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Testing the transmitted wavefront of large aperture long-focal-length lens using a multizone computer-generated hologram

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Abstract. A method for testing the transmitted wavefront of large aperture long-focal-length lens with a multizone computer-generated hologram (CGH) is proposed. The multizone CGH has 5 zones: one main zone for the null testing of long-focal-length lens and four auxiliary zones for the pre-alignment of measured lens. Both 1st order wavefront and 0th order wavefront of CGH are measured, and 0th order wavefront is used to calibrate the substrate error. To verify this test approach, a 450mm×450mm multizone CGH is designed and fabricated for testing the spatial filter lens. Experiments and error analysis are carried out. The results show that the desired precision can be reached with use of CGH.

1 Introduction

Large aperture long-focal-length lens has been widely used as the spatial filter lens in high power laser system, such as National Ignition Facility in Unite States, Laser Mégajoule in France, Gekko XII in Japan. Transmitted wavefront is an important specification for long-focal-length lens and will affect the filtering effect and beam quality directly. One method for testing the transmitted wavefront involves using a large convex mirror [1-2]. This method has a simple test configuration and short optical path. However, measurements of large convex mirrors are notoriously difficult because they require flat interferometer and auxiliary optics that are larger than the surfaces being tested, which results in a high cost.

Current developments in diffractive optics and lithography technology make the use of large aperture computer-generated hologram (CGH) an attractive alternative [3-4]. Therefore, in this paper, we propose to measure the transmitted wavefront of long-focal-length lens by using a reflective multizone CGH. Compared with the convex mirror, CGH has a large advantage in cost, because it is cheaper to manufacture a diffractive element than convex mirrors of equivalent size. Moreover, the design of CGH is very flexible, one multizone CGH can provide the wavefront correction for null testing and pre-alignment of the lens under test simultaneously, which makes the alignment of optical elements easier.

2 Measurement principle

Figure 1 shows the CGH test configuration for long-focal-length lens. A large aperture Fizeau interferometer and a reflective multizone CGH is used to measure the transmitted wavefront. The multizone CGH consists of one main zone and four auxiliary zones. The main zone is located at the center of the substrate. In this zone, testing CGH with circular lines is etched to emulate, in 1st order (or higher order), the reflective properties of the convex mirror. Auxiliary zones are four square zones and located around the main zone. In auxiliary zones, four beam projection CGHs are etched for the prealignment of the measured lens by projecting four marks around the edges of the measured lens.

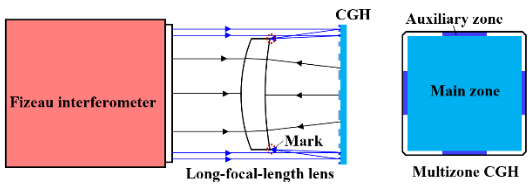

Fig. 1. Schematic drawing of the CGH test configuration for long-focal-length lens.

As we know, CGH substrate figure error is usually the primary error source in the CGH measurement. To calibrate the CGH substrate figure error, two measurements are made: 0th order measurement and 1st order measurement. Through measuring the 0th order diffraction wavefront of the CGH, we can obtain the substrate figure error and back it out from 1st order one.

3 Experiments and results

3.1. 0th and 1st order measurements

To verify the feasibility of this test approach, we designed a multizone CGH for testing the spatial filter lens. This spatial filter lens has a size of 430mm×430mm and thickness of 46.5mm. The effective focal length f is 31250mm (@λ=1053nm) and the vertex radii of curvature are R1=9377.868mm (CX) and R2=28133.886mm (CC), respectively. In 410mm×410mm clear aperture, the requirement of transmitted wavefront is PV<λ/3

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(@λ=632.8nm). The multizone CGH is fabricated on a 450mm×450mm×70mm fused silica substrate and the substrate is specified to have a figure of PV~1/10λ. The testing CGH is 430mm×430mm and the minimum line spacing is 32.1μm. In our experiment setup, the large aperture interferometer is a commercialized Fizeau interferometer INF600-LP produced by Tyggo, which has a test aperture of 610mm, as shown in Fig. 2.

