Achieving high MRR and high surface roughness convergence rates for optical glass polishing using semi-rigid DAWP tool

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Abstract. Ultra-precision optical components have been widely used in various advanced optical instruments and systems. Generally, computer controlled polishing process is utilized for producing these optics, meeting the strict requirements of form error and surface quality. However, due to the 'gentle' tool-workpiece contact feature, most of the existing polishing technologies cause relatively low material removal rates (MRR) and surface roughness convergence rates (SRCR). Therefore, it is hard to meet the requirements of high-efficiency manufacturing for optics, especially for medium-large sizes. This paper presents a dual-axis wheel polishing (DAWP) technology using a semi-rigid polishing wheel, designed to deliver high MRR and high SRCR at the same time. The wheel consists of an aluminum alloy wheel body and polyurethane layer, with the combination of the self-rotating motion and co-rotating motion at the same time in the polishing process. Polishing experiments on 50 mm×50 mm BK7 ground glasses were carried out using DAWP tool, the results show that, after only one pass (68 minutes) polishing, the average surface roughness reduced from Ra 485.99 nm to 1.243 nm, the convergence rate can reach 99.74%, the MRR and the equivalent removal depth are 1.614 mm^3/min and 43.9 μm, respectively, uniform and smooth surface texture was obtained.

Introduction

Ultra-precision optical components have been widely used in various advanced optical instruments and systems. For instance, ground based large telescopes, space telescopes, laser systems, imaging devices and lithographic systems. With the developments of these systems, high requirements on the aspects including processing precision and product efficiency have been proposed for the manufacturing of these optics with ultra-precision.

Wheel polishing has been used for machining optical surfaces in recent years, however, the number of relevant literatures is rather limited. Rao et al. proposed a soft wheel polishing method and equipment to polish the infrared material (MS-CVD ZnS), and the utilized polishing wheel consists of a duralumin wheel body and an external polymer polishing layer [1, 2]. Cheng et al. proposed a wheel-like electrorheological finishing (ERF) technology for the deterministic polishing process of small optical parts [3]. Seo et al. proposed a orthogonal velocity polishing tool with dual-rotational motion for the fabricating process of the CVD SiC components [4].

However, the polishing efficiency and the MRR achieved using these wheel polishing methods are still rather low.

In this paper, a novel high-efficiency dual-axis wheel polishing (DAWP) technology using a semi-rigid polishing wheel is proposed, designed to achieve high material removal rates and high convergence rates of surface roughness. The structure and performance parameters of the proposed semi-rigid DAWP tool is introduced firstly. And a polishing test on BK7 ground flat is carried out. A series of measurement instruments are used to systematically characterize the surface quality before and after one cycle DAWP process. Including SEM, AFM, white light interferometer (WLI) and laser interferometer (LI).

Design of the DAWP tool

The proposed semi-rigid polishing wheel consists of a cylindrical aluminum alloy wheel body and a polyurethane (PU) layer, as shown in Fig. 1(a). And the utilized PU material is a kind of hyperelastic and porous material (the porous feature is illustrated in the green block of Fig. 1(a)), its hardness (with shore A hardness of 73) and elastic modulus is much higher than that of the rubber layer used in the flexible polishing tools, e.g., FADP tools [5] and bonnet tools [6]. During polishing process, the polishing wheel is driven by a co-rotating motion and a self-rotating motion, simultaneously (see Fig.1(a) and (b)). The polishing tool is mounted on the spindle of a CNC machine tool, the spindle rotating generates co-rotating motion of the polishing tool. The self-rotating motion of the polishing wheel is driven by a separate motor.

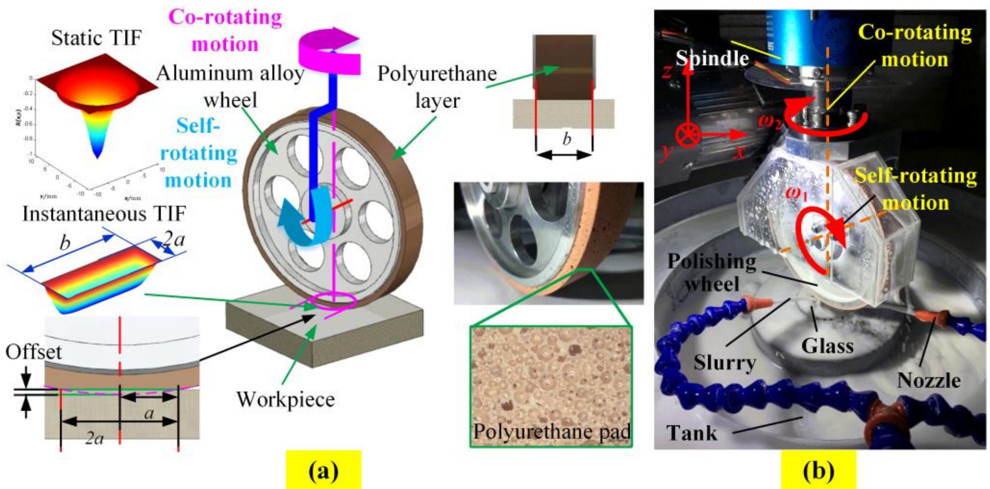

Fig. 1. Illustration of the DAWP system (a) schematic diagram of the semi-rigid polishing wheel; (b) photograph of the DAWP tool during polishing process.

