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The study of ultrasonic vibration assisted polishing optical glass lens with ultrasonic atomizing liquid

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ABSTRACT

In this paper, our study is ultrasonic vibration assisted polishing optical glass lens with ultrasonic atomizing liquid. The ultrasonic vibration is applied to the axial direction of the main shaft, which can make abundant grains to impact the workpiece with the high-frequency reciprocating style. And the ultrasonic atomizing liquid is applied to the nozzle in order to make grains more homogeneous and decrease clustering phenomenon, which can improve the surface quality. The material removal rate model of single and multiple grains in the holes and micro-peaks of the polishing head are established by analyzing the removal mechanism of ultrasonic vibration assisted polishing for optical glass lens with ultrasonic atomizing liquid. Several sets of experiments were designed and the optical glass lenses were polished through contrast experiment. The contrast experiment results show that the material removal rate of ultrasonic assisted polishing of optical glass lens with ultrasonic atomizing liquid is better than that of one-dimensional ultrasonic assisted polishing and common polishing. And the surface roughness of ultrasonic vibration assisted polishing with ultrasonic atomizing liquid can reach 2 nm. And the results of experiments can be seen that the removal rate of the material is related to the abrasive grain diameter, the rotational speed and the feed rate of polishing head, and the ultrasonic amplitude. The experimental results are basically consistent with the prediction model.

1. Introduction

In recent years, with the rapid development of cutting-edge technology such as optoelectronic technology, aerospace technology, atomic energy technology and laser technology [1,2], the market demand is increasing, and the performance requirements of optical components are getting higher and higher [3]. The optical glass not only has high transparency, uniformity and stability, but also has high mechanical strength, low expansion coefficient, low density, corrosion resistance and heat insulation, can achieve a variety of optical functions and other advantages [4–6], which is widely used in national defense, aerospace, microelectronics, information, energy, chemical and other fields [7,8]. But the optical glass is also a kind of hard and brittle material, and has many advantages while it has some shortcomings such as high hardness, low toughness, easy to collapse and difficult to process [9–11]. What's worse, the surface quality of optical glass after processing is difficult to meet the requirements. Because the processing quality of the components directly affects the performance of optical system, solving the problem of precise machining of optical glass will greatly promote the application in the field of high technology, and has an important significance to promote the development of aerospace technology, medicine, energy and other civilian areas.

Using traditional grinding and polishing methods are difficult to meet the requirements of processing efficiency, cost and surface quality [12]. The polishing process is the final process to obtain precise optical devices, and the whole process is time consuming and laborious. Whether the material can be applied to the cutting-edge areas is determined by the polishing effect. The surface quality and the material removal rate are contradictory, but the introduction of ultrasonic vibration to a large extent alleviate this contradiction. The processing of hard and brittle materials by ultrasonic vibration is first proposed by American scientists Loomis and Wood, and the experiments of ultrasonic cutting on glass plates have been carried out [13]. This novel processing method is to give the abrasive large acceleration using ultrasonic vibration [14], and makes grains to frequently impact the surface of workpiece so that micro cracks are formed on the surface. Each loading and unloading of grains will promote the formation and expansion of cracks until the material is broken and detached, and the defects on the surface can be eliminated easily. However, it is impossible to expand into transverse cracks in traditional polishing. In addition, the cavitation [15] caused by ultrasonic vibration also plays a role in accelerating the breakage and abscission of materials, and then

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improving the processing efficiency. Therefore, ultrasonic vibration assisted polishing greatly improves the processing efficiency and surface quality of polishing. In this paper, polishing is done by ultrasonic vibration applied to the axial direction of the spindle.

With the development of precision and ultra-precision machining technology [16], ultrasonic vibration assisted polishing technology has gradually become one of the main methods of precision optical glass lens processing. Kang et al. [17] evaluate the effect of different polishing methods on surface roughness through the polishing of hard and brittle materials. Wu et al. use ultrasonic assisted chemical mechanical elastic polishing technology, and the results show that this method can improve the material removal rate. Wang et al. use ultrasonic magneto-rheological composite technology to polish the optical glass. The experimental results show that the shape of the material changes with the change the angle. Zhang et al. [18] gave a brief review of new advances in micro ultrasonic assisted lapping, micro ultrasonic assisted lapping was first proposed as an effective micromachining technique for hard–brittle materials, and then introduces some problems to be solved in order to put it into practical microfabrication. Li et al. [19] carried out ultrasonic vibration assisted electromechanical fixed grinding and polishing of the optical glass. The experimental results show that it can improve the removal rate of the material. Ikeda et al. developed a new AC electric field friction chemical polishing technology, which shows that this latest polishing technology makes the removal rate two times better than the conventional polishing. Lee et al. [20] adopt ultra-precision polishing method of magneto-rheological fluid. The results show that this method is an effective method to improve the surface roughness and transmittance.

