The effect of clamping stress on the measured surface figure of optical glass BK7

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Abstract. This work probes the effect of clamping stress induced by pad block’s support surface (PBSS) shape error in measured surface figure of optical glass BK7. Under given PBSS topography measured by three coordinate machine, the clamping stress loaded on the workpiece and its effect on workpiece’s surface deformation was simulated by finite element method. Furthermore, the surface figure residual error (SFRE) in simulation was in good agreement with experimental results despite the measurement repeatability error.

1. Introduction
Large flat optical glass BK7 with stringent specifications for low-, medium-, and high-spatial frequency errors is extensively used in high power laser facility [1,2]. Such highly precise surface is generally fabricated by grinding and then polishing. Continuous polishing (CP) using polishing pitch with favorable fluidity is a vital step in control of workpiece’s surface figure [3]. The key challenge in CP is how to convergence the workpiece’s surface figure with fewer iterations [4]. Before single fabrication cycle, the process parameters will be adjusted according to the last measured surface figure [5]. Therefore, eliminating the error in measured surface figure is of great importance to promote fabrication efficiency. The detection fixture used to fix workpiece (BK7) in the measurement of surface figure is schematically shown in Fig.1. The Teflon pad block is bolted to stainless steel substrate with hexagon socket head bolts, and the top surface of pad block is contacting with workpiece. Further, the lateral clamp devices screwed into the two columns on substrate’s both sides are used to prevent the workpiece’s slippage during transport process.
Researchers have tried to reveal the influence of clamping method on workpiece’s surface deformation. Xu et al studied the large flat optics’ surface deformation caused by the gravity under various clamping method with finite element method to acquire more realistic measurement results [6]. Moreover, zhou et al analyzed the effect of clamping method and pre-load on lens’ optical aberration characterized by standard Zernike polynomial [7]. As for fixture’s structure optimization, Shao et al designed an all-metal fixture to achieve stress-free clamping of large flat optical component in vacuum environment [8]. Liu et al optimized the large octagonal Nd glass’ support system with integrated optomechanical analysis method to reduce the transmission wavefront distortion introduced by support system [9]. However, there is little information about the effect of clamping stress on measured BK7 flats’ surface figure.

In the following study, the pad block’s support surface (PBSS) topography will be measured with three coordinate machine, and its effect on the clamping stress will be calculated through finite element method. Then, the workpiece’s surface deformation introduced by clamping stress at different relative positions will be simulated. Next, the measurement repeatability error of surface figure will be acquired and the surface figure at different relative positions will be measured to verify the simulation results.

2. Finite element simulation of clamping stress and surface deformation

2.1. Deterministic measurement of PBSS topography
The contact surface of workpiece was pre-polished by computer controlled optical surfacing to a peak to valley (PV) <0.5 μm, while the PV of PBSS was in the range of 50~100μm introduced in milling process. Hence, the workpiece’s contact surface can be assumed to be flat. Measurement of PBSS topography was accomplished with three coordinate machine, as schematically shown in Fig.2. The y translational motion of detection probe was realized by the relative movement at the gantry and the sliding guide fixed on the marble platform supported by the supporting table. Besides, the pad block bolted to the substrate was fixed on the marble platform and the detection probe was contacting with the PBSS. Thus, the PBSS topography was acquired by contact measurement with grating type measuring path through interpolation algorithm.
2.2. The surface deformation induced by clamping stress at different relative positions

The material parameters of workpiece (600mm × 430mm × 85mm) and Teflon pad block (400mm × 90mm × 35mm) at 20 ℃ are shown in Table 1.

Table 1 material parameters of the workpiece and Teflon pad block (20℃)

| Material                  | Density (g/cm³) | Modulus of elasticity (MPa) | Poisson’s ratio |
|---------------------------|-----------------|-----------------------------|-----------------|
| BK7                       | 2.51            | 81000                       | 0.21            |
| Teflon pad block          | 2.14            | 280                         | 0.40            |

The PBSS topography reconstruction was achieved with Design model software through surface fitting. Furthermore, the contact state between PBSS and workpiece bottom surface was defined as frictional type with friction coefficient equalling 0.1. As for the boundary conditions, the substrate’s bottom surface was fixed and the whole geometric model was subjected to the gravity (g=9.8 m/s²). Because the friction force is proportional to normal stress, the normal stress born by workpiece was used as stress index. Since the focus is on the change of workpiece’s surface figure, the surface deformation vertical to workpiece’s polished surface was used to characterized the error in measured surface figure.

The surface deformation in detection wavelength (λ=632.8nm) induced by clamping stress at different relative positions was shown in Fig.3. L-25 mm means the geometric center of workpiece offsets 25 mm relative to pad block’s geometric center in the horizontal direction, so does R-25mm.

Figure 2. Schematic of measuring PBSS topography.

Figure 3. Surface deformation induced by clamping stress at different relative positions.
3. Experimental results and discussion

3.1. Repeatability of measured surface figure
The workpiece’s surface figure was measured on the laser interferometer (32”, Zygo, USA) and the ambient temperature and humidity was set 21.7℃ and 37.2% RH, respectively. The given workpiece placed on the center of pad block was measured every 48 hours and the surface figure was characterized by PV. Fig.4 displays the measured PV varies with standing time, where the measurement repeatability error is within 0.0471 λ, indicating the measured data has good repeatability.

![Figure 4](image)

**Figure 4.** Measured PV of the given workpiece varies with standing time.

3.2. The measured surface figure at different relative positions
The workpiece was successively placed in the three positions as describes in section 2.2, where standing on the detection fixture for 48 hours in ambient (21.7±0.1℃, 37.2±0.2) % RH. Then, the surface figure was measured with abovementioned laser interferometer, and the measured surface figure can be regard to be composed of the true surface topography, surface deformation induced by clamping stress and measurement repeatability error. To uncover the effect of clamping stress on the surface deformation, the measured surface figure at \( P_2 \) was subtracted from the measured surface figure at \( P_1 \) and \( P_3 \), respectively, which is defined as surface figure residual error (SFRE). Fig.5 depicts the SFRE in the simulation and experiment, which suggests the clamping stress induced by PBSS shape error plays a significant role in measured surface figure. In addition, the SFRE in simulation was less than that in experiment results despite including measurement repeatability error. In addition, there is larger error of \( P_1-P_2 \) between the simulation and experimental results owing to the simplification of the PBSS surface topography in three-dimensional reconstruction. In order to eliminate the surface deformation induced by the clamping stress, the PV of Teflon PBSS should less than 10 μm.
4. Conclusion
The effect of clamping stress induced by the PBSS shape error in the measured surface figure of optical glass BK7 has been investigated. Under specific PBSS topography measured by three coordinate machine, the clamping stress loaded on the workpiece and its effect on workpiece’s surface deformation was simulated by finite element method. Moreover, the SFRE in simulation agrees well with the experimental results despite the measurement repeatability error.

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