Research on Aspheric Testing Based on Off-Axis Computer-Generated Hologram

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Abstract Using null lens such as computer-generated hologram (CGH) is almost the routine for testing asphere at present. The using of on-axis CGH has many advantages, but the central area of the asphere can not be tested due to the ghost. In this paper, a new program is proposed, where the influence of ghost is eliminated by using off-axis CGH and modified Twyman-Green interference setup. In this program, the off-axis CGH is placed on the imaging arm, compensating the testing wavefront secondly and separating the varied diffraction orders in the direction of vertical axis. With the tilt axis and filter, 0th order of the reference wavefront and −1st order of the testing wavefront are adopted to get interferograms which are used to carry out the aspherical testing. In our proposed program, the asphericity is compensated with the combination of standard spherical lenses and off-axis CGH. For comparison, the same asphere is tested by on-axis CGH with Zygo interferometer. The experimental results confirm that the ghost image is eliminated successfully, the results of the two tests keep well agreement, and this program can be used to test large aperture asphere on high accuracy.

Key words measurement; computer-generated hologram; off-axis; asphere

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基于离轴计算全息的非球面检测研究

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摘要 基于计算全息(CGH)的零位干涉检验是非球面检测的主要方法之一。采用共轴计算全息有很多优点，但其中心区域因形成鬼像而无法检测。为消除鬼像对测量的影响，采用离轴计算全息和改进的泰曼-格林干涉装置，将离轴 CGH 置于成像臂，对测试光进行二次补偿并在垂轴方向分离各衍射级次，通过倾轴和滤波选取 0 级参考光和 −1 级测试光发生干涉，对一块高次非球面进行了检测，其中非球面的波差由标准球面透镜组和离轴 CGH 共同进行补偿。作为对比，采用 Zygo 干涉仪和共轴 CGH 检测了同一块非球面。实验结果表明在成功消除鬼像的同时，两种方法的测量数据保持了良好的一致性，这一技术也可用于大口径非球面的高精度检测。

关键词 测量；计算全息；离轴；非球面

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1 Introduction

The asphere can improve image quality and reduce the number of optical elements in the optical system, especially make the design of optical system more flexible, so it is more and more often used in a variety of optical systems. With the development of processing technology, the manufacturing of asphere on high precision achieves new progress, but the lack of convenient and effective testing methods limits the application of asphere.

There are two kinds of methods for aspherical testing, interference testing and non-interference testing, the former can be divided into null test and non-null test. In the interference testing, the measured aspherical surface can be calculated through the interference of reference wavefront and testing wavefront. The difficulty of aspheric testing is the generation of standard aspheric wavefront, but the computer-generated hologram (CGH) can produce the wavefront of arbitrary shape theoretically, and its phase distribution function can be calculated. With the development of domestic microelectronic processing technology, the manufacture of CGH with small linewidth is mature, and CGH is often used as the

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compensator in interference system for aspheric testing. The null testing using CGH technology is one of the methods with high accuracy at present [1].

In the aspheric surface measurement, Twyman-Green interferometer is often adopted due to its adjustable contrast and convenient debugging. According to the different locations of the CGH, the proposed solution adopting Twyman-Green interferometer can be divided into two different conditions[2-3]: CGH is placed on the testing arm[4-5] and the imaging arm[5-8].

According to the different positions of testing wavefront and reference wavefront, CGH can be divided into on-axis CGH and off-axis CGH [9]. On-axis CGH can compensate greater asphericity and be adjusted more conveniently. However, due to varied diffraction orders separating along the axis and overlap of varied diffraction orders, the testing blind zones in the central interferogram come into being. Adjusting the defocus options in CGH phase function can reduce the area of blind zone, but can't eliminate it, and CGH's minimum linewidth be reduced correspondingly which requires a higher processing accuracy[10-12]. In this paper, a modified Twyman-Green interferometer is introduced, with the CGH placed on the imaging arm, asphericity compensated by the combination of standard spherical lenses and the off-axis CGH, as well as varied diffraction orders separated in the vertical axis. The experimental results show that the testing blind zone be eliminated successfully, and testing data have high accuracy relatively.

2 Proposed method

2.1 The description of measured asphere

The asphere measured in the experiment is a rotationally symmetrical high order concave asphere, with the caliber d = 78 mm, the vertex radius of curvature R = 156.47 mm, the coefficients of asphere k = 0, the radius of best fit sphere R = 154.46 mm, and the maximum degree of deviation $\delta = 0.0176$ mm.