Although the ultrasonic vibration assisted polishing glass lens process has made great progress, its removal mechanism [21,22] is very complicated and is the result of many aspects. Gorham et al. [23] did an indentation test on the glass, which is shown that the lateral crack produced by the velocity factor is the main reason for the material removal. Zhou et al. [24] established the critical cutting depth prediction model of ductile brittle transition in ultrasonic vibration assisted grinding of optical glass, which laid a foundation for the removal mechanism of glass. At present, the removal mechanism of ultrasonic assisted polishing is still in the exploratory stage. Therefore, the study of ultrasonic polishing optical glass lens is necessary to enable us to understand the ultrasonic polishing process clearly.

In this paper, the innovative work is ultrasonic vibration assisted polishing optical glass lens with ultrasonic atomizing liquid. The ultrasonic vibration is applied to the axial direction of the main shaft, which can make abundant grains to impact the workpiece with the high-frequency reciprocating style. And the ultrasonic atomizing liquid is applied to the nozzle in order to make grains more homogeneous and decrease clustering phenomenon, which can improve the surface quality.

2. Material removal model of optical glass lens

2.1. Assumptions of the model

For simplicity, the following assumptions for the object of study and the polishing process were made:

(1) All grains in the atomized polishing liquid are regarded as spheres with the same mass and particle size, and are evenly distributed in the polishing fluid.
(2) The grains in the polishing solution act directly on the surface of the optical glass lens and have no energy exchange with the other grains.
(3) The ultrasonic generator provides the unattenuated simple harmonic vibration during the polishing process, that is, the amplitude and frequency remain stable.
(4) The grains don't occur any deformation in the process of ultrasonic polishing. Because the grains are diamond grains, the hardness of grains are greater than the workpiece.
(5) Optical glass lens is considered as an ideal brittle material.

2.2. The impact of grains on the surface of the workpiece

As shown in Fig. 1, the ultrasonic vibration is applied in the axial direction of the spindle, which is generated by the ultrasonic generator. Then vibration is transmitted to the polishing tool head through the transducer and the amplitude-change pole [25]. The frequent reciprocating vibration of the polishing tool head drives the grains in the polishing liquid that is atomized by ultrasound to impact the surface of optical glass lens. The amplitude and frequency of the grains are the same as those of the polishing tool head.

For the convenience of calculation, it was assumed that the grain just begins to contact with the workpiece and the initial phase of ultrasonic vibration is 0 when polishing time is 0. Therefore, the ultrasonic vibration displacement of the grain in the vertical plane is given in Eq. (1).

$$Z(t) = -A\sin(2\pi ft) \tag{1}$$

where, A is the ultrasonic vibration amplitude of grains, f is the ultrasonic vibration frequency of grains, t is the movement time of grains.

The amplitude of the grains is obtained by the amplitude of the ultrasonic generator that is amplified by the amplitude-change pole. So the ultrasonic vibration amplitude of grains is given in Eq. (2).

$$A = kA_0 \tag{2}$$

where, A_0 is the amplitude of the ultrasonic generator, k is the amplified multiple of the amplitude-change pole.

As shown in Eq. (3), the instantaneous velocity of single grain which is the first order derivative of the ultrasonic vibration displacement of

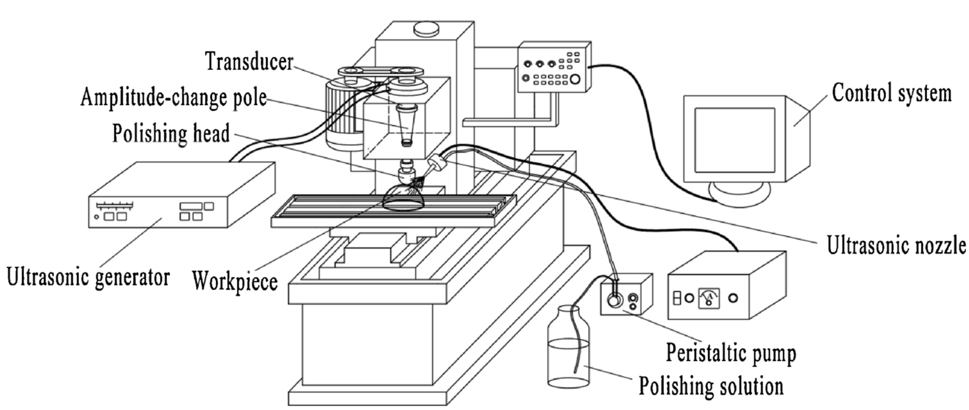

Fig. 1. Schematic diagram of two-dimensional ultrasonic assisted polishing.