool marks on the surface are removed, and the roughness is the same as before. After non-contact polishing, the tool marks on the workpiece surface are completely removed and the workpiece surface becomes smoother, and the surface roughness after polishing converges to 0.4-0.6 nm. The form (Form TalySurf PGI 840, Taylor Hobson, UK) error due to non-contact polishing is less than 600 nm.

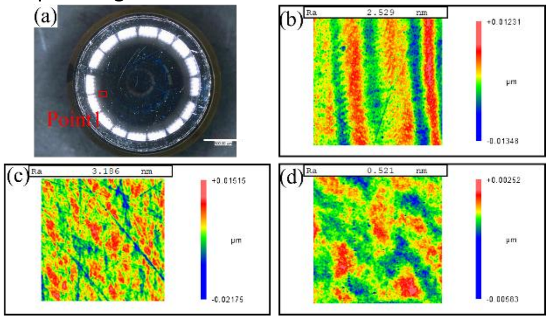

Figure 5. Surface roughness of (a) aspheric surface (b) before polishing, after (c) contact and (d) non-contact polishing

5 Conclusion

In this work, non-contact sub-aperture method is used for ultra-precision polishing of optical aspheric surfaces. The the working gap increases, the surface roughness gradually decreases. The sub-nanometer roughness surface can be obtained under the gap of 0.1-0.3 mm. The tool speed has little effect on the surface quality. When the tool rotation speed is 2000 and 5000 rpm, the obtained surface roughness is about 0.5 nm, and when 8000 rpm, the surface roughness is 0.85 nm. For aspheric optics, sub-nanometer roughness and sub-micron shape accuracy can be obtained by non-contact sub-aperture methods. The surface roughness can reach 0.5nm, and the surface form error is within 600nm. Subsurface damage is an important factor for the performance of optical components. In the future, the formation law of sub-nanometer surface roughness and sub-micron surface accuracy and the formation and evolution law of subsurface damage will be studied.

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