The function of asphere can be written as:

$$Z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + A_4 r^4 + A_6 r^6, \quad (1)$$

where $r^2 = x^2 + y^2$, $c = 1/R_0$, R_0 = 156.47 mm, k = 0, $A_4 = 2.32215\times10^{-8}$, $A_6 = 2.54166\times10^{-12}$.

The deviation and profile of the asphere and its best fit sphere are shown in Fig.1 and Fig.2 respectively.

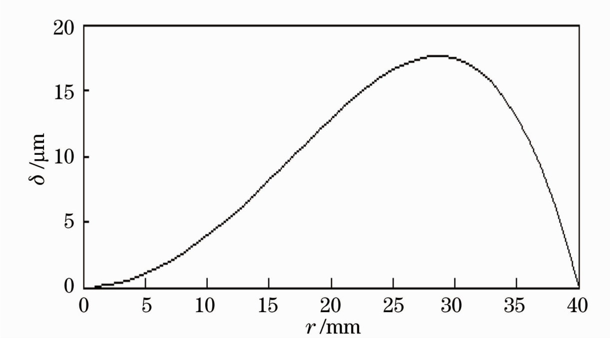

Fig.1 Deviation of the asphere and its best fit sphere

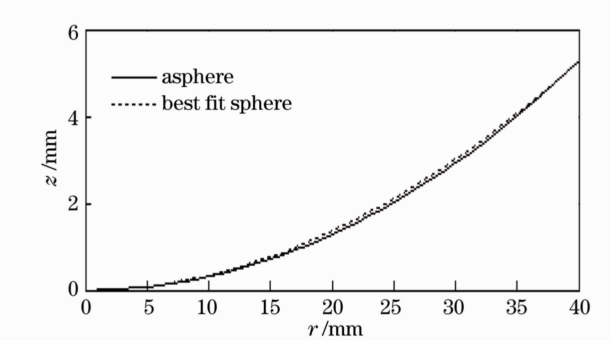

Fig.2 Profile of the asphere and its best fit sphere

2.2 The intervention optical path

The experimental setup is a modified Twyman-Green interferometer with 1 inch effective aperture. The schematic of the layout for test is described in Fig.3.

There are two kinds of wavefronts in interference optical testing, called reference wavefront and testing wavefront respectively. In Fig. 3, the beam emitting from the laser is expanded, collimated and then divided into two parallel wavefronts by beam splitter. The reflection wavefront vertically incidents at the reference mirror and is reflected again, then reference

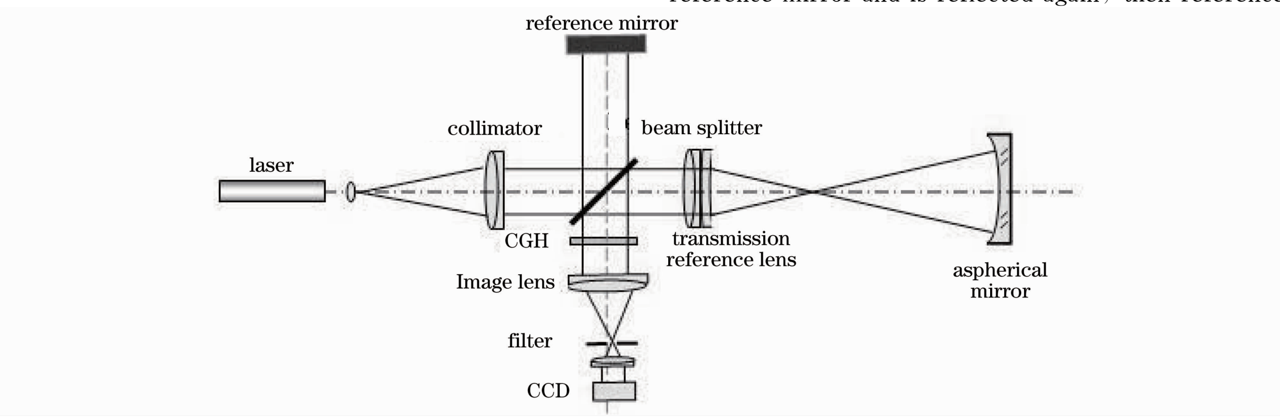

Fig.3 Schematic of the layout for test

wavefront come into being. On the other hand, the transmission wavefront passing through the standard spherical lenses, incidents at the aspherical surface and is reflected by it, then forms the testing wavefront. The off-axis CGH is placed on the tilted imaging arm and its outgong wavefronts contains various diffraction orders, 0th order of reference wavefront and −1st order of testing wavefront are selected for testing. The two wavefronts forms interferograms and collected by CCD. Analyze the acquired interferograms, we can get the deviation information of the aspherical surface. In the test, the asphericity is compensated by the combination of standard spherical lenses and off-CGH. In order to facilitate the separation of varied diffraction orders, the CCD and the image lens etc are tilt from axis.