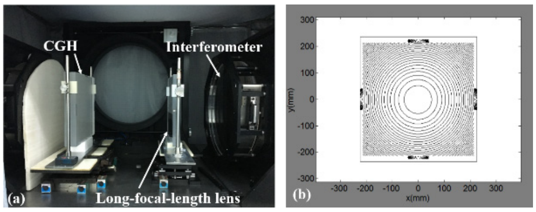

Fig. 2. (a) The experiment setup for testing the long focus lens with CGH; (b) the fringe patterns of multizone CGH.

Figure 3 shows two measurements for 0th and 1st order. We can see that there are ghost fringes near the center of the lens. These ghost fringes are caused by the reflections of lens surface and the diameter are 1.38mm and 49.76mm for the first and second surface, respectively. To calibrate CGH substrate, the 0th order map is transformed to match 1st order map. Figure 4 shows the mapping function between the radius positions of CGH and the measured lens. After CGH substrate calibration, the final transmitted wavefront with CGH substrate calibrated is PV=0.2284λ and RMS=0.0276λ.

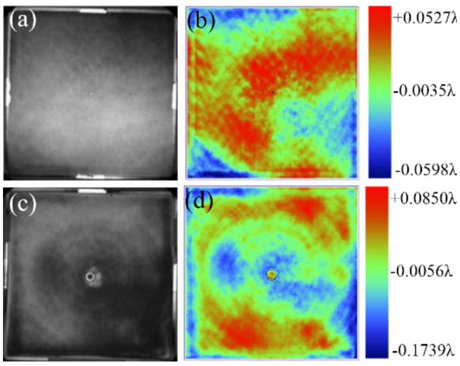

Fig. 3. 0th and 1st order measurements. (a) Interferogram for 0th order; (b) CGH substrate figure map: PV=0.1125λ and RMS=0.0178λ; (c) Interferogram for 1st order; (d) Wavefront map: PV=0.2590λ and RMS=0.0304λ.

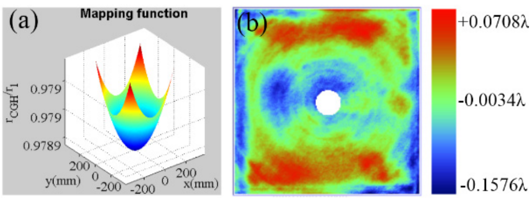

Fig. 4. Data mapping between 0th order and 1st order. (a) Mapping function; (b) Wavefront map with CGH substrate calibrated: PV=0.2284λ and RMS=0.0276λ.

3.2 Error analysis

The CGH test errors includes design error, fabrication errors, alignment errors, and mapping errors, as given in Table 1. Assuming all the errors are un-related and independent, the total wavefront error of this CGH test can be estimated as the root-sum-spuare (RSS) of these errors, which is approximately 0.0091λ RMS. Because the test beam passes through the measured lens twice, the final transmitted wavefront error for long-focal-length lens is half of the RSS value, which is 0.00455λ RMS.

Table 1. Wavefront errors analysis for the CGH test

Source of Errors		Wavefront error (RMS)
Design error of CGH	Design residual	0.0000λ
Fabrication errors of CGH	Pattern distortion error (0.5μm)	0.0051λ
	Etching depth error (5nm)	0.0000λ
	Duty-cycle error (5%)	0.0070λ
	Substrate figure calibration residual (0.0020λ)	0.0020λ
Alignment errors of CGH	*x* tilt (1 fringe)	0.0000λ
	y tilt (1 fringe)	0.0000λ
Fabrication errors of measured lens	Radius of curvature (0.1%)	0.0003λ
	Thickness of lens (0.2mm)	0.0000λ
Alignment errors of measured lens	*x* decenter (0.2mm)	0.0002λ
	y decenter (0.2mm)	0.0002λ
	x tilt (0.04′)	0.0002λ
	y tilt (0.04′)	0.0002λ
	z displacement (1mm)	0.0000λ
Mapping errors	*x* direction (1 pixel)	0.0012λ
	y direction (1 pixel)	0.0012λ
RSS Errors		0.0091λ

Conclusion

A method for measuring the transmitted wavefront of long-focal-length lens with a reflective multizone CGH is proposed. In this method, a reflective CGH with circular lines is employed as an alternative of the convex mirror. This avoids the manufacture of large aperture convex mirror and keeps the advantage of simple test configuration. Four beam projection CGHs are designed to help the pre-alignment of the measured lens, which significantly improves the testing efficiency. Experiments and error analysis exhibit that this multizone CGH approach has a good performance.

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