The Role of Pad Block’s Support Surface Topography in the Measurement of Optical Glass BK7’s Surface Figure

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Abstract. Large flat transmission mirrors made from optical glass BK7 are widely used in the high-power laser facility, which are required of stringent specifications for the whole spatial frequency errors. This work reveals the role of pad block’s support surface (PBSS) topography in measuring BK7 surface figure. Firstly, the PBSS topography was measured with laser displacement sensor. Secondly, the BK7 surface deformation at different pad blocks were simulated with finite element method and validated by experiments. Finally, a method was proposed to quantitively evaluate the different PBSS topography.

1. Introduction

Large flat optical glass BK7 is widely used as transmission mirror for its excellent optical performance in the high-power laser facility [1]. In order to reduce the influence of laser transmission’s wavefront distortion on the focus and density of the final output energy, the BK7 workpiece are required stringent specifications for the whole spatial frequency errors [2]. Fabrication of such highly precise surface generally through three steps: grinding, rough polishing and fine polishing, where costs a great deal of human and financial resources [3-5]. Continuous polishing (CP) using pitch lap performs well in suppressing the medium- and high-spatial frequency errors, and thus plays a vital role in BK7 surface finishing [6]. Owing to the considerable uncertainty lies in material removal distribution during CP, how to achieve the convergence of the BK7’s surface figure, namely spatial frequency error, with fewer iterations remains a key challenge. Before any arbitrary fabrication cycle, the process parameters need to be adjusted according to the last measured surface figure. Hence, eliminating the error in measured surface figure is of vital significance to promote fabrication efficiency. The detection clamp used to measure the surface figure of BK7 is schematically shown in Fig.1. The top surface of the Teflon pad block bolted to the stainless steel substrate bears the gravity of the BK7 workpiece. In addition, the lateral clamp device mounted on the column prevents the BK7 workpiece’s slippage during transport.
Researchers have tried to reveal and eliminate the influence of camp method on the measurement and fabrication of the BK7 workpiece. Zhao et al simulated the clamping and gravity deformation of large flats with the ANSYS finite element analysis method, and provided references for further study on the deformation compensation [7]. Chen investigated the influence of the temperature change on the measured surface figure and proposed a method to compensate the errors [8]. As for the BK7’s fabrication, Sun et al revealed the BK7 substrate deformation induced by gravity played a vital role in vacuum deposition with finite element analysis method [9]. Yin et al studied the influence of the clamping method on the sliced optical glass BK7 [10]. However, there is few studies on the effect of pad block’s support surface (PBSS) topography, and insights are motivated to be given into for higher efficiency.

In the following study, the PBSS topography will be measured with laser displacement sensor, and its effect on the BK7 surface deformation will be calculated through finite element method. Then, the BK7 surface figure will be measured at the different pad block. Finally, a method will be proposed to quantitively evaluate the PBSS topography.

2. Experimental

2.1. Measurement of the PBSS topography
The bottom surface of BK7 workpiece, which was contacting with the PBSS during measurement of surface figure, was pre-polished to a peak to valley (PV) <0.5μm, while the PV of the PBSS was up to hundreds of micrometers introduced during machining. Thus, the bottom surface can be assumed to be flat. The dimension and material parameters at 20°C are shown in Table 1.

| Table 1. The dimension and material parameters of the workpiece and Teflon pad block (20°C). |
|---------------------------------|-----------------|-----------------|
| Dimension parameter            | BK7             | Teflon pad block |
| Density (g/cm³)                | 2.51            | 2.14            |
| Modulus of elasticity (MPa)    | 81000           | 280             |
| Poisson's ratio                | 0.21            | 0.4             |

Measurement of the PBSS topography was finished with laser displacement sensor (LK-G10, KEYENCE, Japan) and precise mobile platform, as schematically shown in Fig.2. During measurement, the gantry reciprocated along the sliding guide fixed onto the marble table. Meanwhile, the laser displacement sensor translated along the gantry, and the measuring path of the PBSS topography was grating type. Besides, the pad block bolted to the substrate was fixed onto the marble.
table. The measured data was firstly filtered out abnormal value and the height of PBSS topography was acquired through interpolation algorithm.

![Figure 2. Schematic of measuring PBSS topography.]

2.2. Measurement of BK7’ surface figure
Before measuring the BK7’ surface figure, it would stand on the detection clamp for 48 hours in the ambient (21.7±0.1℃, 37.2±0.2) % RH). Then, the surface figure was measured on the Zygo 32” laser interferometer.

3. Results and discussion

3.1. The surface deformation induced by the different PBSS topography
The PBSS topography was reconstructed with Design model software through surface fitting, and the von-mises stress at contacting interface between the PBSS and BK7’s bottom surface was calculated in ANSYS software. As for the boundary conditions in finite element analysis, the coefficient of friction at the contacting pair was 0.1, and the substrate’s bottom surface was fixed. Further, the whole geometric model was subjected to the gravity, where the acceleration of gravity is 9.8 m/s². Moreover, the directional deformation vertical to the BK’s polished surface was solved and polished surface tilt was removed using a special matlab data processing program, which was used to characterize the error in the measured surface figure. When the BK7 workpiece was placed at the pad block’s center, the two different PBSS topography and the induced workpiece’s surface deformation (wavelength, wv, 632.8nm) is shown in Fig.3.

![Figure 3. Schematic of measuring PBSS topography.]

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3.2. Measured surface figure at the different pad block

The surface figure was measured five times under the same conditions, and these figures were processed by point to point average to reduce the influence of random error. Then, the average surface figure at the two different pad block was shown in Fig.4.

![Figure 4. Average surface figure at the two different pad blocks.](image)

3.3. Quantitative evaluation of different PBSS topography

When the PBSS topography distributed symmetrically around its geometric center, the BK7 workpiece surface deformation induced by the PBSS topography under gravity was negligible. Consequently, the reference plane of the PBSS topography was set to rotate symmetrically around its geometric center. Then, the height at the different radial distance \( r_j \) can be calculated by:

\[
\begin{align*}
\min \sum_{j=1}^{m} (z(r_j) - z(x_i, y_i)) \\
x_i^2 + y_i^2 = r_j^2
\end{align*}
\]

where the \( z(r_j) \) is height at the rotational symmetry reference plane, \( z(x_i, y_i) \) is the height at the PBSS topography. The peak to valley (PV) of the PBSS height relative to the established reference plane is of importance to the surface deformation. Further, the angle \( \theta \) between the peak and the valley plays a crucial role in the induced surface deformation. Therefore, the product of the PV and \( \theta \) is used to quantitively characterize the PBSS topography. In addition, the result of the 1# and 2# pad block is 135.08μm.rad and 87.96μm.rad, which coincides with the experimental results.

4. Conclusion and future work

The PBSS topography has been measured with laser displacement sensor, and the BK7 workpiece surface deformation induced by PBSS topography has been simulated with ANSYS finite element software and validated by experiments. Moreover, the difference in the two PBSS topography was quantitively evaluated. As for the future research, the studies should be focused on the effect of BK7 workpiece’s relative position at the pad block on the induced surface deformation.

Acknowledgments

Funding by Science Challenge Project (NO: TZ2016006-0501) of china.

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