The thickness of the PU pad does have obvious effects on the flexibility of the wheel, hence, we have carried out contact force tests between the polishing wheel and a flat mirror surface, with different PU pad thickness (1 mm, 2 mm and 5 mm), the photograph of measurements are shown in Fig. 2. The test results are shown in Fig. 3. It shows that, the 'rigidity' of the 1 mm thick PU pad wheel is relatively high. And the wheel with 5 mm thick PU layer is relatively soft according to the test results. The 'rigidity' of the wheel with 2 mm thick PU pad is moderate, when the compression displacement Δz (tool offset) varied from 0.04 mm to 0.12 mm, the contact force is increased from 12.5 N to 79 N. Consequently, the polyurethane pad with 2 mm thick is used in this study, and it works as both a polishing layer and a deformable elastic layer.

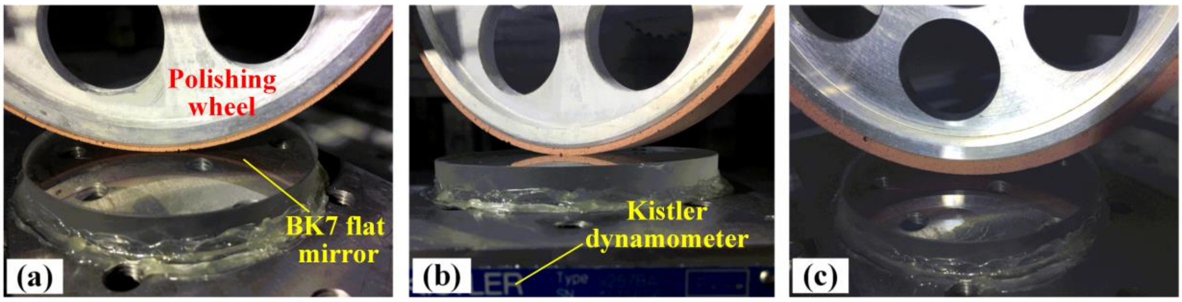

Fig. 2. Contact force measurements for the polishing wheel with different PU thickness (a) 1 mm (b) 2 mm (c) 5 mm.

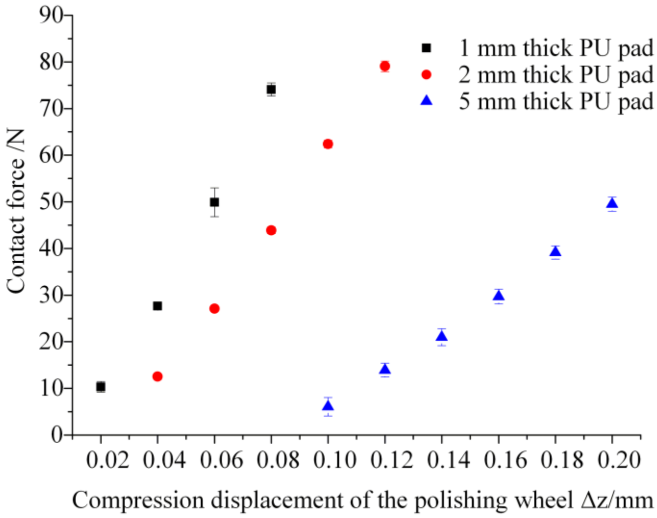

Fig. 3. Measurement results of the polishing contact force.

Experimental

A polishing experiment (namely pre-polishing, to polish the ground or lapped optical surface) is carried out on a 50 mm×50 mm BK7 ground flat workpiece. Using the dual-axis wheel polishing (DAWP) system developed by our research team [7], as shown in Fig. 1(b). And the polishing parameters are listed in Table 1. Before polishing, the polishing wheel is dressed using a CBN cup wheel. After dressing, the run-out error is less than 4 μm.

The surface quality before and after polishing is characterized by SEM (Sigma-HD, Carl Zeiss), WLI (WLI, NewView TM 7100, ZYGO), LI(GPI. XP/4, ZYGO) and AFM (Sigma-HD, Carl Zeiss). And the material removal rate (MRR) on the whole surface is measured by a precision balance.