2.3 The design of CGH

In order to eliminate the ghost introduced by on-axis CGH, the off-axis CGH is selected. The phase distribution function of CGH for compensation is acquired by ray tracing in the design. Then off-axis carrier frequency is added to separating the varied diffraction orders on the direction of vertical axis, finally, the working orders are selected by tilting imaging arm and placing filtering holes. The diagram of the imaging arm is shown in Fig.4.

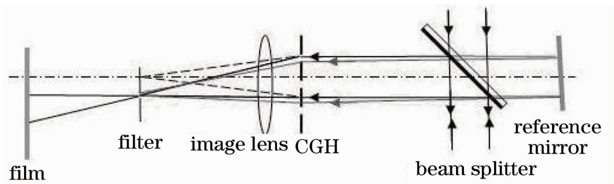

Fig.4 Diagram of the imaging arm

One of the advantages adopted Twyman-Green setup is the better contrast of interferograms. Assuming the intensity of the reference wavefront and the testing wavefront are I_r and I_t respectively, we have

$$I_r = CB_R R_R (1-B_R) B_T D_1,$$
$$I_t = C(1-B_R) B_T T_T R_T T_T B_T B_R B_T D_2, \qquad (2)$$

where C is a constant, B_R is the reflectance of beam splitter′s splitter surface, B_T is the transmittance of beam splitter′s non-splitter surface, R_R and R_T is the reflectance of the reference mirror and asphere under test respectively, T_T is the transmittance of transmission lens, D_1 and D_2 are the diffraction efficiencies of selected working orders. Then, from equation (2) we can obtain

$$\frac{I_r}{I_t} = \frac{R_R D_1}{T_T^2 B_T^2 R_T D_2}. \qquad (3)$$

According to the definition of the contrast of the interferogram, we have

$$K = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}, \qquad (4)$$

where I_{max} and I_{min} are the maximum and minimum of the intensity for a point in the interference fields, respectively. When the intensity ratio of two incident beam is 1∶1, the interferograms with best contrast acquired. Ignoring the absorption of the optical elements, we have $T_T = 99\%$, $R_T = R_R = 4\%$. Considering the beams passing through CGH only once in the optical path, amplitude binary optical elements are choosed, and select 0th order and −1st order as reference and testing wavefront respectively. Interferograms with high contrast are acquired via this program, and simultaneously the difficulty of processing and the precision of CGH are easier to control.

3 Experimental analysis

3.1 CGH element

The off-axis amplitude type CGH is design by zemax, then adopts quartz glass as substrate for its excellent performance, ultimately made by electron beams exposure technology. The CGH phase distribution function includes phase function for compensation and the off-axis carrier frequency. Separation of the varied diffraction orders in the direction of vertical axis is shown in Fig.5. Phase function for compensation is shown in Fig.6.