Table 1 Parameters of the polishing tests.

Parameter name	**Value**
The width of the polyurethane pad	20 mm
Pad thickness	2 mm
Compression displacement Δz	0.06 mm
Rotational speed of self-rotating motion n_1	600 r/min
Rotational speed of co-rotating motion n_2	80 r/min

Feeding velocity	50 mm/min
Abrasive and size	CeO_2 (~1.5 μm)
Slurry concentration	5 wt% (1:20)
Tool path type	Raster
Path interval	1 mm

Results and discussion

After only one pass polishing, mirror like surface is achieved, the initial rough surface features produced from grinding process are completely removed, as shown in Fig. 4. A 99.74% improvement on average surface roughness (the magnification is 5×, the number of measurement points is 5) from Ra 485.99 nm to Ra 1.243 nm. And a MRR of 1.614 mm^3/min have been achieved on BK7 ground surface.

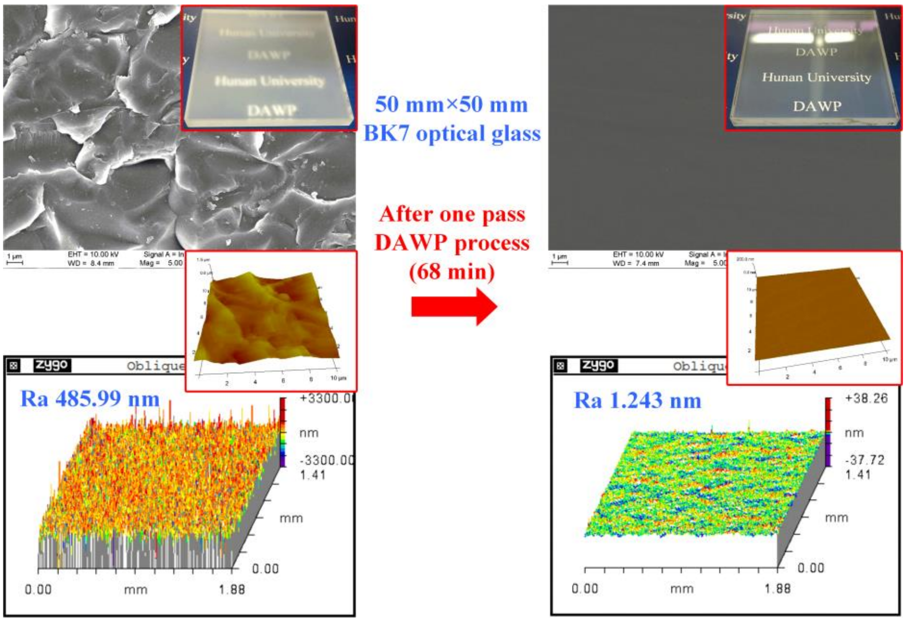

Fig. 4. Surface topography, roughness and appearance of BK7 flats before and after one pass polishing.

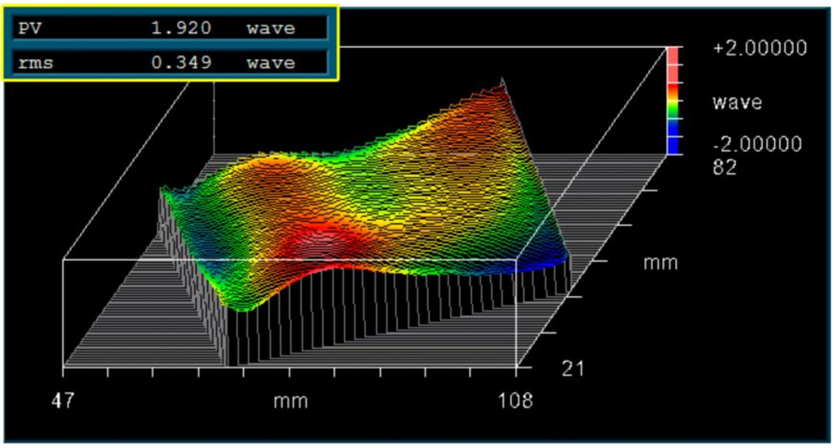

Fig. 5. Measured surface form error of 50 mm×50 mm BK7 flat after one pass polishing.

The polished surface can also be measured by ZYGO interferometer directly after polishing, the measured figure of polished area is shown in Fig. 5, with form error PV 1.920 wave and RMS 0.349 wave (1 wave=632.8 nm).

Conclusions

In this paper, a novel dual-axis wheel polishing system using a semi-rigid polishing wheel is presented which attempts to overcome the problems of low process efficiency related with flexible polishing tool techniques. The present work shows that the semi-rigid DAWP process can achieves excellent surface quality on optical components with ultra-high process efficiency.

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