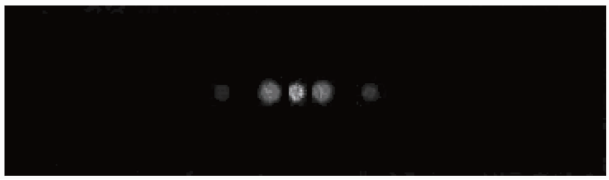

Fig.5 Separation of the varied diffraction orders

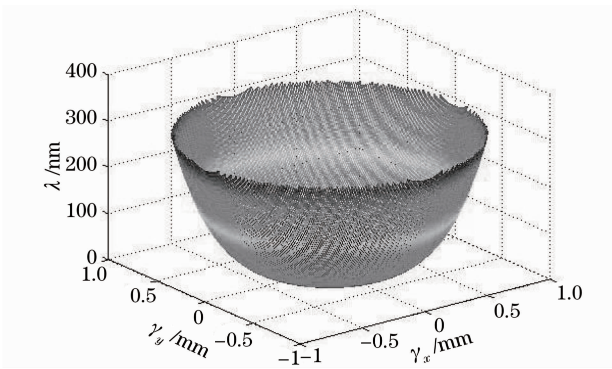

Fig.6 CGH phase function for compensation

3.2 Testing results

As shown in Fig.3, the refractive-diffractive system constituted with standard spherical lenses and off-axis CGH is adopted with modified Twyman-Green setup to complete the test of asphere. The testing diameter of asphere is 36 mm, the results show that the ghost is eliminated effectively as shown in Fig.7. In order to avoid accidental error, the asphere is tested for five times, and then the average of the results is taken. Finally, the peak-valley (PV) value of surface shape is 545.47 nm (0.862λ), and the root mean square (RMS) value is 112.01 nm (0.177λ).

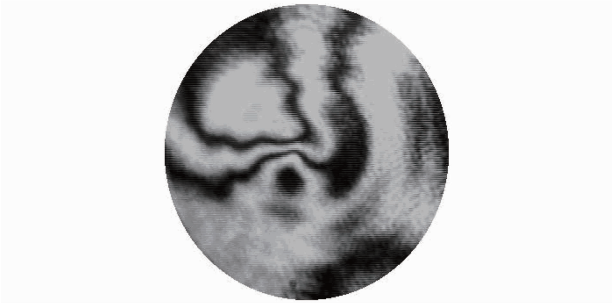

Fig. 7　Interferogram by off-axis CGH

As a comparison, the same asphere is tested with null compensation on Zygo GPI XP interferometer. The testing diameter of asphere is 52 mm. The interferogram is shown in Fig. 8, The outer annular area in the interferogram are CGH assistant positioning zones. Likewise, take the testing five times to avoid incidental error. Finally, the PV value of the surface is 563.19 nm (0.890λ) and the RMS value is 117.07 nm (0.185λ). As there exists centre ghost in the interferogram, full aperture of the surface can't measured.

Fig. 8　Interferogram by on-axis CGH

For ease of comparison, the same testing areas of the two interferograms are selected. Interferograms processed by mask are shown in Fig. 9 and Fig. 10 respectively. The experimental results are shown in Table 1.

The experimental results show that the refractive-diffractive system constituted by standard spherical lenses and off-axis CGH compensates the aspherical wavefront aberration effectively and it eliminates the testing blind zones caused by ghost. According to the testing results of the two methods, the surface characteristics and the testing data keep well agreement.

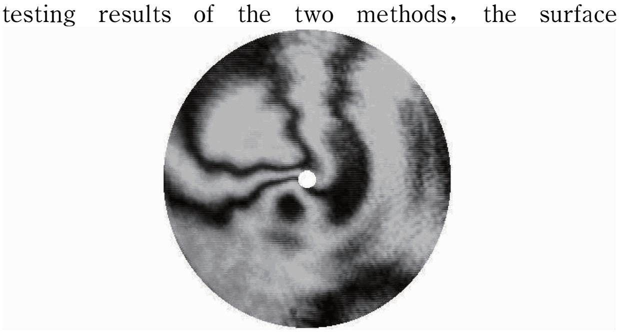

Fig. 9　Intergerogram processed by mask measured by off-axis CGH

Fig. 10　Intergerogram processed by mask measured by on-axis CGH

Table 1　Data comparison of on-axis and off-axis CGH

Type of CGH/interferometer	PV	RMS
Off-axis/Twyman-Green	0.844λ	0.174λ
On-axis/ Zygo GPI XP	0.875λ	0.181λ

4　Conclusion

The program we proposed has completed the measurement of aspherical surface with full aperture successfully. Although it requires higher precision of beam splitter and standard spherical lenses, it also has the following advantages: 1) The design of common optical path that placing CGH on the imaging arm eliminates the error introduced by the substrate of CGH; 2) By adding off-axis carrier frequency on the CGH, varied diffraction orders are separated in the direction of vertical axis, combined with filter, the testing blind zones caused by the varied diffraction orders overlap in the central region can be eliminated, then the aspheric surface with full aperture can be tested; 3) Compared with Fizeau interferometer, the modified Twyman-Green interferometer can obtain interferograms with higher contrast. This program can be used to test large aperture asphere on high accuracy. And our further research focuses on the separation of system errors.

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